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CCIE Practical Studies Volume II

By Karl Solie CCIE No. 4599, Leah Lynch CCIE No. 7220

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Gain hands-on experience for the CCIE Lab Exam with volume two of the best-selling CCIE Practical Studies title from Cisco Press.

- Experience putting concepts into practice with lab scenarios that guide you in applying what you know
- Learn how to build a practice lab for your CCIE lab exam preparation
- Take five full-blown practice labs that mimic the actual lab exam environment

CCIE Practical Studies, Volume II leads CCIE candidates through the process of preparing for the CCIE lab exam by presenting them with a series of challenging laboratory exercises. A perfect companion to the best-selling first edition, this book provides coverage of CCIE lab exam topics not covered in Volume I, like the Cisco Catalyst 3550, route maps, BGP, Multicast, and QoS. Combined with Volume I, the CCIE candidate will get comprehensive coverage of the routing and switching portions of the Routing and Switching, Security, and Service Provider lab exams.

The book begins with brief coverage of the core technologies required on the CCIE lab exam and includes suggested references for further reading. Laboratory exercises covering each of the core technologies follow, providing detailed guides to applying the technologies in real network settings. The final chapter of the book concludes with five hands-on lab exercises. These comprehensive practice labs include all of the technologies and gradually increase in difficulty level. They present readers with scenarios similar to what they will face on the actual lab exam. Study tips and test-taking techniques are included throughout the book.



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Dedications

Leah Lynch: This book is dedicated to my husband, Chad Lynch, who always supports, listens to, and encourages me. I love you.

Karl Solie: This book is dedicated to my family—my mother and father, John and Linda Solie; and my two brothers, Mike and Jim. We have been blessed with a close family and have a king's wealth of a different kind. This book is also dedicated to my wife, Sandra, and my two daughters, Amanda and Paige, for all their sacrifices over the years and their enduring love. You three make every day warmer, brighter, and happier for me.

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Leah Lynch, CCIE No. 7220 R/S, is a network engineer with a large financial institution. Leah has more than seven years of experience in the IT industry, with four years focused on heterogeneous internetwork environments, including banking, retail, medical, government, manufacturing, corporate, sales, network service provider, telecommunications, and 2.5/3G wireless networks. Leah also holds several other Cisco certifications and is currently working on her Communications and Services CCIE. She wrote [Chapters 6](#) through [9](#) (the QoS and BGP chapters) and can be reached at leah.lynch@ieee.org.

Karl Solie, CCIE No. 4599, is a principal engineer for the consulting firm Solie Research, LLC. Karl has more than 14 years of experience in the field designing and implementing some of the largest IP- and SNA-based internetworks in the United States and abroad for companies such as McDonnell Douglas/Boeing, Unisys, and the Fulton and Los Angeles county governments. Karl is also active in Cisco professional development and, along with this volume, he has authored *CCIE Practical Studies, Volume I*, (Cisco Press, 2001). Karl can also be caught in the classroom, as a certified Cisco Systems instructor, training for the Ascolta Training Company in Minneapolis. Karl concentrated in applied mathematics at the University of Wisconsin-Stout and holds a bachelor of arts in law from the University of California, Irvine.

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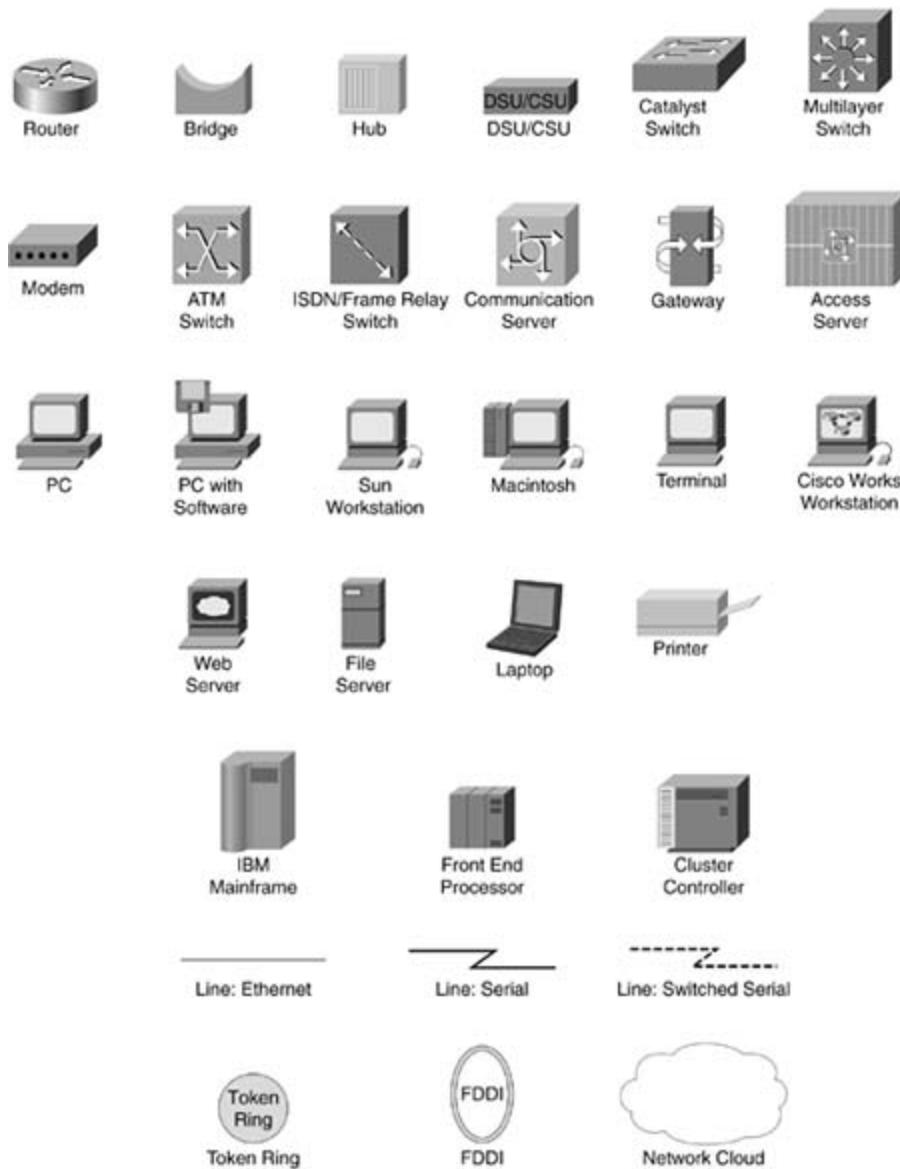
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I also want to say *thank you* to all the readers of *CCIE Practical Studies*, Volume I, especially for the kind letters that people have sent me about their quest to become CCIEs.

Finally, I once again want to thank the good Lord Jesus for His continued blessings and for always being there for me.

Icons Used in This Book



Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the Cisco IOS Command Reference. The Command Reference describes these conventions as follows:

- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets [] indicate optional elements.
- Braces { } indicate a required choice.
- Braces within brackets [{ }] indicate a required choice within an optional element.
- Boldface indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a show command).
- *Italics* indicate arguments for which you supply actual values.

Foreword

Preparing for the CCIE certification is a challenging and individual process, and there are as many paths to success as there are candidates. I've had the pleasure of meeting and talking to thousands of CCIE candidates, and there is no doubt in my mind that the single greatest factor in achieving certification is the amount of "hands-on" practice a candidate logs during their preparation. *CCIE Practical Studies, Volume II*, by Karl Solie and Leah Lynch provides a clear framework to make the all-important hands-on preparation more effective. The hallmark of any CCIE certification is the breadth of the content covered by the exam, and many candidates have difficulty choosing where and how to begin their preparation. This book and its companion, *CCIE Practical Studies, Volume I*, can help the candidate focus on key content likely to appear on the exam. In addition to the knowledge gained by reading and working through the sample lab scenarios, the book can act as a starting point for a more self-directed approach to study, in which candidates explore "what-if" type scenarios requiring true expert-level skills.

The CCIE certification is now ten years old and still stands in the top rank of certification programs in our industry. One measure of that vitality is the growth in quality preparation materials for the exam, and this volume is a worthy addition to the list of resources now available to CCIE candidates. Like its companion volume, I'm sure it will be an excellent addition to any preparation library.

Mike Reid
Manager, CCIE Programs
Cisco Systems, Inc.

Introduction

The CCIE is one of the most challenging certifications available. Most CCIE candidates spend several months studying and even take a few attempts at the lab exam before passing. If you are considering pursuing the CCIE, you are most likely aware of the amount of self-study, training, and experience required to undertake the laboratory exam. Despite the difficulties, pursuing the CCIE certification program is a very rewarding experience requiring candidates to refresh their skills in technologies that they are already familiar with, expand their skills in areas where they have less knowledge, and generally prepare for situations that require a great amount of technical expertise. The skills and hands-on experience working with a number of different technologies under pressure and time limitations add to one's ability to troubleshoot and add value to employers.

The CCIE lab exam is an extended one-day exam that tests the candidate's abilities to work with multiple protocols within a limited amount of time under a considerable amount of pressure. Candidates must use their knowledge of Cisco IOS Software to configure, test, and troubleshoot a network that they are not familiar with, proving their ability to work independently and under pressure. Because the CCIE program is constantly changing to keep up with industry needs, candidates frequently encounter technologies with which they do not have extensive experience working. This makes the CCIE program more versatile to candidates and employers because the candidates are not only tested in areas that apply to their current career situation, but also to situations in a number of different markets. The protocols and technologies covered by the Routing and Switching exam track apply to a number of different network types: corporate enterprise, retail, service providers, and others. This broad range of skills benefits the candidates, their employers, and their coworkers.

Cisco recommends that CCIE candidates have at least two years of experience with Cisco products, formal training with the technologies, and a considerable amount of time dedicated to self-study before undertaking the lab exam. This book is the second volume in a series intended to help CCIE candidates with the self-study part of their preparation. Over the course of this series, the books explore a number of technologies. You can use the examples in the book to test your knowledge of the technologies through various hands-on lab scenarios. It is strongly recommended that you use each book in the series to prepare for the exam, reading through the theory, practicing the lab scenarios, and reviewing familiar technologies. After passing the CCIE exam, most people find a great feeling of accomplishment and are no longer intimidated by time limitations and pressure.

We will be honest with you; your journey on the path to becoming a CCIE will be long and formidable. It will challenge you mentally like nothing else. When it comes to the CCIE lab test, the testing standards are rigid and the proctors are stringent. You will not be able to argue or talk your way into becoming a CCIE. Prepare wisely; there are no shortcuts on the road to becoming a CCIE, so do not waste time looking for them. As long as your journey may be, when all is said and done and you are finally assigned your own CCIE number, the feeling is like nothing else. You will feel that all the hard work, the sacrifices, and the long lonely hours in the lab have paid off. You will have entered the ranks of the most elite group of network engineers on the planet—by becoming a CCIE.

CCIE Practical Studies, Volume I, stressed that there is no shortcut to becoming a CCIE, no "all-in-one" book on becoming a CCIE (including *CCIE Practical Studies, Volume I* and *Volume II*). There are no quick "buy this book and we guarantee you will pass" solutions that will replace a strong level of experience and dedication. It is assumed that most CCIE candidates already have at least some experience with most of the technologies covered in this series. The CCIE lab is ever changing, and the possible test content is deep and vast. For these reasons, it is difficult to

create a "single source" for CCIE knowledge and study. This does not mean that boot camps and such are not valuable tools; they are, and should be treated as one of the many study techniques you can use.

Like Volume I, the text in Volume II does not, in general, go into great detail on specific protocols; instead, it is designed to provide practical configuration guidelines that you can use to help improve network skills and to introduce you to technologies that you might not yet have worked with in the field. Volume II, along with its companion, Volume I, presents a tremendous amount of information on many foundation or core network technologies and includes many new concepts that, if applied with a working network model, can help to produce even stronger network skills, furthering your preparation to take, and pass, the CCIE lab exam.

CCIE Practical Studies, Volume II, picks up where *CCIE Practical Studies*, Volume I, left off. *CCIE Practical Studies*, Volume I, focuses on modeling complex internetwork scenarios from ISO Layer 1 on up. It covers physical access, modeling LAN and WAN data-link protocols such as Frame Relay, HDLC, PPP, ATM, Ethernet, and Token Ring. *CCIE Practical Studies*, Volume I, details Cisco Catalyst platforms, including the Token Ring Catalyst 3924 and the Catalyst 35xx/5500/6500 family. Volume II continues with the Catalyst family of switches, focusing on the powerful new Catalyst 3550 intelligent Ethernet switch. The studies include Layer 3 switching and the new 802.1w and 802.1s Spanning Tree Protocols.

CCIE Practical Studies, Volume I, also covers Interior Gateway Protocols (IGPs), such as RIP, IGRP/EIGRP, and OSPF. *CCIE Practical Studies*, Volume II, takes the next step and concentrates on the primary Exterior Gateway Protocol (EGP) and Border Gateway Protocol (BGP)—more than 300 pages are devoted to BGP.

In addition to modeling routing protocols and Ethernet switching, this text takes a detailed look at quality of service (QoS). As with BGP, a significant portion of the text, more than 200 pages, is devoted to advance QoS techniques, including topics such as Resource Reservation Protocol (RSVP), Differentiated Services Code Point (DSCP) field, and Weighted Random Early Detection (WRED). QoS is also discussed as it relates to ATM and voice technologies.

How This Book Is Organized

The text is arranged into six sections, which provide technical details on specific technologies. It demonstrates how you can implement these technologies and guides you through more advanced technical implementations using practical examples. At the end of each configuration-based chapter, you can test your knowledge of the subject by completing a lab scenario that applies the technology that was just covered. After completing the lab, you can use the lab walkthrough to see how your configuration compares to the configurations created in our labs. The subjects discussed in this book are organized in the following manner:

- [Part I](#): Ethernet Switching
- [Part II](#): Controlling Network Propagation and Network Access
- [Part III](#): Multicast Routing
- [Part IV](#): Performance Management and Quality of Service
- [Part V](#): BGP Theory and Configuration
- [Part VI](#): CCIE Practice Labs

CCIE Practical Studies, Volume II, was designed to be a customizable study resource. The sections are divided into technology-specific areas that enable you to use your study time efficiently. Each chapter begins with basic theory and works up to configuration examples, which you can model in your own lab. Most chapters also include practical examples that apply more complex configuration topics and, with the lab walkthroughs, enable you virtually to work with the author configurations deployed during the writing process. If you have a problem with a certain technology or configuration step, go back to the theory and configuration section for a quick review and then try the example or lab again until you understand how it works. Do not be afraid to go beyond the limits of any of the labs to further investigate technologies or take time to explore one item in detail. The experience you gain working through these network models will add to any other training or experience you already have, preparing you for complex network implementations. When you feel comfortable with a section, move on to the next; and if you think you do not need the information in a section, skip to the end and try the lab scenario to verify that you have mastered the subject. Each chapter in this book also provides you with a "Further Reading" section that directs you to references that can provide additional detail on the subjects contained within for additional study. This book builds on the information covered in Volume I, assuming that you have the solid foundation skills required to configure core technologies such as IGP routing protocols, basic LAN switching concepts, and WAN protocol configuration experience, and that you know how to configure IP services such as Network Address Translation (NAT). For more information on these technologies, refer to the corresponding chapters in Volume I.

[Part I](#) takes an in-depth look at the new Cisco 3550 intelligent switching platform—exploring the capabilities of this new platform, reviewing the old-school switching technologies, and looking at new and improved applications of these switching technologies. You then use the full capabilities of this platform in routing and switching practical examples and practical lab scenarios.

[Part II](#) analyzes and demonstrates the use of the simple, but powerful, route maps and also covers frequently overlooked route maps. You will learn many of the ways to use route maps to change or influence routing behavior, control traffic based on protocol characteristics, or policy route traffic. Route maps are an integral part of many advanced routing schemes, and good route map configuration skills are a must for BGP routing. This part provides a fundamental look

at route maps and their application and prepares you for some of the technologies covered later in this book.

[Part III](#) takes an in-depth look at multicast routing and switching on router and switch platforms, applying practical theory to network models—thereby, demonstrating the application of multicast routing for real-world scenarios.

[Part IV](#) comprehensively examines router performance management and QoS by first analyzing router performance with a brief section on performance-related router show commands. Using the information derived from these commands, you can provide the best level of service by applying some of the Cisco IOS Software extensive QoS technologies. ATM QoS is then covered—first, a review of ATM theory, comparing ATM to Frame Relay, and then a brief review of ATM PVC configuration using newer Cisco IOS Software ATM configuration commands. The focus then turns to ATM QoS mechanisms, and you apply these technologies to traffic based on network service level requirements. This information can also help enterprise network professionals understand some of the terminology that is frequently used by their service providers. This part also covers Layer 3 switching methods, demonstrating how to determine the right switching method for particular network characteristics and router hardware and interface types.

[Chapter 5](#) removes the cloud of mystery surrounding the QoS integrated and differentiated services. This chapter reviews RSVP theory and configuration on Cisco routers, taking an in-depth look at RSVP show and debug commands. You apply RSVP configurations to one of the most popular RSVP network applications, Voice over IP. The chapter then examines the predominant differentiated services currently available for traffic marking and classification using the information stored in the IP Type of Service (ToS) field. This section explores IP precedence, the newly emerging IP Differentiated Services Code Point (DSCP) field, and WRED (the congestion-avoidance algorithm). After you explore the ways that traffic can be classified, you can apply these technologies in several network models using Voice over IP as a network application.

[Chapter 6](#), a little book in itself, dives right in and provides a broad view of the current queuing, shaping, classification, and policing technologies available in Cisco IOS Software. This chapter begins by exploring the primary four basic queuing methods and then delves deeper into queuing theory by exposing newer, more advanced queuing methods such as Class-Based Weighted Fair Queuing and Low Latency Queuing—technologies that integrate many of the subjects covered up to this point in this book. The chapter then revisits traffic shaping and explores the newer, class-based shaping method. Because no QoS chapter would be complete without addressing traffic policing, this chapter demonstrates new policing methods that you can apply in the field as protective measures to prevent or contain the spread of certain viruses and undesirable protocols while maintaining certain levels of network performance.

[Part V](#) explores one of the most exciting and confusing protocols ever written: BGP. In this part, unlike the other parts, an entire chapter is dedicated only to BGP theory, [Chapter 7](#). This chapter provides one of the newest, most comprehensive BGP theory descriptions available today by exploring the states of the BGP finite-state machine, five BGP messages, BGP attributes, route reflectors, and confederations. This chapter is geared specifically to Cisco BGP implementation but is derived from all BGP source information available; providing a concise BGP theory review that prepares you for the following chapters by providing the theory up front without jumping from theory to configuration.

[Chapter 8](#) begins applying the BGP theory from [Chapter 7](#), from a service provider and enterprise perspective, exploring basic BGP configurations, providing a few quick BGP configuration tips, and exploring the impact that BGP routing has on a router. This chapter includes numerous real-world implementation tips that you can use in the field. After reviewing the fundamentals, this chapter examines the heart of a successful BGP implementation—displaying configuration data and diagnosing problems using BGP show and

debug commands. This chapter delves into previously undocumented items displayed during BGP debugging sessions, explaining debug output line by line. This information prepares you to handle almost any BGP problem by introducing a BGP troubleshooting methodology and showing which commands help you diagnose problems quickly with the least network impact.

[Chapter 9](#) examines I-BGP and E-BGP implementations, how BGP uses its tables, advertising BGP networks, and integrating BGP with IGPs. This chapter helps alleviate many confusing or difficult concepts such as multihoming to two service providers and the common I-BGP full-mesh problem. This chapter—designed not just as a study guide but as a real-world field guide that can save you hours of troubleshooting in the field—builds on the information provided in the previous two chapters by delving straight into the good stuff: route reflectors, confederations, redistribution, route filtering, and conditional route advertisement. This chapter then takes an unprecedented look at one of the most confusing and difficult BGP topics: applying regular expressions. This chapter demonstrates how regular expressions work by applying several examples and using little-known show commands to find the right regular expression for the task. After exploring regular expressions, you use them to filter or modify routes by applying the information contained in BGP attributes. This chapter also covers the use of multiple paths, private autonomous system numbers, backdoors, peer groups, and aggregation. And, finally, you apply this information to several real-world type scenarios building a strong BGP foundation that should leave you confident to deal with any problems the BGP protocol can throw at you.

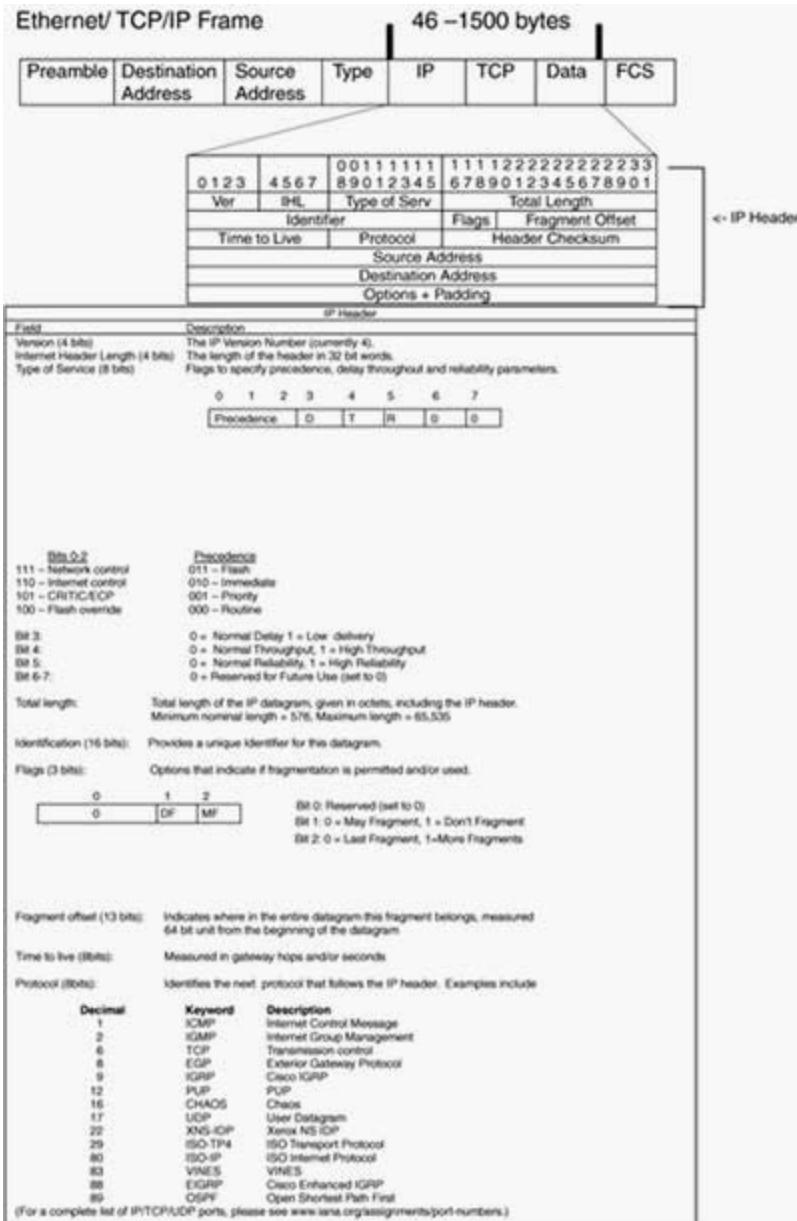
[Part VI, Chapter 10](#), takes all the information from both volumes of the *CCIE Practical Studies* books and combines skills from all these areas to create five challenging lab scenarios. Based on input provided from readers of Volume I, we have included the lab configurations with the book to ease reference.

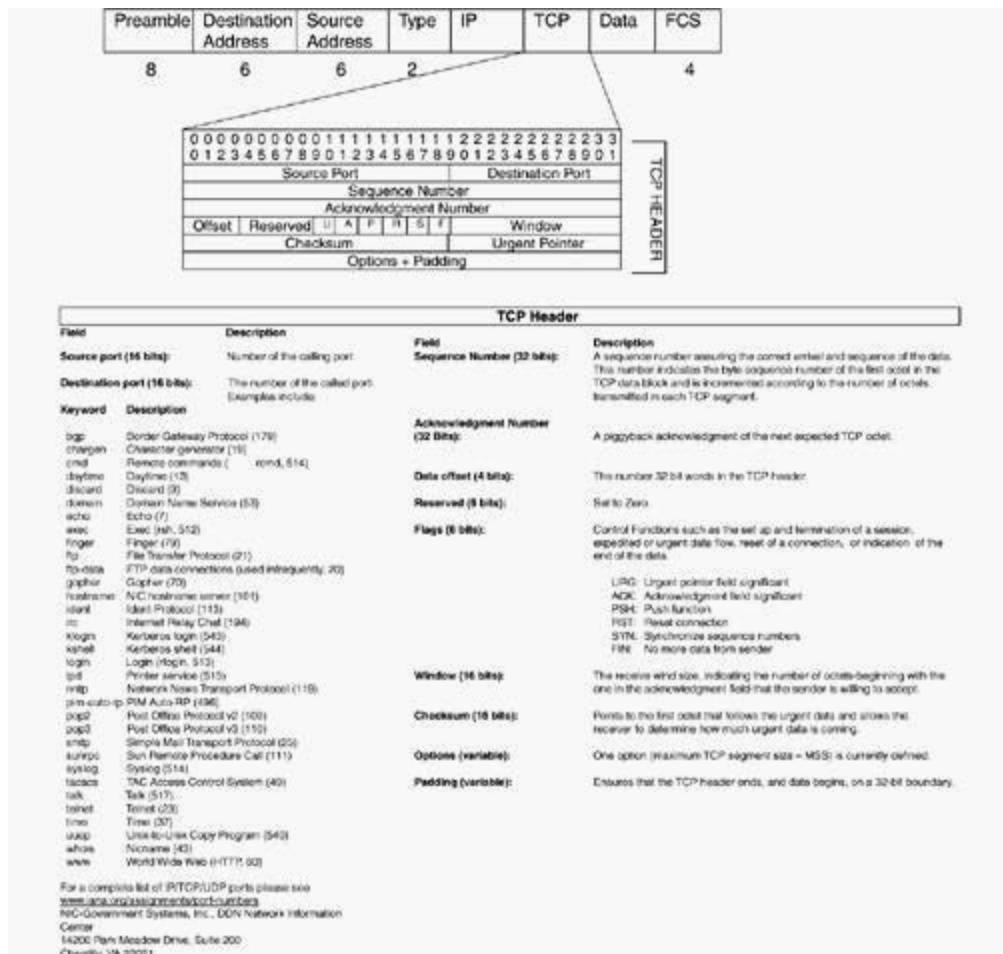
Final Notes

With only just more than 10,000 CCIEs worldwide in 10 years, the CCIE certification is still the most challenging certification one can attain. It is the only exam that requires knowledge in desktop protocols, routing protocols, Ethernet switching, and LAN/WAN skills, plus a strong knowledge of IP services. We sincerely hope *CCIE Practical Studies*, Volume I and Volume II, will be an indispensable tool for your CCIE preparation and in the field. Good luck and Godspeed!

—Karl Solie and Leah Lynch

Inside Front Cover Diagrams





Part I: Ethernet Switching

[Chapter 1](#) Configuring Advanced Switching on the Cisco Catalyst
3550 Ethernet Switch

Chapter 1. Configuring Advanced Switching on the Cisco Catalyst 3550 Ethernet Switch

Ethernet is often referred to as an evolutionary protocol rather than a revolutionary protocol. Over the years, Ethernet has evolved by building on various standards at astonishing speeds. Evolutionary protocols build on the current standard and provide some form of migration path, whereas revolutionary protocols involve some form of scientific breakthrough or use new technology. Revolutionary protocols use few parts, if any, of the existing infrastructure.

The evolution of Ethernet continues to be a remarkable one. The people of the IEEE committee have also been very busy ratifying many new standards, including updating the Spanning Tree Protocol with IEEE 802.1w. Wireless Ethernet IEEE 802.11a and IEEE 802.11b are giving promise to 802.11g operating at 54 Mbps. 10/100-Mbps Ethernet has moved to the home and 10 Gigabit IEEE 802.3ae products have started shipping offering OC-192 speeds! Industry experts predict it will be only a matter of time before Gigabit Ethernet hits the desktop and 40-Gb standards are drafted. Apple computer, for instance, has been shipping Gigabit Ethernet in its PowerBooks and its G4/G5 desktop systems bringing this closer to reality. One might say the evolution might give way to revolution in WANs and MANs. Imagine a day, perhaps not that far off, with Internet service providers (ISPs) using wireless Ethernet to their customers, and points of presence (POPs) connected with 10 Gigabit links! Bandwidth such as this could give way to the next killer application on the Internet.

As the role of Ethernet continues to evolve, so does the Cisco product line, being the first to market with many new Ethernet-based products. One such product that will play an increasing role in the enterprise is the Cisco Catalyst 3550 Intelligent Ethernet Switch. As you will see by the end of this chapter, Cisco does a fantastic job of integrating the Catalyst OS (CAT OS) features with the traditional Cisco IOS Software features. Many portions of the Catalyst 3550 configuration might be familiar to you in one form or another.

This chapter focuses on the software configuration of the Cisco Catalyst 3550 Intelligent Ethernet Switch. The discussion includes the technical aspects of the Catalyst 3550 followed by a detailed overview of Ethernet switching and spanning tree. This chapter presents a complete method for configuring VLAN, VLAN Trunking Protocol (VTP), and trunks, and covers other Layer 2/Layer 3 functionality. This chapter also discusses advanced configuration of the 3550, including Rapid Spanning Tree and Multiple Spanning Tree.

For more information on general Ethernet switching concepts and configuring the Cisco Catalyst 3900 Token Ring switch and the Cisco Catalyst 2900/3500 and 5500/6500 series switches, refer to *CCIE Practical Studies, Volume I*.

Enter the Cisco Catalyst 3550 Intelligent Ethernet Switch

The Cisco Catalyst 3550 is an intelligent Ethernet switch that provides impressive bandwidth, Layer 3 switching, and advanced quality of service (QoS) in a small footprint. The switch is called an *intelligent switch* because of many of the advanced features it brings to the traditional enterprise access switch. The switch can make decisions based on Layer 3 and Layer 4 information, thus making it *intelligent*. The Cisco Enhanced Multilayer Software Image (EMI) allows the switch to serve as a core switch in smaller networks providing inter-VLAN routing and Hot Standby Routing Protocol (HSRP). [Figure 1-1](#) shows a Cisco Catalyst 3550.

Figure 1-1. Cisco Catalyst 3550 Intelligent Ethernet Switch



Some of the key features of the Catalyst 3550 include the following:

- Superior redundancy and fault backup— Features such as Uplinkfast, Backbonefast, and 802.1w Rapid Spanning Tree reduce recovery time significantly between failures. The EMI software feature allows for advance failsafe routing with HSRP.
- Integrated Cisco IOS features for bandwidth optimization— Features such as Layer 2 and Layer 3 EtherChannel provide very large paths between switches up to 16 Gbps! Per VLAN Spanning Tree Plus (PVST+) and VTP pruning allow for advanced spanning tree control.
- Advanced QoS and queuing— The Cisco 3550 supports 802.1p QoS and the Differentiated Services Code Point (DSCP) field, Weighted Round-Robin (WRR), and Weighted Random Early Detection (WRED).

Other features include advanced security and management, granular rate-limiting, and high-performance routing via Cisco Express Forwarding (CEF) with the EMI. Multicast routing is also supported with the EMI.

NOTE

This list highlights some of the more predominate features of the Cisco Catalyst 3550. For more information on these and other features, see www.cisco.com.

The Cisco 3550 also backs the latest in regulatory certifications and standards from the IEEE and other bodies. The following standards are available on the Catalyst 3550 Ethernet switch:

- IEEE 802.1x port-based authentication
- IEEE 802.1w Rapid Spanning Tree
- IEEE 802.1s Multiple Spanning Tree
- IEEE 802.3 Full Duplex on 10BASE-T, 100BASE-T, and 1000BASE-T ports
- IEEE 802.1d Spanning Tree Protocol
- IEEE 802.1p class of service (CoS) prioritization
- IEEE 802.1Q VLAN trunks
- IEEE 802.3 10BASE-T
- IEEE 802.3u 100BASE-TX
- IEEE 802.3ab 1000BASE-T
- IEEE 802.3z 1000BASE-X
- 1000BASE-X (GBICs): 1000BASE-SX, 1000BASE-LX/LH, and 1000BASE-ZX, 1000BASE-T, 1000BASE-CWDM, and the GigaStack GBIC
- Remote Monitoring (RMON) type I and RMON type II
- Simple Network Management Protocol (SNMP) v1 and SNMP v2c

The Catalyst 3550 currently comes in four base models with multiple variations of each, and the number of models is constantly growing. The Catalyst 3550-24 and 3550-48 come with the Standard Multilayer Software Image (SMI) or the EMI. The Catalyst 3550-12T and 3550-12G are shipped only with the EMI software, whereas the Catalyst 3550-24 and 3550-48 might be field upgraded to the EMI image. The EMI provides a set of enterprise-class features, such as hardware-based IP unicast and multicast routing, inter-VLAN routing, HSRP, and many other features that you would find on a router. Performance and capacity also vary from model to model. [Table 1-1](#) lists the various models and capacities of the Catalyst 3550 switch.

Table 1-1. Performance Characteristics of the Various Catalyst 3550s

Switch/ Characteristic	Switch Fabric	Max Forwarding Bandwidth Layer 2/3	Port Memory	64-byte Forwarding Rate	Mac Addresses	Gbps Ports GBICs	10/100 Ports
3550-24	8.8 Gbps	4.4 Gbps	2 MB	6.6 Mpps	8000	2	24
3550-48	13.6 Gbps	6.8 Gbps	4 MB	10.1 Mpps	8000	2	48
3550-12T	24 Gbps	12 Gbps	4 MB	17 Mpps	12,000	2	10 -10/100/1000 BASE-T ports
3550-12G	24 Gbps	12 Gbps	4 MB	17 Mpps	12,000	10	2 -10/100/1000 BASE-T ports

* All 3550 switches have 64 MB of dynamic random-access memory (DRAM) and 16 MB of Flash memory. The maximum transmission unit (MTU) and the number of unicast and multicast routes also vary by switch type. For more detailed information, see www.cisco.com.

Ethernet Switching Review

Before discussing the detailed configuration of the Cisco 3550, it's necessary to review some important technologies. The following sections briefly review VLANs, VTP, VLAN trunking, spanning-tree 802.1d, and port autonegotiation. If you have previously read *CCIE Practical Studies, Volume 1 (CCIE PSV1)*, you might want to glance only at this section, because it is intended as a review. For a more comprehensive explanation of these and other Ethernet switching principals, refer to *CCIE PSV1*.

Virtual LANs (VLANs)

There are many definitions for the term *VLAN*. For this discussion, the definition is very simple. Virtual LANs (VLANs) are broadcast domains that can extend geographical distances. Within the VLAN, unicast, broadcast, and multicast, frames are forwarded to members of that VLAN; this is referred to as intra-VLAN traffic. Members of separate VLANs do not forward traffic to each other; this can provide some form of inherent security. For one VLAN to communicate with another, some form of routing must be used. To put VLANs in their simplest form, remember the following:

A VLAN = A broadcast domain = A Layer 3 network (IP subnet)

In a nutshell, VLANs offer the following:

- Network segmentation
- Flexibility and management
- Security

When Ethernet switching is configured, every port is assigned to a VLAN by default. The default VLAN is always VLAN 1. When switches ship from the factory, they are in some ways "plug and play." Every port is assigned to VLAN 1; therefore, every port of the switch will be in a single broadcast domain. This makes migrating from shared Ethernet hubs to a basic switched network very easy. VLANs should always be thought of as just broadcast domains. Most VLANs eventually become IP/IPX subnets or bridging domains. The basic design rules that apply to broadcast domains also apply to VLANs, such as the following:

- There should be a single subnet per VLAN. Each VLAN is like a separate bridging domain.
- Do not bridge different VLANs together.
- VLANs can span across multiple switches and geographic areas.
- Trunks carry traffic for multiple VLANs by using a special encapsulation.
- A router or Layer 3 switch will be needed to route between VLANs.
- Spanning Tree Protocol runs a per-VLAN level to prevent loops. This can be disabled but is not recommended.

[Table 1-2](#) lists the various VLAN default values for Catalyst switches.

Table 1-2. Default VLAN Settings

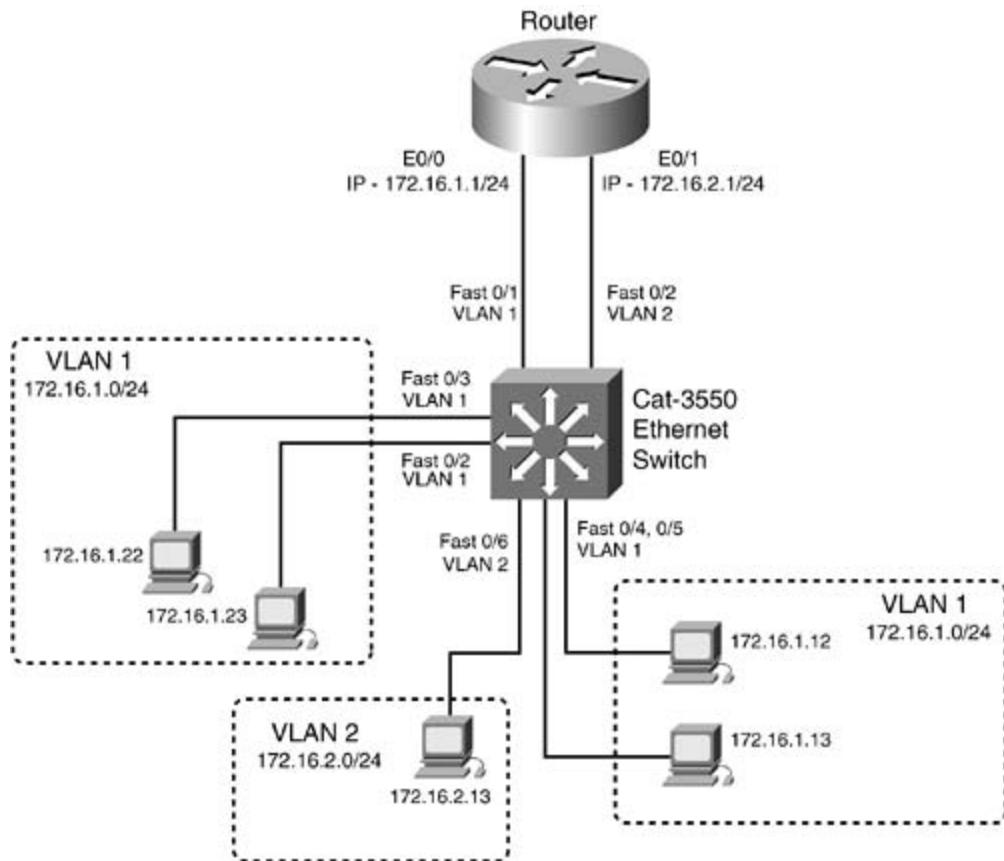
Feature	Default Value
Native VLAN	VLAN 1.
Default VLAN	VLAN 1.
Port VLAN assignments	All ports assigned to VLAN1; Token Ring ports are assigned to VLAN 1003 (TrCRF-default).
VTP mode	Server.
VTP name	Null.
VLAN state	Active.
Reserved VLAN range ^[*]	VLAN 0, VLAN 1006–VLAN 1009, VLAN 4095.
Normal VLAN range	VLAN 2–VLAN 1001.
VLAN extended range ^[*]	VLAN 1006–VLAN 4094.
MTU size	1500 bytes for Ethernet. 4472 bytes for Token Ring.
SAID value	100,000 plus VLAN number. Example: VLAN 2 = SAID 100002
Prune eligibility	VLANS 2–1000 are prune eligible; VLANs 1025–4094 are not.
MAC address reduction	Disabled.
Spanning-tree mode	PVST+ (128 spanning tree instances).
Default FDDI VLAN	VLAN 1002.
Default Token Ring TrCRF VLAN	VLAN 1003.
Default FDDI Net VLAN	VLAN 1004.
Default Token Ring TrBRF VLAN	VLAN 1005 with bridge number 0F.
Spanning-tree version for TrBRF VLANs	IBM.
TrCRF bridge mode	SRB.

[*] The VLAN reserved range is used on the Catalyst 6000 series to map nonreserved VLANs to reserved VLANs. The VLAN extended range is available on the Catalyst 6000 series and 3550 series switches. The extended and reserved VLAN range is not propagated by VTP at this time and requires the switch to be in VTP transparent mode. Token Ring and FDDI VLANs are listed on Ethernet-only switches because it is global VTP information.

Now consider some of the basic switched networks; this discussion focuses on the differences in each one.

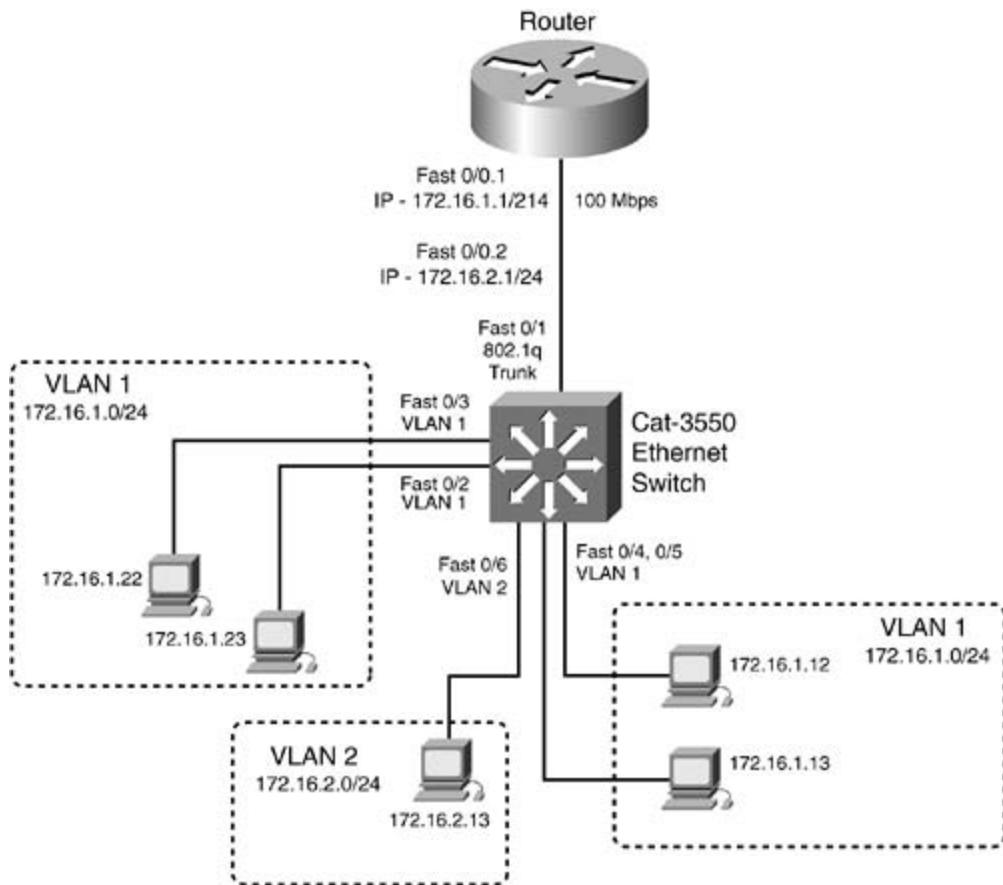
[Figure 1-2](#) shows a basic LAN configuration. The switch has VLANs 1 and 2 configured on it and various ports assigned to those VLANs. Each VLAN is configured with a separate IP subnet. If information needs to pass from VLAN 1 to VLAN 2, a router is required. Here the router has an interface in each VLAN. Traffic going from VLAN 1 to VLAN 2 needs to first hit the router. This type of configuration requires a single interface for every VLAN that needs to be routed; therefore, it is very expensive and not very scalable.

Figure 1-2. Per-Interface VLAN routing



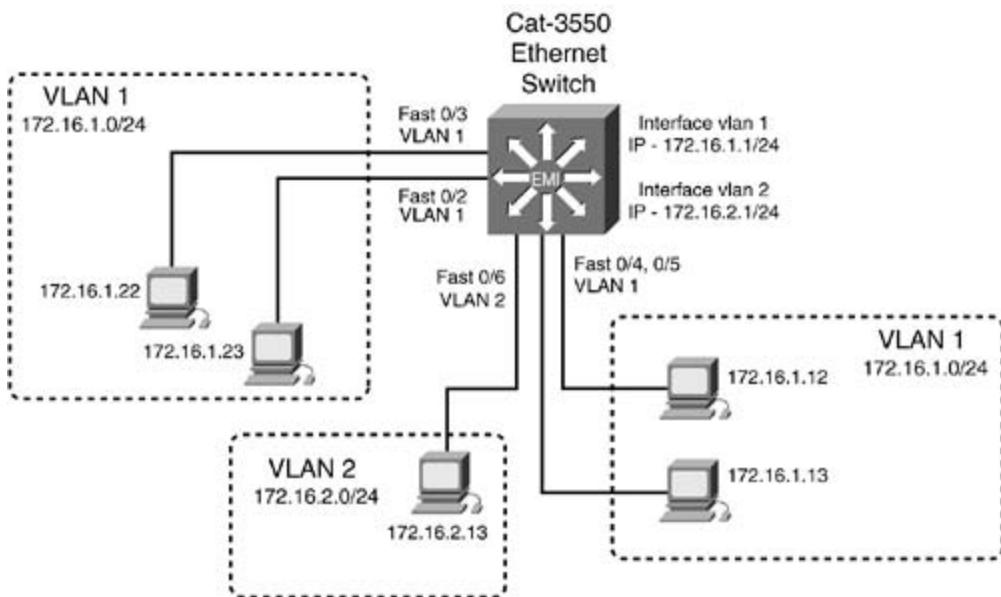
[Figure 1-3](#) shows another basic VLAN configuration. The switch has VLANs 1 and 2 configured on it again. Here the router has a single 100-Mbps interface running a VTP, such as 802.1Q. Traffic going from one VLAN to the other must travel up the trunk to the router and then back down the same trunk. Using a single trunk to route between VLANs is one of the more economical ways to accomplish routing between VLANs. This type of configuration is often referred to as a "router on a stick."

Figure 1-3. Router on a Stick



The next evolution was to move the routing function from a standalone router to the switch itself. This move was only logical, because traffic is doubled up coming in and exiting the same interface. Switches such as the Catalyst 3550 with the EMI software support this type of configuration. [Figure 1-4](#) illustrates Layer 3 Switching.

Figure 1-4. Layer 3 Switching



VTP and Trunking Protocols

A powerful function of VLANs is their capability to span geographic distance. The VLANs present on a switch are communicated from switch to switch by the means of a VLAN Trunking Protocol (VTP). VTP maintains global VLAN information between switches. This includes synchronizing the VLAN database and the management of additions, deletions, and VLAN name changes across the network. A VLAN management domain, or VTP domain, consists of one or more switches interconnected and sharing the same administrative responsibility. Anytime you desire the VLANs on one switch to have information about the VLANs on another switch, you must configure a VTP domain and a trunk. VTP also tracks all the VLANs in a VTP domain and propagates these in a client/server fashion from one switch to another. The intent of VTP is to ease management and provide a common VLAN database across the VTP domain. An advanced function of VTP includes VTP pruning, which helps control inter-VLAN broadcast traffic between switches.

VTP operates in one of three modes:

- **VTP server mode**— In VTP server mode, VLANs can be created, modified, and deleted. VLAN information is automatically sent to all adjacent VTP servers and clients in the same VTP domain. Always exercise caution when "clearing" a VLAN from the VTP server because that VLAN will be deleted on all VTP servers and clients in that VTP domain. If two devices are configured as servers, the switch/server with the highest VTP configuration revision serves as the primary server. VLAN information is stored in the switch's nonvolatile random-access memory (NVRAM).
- **VTP client mode**— In VTP client mode, VLANs cannot be created, modified, or deleted. Only the name and the VTP mode and pruning can be changed. The VTP client is at the mercy of the VTP server for all VLAN information. The client must still assign ports to a VLAN, but the VLAN will not be active on the switch unless the VTP server sends information to the client about that VLAN. On Catalyst 2900XL/3500XL/3550 series switches, VLAN information is stored in Flash memory in the VLAN.DAT file after it is received from the server. The Catalyst 4000/5500/6500 series of switches do not store the VLAN database on VTP client switches.

- VTP transparent mode— In VTP transparent mode, VLAN information that is local, or created, on the switch will not be advertised, and VTP will not synchronize VLAN databases between switches. VTP information received from other switches can be forwarded if *all* the switches are in the same VTP domain. For VTP updates to flow through a VTP transparent switch, the transparent switch and any other client or server switches must be in the same VTP domain. VLANs can be created, modified, and deleted on transparent switches. Transparent switches also support extended-range VLANs. As a matter of fact, VLANs 1006 through 4094 can only be created on VTP transparent switches. VTP will also not propagate VLANs in this range. VLAN information is stored in Flash memory in the VLAN.DAT file on transparent switches on the Catalyst 2900XL/3500XL/3550 series switches. [Table 1-3](#) highlights the various VTP modes and operation.

Table 1-3. Various VTP Modes of Operation

VTP Mode	Source VTP Messages	Propagate Local VLAN Database	Listen to VTP Messages	Create, Modify, and Delete VLANs	Sync VLAN Database to VTP Servers	VLAN Database Saved in NVRAM
Server	Yes	Yes	Yes	Yes	Yes	Yes
Client	Yes	N/A	Yes	No	Yes	Yes/No*
Transparent	No**	No	Yes**	Yes	No	Yes

* The Catalyst 4000/5500/6500 series of switches do not store the VLAN database on VTP client switches. The Catalyst 2900XL/3500G/3550 series of switches save VTP and VLAN information in the VLAN.DAT file in Flash memory. The switch will have the VLAN database upon initialization.

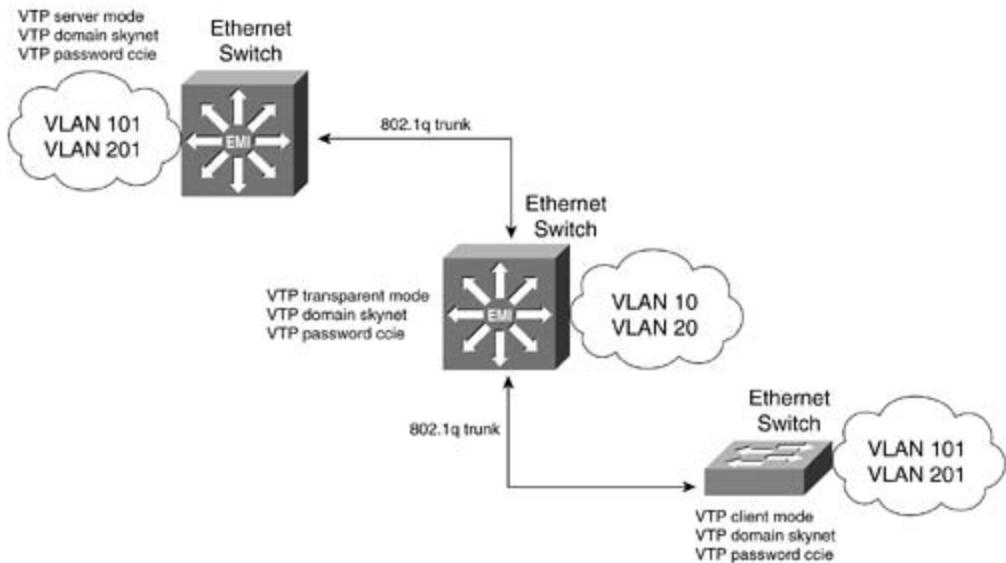
** In transparent mode, the switch will not participate in VTP; that is, it will not synchronize VLAN databases. However, VTP information received can be forwarded out other trunk ports. The trunks will not propagate local VLAN information.

[*] The Catalyst 4000/5500/6500 series of switches do not store the VLAN database on VTP client switches. The Catalyst 2900XL/3500G/3550 series of switches save VTP and VLAN information in the VLAN.DAT file in Flash memory. The switch will have the VLAN database upon initialization.

[**] In transparent mode, the switch will not participate in VTP; that is, it will not synchronize VLAN databases. However, VTP information received can be forwarded out other trunk ports. The trunks will not propagate local VLAN information.

[Figure 1-5](#) illustrates how VTP information can be propagated across a LAN.

Figure 1-5. VTP Modes and Propagation



VTP advertisements are sent out on all trunk connections in Inter-Switch Link (ISL) frames, 802.1Q frames, IEEE 802.10, or ATM LAN Emulation (LANE) cells. VTP frames are sent to the destination MAC address of 0100.0ccc.cccc with a logical link control (LLC) code of SNAP (AAAA). IEEE 802.1Q frames have an Ethernet type code of 0x8100. VTP advertisements are also sent out every 5 minutes or when there is a change in a VLAN. For VTP messages to be successfully transmitted, the following must occur:

- VTP domain name— VTP server and client switches only accept messages with the same domain name. If authentication is configured for that VTP domain, the VTP passwords must also match. The VTP name and VTP password are case sensitive.
- VTP version mode must match— VTP only accepts messages with the same version: version I or version II. The VTP version is controlled by enabling/disabling V2 mode on both sides of the trunk. A switch might be VTP version II capable and have V2 mode disabled. This is the default setting. V2 mode is used only for Token Ring switches; therefore, you see it primarily on the Catalyst 3924s and the Catalyst 5500/6500 series switches with Token Ring switching modules installed.
- VTP clients synchronize with VTP servers only if the client's VTP revision number is less than the VTP server's revision number— If the VTP client's revision number is equal to or greater than the VTP revision number of the server, the VLAN databases will not synchronize, and the VTP client will not receive any VLAN information from the server.

When a trunk is established, VTP sends periodic advertisement out each trunk port, once every 5 minutes or when there is a change in a VLAN. The VTP advertisement contains the following:

- VLAN IDs (ISL and 802.1Q).
- Emulated LAN names for ATM LANE.
- 802.10 SAID values.
- VTP domain name and configuration revision number. The server with the highest revision number will become the primary server and send its VLAN database to the other switches. This process is referred to as *synchronization*. When VTP is synchronized, all VTP servers

and clients will have the same VTP revision number. The VTP revision number is incremented every time a VLAN configuration change is made.

- VLAN configuration, VLAN ID, VLAN name, and MTU size for each VLAN.
- Ethernet frame format.

VTP has two versions: version I and version II. All the switches in the VTP domain must be on the same version. This rule does not apply to the transparent mode switches. VTP version II offers the following, the most important being support for Token Ring:

- Token Ring support— VTP version II supports Token Ring LAN switching and VLANs (Token Ring Bridge Relay Function [TrBRF]).
- Unrecognized Type Length Value (TLV) support— Unrecognized TLVs are saved in NVRAM when the switch is in VTP server mode.
- Version-dependent transparent mode— VTP forwards VTP messages that do not match the domain name and version to switches operating in VTP transparent mode version II switches. In transparent mode version I, VTP inspects the frame for a version number; if the numbers match, VTP forwards the frame. This inspection process does not happen in VTP version II.
- Consistency checks— Consistency checks are performed on VLAN names and values when information is changed from the command-line interface or Simple Network Management Protocol.

[Table 1-4](#) lists the default VTP settings on the Catalyst 3550 switch.

Table 1-4. Default VTP Settings on Catalyst 3550

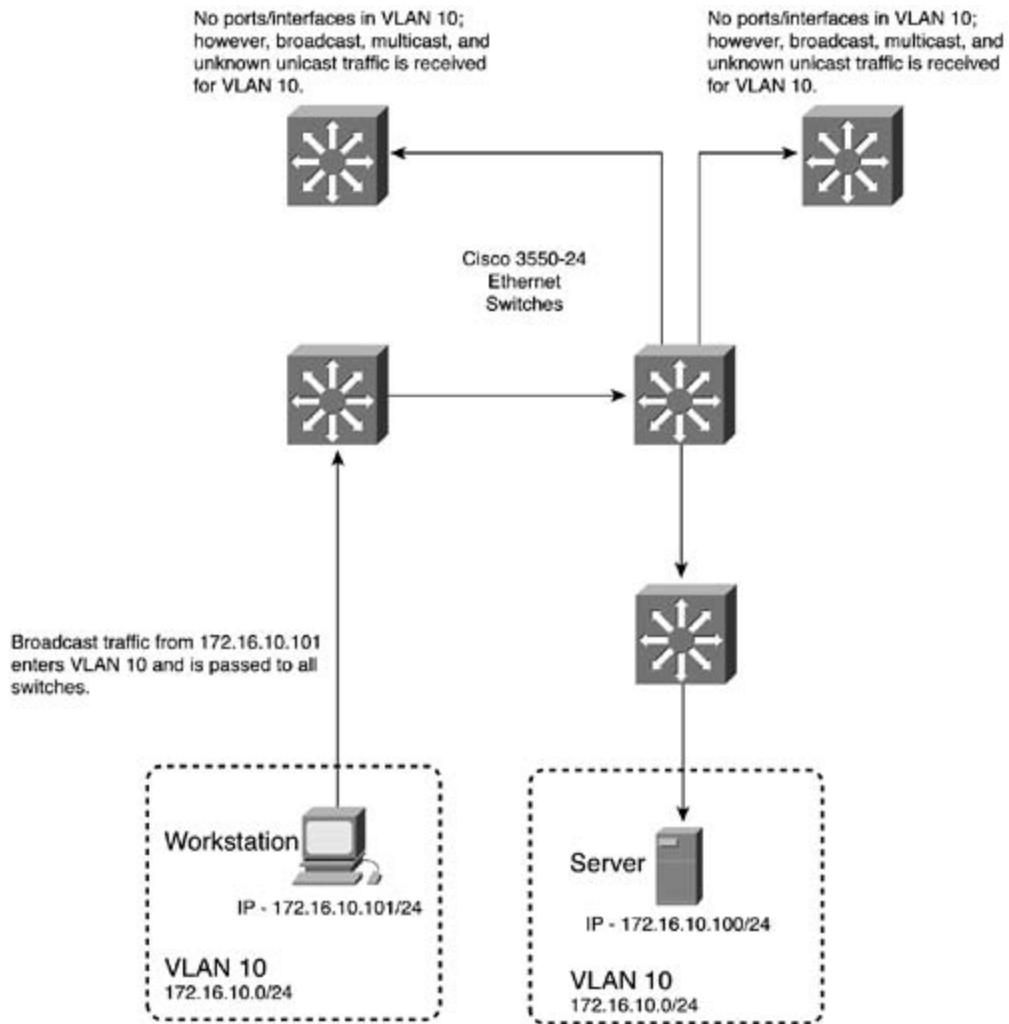
VTPFeature	Default Setting
VTP domain name	Null
VTP mode	Server
VTP version 2 updates	Disabled
VTP security/password	Disabled
VTP pruning	Disabled
VLAN trunking	DTP

VTP Pruning

VTP pruning basically controls broadcast, multicast, and unknown unicast traffic from crossing trunk lines where it is not needed. A common misconception is that VTP pruning controls Spanning Tree Protocol (STP) traffic, which it does not. With VTP pruning disabled, the default setting on the 3550, all broadcast, multicast, and unknown unicast traffic is forwarded down trunk lines on the switch to downstream switches, regardless of whether the switch needs or will discard the traffic. VTP pruning essentially only forwards broadcast, multicast, and unknown

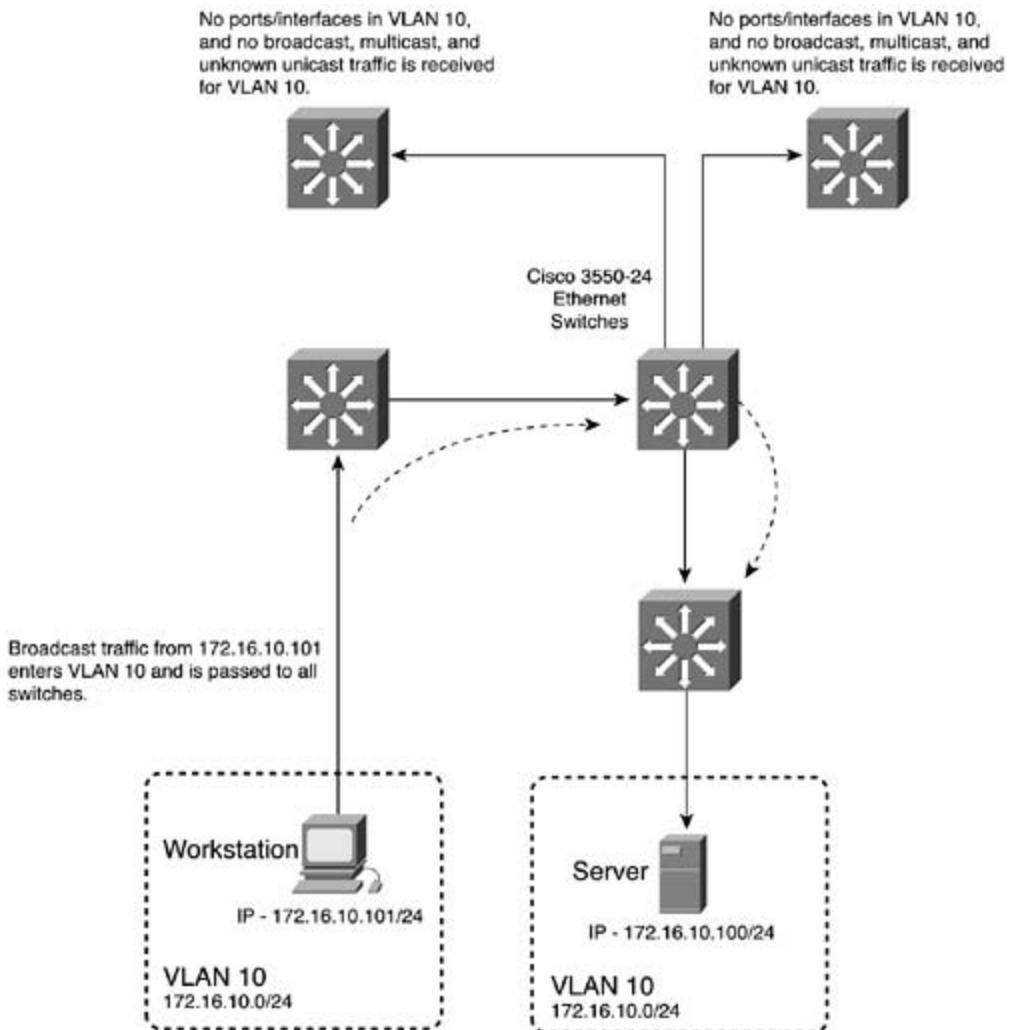
unicast traffic across a trunk if the downstream switch has an active port in the same VLAN as the VLAN that originated the traffic. If the destination switch is not adjacent, switches in between the source and destination switches receive and forward the traffic. In [Figure 1-6](#), a workstation in VLAN 10 sends a broadcast, with VTP pruning disabled; all switches in the LAN will receive that broadcast.

Figure 1-6. VTP Pruning



In [Figure 1-7](#), VTP pruning is enabled. With VTP pruning enabled, only switches with ports/interfaces in VLAN 10 will receive and forward VLAN 10's traffic, along with any intermediary switches.

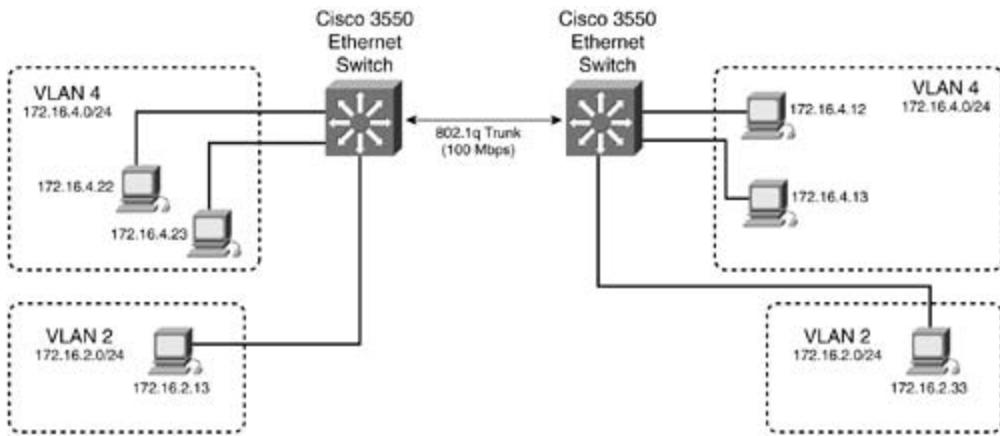
Figure 1-7. VTP Pruning



VLAN Trunking Protocols

VTP requires trunks to transport VTP information. A trunk is considered a point-to-point link between Ethernet switch ports and another networking device, such as a router or another switch. Trunks have the capability to carry the traffic of multiple VLANs over a single link and extend VLANs across the internetwork. Without the use of VTP and trunks, an IP subnet could never be partitioned across switches. VTP trunks allow for an effective way to tie two broadcast domains together that are separated by geographical distance. [Figure 1-8](#) illustrates how 802.1Q trunks tie VLANs 2 and 4 together.

Figure 1-8. VLAN Trunking



Three types of encapsulation are supported on the Cisco Catalyst family of switches: ISL, 802.1Q, and 802.10. The Catalyst 3550 Ethernet switch supports ISL and 802.1Q; therefore, this discussion focuses on these switches:

- **Inter-Switch Link (ISL)**— ISL is a Cisco proprietary trunking encapsulation. ISL is a frame-tagging protocol that allows for low-latency multiplexing of traffic from multiple VLANs to a single physical path. Ports configured as ISL trunks encapsulate each frame with a 26-byte ISL header followed by a 4-byte cyclic redundancy check (CRC) before forwarding it out the trunk. The encapsulation of each frame is a low-latency process. This operation is performed by application-specific integrated circuits (ASICs), so it is very fast. This is referred to as "wire speed." The frames on the link contain the standard Ethernet, or FDDI or Token Ring frame, and the VLAN information associated with that frame along with a bridge packet data unit (BPDU). ISL is supported on links that are 100 Mbps or greater in speed, and it can operate in full or half duplex. STP on ISL trunks is implemented on a per-VLAN basis, called PVST+. This means that every VLAN has a root bridge, and trunks go into a forward/blocking mode for each VLAN on each trunk. PVST+ is critical to control on large networks, as discussed later in this chapter.
- **IEEE 802.1Q**— 802.1Q is the industry standard trunking protocol. An 802.1Q frame uses an Ethernet type code of 0x8100 and inserts VLAN information and recomputes the frame control sequence at the end of the frame. 802.1Q operates slightly different from ISL. For instance, it runs Mono Spanning Tree on the native VLAN for all VLANs in the VTP domain. The native VLAN 802.1Q uses by default is VLAN 1. In Mono Spanning Tree, one root bridge is elected for the entire VTP domain; this is called the Common Spanning Tree (CST) domain. All VLAN traffic follows one path in this type of configuration. Cisco, understanding the need to control spanning tree on large networks while controlling load, implements PVST+ on all 802.1Q VLANs in addition to Mono Spanning Tree. The following restrictions apply to 802.1Q trunks:

- The native VLAN needs to be the same on both ends of the trunk. Mono Spanning Tree will run in this VLAN. It is critical that the native VLAN be the same on third-party switches interacting with Cisco switches.
- As mentioned, 802.1Q uses Mono Spanning Tree. Cisco enhances this with PVST+. Because the BPDU are handled differently between Cisco and third-party switches, care should be taken whenever integrating these domains, that spanning tree and the default VLANs are consistent in both switches. The entire non-Cisco domain will look like a single broadcast/spanning-tree domain to the Cisco PVST+ VTP domain. The Mono Spanning Tree of the non-Cisco domain will map to the CST of the Cisco

domain, which is by default VLAN 1.

- BPDUs on the native VLAN of the trunk are sent untagged to the reserved IEEE 802.1d spanning-tree multicast MAC address (0180.c200.0000). The BPDUs on all other VLANs on the trunk are sent and tagged on the reserved Cisco Shared Spanning Tree (SSTP) multicast MAC address (0100.0ccc.cccd).

Dynamic ISL (DISL) and Dynamic Trunk Protocol (DTP)

Dynamic ISL was Cisco's first trunk negotiation protocol. DISL was slowly replaced with Dynamic Trunk Protocol (DTP) on newer versions of CAT OS and Cisco IOS Software. DTP is essentially DISL that attempts to automate ISL and 802.1Q trunk configuration. DTP uses the reserved destination multicast address of 0100.0ccc.cccc for LAN networks to negotiate trunks. In the default "auto" state, DTP messages are sent out every 30 seconds on all trunk lines. Depending on the "mode" of the port, the port might become an ISL or 802.1Q trunk. DTP operates in the following modes. (Note that these modes are not available on all switches and might differ slightly syntactically.)

- On— Puts the port in a permanent trunking state. It also tries to negotiate the link to be a trunk.
- Off— Turns the port into a nontrunk link, and thereby disables the trunk.
- Desirable— Makes the port attempt to convert to a trunk link. The port becomes a trunk if the neighboring port is set to on, desirable, or auto mode.
- Auto— The port converts to a trunk if the neighboring port is set to on or desirable mode.
- Nonegotiate— Puts the port into trunking mode but prevents the port from sending DTP frames.

In practicality, this is really too many options for a trunk. Network administrators either configure a port as trunk or they don't. It could even be argued that having dynamic trunks is a potential security risk. [Table 1-5](#) charts the possible combinations of trunks and the modes on CAT OS. As you will see, the most reliable and simplest way to configure a trunk is to statically configure it on both sides of the link as a trunk and in the on mode.

Table 1-5. Ethernet DTP Configuration Outcomes on CAT OS

Neighbor Port	Trunk Mode and Trunk Encapsulation	Off	On	Desirable	Auto	On	Desirable	Auto	Desirable	Auto
Off	ISL or DOT1Q	Local: Nontrunk Neighbor: Nontrunk	Local: ISL trunk Neighbor: ISL trunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: 1Q TRUNK Local: ISL trunk Neighbor: ISL trunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk
On	ISL	Local: Nontrunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk	Local: Nontrunk Neighbor: ISL trunk	Local: 1Q trunk Local: ISL trunk Neighbor: ISL trunk	Local: Nontrunk Neighbor: ISL trunk	Local: Nontrunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk
Desirable	ISL	Local: Nontrunk Neighbor: Nontrunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk	Local: Nontrunk Neighbor: Nontrunk	Local: 1Q trunk Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: ISL	Local: ISL Neighbor: ISL	Local: ISL Neighbor: ISL
Auto	ISL	Local: Nontrunk Neighbor: Nontrunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: 1Q trunk Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: ISL Neighbor: ISL	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk
On	DOT1Q	Local: Nontrunk Neighbor: 1Q trunk	Local: ISL trunk Neighbor: 1Q trunk	Local: Non 1Q trunk	Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk
Neighbor Port	Trunk Mode and Trunk Encapsulation	Off	On	Desirable	Auto	On	Desirable	Auto	Desirable	Auto
Desirable	DOT1Q	Local: Nontrunk Neighbor: Nontrunk	Local: ISL trunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk
Auto	DOT1Q	Local: Nontrunk Neighbor: Nontrunk	Local: ISL trunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: Nontrunk Neighbor: Nontrunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: Nontrunk Neighbor: Nontrunk
Desirable	Negotiate	Local: Nontrunk Neighbor: Nontrunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL trunk Neighbor: ISL trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: ISL trunk Neighbor: ISL trunk	Local: ISL Neighbor: ISL	Local: ISL Neighbor: ISL
Auto	Negotiate	Local: Nontrunk Neighbor: Nontrunk	Local: ISL Neighbor: ISL trunk	Local: ISL Neighbor: ISL trunk	Local: Nontrunk Neighbor: Nontrunk	Local: 1Q trunk Local: Non 1Q trunk	Local: 1Q trunk Local: Non 1Q trunk	Local: Nontrunk Neighbor: Nontrunk	Local: ISL Neighbor: ISL	Local: Nontrunk Neighbor: Nontrunk

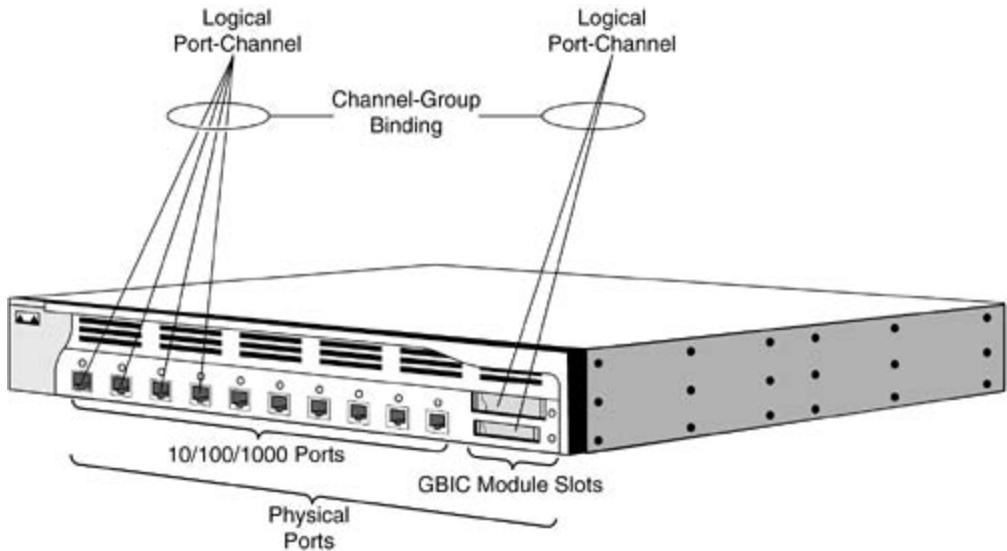
Layer 2 and Layer 3 EtherChannel Trunks

EtherChannel combines multiple physical Fast Ethernet or Gigabit ports/interfaces into a single logical interface called a *channel group*. For instance, up to eight Fast Ethernet ports/interfaces might be grouped together to provide a full-duplex 1600-Mbps logical link. Gigabit EtherChannel can group up to 8 ports together for an aggregate speed of 16 Gbps in full-duplex mode.

NOTE

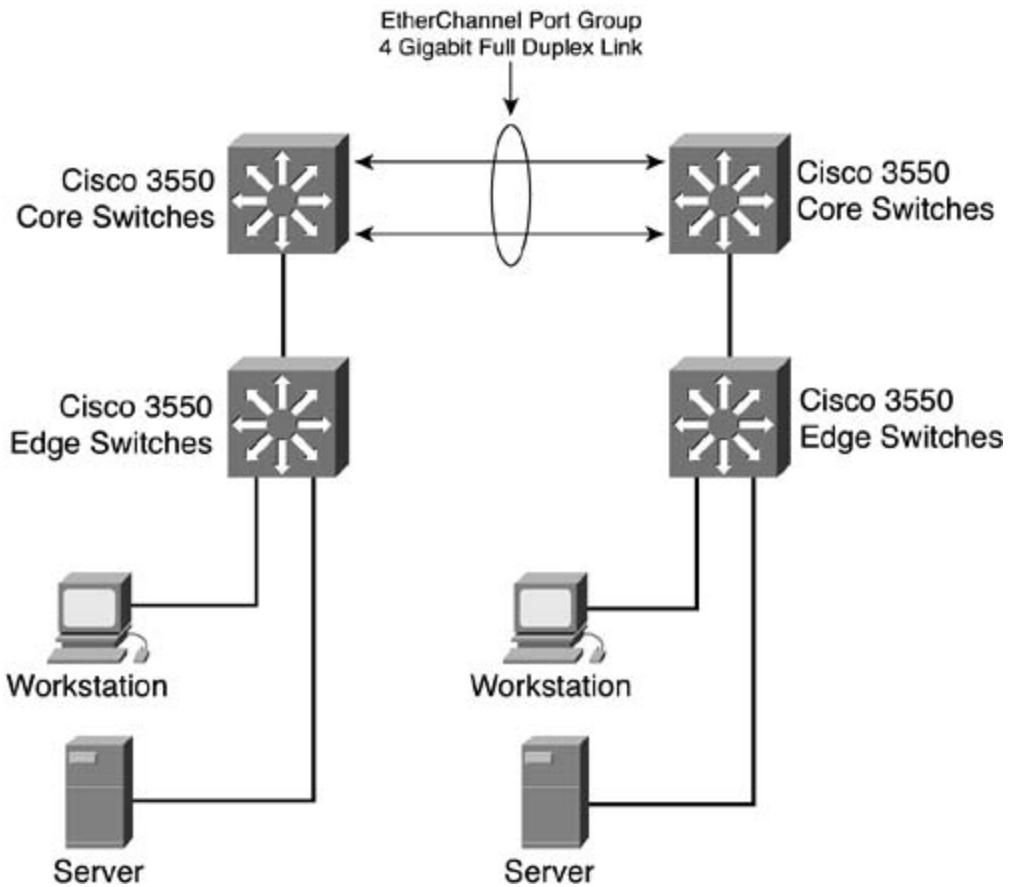
GigaStack Gigabit Ethernet modules cannot be used as Gigabit EtherChannel trunks.

Figure 1-9. Physical, Logical, and Channel Group Relationship



EtherChannel can serve as a great alternative when trunking Cisco switches together. One of the improvements it offers over normal multiple trunks is that STP will see normal multiple links as individual links to the same bridge; therefore, bandwidth will not be wasted by an interface in blocking mode. Traditionally, VLAN traffic can become tricky to load balance across, and bandwidth is limited because of STP blocking on redundant ports. In a link failure, STP will also have to wait a default of 50 seconds for convergence. EtherChannel load shares across all physical ports in the EtherChannel group. If a physical link goes down, the EtherChannel group only loses the bandwidth that the link provided. EtherChannel proves especially useful between core switches. [Figure 1-10](#) illustrates two Cisco Catalyst 3550s serving as the core switches with the Gigabit Ethernet interfaces channeled into a single Gigabit EtherChannel port group.

Figure 1-10. Gigabit EtherChannel on Catalyst 3550s



The number and type of interfaces that you can put into an EtherChannel port group varies from switch to switch. One standing rule is that you can only group Fast Ethernet together with Fast Ethernet ports, and Gigabit ports together with Gigabit ports. Because there exist very specific rules for which ports and how many you can group into a channel that are switch-type specific, check with Cisco at www.cisco.com as to the limitations that EtherChannel might have on the switch you are configuring.

Port Aggregation Protocol (PAgP) and Link Aggregation Protocol (LACP)

EtherChannel uses a protocol called *Port Aggregation Protocol* to dynamically build an EtherChannel port group between adjacent switches. Cisco defines PAgP and the way it operates as follows:

Port Aggregation Protocol (PAgP) facilitates the automatic creation of EtherChannel port groups. By using PAgP, the switch learns the identity of adjacent switch capable of supporting PAgP and then learns the capabilities of each interface. It then dynamically groups similarly configured interfaces into a single logical link (channel or aggregate port); these interfaces are grouped based on hardware, administrative, and port parameter constraints. For example, PAgP groups the interfaces with the same speed, duplex, native VLAN, VLAN range, and the trunking status and type. After grouping the links into an EtherChannel, PAgP adds the group to the spanning tree as a single switch port.

For these reasons, it is extremely important to have the same physical VLAN and STP parameters configured on each interface in the channel group.

PAgP works along with LACP to negotiate the EtherChannel trunk. LACP is defined in IEEE 802.3AD and allows Cisco switches to manage Ethernet channels between switches that conform to the 802.3AD protocol.

Port Aggregation Protocol (PAgP) Modes

PAgP has four modes in the CAT OS and six in Cisco IOS Software:

- Auto— Auto mode places an interface into a passive negotiating state; the interface responds to PAgP frames it receives but does not initiate PAgP negotiation. This setting is the default and minimizes the transmission of PAgP.
- Desirable— Desirable mode places an interface into an active negotiating state, in which the interface initiates negotiations with other interfaces by sending PAgP packets.
- On— On forces the interface to channel without PAgP or LACP. With the on mode, a usable EtherChannel exists only when an interface group in the on mode is connected to another interface group in the on mode. An interface in the on mode that is added to a port channel is forced to have the same characteristics as the already existing on mode interfaces in the channel.
- Off— In this mode, the port will not form an Ethernet channel, and no PAgP frames will be exchanged.
- Active (LACP)-IOS only— Active sets the interface into an active negotiating state, in which the interface starts negotiations with other interfaces by sending LACP packets.
- Passive (LACP)-IOS only— Passive sets the interface into a passive negotiating state. In this mode, the interface responds to LACP packets that it receives but does not start LACP packet negotiation. This setting uses minimal LACP packets.

Switch interfaces exchange PAgP packets only with partner interfaces configured in the auto or desirable modes; interfaces configured in the on mode do not exchange PAgP frames.

Interfaces can form an EtherChannel when they are in different PAgP modes as long as the modes are compatible. For example, an interface in desirable mode can form an EtherChannel with another interface that is in desirable or auto mode. However, an interface in auto mode cannot form an EtherChannel with another interface that is also in auto mode because neither interface initiates PAgP negotiation.

If your switch is connected to a partner that is PAgP capable, you can configure the switch interface for nonsilent operation. This is accomplished by using the non-silent keyword. If you do not specify the non-silent keyword with the auto or desirable mode, silent is assumed.

PAgP Physical Learners and Aggregate-Port Learners

Network devices are classified into two groups called *PAgP physical learners* and *aggregate-port learners*. A device is a physical learner if it learns addresses by physical ports and directs traffic based on that learning. A device is an aggregate-port learner if it learns addresses by aggregate (logical) ports.

When a device and its partner are both aggregate-port learners, they learn the address on the logical port channel. The device transmits frames to the source using any of the interfaces in the EtherChannel bundle.

PAgP cannot automatically detect when the partner device is a physical or aggregate port. You must manually set the learning method on the local device for source-based distribution by using the `pagp learn-method src-mac` interface configuration command. With source-based distribution, any given source MAC address is sent on the same physical port.

Some EtherChannel features and limitations are as follows:

- The number of interfaces you can put in a bundle is tightly related to the switch hardware. Be sure to check the Cisco website at www.cisco.com for the latest software and hardware limitations.
- Dynamic Trunking Protocol (DTP), VTP, and Cisco Discovery Protocol (CDP) can transmit and receive frames over the physical interfaces in the EtherChannel. Trunk ports transmit and receive PAgP protocol data units (PDUs) on the lowest-numbered VLAN.
- STP sends frames over the first interface in the EtherChannel group. STP views the channel group as a single physical link.
- The MAC address of a Layer 3 EtherChannel is the MAC address of the first interface in the port channel.
- PAgP transmits and receives PAgP PDUs only from interfaces that are up and have PAgP enabled for the auto or desirable mode. Statically configuring a trunk disables PAgP.
- EtherChannel will not form with ports that have different GARP VLAN Registration Protocol (GVRP), GARP Multicast Registration Protocol (GMRP), and QoS configurations.
- Port security cannot be used on EtherChannel ports.
- An EtherChannel will not form if one of the ports is a Switch Port Analyzer (SPAN) destination port. You can use the EtherChannel group as the source of SPAN to monitor the entire group.
- Speed, duplex, native VLAN, VLAN range, and trunk type (if you are trunking over the EtherChannel) must match on both ends of the EtherChannel link.

Layer 3 EtherChannel

Layer 3 EtherChannel is configuring EtherChannel on a routed interface on the switch. The EtherChannel group will have a single IP address assigned to it, and the port must have switching functions disabled with the interface command `no switchport`. For all practical purposes, Layer 3 EtherChannel operates in the same functional manner as Layer 2 EtherChannel. Layer 3 EtherChannel is only available with the EMI software installed on the switch.

Ethernet Physical Properties: Half- and Full-Duplex Ethernet

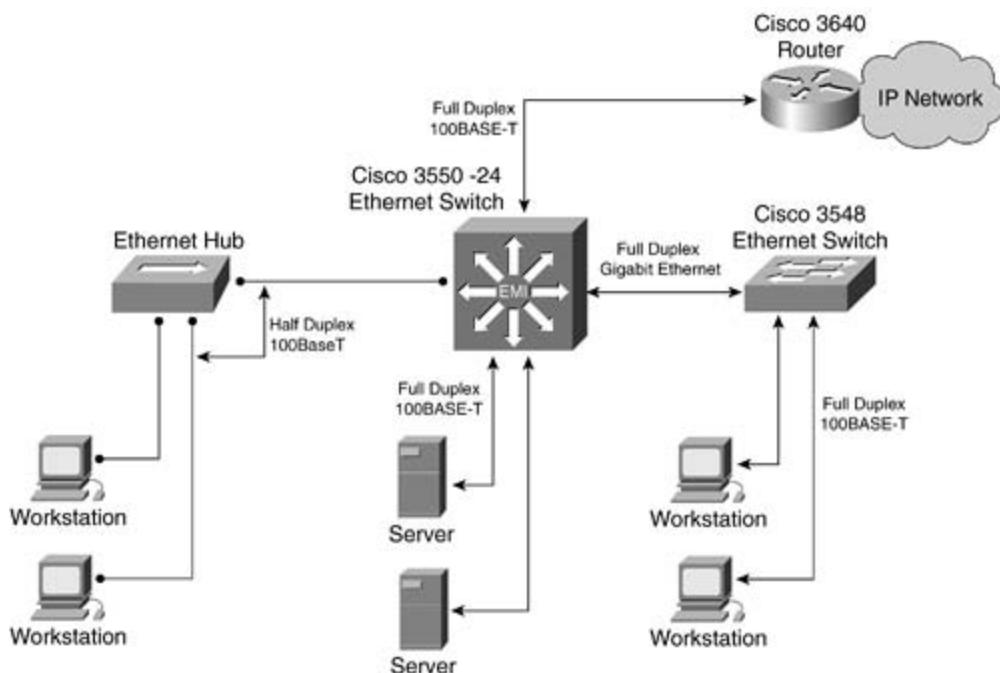
Half-duplex mode fundamentally operates Ethernet in the classic carrier sense multiple access collision detect (CSMA/CD) mode. Ethernet hubs are a good example of a device requiring half duplex. Half-duplex Ethernet has the following characteristics:

- Unidirectional data flow.

- High potential for collisions.
- Operates on shared media devices such as a hub, or a workstation.
- Operational efficiency is rated at 50 percent to 60 percent of the total bandwidth of the link.

Full-duplex Ethernet allows for a station to simultaneously transmit and receive data. Ethernet frames are transmitted and received simultaneously on two pairs of unshielded twisted-pair (UTP) or a single pair of fiber. Full-duplex Ethernet is essentially Ethernet without CSMA/CD. Full-duplex mode basically doubles the bandwidth of Ethernet! To run full-duplex Ethernet, both Ethernet devices must be capable and configured for autonegotiation or full duplex. [Figure 1-11](#) illustrates a common Ethernet network and the duplex setting of the links.

Figure 1-11. Ethernet Network Duplex Settings



NOTE

A station not operating in the correct duplex mode will generate enormous amounts of collisions or frame check sequence (FCS) errors on the port to which it is connected. These collisions will most likely be registered as *late collisions*. Be sure the port on the switch and the end station are operating in the same duplex mode.

Ethernet Autonegotiation

To aid in simplifying the configuration of Ethernet devices, the IEEE committee defined normal link pulse (NLP) for 10BASE-T networks and fast link pulse (FLP) for 100BASE-T and 1000BASE-T

networks. NLP and FLP are a series of pulses on the network that are able to deduce what the duplex and speed at which the link is operating. The station and the hub/switch agrees on the highest priority and configures the station in that manner. All autonegotiation occurs at the physical layer. [Table 1-6](#) lists the priority FLP uses and the associated data transfer rate. For autonegotiation to work, both devices must support autonegotiation logic.

Table 1-6. Ethernet Autonegotiation Prioritization

Priority	Total Data Transfer Rate (Mbps)	Speed and Duplex Settings
1 (highest)	2000	1000BASE-T full duplex
2	1000	1000BASE-T half duplex
3	200	100BASE-T2 full duplex
4	200	100BASE-TX full duplex
5	100	100BASE-T2 half duplex
6	100	100BASE-T4 half duplex
7	100	100BASE-TX half duplex
8	20	10BASE-T full duplex
9 (lowest)	10	10BASE-T half duplex

Infrastructure devices, such as routers and servers, should always have speed and duplex settings fixed. Most 100-Mbps and greater network interface cards (NICs) support full duplex. Running at full duplex essentially doubles the capacity of Ethernet. Taking advantage of this is the cheapest network upgrade you will ever do!

NOTE

Duplex modes are a function of the hardware built in to the NIC. Software upgrades will not enable you to run full-duplex mode. For full-duplex mode to work, both stations must be capable of full-duplex operation.

IEEE 802.1d Spanning Tree Protocol (STP)

As Ethernet was evolving from a single shared cable to networks with multiple bridges and hubs, a loop detection and prevention protocol was needed. The 802.1d protocol, developed by Radia Perlman, provided this loop protection. As a matter of fact, it did such a good job at this that when most networks went from bridged networks to switched networks, the importance of spanning tree was almost forgotten. STP did an excellent job of preventing loops from occurring on redundant switched networks. For many network engineers, this protocol ran in the background on their networks without manual configuration. Because of this, spanning tree is probably the most used but least understood protocol in the modern switched LAN. Over the next few years, you might see LANs start to migrate from IEEE 802.1d STP to IEEE 802.1w Rapid STP. IEEE 802.1w networks allow for very quick convergence, using concepts originally developed by Cisco Systems, such as PortFast, UplinkFast, and BackboneFast. This section focuses on IEEE 802.1d STP; IEEE 802.1w and IEEE 802.1s are discussed in upcoming sections.

Spanning-Tree Operation

Spanning tree's sole purpose in life is to elect a *root bridge* and build loop-free paths leading toward that root bridge for all bridges in the network. When spanning tree is converged, every bridge in the network will have its bridged interfaces in one of two states: *forwarding* or *blocking*. STP accomplishes this by transmitting special messages called bridge protocol data units (BPDUs). 802.1d uses two types of BPDUs:

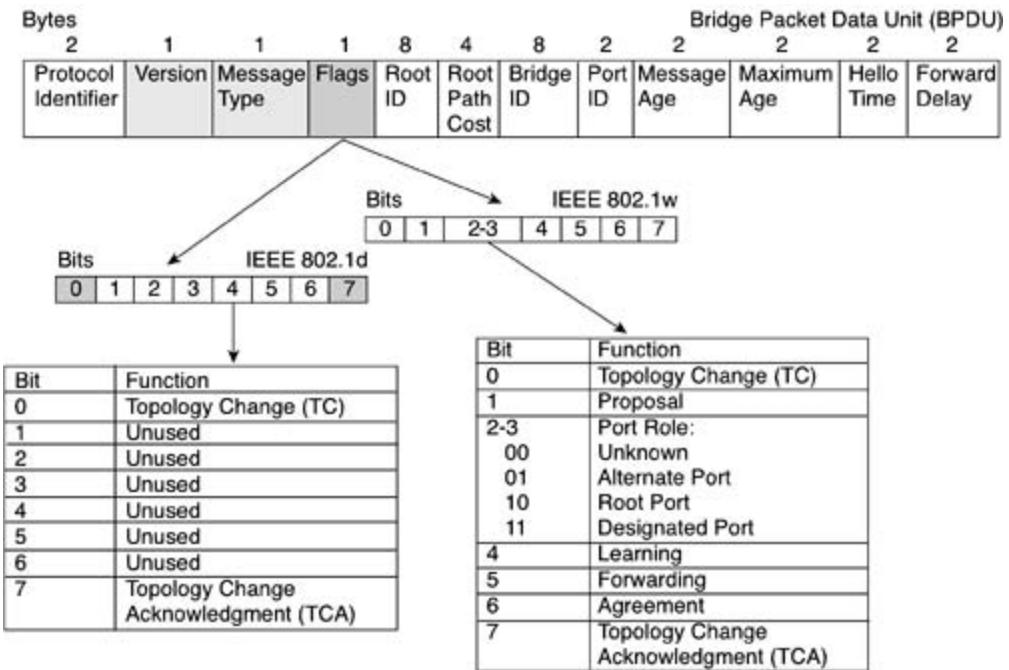
- A configuration BPDU, used for initial STP configuration
- A topology change notification (TCN) BPDU used for topology changes

BPDUs are transmitted using a reserved multicast address assigned to "all bridges." The BPDU is sent out on all bridged LAN ports and is received by all bridges residing on the LAN. The BPDU will not be forwarded off the LAN by a router.

The BPDU contains the following relevant information:

- Root ID— This is the ID of the bridge assumed to be root. Upon initialization, the bridge assumes itself to be root.
- Transmitting bridge ID (BID) and port ID— This is the bridge ID (BID) of the bridge transmitting the BPDU, and what port the BPDU originated from.
- Cost to root— This is the least-cost path to the root bridge from the bridge transmitting the BPDU. Upon initialization, because the bridge assumes itself to be root, it transmits a 0 for the cost to root.
- Other STP information and timers— The complete 802.1d frame is illustrated later in [Figure 1-26](#). Here you will see the three STP timers listed along with other STP information.

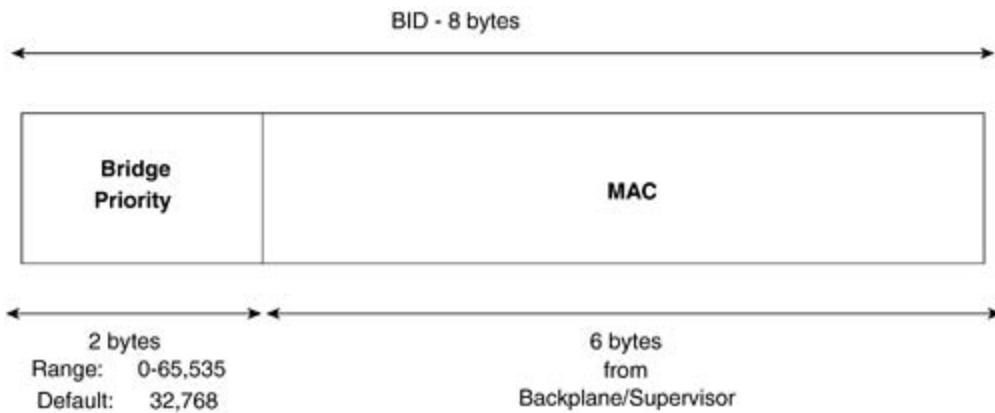
Figure 1-26. 802.1d and 802.1w Frame Comparison



Bridge ID

The BID is an 8-byte field composed from a 6-byte MAC address and a 2-byte bridge priority. The MAC address used for the BID is generated from a number of sources depending on the hardware in use for the bridge. Routers use a physical address, whereas switches use an address from the backplane or supervisor module. [Figure 1-12](#) illustrates the BID. The priority value ranges from 0 to 65,535; the default value is 32,768.

Figure 1-12. The Bridge ID (BID)



Extended System ID and IEEE 802.1T

IEEE 802.1T spanning-tree extensions address the fact that the priority value is really too large.

802.1T remedies these situations by using an extended system ID. The extended system ID was created in part to start to conserve MAC addresses. The IEEE 802.1d standard requires that each bridge/switch have a unique BID. In PVST+, each VLAN requires a unique BID; therefore, the same switch must have as many unique BIDs as VLANs configured on it. This can cause a limit on the number of STP instances a switch can run. STP uses the extended system ID, the switch priority, and the allocated STP MAC address to make a unique BID for each VLAN.

In Release 12.1(8)EA1 and later, Catalyst 3550 switches support the 802.1T spanning-tree extensions, and some of the bits previously used for the priority are now used as the extended system ID, which is set equal to the VLAN identifier. The result is that fewer MAC addresses are reserved for the switch, and a larger range of VLAN IDs can be supported, all while maintaining the uniqueness of the BID. [Table 1-7](#) illustrates the switch priority value and the extended system ID.

Table 1-7. Switch Priority Value and Extended System ID

Switch Priority Value		Extended System ID (Set Equal to the VLAN ID)														
Bit																
16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
32,768	16,384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1	

From [Table 1-7](#), the 2 bytes previously used for the switch priority ([Figure 1-12](#)) are re-allocated into a 4-bit priority value and a 12-bit extended system ID value equal to the VLAN ID. To configure the switch to use the extended system ID, use the following global configuration command:

```
3550_switch(config)#spanning-tree extend system-id
```

The extended system ID is enabled by default on the Catalyst 3550 series switches.

If your switch is using the extended system ID, it will be noted with the show spanning-tree summary command and it will appear in the configuration listing.

STP Path Cost

Bridges to determine the best possible path to root use STP path cost. Path costs have recently been updated by the IEEE to include gigabit speeds and greater. The lower the path cost, the

more preferable the path. [Table 1-8](#) lists the STP cost values for LAN links.

Table 1-8. STP Cost Values for LAN Links

Bandwidth	[*] RevisedSTPCost
4 Mbps	250
10 Mbps	100
16 Mbps	62
45 Mbps	39
100 Mbps	19
155 Mbps	14
622 Mbps	6
1 Gbps[*]	4
10 Gbps	2

[*] Before the IEEE standard was updated, the lowest cost STP could attain was 1. An STP cost of 1 was used for all links greater than, or equal to, 1 gigabit; a cost of 10 was used for 100-Mbps links, and a cost of 100 was used for 10-Mbps links.

STP has six primary states, and four states it transitions through during its operation, and Cisco switches have two additional proprietary states that can be assigned during operation. When STP converges, it will be in one of two states: forwarding or blocking. [Table 1-9](#) lists the states of STP.

Table 1-9. Various STP States

STPState	STPActivity	User Data Being Passed
Disabled	Port is not active; it is not participating in any STP activity.	No
Broken	The 802.1Q trunk is misconfigured on one end, or the default/native VLANs do not match on each end. STP root guard is in effect.	No
Listening	Port is sending and receiving BPDUs.	No
Learning	Building loop-free bridging table.	No
Forwarding	Sending and receiving user data.	Yes
Blocking	Not permitting user traffic out the port.	No
PortFast ^[*]		Yes
UplinkFast ^[*]		Yes

[*] PortFast and UplinkFast are Cisco proprietary states that allow user data traffic to be forwarding during the STP convergence process.

STP also assigns a port status to each port participating in the spanning tree. The STP port states are as follows:

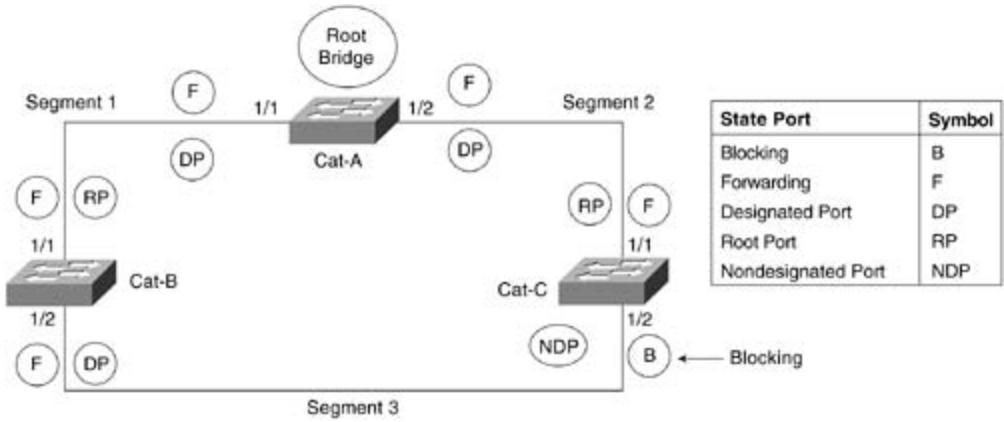
- Designated ports— Designated ports are ports that lead *away* from the root bridge. On the root bridge, all ports are designated ports. Only one designated port is elected per segment. Designated ports are placed into the forwarding state.
- Root ports— The root port is the port that leads *toward* the root bridge. The root port is the lowest-cost path from the nonroot bridge to the root bridge. There is only one root port elected per nonroot bridge. Root ports are placed into the forwarding state.
- Nondesignated ports— Any port that is not elected as a root port or as a designated port becomes a nondesignated port. Nondesignated ports are placed into the blocking state.

NOTE

In some switch documentation, you might see STP bridges represented with the traditional bridge symbol. In practicality, there really exists no physical bridge, and the bridge icon is synonymous with the switch icon. This text uses the switch icon to represent switches and the STP bridge that resides on them.

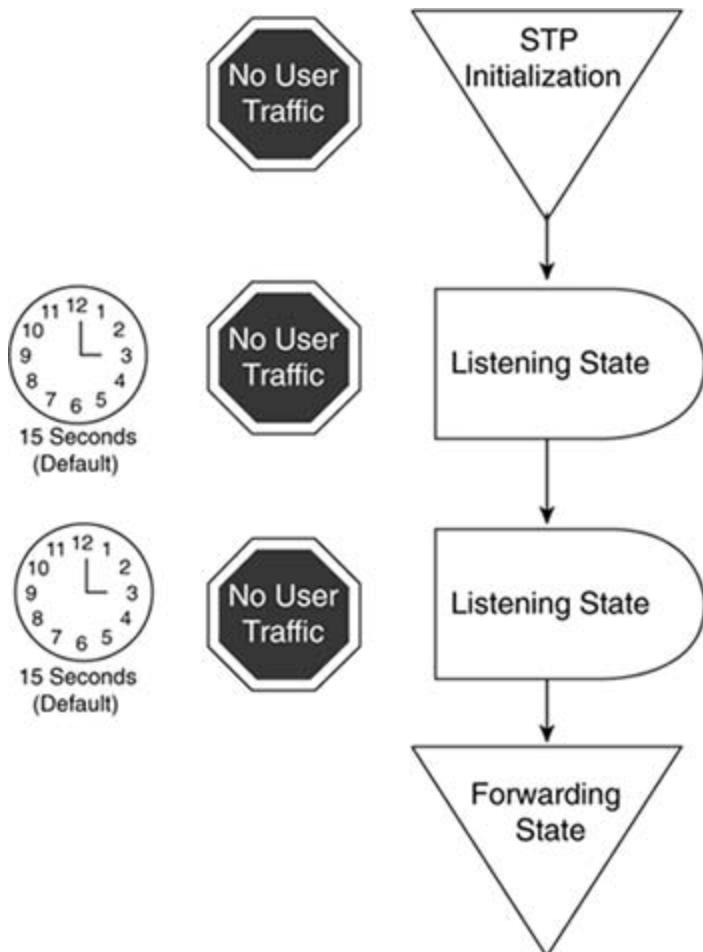
The STP port and role relationship is represented in [Figure 1-13](#).

Figure 1-13. STP Ports and Roles



A port transitions from one STP state to another, as depicted in [Figure 1-14](#). The following sections examine each one of these states in more detail.

Figure 1-14. The STP Transition



Disabled or Broken

The broken state occurs when a bridge is having problems processing BPDUs or a trunk is improperly configured. The broken state occurs when an 802.1Q trunk is misconfigured on one end, or the native VLANs do not match on each end of the trunk. The broken state also occurs on a trunk with STP root guard in effect. Disabled state occurs when the port is administratively down from an STP point of view.

Listening

When a bridge port initializes, or during the absence of BPDUs for longer than the max age timer (usually 20 seconds), STP transitions to the listening state. When STP is in this state, the port is actually blocking, and no user data is sent on the link. The port stays in this state for 15 seconds, called the *forward delay timer*.

STP follows a three-step process for convergence:

1. Elect one root bridge. Upon initialization, the bridge begins sending BPDUs on all interfaces. A root bridge is chosen based on the bridge with the lowest BID. Recall that the BID is a combination of a priority and MAC address. Because the priority comes first in the BID, the bridge with the lowest priority is elected root bridge. In the event of a tie on bridge priority, the bridge with the lowest MAC address is chosen as root. All ports of the root bridge become designated ports and are put in the forwarding state.
2. Elect one root port for every nonroot bridge. After a single root bridge has been elected, STP elects a *single* root port on each nonroot bridge. The root port is the bridge's best path to the root bridge. When a root port is elected, it is put into the forwarding state. To determine what port should be a root port, STP follows this decision process:

- a. Lowest root BID; the BID from the root bridge
- b. Lowest path cost to root bridge; the cumulative cost of all the paths to Root
- c. Lowest sender BID; lowest port ID

The primary variable that influences the root port election is the *cost to root bridge*. This is because most bridges are not adjacent to the root bridge.

When a bridge receives a BPDU, it stores it in a bridge table for that port. As new BPDUs are received on that port, they are compared to existing BPDUs. BPDUs that are more attractive or have lower costs are kept, and the other ones are discarded; this might also cause the switch/bridge to change the port's state to forwarding or blocking.

3. Elect one designated port on every segment. For every segment, STP elects only one port that leads away from the root bridge, called the *designated port*. The designated port is put into the STP forwarding state.

All remaining ports become nondesignated ports and are put in the blocking state.

Learning

Ports that remain designated or root ports for a period of 15 seconds, the default forward delay, enter the learning state. The learning state is another 15 seconds that the bridge waits while it builds its bridge table; this is done to ensure that the bridge topology is stable.

Forwarding and Blocking

When the bridge reaches this phase, ports that do not serve a special purpose, such as a root port or designated port, are called *nondesignated ports*. All *nondesignated ports* are put into the STP blocking state. In the blocking state, a bridge does not send configuration BPDUs but still listens to BPDUs. A blocking port also does not forward user data.

STP Timers

STP has three basic timers that regulate and age BPDUs: hello, forward delay, and max age. The timers accomplish the following for STP:

- Hello timer— The default hello timer is 2 seconds; this is the length of time between configuration BPDUs sent by the root bridge.
- Forward delay timer— This timer is the default 15 seconds that the router waits while building its bridging table. The listening and learning stages each use this single 15-second timer.
- Max age timer— The default max age timer is 20 seconds. The max age timer is how long a BPDU is stored before it is flushed. If this timer expires before the interface receives a new BPDU, the interface transitions to the listening state. An expired max age parameter is usually caused by a link failure.

STP uses the hello timer to space BPDUs and has a keepalive mechanism. The hello timer should always prevent the max age value from being hit. When the max age timer expires, it usually indicates a link failure. When this happens, the bridge re-enters the listening state. For STP to recover from a link failure, it takes approximately 50 seconds: 20 seconds for the BPDU to age out, the max age, 15 seconds for the listening state, and 15 seconds for the learning state.

NOTE

There are two other forms of STP besides IEEE 802.1d. DEC and IBM are two other forms of spanning tree in use. The operation of all forms of STP is very similar. Cisco routers support all forms, whereas Cisco Ethernet switches currently support IEEE STP, and Token Ring switches support IBM STP.

Catalyst 3550 Configuration Modes and Terminology

Configuring a Catalyst 3550 is much like configuring the Cisco IOS Software found in predecessor switches such as the Cisco Catalyst 3500XL series, or like configuring the combined routing and QoS features found in traditional Cisco IOS on router platforms. The upcoming sections focus on configuring the Catalyst switches with the EMI software installed.

The Catalyst 3550 CLI has different configuration modes and different interfaces types. For instance, ports are configured different from *switched virtual interfaces*, which are different from *access ports*. Each type of interface is configured from different configuration modes. Therefore, it is important to have a clear understanding of the terminology when discussing the configuration of the Catalyst 3550.

These configuration modes might all be common to you in one form or another. The Catalyst 3550, probably the first platform in which you will see them all together. [Table 1-10](#) lists the configuration modes available and a brief description of them.

Table 1-10. Configuration Command Modes on the Catalyst 3550

Mode Name	Prompt	Starting Prompt ^[*]	Description
User exec	Switch>	Switch>	The default mode, used for basic show commands.
Privileged exec	Switch#	Switch>	Privileged mode is required for VLAN configuration modes and global configuration mode.
Global configuration	Switch(config)#	Switch#	Used to configure parameters that affect the whole switch. Routing protocols are configured here.
VLAN interface	Switch(config-vlan)#	Switch(config)#	Used to create switched virtual interfaces (SVIs) ^[**] on the management VLAN. Other VLANs are also created from this mode.
VLAN configuration	Switch(vlan)#	Switch#vlan database	Used to configure VLANs and VTP parameters. VLANs 1 to 1005, such as VTP and VLANs 1–1001.
Multiple spanning-tree configuration	Switch(config-mst)	Switch(config)#	Used to configure MST features, such as revision, and instances.
Interface configuration	Switch(config-if)#	Switch(config)#	Used to configure the parameters for an interface, such as VLAN membership mode.
Line configuration	Switch(config-line)#	Switch(config)#	Used to configure console and vty port access.

[*] The starting prompt is the configuration mode you would use or must be in to access the new configuration mode.

[**] SVIs = switch virtual interfaces

The Catalyst 3550 also supports a variety of interface types. Each interface type is configured to support specific feature on the switch. The following section lists and briefly describes the various ports and types supported on the Catalyst 3550 switch. You will learn more about configuring each of these interfaces in later sections.

Switch Ports

A *switch port* is a Layer 2 interface associated with a physical port. The Catalyst 3550 has three primary switch ports: *access ports*, *trunk ports*, and *tunnel ports*. The default mode of a port on a 3550 is *switchport*. This differs slightly from switches such as the Catalyst 3548XL, where the default mode is *access*. The *switchport* command enables you to put the port either in a routed mode or a switch mode. When a port is in switch mode, it can be configured as an access port, trunk, or tunnel port.

- **Access ports**— Access ports are ports that belong to only one VLAN and are statically assigned to a VLAN. They carry traffic that is not tagged, and traffic from that port is assumed to belong to the VLAN assigned to the port. If an access port receives tagged traffic (ISL or 802.1Q), that traffic is discarded.
- **Trunk ports**— Trunk ports are configured as 802.1Q or ISL trunks. An ISL trunk port expects only ISL tagged frames on this port. An 802.1Q trunk has a native VLAN. All untagged frames belong to the native VLAN, which is 1 by default. All tagged and untagged traffic with a null VLAN ID is assured to the native VLAN. A frame with a VLAN ID equal to the native VLAN is sent untagged; all other frames are sent with a VLAN tag.
- **802.1Q tunnel ports**— 802.1Q tunnel ports transport information and data of a VLAN within across the LAN. Edge switches are able to tag frames with the appropriate VLAN information and then forward that tagged frame on to a core/distribution switch via the 802.1Q tunnel. The core/distribution switch adds yet another tag to the frame and forwards it across the LAN. Switches with ports configured as 802.1Q tunnels can recognize these frames and handle them appropriately. 802.1Q tunnels are used in very large enterprise networks, where the VLAN capacity has exceeded the limit of 4096 VLANs. Because of the number of switches involved in modeling 802.1Q tunnels and the fact that their application is primarily toward large enterprise customers, 802.1Q tunnels are beyond the scope of this chapter.

EtherChannel Port Groups

An EtherChannel port group combines multiple physical switch ports into a single logical port. EtherChannel groups bind the physical port features to the new logical port. If the ports in the group are configured as trunks, for example, the logical EtherChannel port is an 802.1Q trunk. The switch load shares over the ports in the EtherChannel port group. Very definite rules, which are switch architecture-specific, apply to the ports and how many can be put into an EtherChannel port group.

Switch Virtual Interface (SVI)

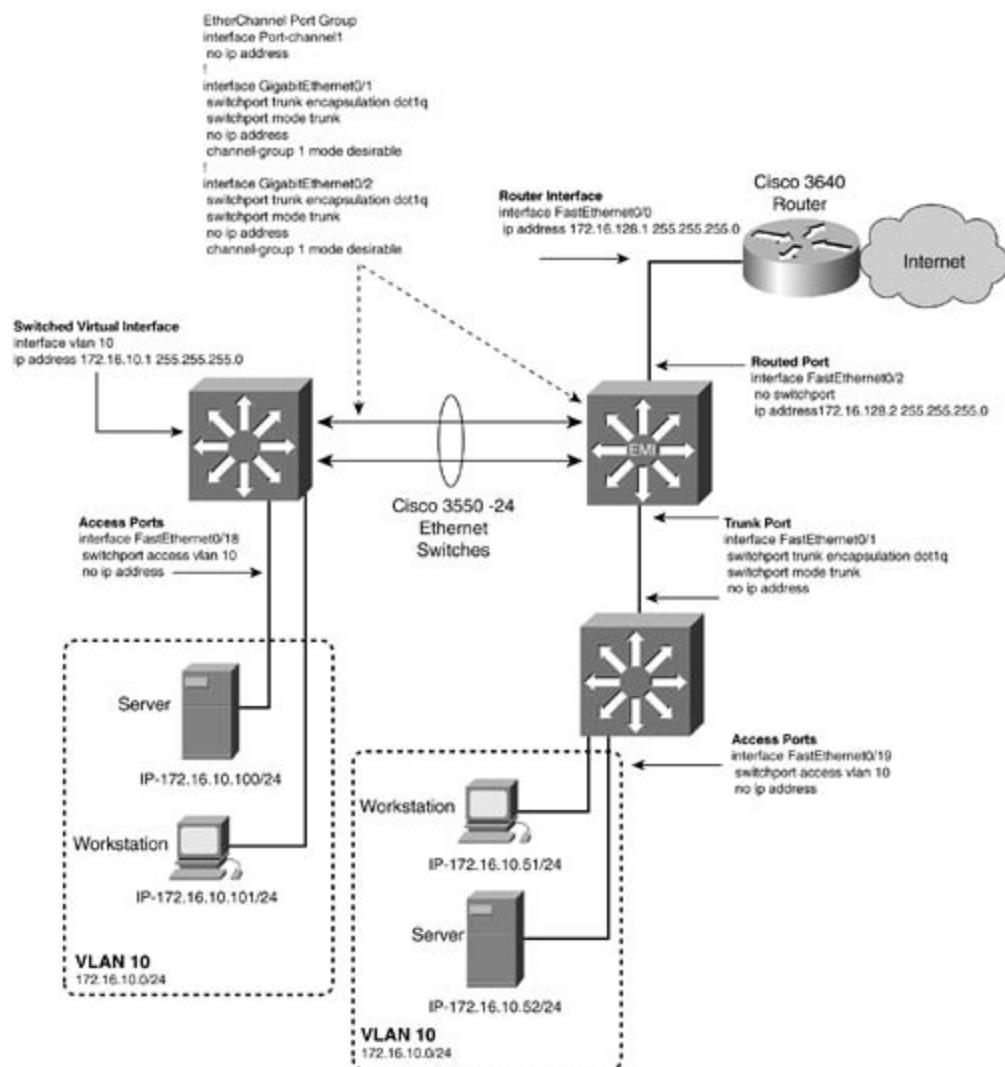
A *switch virtual interface* (SVI) is a logical interface that ties Layer 3 functionality, such as IP interfaces, to a VLAN. The SVI, in turn, can be used for inter-VLAN routing, to fallback-bridge nonroutable protocols between VLANs, and to represent the VLAN to a routing domain. By default, an SVI is created for VLAN 1 for management. If you are familiar with the Cisco 2900XL/3500XL series switches from CCIE PSV1, a similar concept exists, much like the "interface VLAN 1" used for management. Unlike the previous switches, you can configure multiple SVIs and a routing protocol to provide connectivity between the VLANs. To configure an SVI, aside from the single default, you must have the EMI software image installed on the switch.

Routed Ports

A routed port acts very much like its name implies. It is a physical port on the switch that has no VLAN information. In place of VLAN information, it has Layer 3 information, such as IP addresses. A routed port functions just like an interface on a router. A routed port cannot contain VLAN subinterfaces and requires software to be installed on the switch. To become a routed port, switching must be disabled for the port (you can accomplish this by using the `no switchport` command). Router ports also use an internal VLAN.

The various ports and interfaces can be used in a number of different ways. [Figure 1-15](#) illustrates how they can be used in a common network.

Figure 1-15. Various Ports and Interfaces on the Catalyst 3550



Configuring Catalyst 3550 Ethernet Switches

The Catalyst 3550 is an extremely versatile switch. With the EMI image installed, the switch essentially becomes a full-featured router.

of the configuration options of the Cisco IOS Software found on a router. General management and functions are configured just like they are on a router. For instance, the host name, enable password protocols, and IP addresses are all configured just as you would configure them on a router. If you are experienced with configuring Catalyst 2900XL/35xx series switches and Cisco routers, you'll find the Catalyst 3550 a familiar environment. The remaining sections of this chapter focus primarily on core switching aspects of the Catalyst 3550.

LAN switches were designed to be easy to install and configure. On smaller networks, little to no configuration might be required. On large redundant networks, with multiple VLANs and trunks, switching becomes a task. Configuring Ethernet switching on the Catalyst 3550 requires a seven-step process, as follows:

- Step 1. Configure switch management.
- Step 2. Configure VTP and VLANs and assign ports/interfaces to VLANs.
- Step 3. Configure connections between switches using EtherChannel, 802.1Q, or ISL encapsulation.
- Step 4. Optional: Control STP and VLAN propagation.
- Step 5. Optional: Configure SVIs.
- Step 6. Optional: Configure routed ports.
- Step 7. Optional: Configure Layer 3 switching.

Step 1 involves configuring the management VLAN, IP addresses, and default gateways on the switch so that it can be accessed in-band from the internetwork.

Step 2 is where you define the VTP domain and the VLANs on the VTP servers or transparent mode. During this step, you also assign ports to VLANs.

Step 3 involves configuring VLAN trunks, if there are any on the network.

Step 4 is optional but critical to large networks. It involves controlling STP through the setting of root guard, clearing VLANs from trunks, and using VLAN prune eligibility.

Whereas Steps 1 through 4 can be performed for most Catalyst series switches, Steps 5 and 6 apply specifically to the Catalyst 3550. Step 5 involves configuring SVIs, which can be used for inter-VLAN connectivity.

Step 6 calls for you to configure routed ports. Routed ports are used when you want to put a static IP address on an interface, and you want the interface to behave like a *normal*/router interface; that is, IEEE 802.1Q tagging will occur on the interface and no VLAN information will be sent. A routed interface will, of course, be routable. The EMI software needs to be installed for routed interfaces.

Step 7 also applies only to switches with the EMI software installed. Layer 3 switching for all intents and purposes means enabling a routing protocol on the switch.

Step 1: Configuring Switch Management

All Catalyst switches have the capability to be managed remotely by an IP address. The Catalyst 3550, by default, uses Dynamic Host Configuration Protocol (DHCP) to resolve a default gateway on virtual interface 0. If a DHCP server is not available, an IP address and default gateway can be assigned manually. To do this, you must assign an IP address to the switch, along with a default gateway or default route for traffic to forward on. The default management VLAN is VLAN 1; you can specify another VLAN.

The Cisco IOS Software on Catalyst 3550 resembles a router with a special *VLAN database* added to capability to create multiple VLAN interfaces (SVIs). The commands for assigning ports, trunks, and management are all performed from within the global configuration mode on the switch. VLAN info for VLANs 1 through 1001, and VTP information, is configured from either the global configuration mode or *configuration mode*, sometimes referred to as the *VLAN database*. Keying in `vlan` database from the enable/privileged mode accesses the VLAN configuration mode, or VLAN database.

The 3550 switch has a default virtual interface called interface VLAN 1. This is the default VLAN for management and is in an administratively Down state. To assign a management IP address, enter an IP address for VLAN interface mode and activate the virtual interface with the `no shutdown` command. If VLAN 1 is assigned for management, the interface becomes active and no further configuration is necessary. [Example 1-1](#) demonstrates how to configure the management interface on VLAN 1.

Example 1-1. Configuring the Management Interface on a Catalyst 3550

```
3550_switch(config)#interface vlan 1
3550_switch(config-if)#ip address 172.16.100.10 255.255.255.0
3550_switch(config-if)#no shut
3550_switch(config-if)#
00:07:25: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:07:26: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed state up
```

If configuring a management address on a VLAN other than VLAN 1, you must ensure the following before the interface will become up and active.

1. The VLAN matching the interface must be in the VLAN database.
2. An interface with that VLAN must be up, or a trunk line must be up.

In [Example 1-2](#), the management interface is on VLAN 128. For this interface to become active, you must have VLAN 128 on the switch, create the virtual interface called interface VLAN 128, and have an active interface on VLAN 128. If a trunk is configured on the switch, the virtual interface also becomes active. [Example 1-2](#) demonstrates the configuration of a management interface on VLAN 128. Notice how VLAN 128 does not become active until the physical interface FAST 0/10 becomes active.

Example 1-2. Configuring the Management Interface on VLAN 2

```
3550_switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
```

```

3550_switch(config)#vlan 128
3550_switch(config-vlan)#exit
3550_switch(config)#interface vlan 128
3550_switch(config-if)#ip address 172.16.128.16 255.255.255.0
3550_switch(config-if)#exit
3550_switch(config)#interface fast 0/10
3550_switch(config-if)#switchport access vlan 128
3550_switch(config-if)#no shut
3550_switch(config-if)#
00:52:36: %LINK-3-UPDOWN: Interface FastEthernet0/10, changed state to down
00:52:37: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/10, change
➥ to down
00:52:40: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/10, change
➥ to up
00:53:10: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan128, changed state t

```

The management interface can be viewed just like a physical interface, with the show interface v command.

To configure a default gateway, use the ip default-gateway *ip_address* command, the same as it router. [Example 1-3](#) shows how to configure the default gateway followed by the show ip route command verifying the new default gateway/route. Here the default gateway points at the router 172.16.128

Example 1-3. Configuring Default Routing on Catalyst 3550

```

3550_switch(config)#ip default-gateway 172.16.128.5
3550_switch(config)#exit
3550_switch#
3550_switch#show ip route
Default gateway is 172.16.128.5

```

Host	Gateway	Last Use	Total Uses	Interface
ICMP redirect cache is empty				
3550_switch#				

NOTE

VLAN 1 - "Just Say No"

CCIE PSV1 stressed avoiding use of VLAN 1 for user traffic. A personal design rule I use in the avoid VLAN 1 if at all possible. There are numerous reasons for this. VLAN 1 is the default VLA Catalyst switches and the native VLAN. Any switch added to the network will, by default, be in This leaves the network vulnerable to potential VTP, VLAN, and data corruption. Mono Spanning on 802.1Q uses VLAN 1 for its entire spanning-tree domain. The switch will also tag frames di on VLAN 1 depending on the encapsulation used. Some Catalyst switches enable you to clear ' from a trunk, whereas some will not; this could force VLAN 1 to span the entire switched netw these reasons and more that aren't listed, I personally don't run production traffic or manager traffic on VLAN 1. When designing LANs and VLAN 1 comes up, just say no!

Controlling IP and Console Access on Catalyst 3550

Controlling access on the Catalyst 3550 switch is identical to controlling access on the router. An enable password might be set, and an enable secret password might also be set. All the rules that apply to and enable secret passwords on routers apply to the switch. The syntax to accomplish this is as fol

```
3550_switch(config)#enable password cisco
```

The enable password is not encrypted and can be viewed in the configuration. The enable password is encrypted with the global command:

```
3550_switch(config)#service password-encryption
```

The **service password-encryption** command encrypts all passwords on the switch with Cisco proprietary encryption, simply called *type-5*:

```
3550_switch(config)#enable secret ccie
```

The enable secret password is always encrypted with a very strong Cisco proprietary encryption called *type-7*. The enable secret password takes precedence over the enable password if both are configured. The enable secret password is not in a readable form in the configuration. The full syntax for the enable secret password is as follows:

```
3550_switch(config)#enable secret [level level] {password | [encryption-type]  
[encrypted-password]}  
[keyid]
```

You can use the full syntax to cut and paste encrypted passwords from one source to another. Be very careful when setting the level or encryption type with this command, because it is very easy to enter a password incorrectly. A highly recommended practice is that you encrypt all passwords after they have been configured with the **service password-encryption** command. This avoids typos and many syntactical issues that can occur.

Access to the 3550 switch is controlled by configuring passwords and access control lists (ACLs) on the console (cty) and virtual terminal (vty) lines. Recall from [CCIE PSV1](#) that the cty is the console port on the switch and the vty lines are virtual Telnet sessions. You can view the absolute line values on the switch with the **line** command, as demonstrated in [Example 1-4](#). Line 0 is the vty or console port, whereas lines 1 through 4 are vty or virtual Telnet sessions.

Telnet access can be controlled through creating ACLs and applying them to the vty lines on the switch with the **access-class** line configuration command. ACLs can also be called on the SNMP community string configuration command.

Example 1-4. Absolute Line Values on the Catalyst 3550

```
3550_switch#show line

  Tty Typ      Tx/Rx   A Modem   Roty AccO AccI   Uses   Noise   Overruns   Int
*   0 CTY          - -       - -       - -       0       0       0/0       -
    1 vty          - -       - -       - -       0       0       0/0       -
    2 vty          - -       - -       - -       0       0       0/0       -
...text omitted
    15 vty         - -       - -       - -       0       0       0/0       -
    16 vty         - -       - -       - -       0       0       0/0       -
```

[Example 1-5](#) demonstrates the configuring of a username and password that will be used to control access and Telnet access. The example shows login local being entered on the console port and the ports. This forces the switch to use the locally entered username password command for authentication. ACL 10, is also being applied to the vty sessions. In this example, the ACL will only allow users to switch from networks in the range of 172.16.0.0. For more information on configuring CTY and vty absolute line numbers, refer to [CCIE PSVI Chapter 1](#), "The Key Components for Modeling an Internetwork."

Example 1-5. Configuring Default Routing on Catalyst 3550

```
3550_switch(config)#username solie password cisco
3550_switch(config)#line 0
3550_switch(config-line)#login local
3550_switch(config-line)#exit
3550_switch(config)
3550_switch(config)#line 1 16
3550_switch(config-line)#login local
3550_switch(config-line)#access-class 10 in
3550_switch(config-line)#exit
3550_switch(config)
```

```
3550_switch(config)#username ksolie password cisco  
3550_switch(config)#access-list 10 permit 172.16.0.0 0.0.255.255
```

Step 2: Configuring VTP and VLANs on Catalyst 3550 Switches

Configuring VTP and VLANs on the 3550 series switches requires a three-substep process, as follows:

- Step 1. Configure a VTP domain and mode.
- Step 2. Configure VLANs, if the switch is operating in VTP server or transparent mode.
- Step 3. Configure physical port properties and assign ports to VLANs.

Configuring VTP Domain and Mode on Catalyst 3550 Switches

You can configure VLANs on the Catalyst 3550 from the VLAN database or VLAN configuration mode, which is a traditional router-like global configuration mode. For the most part, the syntax is identical. If you have experience configuring Catalyst 2900XL/35xx switches, the VLAN configuration mode might be more familiar to you. This mode is entered by the privileged-mode command `vlan database`. When in the VLAN database, you must enter the following commands:

- `abort`— Exits the VLAN database and undoes any VLAN changes you have made since you entered the VLAN database. VTP changes are not aborted.
- `exit`— Exits the VLAN database and applies all VLAN changes; also increments the VTP revision number.
- `apply`— Applies current VLAN changes and increments the VTP revision number but does not commit the changes to the VLAN database.
- `reset`— Clears any current VLAN changes and rereads the VLAN databases.

A VTP domain should always be configured for security reasons. This prevents a new switch from injecting bad configuration information into your network. The default VTP name is Null and the mode is server. To configure the VTP domain, use the following syntax in the VLAN configuration mode:

```
3550_switch#vlan database  
3550_switch(vlan)#vtp domaindomain_name [password]
```

If you add a password behind the domain name, VTP updates will use a Message Digest Algorithm to encrypt the password. Using VTP passwords is a very effective way to add a layer of security and your switching domain. In the current Cisco IOS Software release, you can only configure a VTP password in VLAN configuration mode. You cannot enter a VTP password from the global configuration mode. To enter VTP mode, use the following command from the VLAN configuration mode:

```
3550_switch(vlan)#vtp [server | client | transparent]
```

To configure the VTP domain and mode from the global configuration mode, use the following syntax:

```
3550_switch(config)#vtp domaindomain_name  
3550_switch(config)#vtp [server | client | transparent]
```

You can view the VTP domain by using the show vtp status command. This command displays information about the VTP domain, such as configuration revision, domain name, operating mode, and so on. Near the bottom of the display the new information that appears on Catalyst 3550. It shows the IP address used by VTP to identify which specific switch you are synchronizing VTP information with. If no router is configured, or improperly configured with an all-0s address, 0.0.0.0 appears. If the switch is a VTP server and has not received updates via its trunk lines, its own address displays. [Example 1-6](#) lists the output of the vtp status command.

Example 1-6. Viewing the VTP Domain Information

```
3550_switch#show vtp status  
  
VTP Version : 2  
  
Configuration Revision : 1
```

```

Maximum VLANs supported locally : 1005

Number of existing VLANs      : 6

VTP Operating Mode           : Server

VTP Domain Name               : psv2

VTP Pruning Mode              : Disabled

VTP V2 Mode                   : Disabled

VTP Traps Generation         : Disabled

MD5 digest                   : 0x03 0xE2 0xB2 0x25 0x2B 0xF1 0xBE 0x19

Configuration last modified by 172.16.128.16 at 3-1-93 03:16:46

Local updater ID is 172.16.128.16 on interface Vl128 (lowest numbered VLAN interface
found)

Preferred interface name is 3550

3550_switch#

```

You can configure the interface or IP address VTP uses to identify the switch to other switches in the network with the following global configuration command:

```
3550_switch(config)#vtp interface [ VTP_updater_name | ip_address ]
```

NOTE

VLAN information is propagated only if the VTP revision number of the server is *higher* than the VTP revision number. If the VTP client's revision number is equal to or higher than the server's, the server will not accept VLAN information. To view the current VTP revision numbers, use the commands show vtp domain on Catalyst 4000/5500/6500 series switches and show vtp status on Catalyst 2900/3500 series switches.

Configuring Normal and Extended-Range VLANs on Catalyst 3550 Switches

The second step involves VLAN configuration if the VTP mode is set as a *server* or *transparent*. If the switch is configured as a VTP *client*, VLANs appear when the trunk line comes up and the VLAN databases are synchronized. VLANs are configured in the VLAN database, just by entering `vlan [1-1001] options` as mentioned previously, VLANs 1002 through 1005 and VLAN 1009 are default and special VLANs that can be used in Ethernet switching. VLANs may also be configured from the global configuration mode via `vlan [1-4094]`. VLANs 1006 through 4094 are extended-range VLANs that are configured from the extended-range configuration mode. The switch must also be in VTP transparent mode to configure extended range VLANs.

Configuring Normal-Range VLANs

You can configure normal-range VLANs, VLANs 1 through 1001, in the global configuration mode or via the VLAN database. If VLANs are configured from the VLAN database, changes in VLANs must be committed with the `commit` command. All changes are also applied when the VLAN database is exited. If a mistake is made, you can cancel VLAN changes with the `abort` or `reset` command as mentioned previously. The VLAN database is stored in the file `VLAN.DAT` in Flash memory. You can copy the `VLAN.DAT` file to a TFTP server just as you can copy any other memory file for backup purposes. [Example 1-7](#) demonstrates two ways to configure a VLAN on the switch. The first way uses the VLAN database, and the second way demonstrates using the global configuration mode. In the example, two VLANs are created: VLAN 128 with the name `psv2_vlan128`, and VLAN 10 with the name `psv2_vlan10`.

Example 1-7. Configuration of VLAN 128 and VLAN 10

```
3550_switch#vlandatabase
3550_switch(vlan)#vlan 128 name psv2_vlan128
VLAN 128 added:
    Name: psv2_vlan128
3550_switch(vlan)#apply
APPLY completed.

3550_switch(vlan)#exit
! The preceding command automatically applies updates
APPLY completed.

Exiting.....
Global Configuration mode----->
3550_switch#conf t
```

```
3550_switch(config)#vlan 10  
3550_switch(config-vlan)#name psv2_vlan10
```

Some common options that may be configured on the VLAN from the VLAN configuration mode include the following:

```
Switch(vlan)#vlanvlan_num [namevlan_name] [state {active | suspend}] [saidsaid_val]  
[mtumtu] [bridgebridge_number] [stp type {ieee/ibm/auto}]
```

- name— Enables you to attach a 32-character name to the VLAN.
- state— Enables you to suspend the VLAN. A suspended VLAN is propagated via VTP, but no traffic is carried on the VLAN.
- said— Enables you to change the SAID value of the VLAN; the SAID value is used primarily in RSTP calculations.
- mtu, bridge, and stp— Enables you to change the default MTU value, bridge number, and Spanning Tree parameters.
- No **vlan**[*vlan_num*— Deletes a VLAN from the VLAN database. When you delete a VLAN, any ports assigned to that VLAN become inactive, including the management interface.

If you are configuring the VLAN options from the global configuration mode, the VLAN options are configured from the VLAN interface mode.

For the default VLAN values, see [Table 1-2](#) earlier in this chapter.

To view the status of the VLANs, use the **show vlan** command, which displays all the VLANs on the switch, their state, and which ports are assigned to each VLAN. To display specific physical and logical information about a single VLAN, use the **show vlan id [*vlan_number*]** command. [Example 1-8](#) lists the output of the **show vlan** command, followed by the more specific version of the command. Notice how the VLAN logical names immediately identify the port purpose.

Example 1-8. show vlan Command Output

```
3550_switch#show vlan
```

VLAN	Name	Status	Ports
------	------	--------	-------

```
-----  
1      default          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4  
                                Fa0/5, Fa0/6, Fa0/7, Fa0/8  
                                Fa0/9, Fa0/11, Fa0/12, Fa0/13  
                                Fa0/14, Fa0/15, Fa0/16, Fa0/17  
                                Fa0/18, Fa0/19, Fa0/20, Fa0/21  
                                Fa0/22, Fa0/23, Fa0/24, Gi0/1  
                                Gi0/2  
10     psv2_vlan10      active  
128    psv2_vlan128      active    Fa0/10  
1002   fddi-default      active  
1003   token-ring-default active  
1004   fddinet-default    active  
1005   trnet-default      active  
-----
```

VLAN	Type	SAID	MTU	Parent	RingNo	BridgeNo	Stp	BrdgMode	Trans1	Trans2
1	enet	100001	1500	-	-	-	-	-	0	0
10	enet	100010	1500	-	-	-	-	-	0	0
128	enet	100128	1500	-	-	-	-	-	0	0
1002	fddi	101002	1500	-	-	-	-	-	0	0
1003	tr	101003	1500	-	-	-	-	-	0	0
1004	fdnet	101004	1500	-	-	-	ieee	-	0	0
1005	trnet	101005	1500	-	-	-	ibm	-	0	0

```
3550_switch#-----
```

```
3550_switch#show vlan id 128-----
```

VLAN	Name	Status	Ports
------	------	--------	-------

```
-----
```

```

128 psv2_vlan128           active    Fa0/10

VLAN Type  SAID      MTU   Parent RingNo BridgeNo Stp  BrdgMode Trans1 Trans2
-----  -----  -----  -----  -----  -----  -----  -----  -----  -----  -----  -----
128  enet  100128     1500   -     -     -     -     -     0     0
3550_switch#

```

CAUTION

The Catalyst 3550 switch supports 128 STP instances. Each VLAN runs a single instance of STP. If a switch has more active VLANs than supported 128 STP instances, STP is disabled on the remaining VLANs. If you have already used up all available 128 STP instances on a switch, adding another VLAN anywhere in the VTP domain creates a VLAN on that switch that is not running STP. If you have a "default allowed list" on the trunk ports of that switch (which is to allow all VLANs), the new VLAN is carried on all trunk ports. Depending on the topology of the network, this could create a loop. This is because the new VLAN could be partitioned, particularly if there are several adjacent switches that have more than 128 STP instances. You can prevent this by setting allowed lists on the trunk ports of switches so that they will not propagate STP for all VLANs. This is the same as clearing the trunk ports on Catalyst 5500/6500 series switches.

Configuring Extended-Range VLANs

The Catalyst 3550 switch enables you to configure extended VLANs. *Extended VLANs* are VLANs in the range of 1006 to 4094. However, the 3550 switch uses an extended VLAN ID for each routed port. Therefore, the safe range, and safe range, for extended VLANs is roughly 1027 through 4094. When configuring extended VLANs, you must follow certain guidelines. Those guidelines are as follows:

- The switch must be in VTP transparent mode prior to any extended VLAN configuration.
- Routed ports use an extended VLAN starting at the lower ranges 1006 through 1026. Always use an extended VLAN ID starting at 4094 and go backward. For caution, use the command `show vlan` to verify what internal VLANs are in use and the interface that is using them. [Example](#) demonstrates the use of this command prior to configuring an extended VLAN.
- Extended VLANs can only be created from the configuration mode. They cannot be created from the configuration mode.
- Extended VLANs are not saved in the VLAN database and are not advertised via VTP.
- Extended VLANs are not supported by VLAN Query Protocol (VQP) or VLAN Membership Policy (VMPS).
- STP is enabled by default on extended VLANs.
- At this time, you cannot name an extended VLAN; you can only change the MTU value.

The configuration to configure extended VLANs is identical to configuring a normal-range VLAN, except you must adhere to the guidelines previously listed. [Example 1-9](#) demonstrates the configuration of an extended VLAN 4094. Prior to configuring the extended VLAN, the switch is put into VTP transparent mode, a `vlan internal usage` command is executed to avoid a VLAN conflict.

Example 1-9. Creating an Extended VLAN

```
3550_switch#show vlan internal usage ← Verify internal VLANs

VLAN Usage

-----
1017 -

1025 FastEthernet0/11

! VLAN 1025 in use by INT FAST 0/11

1026 GigabitEthernet0/2

! VLAN 1026 in use by INT GIG 0/2

3550_switch#

3550_switch#conf t

3550_switch(config)#vtp mode transparent

! VTP transparent mode set

Setting device to VTP TRANSPARENT mode.

3550_switch(config)#vlan 4094

! VLAN 4094 created
```

You can view an extended VLAN with the `show vlan` command. [Example 1-10](#) lists the output of the `show vlan` command after the extended VLAN 4094 has been created.

Example 1-10. Viewing an Extended VLAN

```
3550_switch#show vlan

VLAN Name          Status    Ports
```

```

-----  

1     default           active    Fa0/1, Fa0/2, Fa0/3, Fa0/4  

                           Fa0/5, Fa0/6, Fa0/7, Fa0/8  

                           Fa0/9, Fa0/12, Fa0/13, Fa0/14  

                           Fa0/15, Fa0/16, Fa0/17, Fa0/18  

                           Fa0/19, Fa0/20, Fa0/21, Fa0/22  

                           Fa0/23, Fa0/24, Gi0/1  

10    psv2_vlan10       active  

128   psv2_vlan128     active    Fa0/10  

1002  fddi-default     active  

1003  token-ring-default active  

1004  fddinet-default  active  

1005  trnet-default    active  

4094  VLAN4094        active  

VLAN Type  SAID      MTU   Parent RingNo BridgeNo Stp  BrdgMode Trans1 Trans2
-----  

1     enet   100001    1500  -     -     -     -     -     0     0  

10    enet   100010    1500  -     -     -     -     -     0     0  

128   enet   100128    1500  -     -     -     -     -     0     0  

1002  fddi   101002    1500  -     -     -     -     -     0     0  

1003  tr     101003    1500  -     -     -     -     -     0     0  

1004  fdnet  101004    1500  -     -     -     ieee  -     0     0  

1005  trnet  101005    1500  -     -     -     ibm  -     0     0  

4094  enet   104094    1500  -     -     -     -     -     0     0  

3550_switch

```

The Catalyst 3550 enables you to configure a range of interfaces at a single time. This can be a timesaver if you have to configure many ports on a switch with the same characteristics. To configure a range of interfaces, use the following global configuration command:

```
Switch(config)#interface range interface_type starting_int - ending_interface
```

To configure the range of interfaces 0/1 through 0/10, for example, use the following command:

```
3550_switch#(config)interface range fastethernet 0/1 - 10
```

Configuring Physical Port Properties and Assigning Ports to VLANs on Catalyst 3550

The next step for VTP and VLAN configuration is to configure any physical port properties, along with the port to a VLAN. Physical port properties are changed from the interface configuration mode. [To change the default Layer 2 interface settings on the Catalyst 3550 switch.](#)

Table 1-11. Default Layer 2 Ethernet Settings on Catalyst 3550

Feature	Default Setting
Operating mode	Layer 2 switching (switchport).
Allowed VLAN range	VLANs 1–4094.
Default VLAN	VLAN 1.
Native VLAN	VLAN 1.
VLAN trunking	DTP.
All ports enabled	
Speed	Autonegotiate.
Duplex mode	Autonegotiate.
Flow control	Off for receive and desired for send for 10/100/1 (Send is always off for 10/100 Mbps.).
EtherChannel (PAgP)	Disabled.
Port blocking of unknown multicast and unicast traffic and storm control	Disabled.
Protected port	Disabled.
Port security	Disabled.
PortFast	Disabled.

[Example 1-11](#) demonstrates configuring an Ethernet port to 100 Mbps half duplex on a 3550 series example also assigns the logical name management_vlan_128 to the interface.

Example 1-11. Configuring Physical Port Properties

```
3550_switch(config)#interface fast 0/10
3550_switch(config-if)#speed 100
3550_switch(config-if)#duplex half
3550_switch(config-if)#description management_vlan_128
```

NOTE

To change the duplex setting of a port, you first must change the speed from auto to 100 or 1 Gbps. The switch does not allow you to change duplex when the port is configured for autonegotiation.

Some common physical properties of Ethernet that you can change in the interface configuration are as follows:

- duplex[full|half|auto]— Sets the port duplex mode.
- speed[10|100|auto]— Sets the port speed.
- mtu[1500bytes-2018bytes]— Configures the MTU of the interface. Ensure that the MTU of the interface matches that of VLAN, if you change this value.
- description*interface_description*— Enables you to set a description for the interface.
- shutdown|no shutdown— Disables and enables the interface.

The interface command switchport is used with no options to put the port into a Layer 2 switching mode. The port can be an access port, trunk port, 802.1Q tunnel port, voice port, or protect port. The following table lists the subcommands of the switchport command:

- access— Assigns the interface to a single VLAN.
- trunk— Used to configure the port as an 802.1Q or ISL trunk. The next section discusses this mode in greater detail.
- 802.1q tunnel ports— 802.1Q tunnel ports transport information and data of a VLAN within a single frame across the LAN.
- voice vlan— The port can use 802.1Q and 802.1p for QoS.
- protected ports— Protected ports prevent unicast, multicast, and broadcast traffic between two ports on the same switch.

Upcoming sections discuss the various modes in greater detail; at this time, however, the focus is on assigning the port to a single VLAN. To accomplish this, first you configure the port to be in access mode, and then assign the VLAN to the port. The syntax used to accomplish this is as follows:

```
(config-if)#switchport access vlan [1-4094 | dynamic]
```

The dynamic keyword is used in VLAN Membership Policy Server (VMPS) configurations. VMPS is not discussed in this text. For more information on VMPS, refer to *Cisco LAN Switching* (Cisco Press, 1999).

[Example 1-12](#) demonstrates the configuration of Fast Ethernet 0/5 for VLAN 2.

Example 1-12. Assigning VLAN 2 to Interface fast 0/5

```
Switch(config)#int fastEthernet 0/5
Switch(config-if)#switchport mode access
Switch(config-if)#switchport access vlan 2
```

When the VTP mode is set to *transparent*, VLANs are automatically created with the switchport **access** command; you do not need to statically configure them in the VLAN database. If the VTP mode is **server**, you cannot configure VLANs on this switch. The VLANs must be configured on the server switch and then propagated via VTP over a trunk to the client switch.

Step 3: Configuring Trunks Between Switches Using EtherChannel, 802.1Q, and ISL Encapsulations

Step 3 involves configuring trunk lines between Ethernet switches. A trunk line can be a normal trunk line using 802.1Q encapsulation, or it can be an EtherChannel trunk, which could also be using 802.1Q or ISL encapsulation. This discussion first focuses on configuring a normal trunk line, and then turns to configuring an EtherChannel trunk.

Configuring trunks on the Catalyst 3550 is a two-step process. Depending on the state of the port prior to configuration, you may have to disable autonegotiation mode. By default, a port is set to negotiate its own encapsulation and to be in the dynamic and desirable mode.

Step 1. Configure the trunk encapsulation as ISL or 802.1Q.

Step 2. Configure the port as a normal trunk or EtherChannel trunk.

These steps are accomplished with the following commands from the interface configuration mode:

```
Switch#(config-if)#switchport trunk encapsulation [isl | dot1q | negotiate ]
Switch#(config-if)#switchport mode [trunk | dynamic {auto | desirable}]
```

The different encapsulation types and subcommands mean the following:

- **switchport trunk encapsulation isl**— Specifies ISL encapsulation on the trunk link.

- **switchport trunk encapsulation dot1q**— Specifies 802.1Q encapsulation on the trunk link.
- **switchport trunk encapsulation negotiate**— Specifies that the interface negotiate with the interface to become an ISL (preferred) or 802.1Q trunk, depending on the configuration and the neighboring interface. This is the default encapsulation type.

The port, as a trunk, may be statically configured or dynamically configured. The different trunk modes are as follows:

- **dynamic auto**— Sets the interface to a trunk link if the neighboring interface is set to trunk mode.
- **dynamic desirable**— Sets the interface to a trunk link if the neighboring interface is set to trunk desirable, or auto mode. This is the default trunking mode.
- **trunk**— Sets the interface in permanent trunking mode and negotiates to convert the link to a trunk even if the neighboring interface is not a trunk interface.

You might find that configuring the auto-negotiation, or DTP, is more difficult than just statically defining a trunk. This is mainly due to some of the differences in the default trunks for the various Catalysts switches. Catalysts default to ISL; however, the Catalyst 4000 without the Layer 3 module or the latest Cisco routers doesn't support ISL. Another example is that 802.1Q autonegotiation is only supported in CAT OS switches starting from Release 4.2. These little things can make DTP unreliable in large heterogeneous networks.

NOTE

Another autoconfiguration issue may arise with VTP and DISL. When DISL negotiates an ISL trunk, it includes the VTP name in the message. If the VTP domain names differ on the switches, the trunk will not become active. Again, to circumvent this, just statically configure the trunk and configure the trunk encapsulation type. For VTP to work, you still need to match VTP names.

Example 1-13 demonstrates the configuration of an 802.1Q trunk on the Gigabit Ethernet interface G0/1.

Example 1-13. Configuring an ISL Trunk

```
3550_switch(config)#interface gigabitEthernet 0/1
3550_switch(config-if)#switchport trunk encapsulation dot1q
3550_switch(config-if)#switchport mode trunk
```

To verify whether the trunk is working, be sure to status both sides of the link. The output of the `sh interface_name switchport` command and the output of the `show interface/interface_name trunk` command present a general status of the trunk. The information presented here is very similar to the `show trunk` command on the Catalyst 4000/5500/6500 series switches.

This command shows the status of the trunk and the encapsulation. VLAN information, such as the active VLANs on the links, and any prune-eligible VLANs, will also be listed. Furthermore, prote and voice VLANs are listed with this command. [Example 1-14](#) lists the output of the show interface_name switchport command. If the trunk is not listed, some configuration areas to note following:

- Mode
- Encapsulation
- Native VLANs for 802.1Q trunks

Set the status of the trunk to be trunking and the mode to be on, or match a valid setting for DTP as previously. The encapsulation must match on both sides of the trunk. The native VLAN ID is the VLAN used for its single instance of spanning tree (MST). This VLAN must be the same throughout the VTF

Example 1-14. Status of a Trunk Line

```
3550_switch#show interface gigabitEthernet 0/1 switchport
```

```
Name: Gi0/1
```

```
Switchport: Enabled
```

```
Administrative Mode: trunk
```

```
Operational Mode: trunk
```

```
Administrative Trunking Encapsulation: dot1q
```

```
Operational Trunking Encapsulation: dot1q
```

```
Negotiation of Trunking: On
```

```
Access Mode VLAN: 1 (default)
```

```
Trunking Native Mode VLAN: 1 (default)
```

```
Trunking VLANs Enabled: ALL
```

```
Pruning VLANs Enabled: 2-1001
```

```
Protected: false
```

```
Unknown unicast blocked: disabled
```

```
Unknown multicast blocked: disabled
```

```
Voice VLAN: none (Inactive)
```

```
Appliance trust: none
```

```
3550_switch#
```

In 802.1Q networks, it is critical to ensure that the native VLAN is the same throughout the entire network. This is because 802.1Q uses Mono Spanning Tree. Mono Spanning Tree makes the entire VTP domain a single-bridged domain to all third-party 802.1Q switches. Cisco ensures compatibility with MST by implementing PVST+ along with MST. This is an extended version of Per VLAN Spanning Tree Plus which provides seamless transparent integration for 802.1Q networks. Mono Spanning Tree runs on each VLAN. For this reason, it is important to have the same native VLAN throughout the entire internet. The default VLAN is 1, which is also the default native VLAN. To change the native VLAN, use the following command on the trunk:

```
Switch#(config-if)#switchport trunk native vlanvlan-id
```

The show interface with the trunk keyword command will also list the VLANs that are *prune eligible* or *confuse-prune eligible*. VLANs with VLAN propagation. *Prune eligible* means that unnecessary broadcast and unknown unicast traffic will not be forwarded over trunk lines to switches that do not have an interface that is part of that particular VLAN. By default, all VLAN information and spanning-tree frames for each VLAN are sent out all trunking interfaces. VLANs and STP can only be removed from a trunk by using the clear trunk command on the Cisco Catalyst 5500/6500 series or by changing the VLANs allowed on a trunk on the Cisco 3550 switch. You will learn more about these functions in the upcoming section "[Step 4: Controlling STP Propagation](#)."

[Example 1-15](#) lists the output of the show trunk command. The trunk keyword displays similar information to the show switchport keyword. This command, however, focuses more on the VLAN information of the trunk.

Example 1-15. Status of a Trunk Line with the trunk Keyword

```
3550_switch#show interface gigabitEthernet 0/1 trunk
```

Port	Mode	Encapsulation	Status	Native vlan
Gi0/1	on	802.1q	trunking	1

Port	Vlans allowed on trunk
Gi0/1	1-4094

```
Port      Vlans allowed and active in management domain
Gi0/1    1,10,20,128
Port      Vlans in spanning tree forwarding state and not pruned
Gi0/1    1,10,20,128
3550_switch#
```

At times, it might be hard to determine whether a trunk line is functioning. The trunk can report a trunking but not be fully exchanging VTP updates. You should view the trunk status on each side of ensure it is functioning properly.

As VTP synchronizes within the domain the VLAN database from server to server and server to client will have the same VLANs listed in their VLAN database. Only switches in the VTP transparent mode that have VLANs *cleared* or *removed* will have different VLAN databases. Comparing the VLAN database of two switches connected together by a trunk is another way to verify that the trunk is working.

When the trunk becomes active, VTP advertisements are sent and received. The following three types of advertisements occur on the trunk.

- Subset advertisements— Subset advertisements are issued when you create, delete, or modify a VLAN.
- Request advertisements— Request advertisements are issued from the switch whenever the switch is reset or a change in the local VTP domain occurs, such as a name change, or when the switch receives a summary advertisement with a higher configuration revision number than its own.
- Summary advertisements— Summary advertisements are issued every 5 minutes by the switch. The main purpose of the summary advertisement is for the switch to verify the VTP revision number and thereby ensure that the VLAN databases are current. If it has a lower revision number, it issues a request for new VLAN information.

You can observe VTP statistics with the `show vtp status` and the `show vtp counters` command. These commands tell you what advertisements are received and transmitted by the switch. These should be another indicator that the trunk line is functioning properly. After you verify the trunk is up, you should verify that the VTP updates are being exchanged. Remember that the goal of trunking is to pass VLAN information which requires VTP. Along with the trunk lines, you should also examine the VTP domain counters in the `show vtp counters` command. [Example 1-16](#) lists the output of the `show vtp counters` command.

Example 1-16. Statusing a Trunk by Viewing VTP Counters

```
3550_switch#show vtp counters

VTP statistics:

Summary advertisements received      : 101
Subset advertisements received       : 4
```

```
Request advertisements received      : 1
Summary advertisements transmitted : 116
Subset advertisements transmitted  : 3
Request advertisements transmitted : 0
Number of config revision errors   : 0
Number of config digest errors     : 0
Number of V1 summary errors        : 0
```

VTP pruning statistics:

Trunk	Join Transmitted	Join Received	Summary advts received from non-pruning-capable device
Gi0/1	0	0	0

```
3550_switch#
```

The `show vtp status` command lists very useful VTP information. The VTP version, VTP revision, operating mode, and domain name are listed along with VLAN information. When the VLAN databases are synchronized, each switch should have the same number of VLANs.

[Example 1-17](#) demonstrates the `show vtp status` command.

Example 1-17. Statusing a Trunk by Viewing VTP Status

```
3550_switch#show vtp status

VTP Version          : 2
Configuration Revision : 3
Maximum VLANs supported locally : 1005
Number of existing VLANs       : 12
VTP Operating Mode          : Server
VTP Domain Name             : psv2
```

```
VTP Pruning Mode : Disabled
VTP V2 Mode : Disabled
VTP Traps Generation : Disabled
MD5 digest : 0x40 0x2B 0xD9 0xD1 0x05 0xA4 0x98 0xF8
Configuration last modified by 206.191.241.43 at 3-1-93 18:06:59
Local updater ID is 172.16.128.16 on interface Vl128 (lowest numbered VLAN interface)
Preferred interface name is 3550
3550_switch#
```

Configuring Layer 2 and Layer 3 EtherChannel

EtherChannel is yet another form of trunk line you can configure. The common way to configure EtherChannel is as Layer 2 between two switches. Usually ISL or 802.1Q is also configured. On the Catalyst 3550 with software installed, you can also configure Layer 3 EtherChannel.

EtherChannel has some limitations you should be aware of when configuring it. Some of these limitations are hardware specific; therefore, it is a good idea to look up the specific EtherChannel limitations for the hardware you are configuring.

The following list applies to the configuration guidelines of the Catalyst 3550 Ethernet switch:

- Each EtherChannel can have up to eight compatibly configured Fast Ethernet interfaces and up to eight Gigabit Ethernet interfaces.
- Do not configure a GigaStack GBIC port as part of an EtherChannel.
- Configure all interfaces in an EtherChannel to operate at the same speeds and duplex modes.
- Enable all interfaces in an EtherChannel. An interface in an EtherChannel disabled by using the no interface configuration command is treated as a link failure, and its traffic is transferred to one of the remaining interfaces in the EtherChannel.
- When a group is first created, all ports follow the parameters set for the first port to be added to the group. If you change the configuration of one of these parameters, you must also make the changes to all ports in the group.
- An EtherChannel does not form if one of the interfaces is a Switch Port Analyzer (SPAN) destination. You may use the EtherChannel group as a source of SPAN to monitor the entire group.
- A port that belongs to an EtherChannel port group cannot be configured as a secure port.
- Assign all interfaces in the EtherChannel to the same VLAN, or configure them as trunks. Interfaces assigned to different native VLANs cannot form an EtherChannel.
- If you configure an EtherChannel from trunk interfaces, verify that the trunking mode (ISL or IEEE 802.1Q) is the same on all the trunks.

- An EtherChannel supports the same allowed range of VLANs on all the interfaces in a trunking EtherChannel. If the allowed range of VLANs is not the same, the interfaces do not form an EtherChannel even when PAgP is set to the auto or desirable mode.
- Before enabling 802.1X on the port, you must first remove it from the EtherChannel. If you enable 802.1X on a not-yet-active port of an EtherChannel, the port does not join the EtherChannel.
- Interfaces with different STP path costs can form an EtherChannel as long they are otherwise configured. Setting different STP path costs does not, by itself, make interfaces incompatible for formation of an EtherChannel.
- For Layer 3 EtherChannels, assign the Layer 3 address to the port-channel logical interface, not to the physical interfaces in the channel.
- By default, PAgP will have no Layer 2 or Layer 3 Channel groups assigned or defined. The Eth configuration for PAgP is auto and silent; the interface will respond to PAgP packets but will not negotiate. PAgP is configured as an aggregate-port learner with a PAgP priority of 128 on all ports.

Configuring Layer 2 EtherChannel ISL/802.1Q trunks on the Catalyst 3550 is a three-step process. Depending on the state of the port prior to configuration, you may have to disable autonegotiation mode. By default, the port is set to negotiate the encapsulation and to be in the dynamic and desirable mode.

Step 1. Configure the trunk encapsulation as ISL or 802.1Q.

Step 2. Configure the port as a trunk.

Step 3. Configure EtherChannel port groups.

These steps are accomplished with the following commands from the interface configuration mode:

```
Switch#(config-if)#switchport trunk encapsulation [isl | dot1q / negotiate]
Switch#(config-if)#switchport mode [trunk | dynamic {auto | desirable}]
Switch#(config-if)#channel-group [1-64]mode {auto [non-silent] | desirable [non-silent]}
```

The first two commands are identical to configuring a normal ISL or 802.1Q trunk. The channel-group command creates a virtual interface called interface port channel x , where x is the channel group number. This virtual interface lists all the common properties that must be associated with any link joining the ports. This virtual interface is also where you assign an IP address for Layer 3 EtherChannel. The channel group number ranges from 1 to 64. The mode keyword enables or disables PAgP. PAgP works rather reliably, but it is important that when you choose the mode in which to run PAgP that you use the same mode on all interfaces in the channel group. The mode keyword has the following parameters:

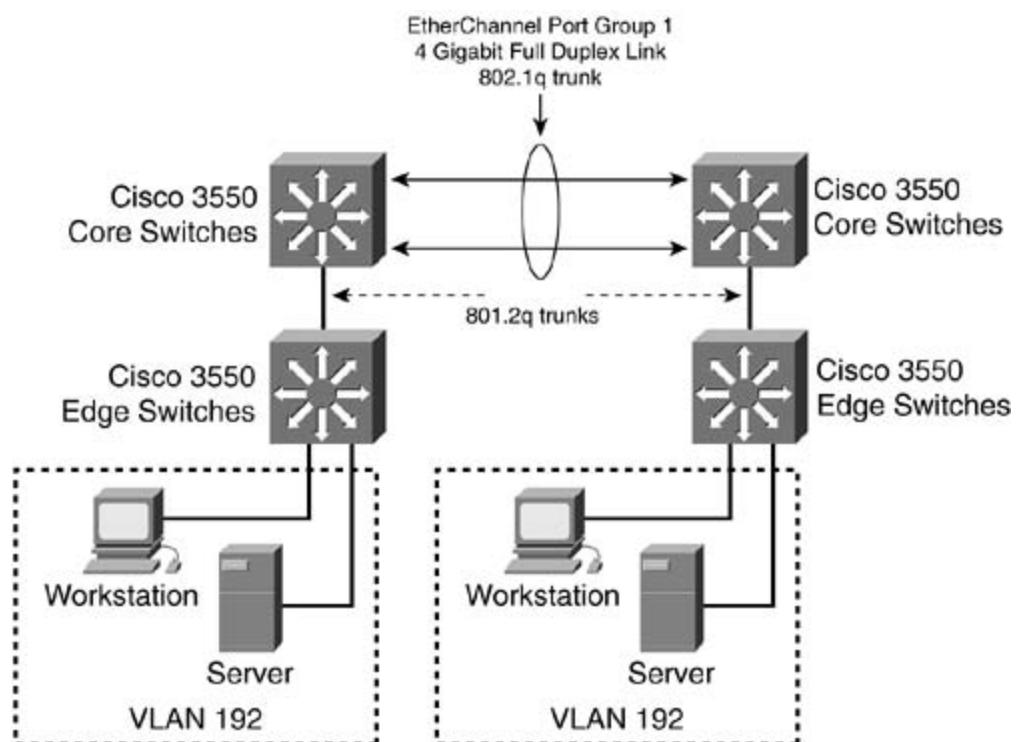
- auto— Enables PAgP only if another PAgP device is detected. It places the interface into a passive negotiating state, in which the interface responds to PAgP frames it receives but does not start negotiation.
- desirable— Unconditionally enables PAgP. This keyword places the interface into an active negotiating state, in which the interface starts negotiations with other interfaces by sending PAgP frames.
- on— Forces the interface to channel without PAgP. With the on mode, a usable EtherChannel is formed when an interface group in the on mode is connected to another interface group in the on mode.
- active(LACP)— Sets the interface into an active negotiating state, in which the interface starts negotiations with other interfaces by sending LACP packets.
- passive(LACP)— Sets the interface into a passive negotiating state. In this mode, the interface receives LACP packets that it receives but does not start LACP packet negotiation. This setting uses minimal processing power.

An EtherChannel can also be assigned to a specific VLAN, although this is less common. To accomplish this, assign all interfaces as static-access ports in the same VLAN.

When configuring EtherChannel, you will notice the link drops and initializes quite a bit—once for a port encapsulation change, and at least one other time when it joins the channel group. To prevent this from happening, just shut down the link before configuring any trunking or EtherChannel parameters. To remove an interface from the EtherChannel group, use the no channel-group interface configuration command.

[Figure 1-16](#) represents a common network. In this LAN, the core switches are connected to each other and to the edge switches. The core switches are going to use Gigabit EtherChannel to trunk the two switches together. 802.1Q will be the VLAN trunking protocol and will eventually allow VLAN 192 full connectivity between the two switches.

Figure 1-16. Gigabit EtherChannel on the Catalyst 3550



[Example 1-18](#) demonstrates the configuration of the EtherChannel between the core switches in [Figure 1-18](#).

Example 1-18. Configuring Gigabit EtherChannel with 802.1Q Encapsulation

```
3550_switch(config)#interface gigabitEthernet 0/1
3550_switch(config-if)#switch trunk encapsulation dot1q
3550_switch(config-if)#switchport mode trunk
3550_switch(config-if)#channel-group 1 mode on
Creating a port-channel interface Port-channel1
3550_switch(config-if)#exit
00:23:18: %LINK-3-UPDOWN: Interface Port-channel1, changed state to up
00:23:19: %LINEPROTO-5-UPDOWN: Line protocol on Interface Port-channel1, changed state to up
3550_switch(config)#interface gigabitEthernet 0/2
3550_switch(config-if)#switchport trunk encapsulation dot1q
3550_switch(config-if)#switchport mode trunk
3550_switch(config-if)#channel-group 1 mode on
00:24:29: %LINK-3-UPDOWN: Interface GigabitEthernet0/2, changed state to up
00:24:31: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/2, changed state to up
☞ state top
3550_switch(config-if)#exit
```

Cisco offers some useful commands to verify the operation status of an EtherChannel:

```
show etherchannel [channel-group-number] {brief | detail | load-balance | port |
```

```
Port-channel | summary}

show interface etherchannel
```

The `show etherchannel` command displays the number of ports and the mode that they are in along with information on the EtherChannel port group. You should see the port state as up, and all the interfaces belonging to the channel should be listed. The command also displays information about the load-balancing distribution scheme, port, and port channel. The L2 in the group state defines the EtherChannel as EtherChannel. [Example 1-19](#) demonstrates the `show etherchannel` command.

Example 1-19. Output of the `show etherchannel` Command

```
3550_switch#show etherchannel 1 detail

Group state = L2

Ports: 2    Maxports = 8

Port-channels: 1 Max Port-channels = 1

        Ports in the group:

        -----
        Port: Gi0/1

        -----
        Port state      = Up Mstr In-Bndl
        Channel group = 1           Mode = On/FEC      Gcchange = 0
        Port-channel   = Po1         GC    = 0x00010001    Pseudo port-channel = Po1
        Port index     = 0           Load = 0x00
        Age of the port in the current state: 00d:03h:04m:31s

        Port: Gi0/2

        -----
        Port state      = Up Mstr In-Bndl
        Channel group = 1           Mode = On/FEC      Gcchange = 0
        Port-channel   = Po1         GC    = 0x00010001    Pseudo port-channel = Po1
        Port index     = 0           Load = 0x00
```

```
Age of the port in the current state: 00d:03h:03m:17s
```

```
Port-channels in the group:
```

```
-----
```

```
Port-channel: Po1
```

```
-----
```

```
Age of the Port-channel = 00d:03h:04m:33s
```

```
Logical slot/port = 1/0 Number of ports = 2
```

```
GC = 0x00010001 HotStandBy port = null
```

```
Port state = Port-channel Ag-Inuse
```

```
Ports in the Port-channel:
```

```
Index Load Port EC state
```

```
-----+-----+-----+-----
```

```
0 00 Gi0/1 on
```

```
0 00 Gi0/2 on
```

```
Time since last port bundled: 00d:03h:03m:19s Gi0/2
```

```
3550_switch#
```

To verify the PAgP status of a EtherChannel group, use the following command:

```
show pagp [channel-group-number] {counters | internal | neighbor}
```

This command displays PAgP information such as traffic information, the internal PAgP configuration and neighbor information.

Configuring Layer 3 EtherChannel

To configure Layer 3 EtherChannel, you create the port-channel logical interface and then put the E interfaces into the port channel. The no switchport command must be used on the port channel a physical interface. The steps and syntax used to create a Layer 3 EtherChannel are as follows:

Step 1. Configure the port channel, disable Layer 2 switching, and assign an IP address to the channel, as follows:

```
3550_switch(config)#interface port-channel [1-64]  
3550_switch(config-if)#no switchport  
3550_switch(config-if)#ip address address subnet_mask
```

Step 2. Configure the physical interfaces that will reside in the EtherChannel group and assign the port channel, as follows:

```
3550_switch(config)#interface interface_name  
3550_switch(config-if)#no switchport  
3550_switch(config-if)#channel-group [1-64] mode {auto [non-silent] | desirable  
➥ [non-silent] | on}
```

[Example 1-20](#) demonstrates the configuration of a Layer 3 EtherChannel with an IP address of 172

Example 1-20. Configuring Layer 3 EtherChannel

```
3550_switch(config)#interface port-channel 2  
3550_switch(config-if)#no switchport
```

```
3550_switch(config-if)#ip address 172.16.50.1 255.255.255.0
3550_switch(config-if)#exit
3550_switch(config)#interface fast 0/17
3550_switch(config-if)#channel-group 2 mode auto
3550_switch(config-if)#interface fast 0/18
3550_switch(config-if)#no switchport
3550_switch(config-if)#channel-group 2 mode auto
```

Configuring EtherChannel Load Balancing

You can configure EtherChannel for different types of load balancing. Two types of load balancing are source-based and destination-based forwarding methods. The default load balancing type is src-mac. EtherChannel balances the traffic load across the links in a channel by reducing part of the binary representation of the addresses in the frame to a numeric value that selects one of the links in the channel.

With source MAC address forwarding, when packets are forwarded to an EtherChannel, they are distributed across the ports in the channel based on the source MAC address of the incoming packet. Therefore, for load balancing, packets from different hosts use different ports in the channel, but packets from the same host always use the same port in the channel (and the same MAC address learned by the switch does not change).

When the source MAC address forwarding method is used, load distribution based on the source or destination IP address is also enabled for routed IP traffic. All routed IP traffic chooses a port based on the source or destination IP address. Packets between two IP hosts always use the same port in the channel, and packets between any other pair of hosts can use a different port in the channel.

With destination MAC address forwarding, when packets are forwarded to an EtherChannel, they are distributed across the ports in the channel based on the destination host's MAC address of the incoming packet. Packets to the same destination are forwarded over the same port, and packets to a different destination are sent on a different port in the channel.

To configure load balancing across EtherChannel, use the following global configuration command:

```
3550_switch(config)#port-channel load-balance {dst-mac | src-mac}
```

To verify the type of load balancing in effect, use the show etherchannel load-balance command. This command shows whether dst-mac or src-mac load balancing is being used.

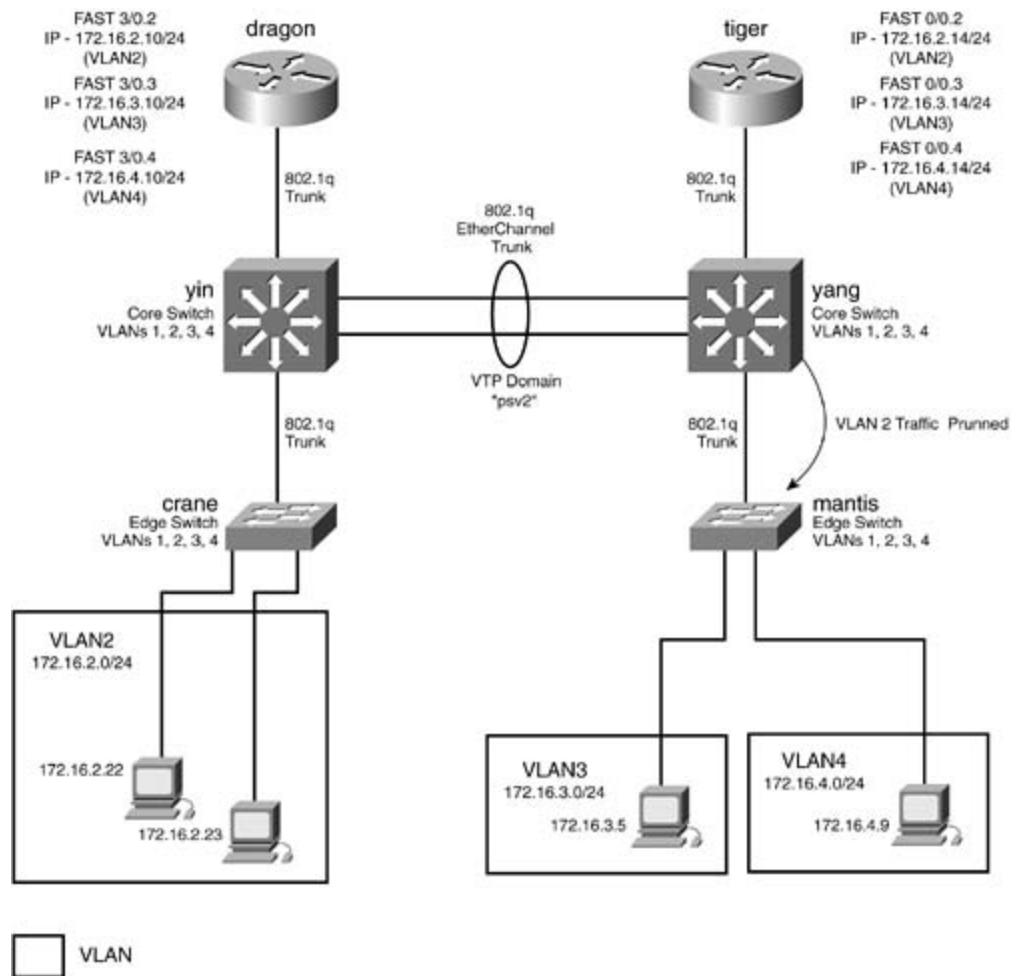
To return EtherChannel load balancing to the default configuration, use the no port-channel load global configuration command.

Step 4: Controlling STP and VLAN Propagation

The next step is optional but can be imperative in large networks. Cisco implements a couple of features that allow for switches to be plug and play in small networks but can have the negative effect of generating significant amounts of traffic in large networks. Features such as Per VLAN Spanning Tree (PVST), which is the default setting that every VLAN is communicated on every trunk port, can cause the edge switches to overrun processing spanning-tree requests and other broadcasts.

In the network in [Figure 1-17](#), for example, the crane switch has only a single VLAN, VLAN 2. Because it is in the same VTP domain as the other switches, however, it will participate in spanning tree for VLAN 4. There is really no need for this switch to waste resources processing spanning-tree requests that is not even on the switch. The larger and more redundant the network, the worse the problem. Suppose, for instance, that you have 75 edge switches; there would be 75 separate spanning-tree instances, one trunk per edge switch! In addition, all of this happens before any user traffic can use the switches.

Figure 1-17. VLAN Trunking and STP



It is a common misconception that *VLAN pruning* will solve STP issues. However, VLAN pruning affects broadcast, multicast, and unknown/flooded unicast traffic. Basically, STP constructs the path the data or "road" that the data can flow on, and pruning controls the broadcast data or "traffic" that flows on that road.

There are two very effective ways Cisco offers for dealing with excessive broadcasts and STP:

- VLAN pruning— VLAN pruning states that if VTP pruning is enabled, and if a downstream switch has an active port in that VLAN being pruned, the switch prevents the forwarding of flooded prune-eligible downstream VLAN. VTP pruning is a method of traffic control that reduces unnecessary broadcast, multicast, and unknown unicast traffic. VTP pruning blocks flooded traffic to VLANs ports that are included in the pruning-eligible list. If the VLANs are configured as "pruning ineligible", flooding continues.
- Clearing VLANs from trunks— Clearing VLANs off of a trunk essentially removes that spanned instance from the trunk. The downstream switch will no longer receive BPDUs for the VLAN clearing traffic for that VLAN will be able to pass down this trunk.

Configuring VTP Pruning

In [Figure 1-17](#), a port is active on VLAN 2 on the crane, yin, and yang switches, but not on the man. VTP pruning is enabled for VLAN 2 on the yang switch, the mantis switch will not receive broadcast and unknown/flooded unicast traffic for VLAN 2. Likewise, the crane switch will not receive the same traffic from VLAN 3 and VLAN 4, assuming pruning is enabled on the yin switch. By default, VTP pruning is disabled; therefore, global VTP pruning must be enabled. Enabling VTP pruning is a two-step process. The second step is optional:

Step 1. Enable VTP pruning from the VLAN configuration mode or the VLAN database with the **vtp pruning** command. This command enables pruning for VLANs, and no further configuration is required unless you only want to prune specific VLANs.

```
3550_switch(vlan)#vtp pruning
```

Step 2. (Optional) Add VLANs to the prune-eligible list. By default, all VLANs are prune eligible. This step may be bypassed. You may mark only certain VLANs as prune eligible by using the following command:

```
3550_switch(config-if)#switchport trunk pruning vlan {add | except | none | remove
```

You may add multiple VLANs, separated by a comma, or a range of VLANs, using a hyphen (-). For interface command switchport trunk pruning vlan add 2-10 makes only the VLANs 2 through 10 eligible. You can control VTP pruning on a trunk-by-trunk basis with this command.

Global VTP pruning, whether it is enabled or not, can be verified by the show vtp status command. To verify VTP pruning for individual VLANs by using the show interface command with the switchport command by viewing the VTP status. [Example 1-21](#) demonstrates how to verify whether VTP pruning is enabled. Use the show vtp status command.

Example 1-21. Verifying Global VTP Status

```
yin#show vtp status

VTP Version : 2
Configuration Revision : 6
Maximum VLANs supported locally : 1005

Number of existing VLANs : 14
VTP Operating Mode : Server
VTP Domain Name : psv2
VTP Pruning Mode : Enabled
VTP V2 Mode : Disabled
VTP Traps Generation : Disabled
MD5 digest : 0x13 0xF9 0xA7 0x89 0x56 0x56 0x8D 0x54
Configuration last modified by 172.16.192.16 at 3-1-93 02:35:01
Local updater ID is 172.16.192.16 on interface Vl192 (lowest numbered VLAN interface)
```

[Example 1-22](#) demonstrates the use of the show interface command in verifying VLAN prune eligibility. The show interface command was executed after the interface command switchport trunk pruning was entered on the yin switch.

Example 1-22. Verifying VLAN Prune Eligibility

```
yin#show interfaces fast 0/20 switchport

Name: Fa0/20

Switchport: Enabled

Administrative Mode: trunk

Operational Mode: trunk

Administrative Trunking Encapsulation: dot1q

Operational Trunking Encapsulation: dot1q

Negotiation of Trunking: On

Access Mode VLAN: 1 (default)

Trunking Native Mode VLAN: 1 (default)

Trunking VLANs Enabled: ALL

Pruning VLANs Enabled: 2-1001

Protected: false

Unknown unicast blocked: disabled

Unknown multicast blocked: disabled
```

Controlling STP by Removing It from Trunk Lines

In medium to large networks, it becomes crucial to control how many instances of STP there are or and how many traverse the trunks. Recall that by default every VLAN will have an instance of STP, calls PVST+. Switches will run an instance of STP on all trunks for every VLAN they are aware of. If has five VLANs, there are five instances of STP, and each instance has a single root switch, and so Catalyst 3550 supports 128 instances of STP per switch. Other switches, such as Catalyst 3548XL can support 64 STP instances, and this varies on a switch-by-switch basis. To find out how many STP your switch supports, refer to www.cisco.com. If more VLANs are added, STP is disabled for the VLANs on that switch. A more common problem is the amount of strain many STP instances put on wiring-closet switches. Unfortunately, VTP pruning does not affect spanning tree. To remove an STP from a trunk, use the following interface command:

```
Switch(config-if)#switchport trunk allowed vlan [add | all | except | remove] vla
```

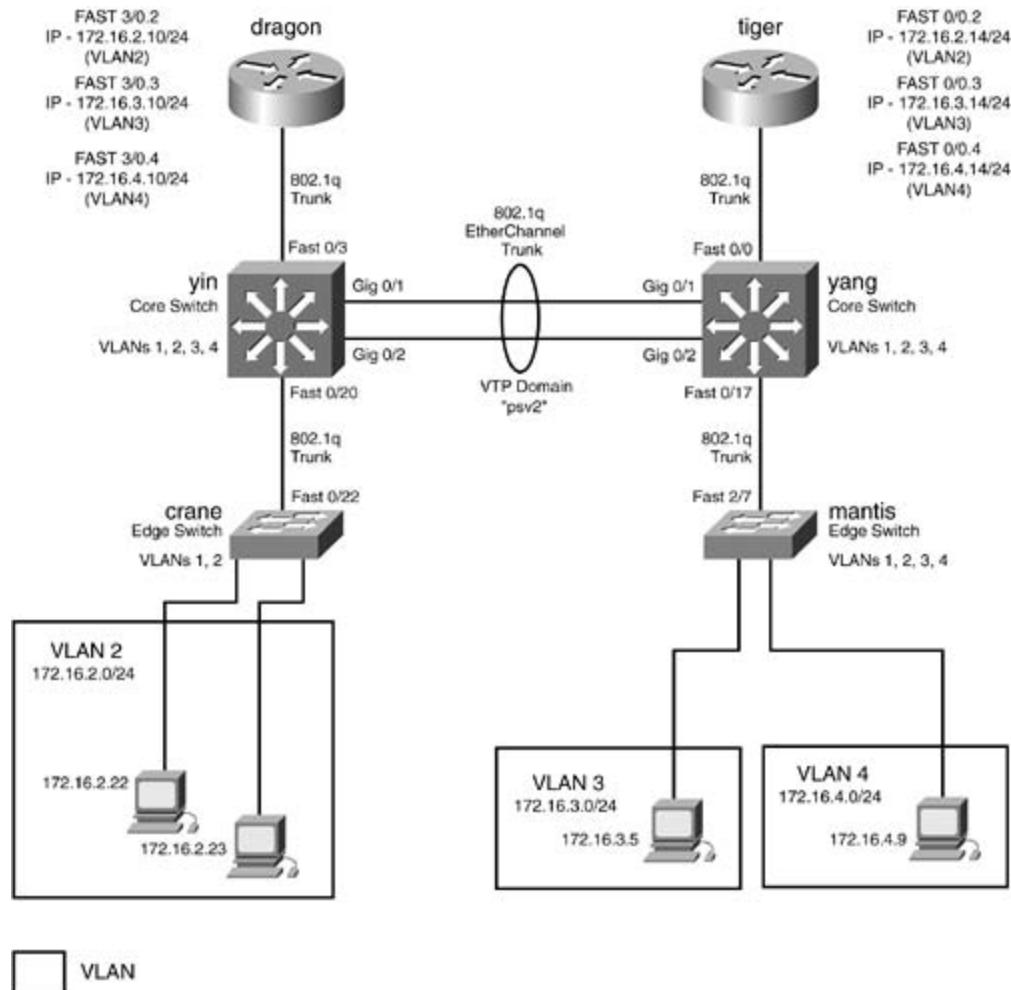
- add— Adds the following VLANs to the trunk
- all— Includes all VLANs on the trunk
- except— Includes all VLANs except those specified
- remove— Removes the following VLANs from the trunk

To remove VLAN 3 through VLAN 6, you would use the following cryptic-looking command:

```
Switch(config-if)#switchport trunk allowed vlan remove 3-6
```

[Figure 1-18](#) shows the same network as [Figure 1-17](#), with updated interface names. In this example switch, all VLANs are cleared, except 1 and 2, on the trunk to the crane switch.

Figure 1-18. VLAN Trunking and STP



VLAN

In this particular example, to remove STP from the trunk, you use the `switchport` command. Prior to the trunks, you examine the STP state of VLAN 3. [Example 1-23](#) shows the `show spanning-tree` on the yin switch. Notice at the bottom that STP is forwarding VLAN 3 information out fast 0/3, the dragon's fast 0/20 to the crane switch; and po1, the EtherChannel port.

Example 1-23. `show spanning-tree` Command on the Yin Switch

```
yin#show spanning-tree vlan 3

VLAN0003

Spanning tree enabled protocol ieee

Root ID      Priority    32768
Address      0004.275e.f0c8
Cost         3
```

```

Port          65 (Port-channel1)

Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

Bridge ID   Priority      32771  (priority 32768 sys-id-ext 3)

Address      000a.8a0e.ba80

Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

Aging Time  300

Interface    Port ID           Designated          Port ID
Name          Prio.Nbr        Cost Sts          Cost Bridge ID      Prio.Nbr
-----  -----  -----  -----  -----
Fa0/3         128.3            19 FWD            3 32771 000a.8a0e.ba80 128.3
Fa0/20        128.16           19 FWD            3 32771 000a.8a0e.ba80 128.16
Po1           128.65           3 FWD             0 32768 0004.275e.f0c8 128.1
yin#

```

[Example 1-24](#) demonstrates the clearing of VLANs 3 through 1001 on the trunk between the yin and yang switches. The second portion of the example shows the spanning tree for VLAN 3. Notice that VLAN 3 is forwarded out the trunk Fa0/20, the trunk line to the crane switch.

Example 1-24. Clearing/Removing a VLAN from a Trunk

```

yin(config)#int fastEthernet 0/20

yin(config-if)#switchport trunk allowed vlan remove 3-1001

yin(config-if)#^Z

yin#show spanning-tree vlan 3

11:55:53: %SYS-5-CONFIG_I: Configured from console by console

VLAN0003

Spanning tree enabled protocol ieee

Root ID     Priority      32768
Address      0004.275e.f0c8

```

```

Cost          3

Port          65 (Port-channel1)

Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

Bridge ID    Priority 32771 (priority 32768 sys-id-ext 3)

Address       000a.8a0e.ba80

Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

Aging Time 15

Interface      Port ID          Designated          Port ID
Name           Prio.Nbr        Cost Sts          Cost Bridge ID      Prio.Nbr
-----  -----  -----  -----  -----
Fa0/3          128.3           19 FWD            3 32771 000a.8a0e.ba80 128.3
Po1            128.65          3 FWD             0 32768 0004.275e.f0c8 128.1
yin#

```

The command `show interface(interface_name)switchport` also shows which VLANs are carried on the interface.

The `show interface trunk` command is a very useful command to determine the trunking status of VLANs. The `show interface trunk` command lists port, its mode and encapsulation, and whether it is trunking. It also lists the VLANs allowed on each trunk and STP status of those VLANs. [Example 1-25](#) shows the output of the `show interface trunk` command, showing that VLANs 3 through 1001 no longer appear on trunk fast 0/20. VLANs 1002 through 4094 are other default and extended-range VLANs.

Example 1-25. Showing the Allowed VLANs on a Trunk

```

yin#show interface trunk

Port      Mode       Encapsulation  Status      Native vlan
Fa0/3    on        802.1q        trunking    1
Fa0/20   on        802.1q        trunking    1
Po1     on        802.1q        trunking    1
Port      Vlans allowed on trunk
Fa0/3    1-4094

```

```
Fa0/20      1-2,1002-4094
Po1        1-4094
Port       Vlans allowed and active in management domain
Fa0/3      1-4,10,20,30,40,50,192
Fa0/20     1-2
Po1        1-4,10,20,30,40,50,192
Port       Vlans in spanning tree forwarding state and not pruned
Fa0/3      1-4,10,20,30,40,50,192
Fa0/20     1-2
Po1        1,192
yin#
```

Removing VLANs from the trunks is one way to control STP; for the switches that need redundancy you must use additional methods to control STP.

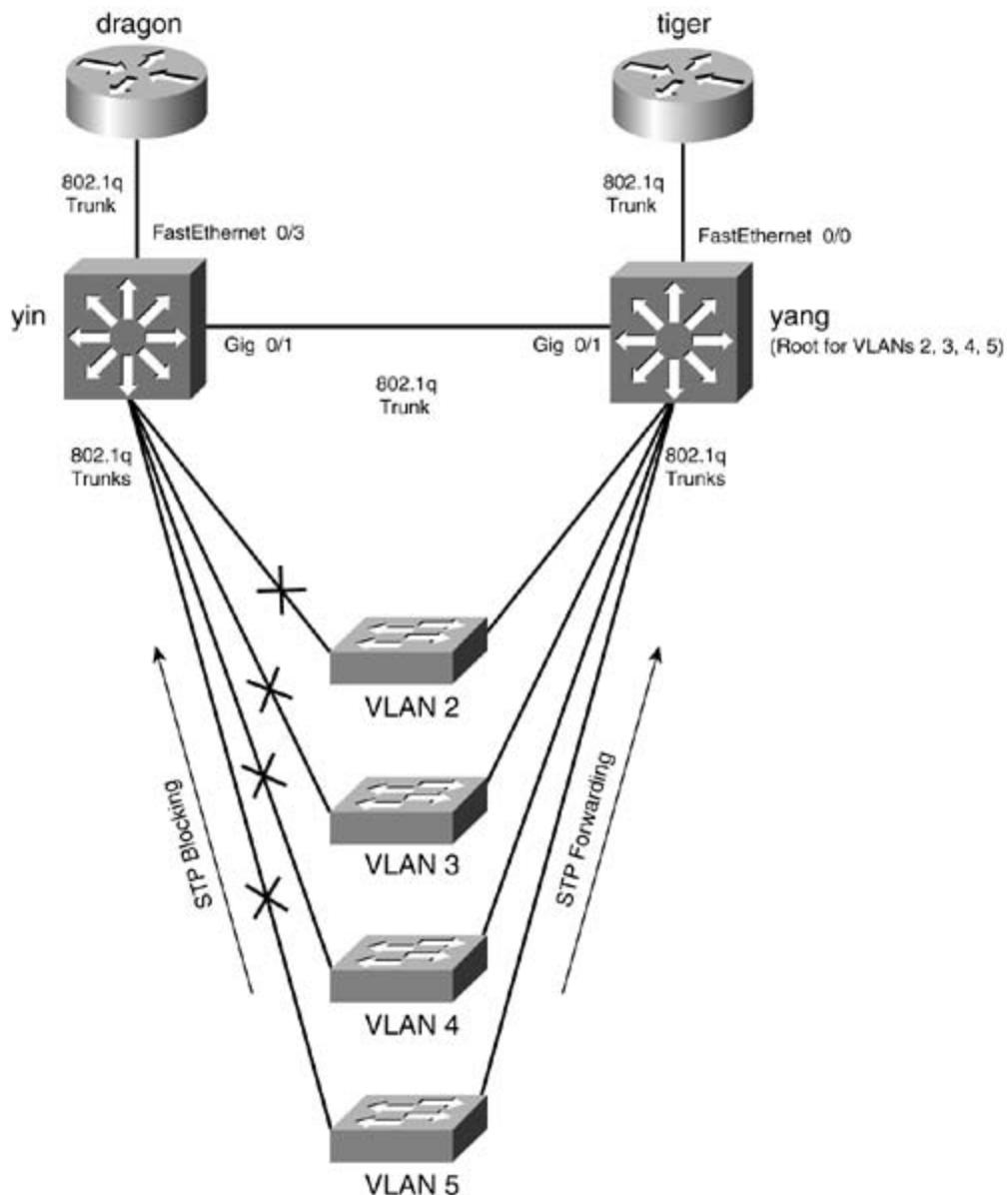
NOTE

Newer versions of Catalyst software allow for the clearing/removing of VLAN 1. However, most still will not allow you to clear/remove VLAN 1. Always exercise caution if removing VLAN from trunk lines. Remember, this is the native VLAN for 802.1Q by default, and other protocols may use untagged frames on VLAN 1.

Configuring STP Load Balancing and Root Placement

Redundant switched networks do not perform automatic load balancing. Because the STP forwarding decision is based, in part, on static MAC addresses, all traffic tends to follow the same direction and path for all VLANs. This leads to some links being overused, while others remain idle. [Figure 1-19](#) illustrates a network that has all converged on a single switch. The Yang switch is the root of STP for VLANs 2, 3, and 4.

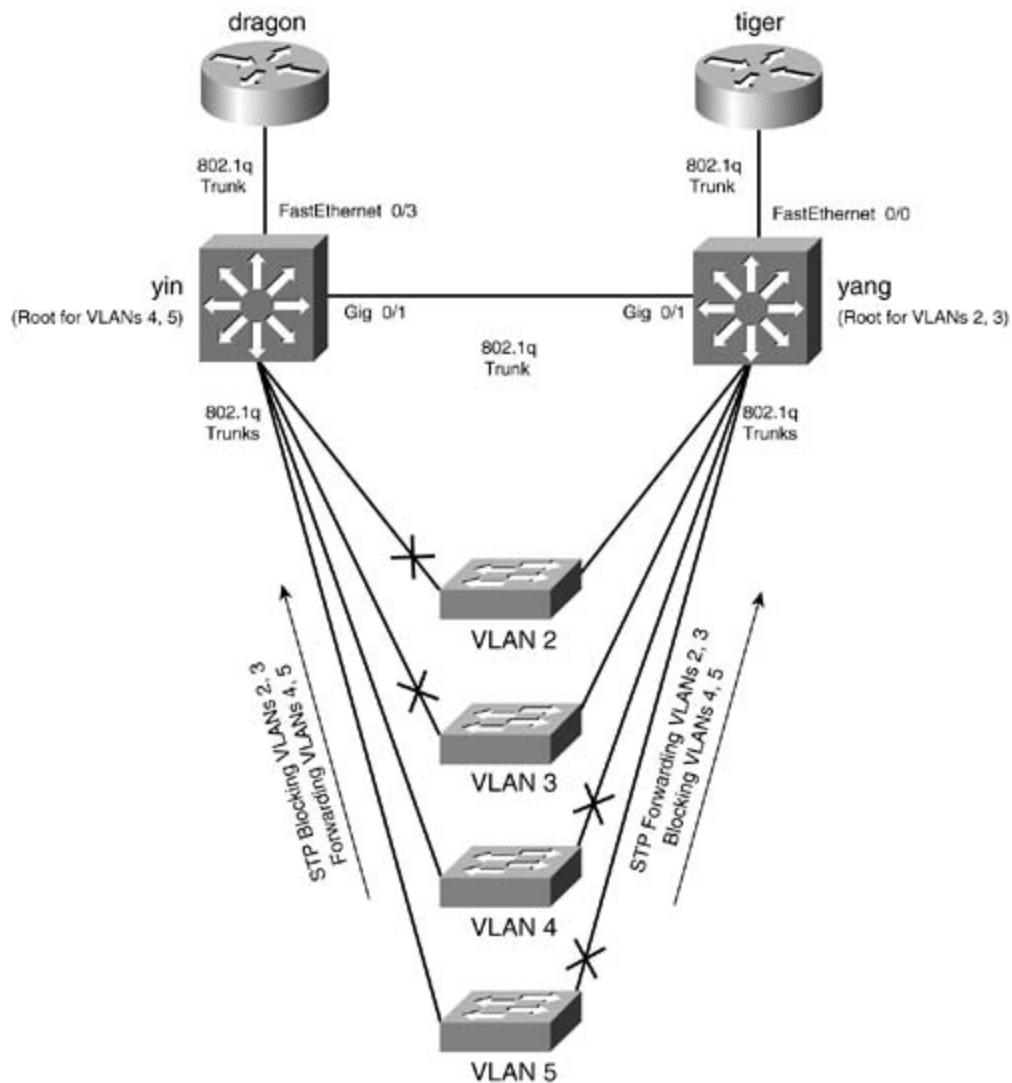
Figure 1-19. STP Root



If you wanted to load balance between the yin and yang switches or if you were using HSRP on the tiger routers, you would want to control STP root placement. If the dragon router were the HSRP primary for VLAN 2, for instance, you would want traffic to go through the yin switch rather than the yang switch. To distribute traffic in a switched network, you must manually configure the root for STP.

You can configure the root of spanning tree for Catalyst switches in many ways. The methods you use to set the root depend mostly on the environment you are trying to control. When setting the root bridge, you are essentially telling STP which ports to put into blocking and which ports to put into forwarding. Because STP runs on a PVST basis, each VLAN has a different root bridge. In [Figure 1-20](#), the yin switch is set to be the root for VLAN 4 and VLAN 5, and the yang switch is the STP root for VLAN 2 and VLAN 3. This causes the switches to balance their load more evenly over the trunk's lines. VLANs 4 and 5 forward to yin, and VLANs 2 and 3 forward to yang.

Figure 1-20. STP Root



Before further exploring how to set the STP root, you must first learn how to determine where the **root** is located. The **show spanning-tree root** command displays a quick overview of the root of each VLAN, the MAC address of the root, the root port, the priority, the cost, and the STP timers for that VLAN. The following example lists the output of the **show span** command.

Example 1-26. Viewing Spanning Tree for VLAN 2

```
yin#show spanning-tree root
```

Vlan	Root ID	Root			Hello Max Fwd		
		Cost	Time	Age	Dly	Root Port	

```

VLAN0001      32768 0004.275e.f0c0      3   2   20  15  Po1
VLAN0002      32768 0004.275e.f0c7      3   2   20  15  Po1
VLAN0003      32768 0004.275e.f0c8      3   2   20  15  Po1
VLAN0004      32768 0004.275e.f0c9      3   2   20  15  Po1
VLAN0005      32768 0004.275e.f0c1      3   2   20  15  Po1

yin#

```

The `show spanning-tree` command and its subcommand, `show spanning-tree vlan`, display valuable information about spanning tree. There are a few variations of this command depending on what information you may want. [Example 1-27](#) lists a portion of VLAN 2 output from the `show spanning-tree` command on the yin switch.

Example 1-27. Viewing Spanning Tree for VLAN 2

```

yin#show spanning-tree

VLAN0001

  Spanning tree enabled protocol ieee

    Root ID      Priority      32768
                  Address       0004.275e.f0c8
                  Cost          3
                  Port          65 (Port-channel1)
                  Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

    Bridge ID    Priority      32770  (priority 32768 sys-id-ext 2)
                  Address       000a.8a0e.ba80
                  Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
                  Aging Time   300

```

Interface	Port ID	Designated	Port ID	
Name	Prio.Nbr	Cost Sts	Cost Bridge ID	Prio.Nbr
<hr/>				
Fa0/3	128.3	19 FWD	3 32770 000a.8a0e.ba80	128.3
Fa0/20	128.16	19 FWD	3 32770 000a.8a0e.ba80	128.16
Po1	128.65	3 FWD	0 100 0004.275e.f0c7	128.1
<<<text omitted>>>				

Every bit of information provided by this command is useful. The fields are defined as follows:

- Spanning tree type— The type of Spanning Tree Protocol in use: IBM, DEC, or IEEE.
- Root ID— The MAC address of the root bridge.
- Root ID Priority— The bridge priority that was received from the root bridge. The values of priority range from 0 to 65,535, with 32,768 as the default.
- Root ID Cost— The cumulative cost to the root bridge.
- Root ID Port— The root port for that segment.
- Root Max Age, Hello Time, Forward Delay— The three STP timers as sent by the root bridge.
- Bridge ID MAC ADDR— The MAC address that is being used for this VLAN by this local bridge.
- Bridge ID Priority— The priority of the local bridge.
- Bridge Max Age, Hello Time, Forward Delay— The three STP timers on the local bridge.

The final rows show each port that is participating in STP within the VLAN and lists whether the port is forwarding or blocking, as well as the cost and service priority of the port. Do not confuse this with spanning-tree bridge priority. The values of the port priority range from 0 to 63, with 32 as the default.

Another command that is useful in presenting a general operational picture of spanning tree is the `spantree summary` command. This command provides an overview of the VLANs and the state of an STP perspective. [Example 1-28](#) lists the output for this command.

Example 1-28. Viewing Spanning Tree for VLAN 2

```
3550_switch#show spanning-tree summary
```

```
Root Bridge for: none.
```

Extended system ID is enabled.

PortFast BPDU Guard is disabled

EtherChannel misconfiguration guard is enabled

UplinkFast is disabled

BackboneFast is disabled

Default pathcost method used is short

Name	Blocking	Listening	Learning	Forwarding	STP Active
<hr/>					
VLAN0001	0	0	0	5	5
VLAN0002	0	0	0	3	3
VLAN0003	0	0	0	2	2
VLAN0004	0	0	0	2	2
VLAN0005	0	0	0	2	2
<hr/>					
5 vlans	0	0	0	14	14

yin#

To properly set the STP root, it helps to recall the four-step decision process of STP and how Spann determines root. The root is selected by the lowest-cost BID. The BID is composed of priority followed by address.

1. Lowest root BID (priority followed by MAC address, adjacent to root bridge)
2. Lowest-path cost to root bridge; the cumulative cost of all paths to root
3. Lowest sender BID
4. Lowest port ID

From this process, you can influence the decision of the root at multiple levels. At times, you may want a port to have the same STP priority; at other times, however, you may want a specific port to have priority, such as in a load-sharing environment. [Table 1-12](#) lists the four primary STP election states and Catalyst 3550 global configuration command.

Table 1-12. Ethernet STP Configuration Outcomes

STPElection State	Catalyst 3550 Configuration Command
1. Lowest BID	[+] <code>spanning-tree [vlan <i>vlan_id</i>] [priority 0-65535]</code> [+] <code>spanning-tree vlan <i>vlan_id</i> root [primary secondary] [diameter 2-7 seconds]</code>
2. Lowest path cost to root	[*] <code>spanning-tree [vlan <i>vlan_id</i>] [cost 1-200000000]</code>
3. Lowest sender BID	[+] <code>spanning-tree [vlan <i>vlan_id</i>] [priority 0-65535]</code>
4. Lowest port ID	[+] <code>spanning-tree [vlan <i>vlan_id</i>] [port-priority 0-255]</code>

[+] Global configuration commands

[*] Interface configuration commands

You can influence the root bridge selection process in many ways. The way you choose depends on trying to accomplish by setting root. The higher up in the election process you use to influence root will help safeguards against possible ties or other STP configurations present on other switches that have control over.

- The global spanning-tree [vlan *vlan_id*] [priority 0-65535] command can influence the Prior the BID; the lower the priority, the more likely the switch will become root. It can be set on a level or globally for the entire switch. The valid values for the VLAN ID are 1 through 4094. V. values are 4096, 8192, 12,288, 16,384, 20,480, 24,576, 28,672, 32,768, 36,864, 40,960, 45 53,248, 57,344, and 61,440. All other values are rejected.
- The global command spanning-tree vlan *vlan_id*root [primary|secondary] [diameter 2-7 seconds] is a macro much like the set root macro on CAT OS. When the command is entered primary keyword, it examines the VLAN(s) on the switch for the highest priority, the root, at priority less than that. The command may also adjust the max age, hello, and forwarding delay command also uses the extended system ID. The optional diameter keyword specifies the maximum number of switches between any two end stations. The valid range is 2 to 7. The optional hello specifies the interval, in seconds, between the generation of configuration messages by the root. The range is 1 to 10 seconds; the default value is 2 seconds. [Example 1-29](#) demonstrates the use of this macro command.

Example 1-29. Using the Spanning-Tree root Macro Command

```
3550_switch(config)#spanning-tree vlan 192 root primary

vlan 192 bridge priority set to 24576

vlan 192 bridge max aging time unchanged at 20

vlan 192 bridge hello time unchanged at 2

vlan 192 bridge forward delay unchanged at 15
```

```
3550_switch(config)#
```

- When this command was entered, the default priority found on VLAN 192 was 32,768; therefore set the priority less than that (in this case, 24,576). The value of 24,576 is a unique value that extended system ID is in use. If the value of the priority were changed to 8192, extended sys not be in use.
- The interface command `spanning-tree [vlan vlan_id] [cost 1-200000000]` influences the STP interface. The valid VLAN ID is 1 to 4094, and the valid cost ranges from 1 to 200,000,000. [I](#) the default STP cost.

Table 1-13. STP Cost Values for LAN Links

Bandwidth	Revised IEEE802.1D STP Cost
4 Mbps	250
10 Mbps	100
16 Mbps	62
45 Mbps	39
100 Mbps	19
155 Mbps	14
622 Mbps	6
1 Gbps	4
10 Gbps	2

- The interface command `spanning-tree [vlan vlan_id] [port-priority 0-255]` configures the port priority for the interface. The default port priority is 128, and the valid ranges are 0 to 255. The lower the priority, the better the priority. [Table 1-14](#) lists the default STP configuration.

Table 1-14. Default STP Configuration

Feature	Default Setting
Enable state	Enabled on VLAN 1 128 STP instances /switch
Switch/bridge priority	32768
STP port priority	128
STP port cost	See Table 1-12
Hello timer	2 seconds
Forward delay time	15 seconds
Maximum aging time	20 seconds

STP hello, forward delay, and max age timers can be configured and tuned with the following global configuration commands. Exercise caution anytime you are configuring STP timers. PVST+ runs on STP per VLAN. If you change the timers on one switch for this VLAN, you must change the timers on all other switches for that particular VLAN.

- `spanning-tree vlan vlan-id hello-time [1-10]`
- `spanning-tree vlan vlan-id forward-time [4-30]`
- `spanning-tree vlan vlan-id max-age [6-40]`

For the most part, configuring STP on the Catalyst 3550 is fairly similar to configuring STP on the C3500XL/2900XL series switches. For detailed walkthroughs of STP and general switch configuration see [Chapter 2 of CCIE PSV1](#).

Step 5: Configuring Switch Virtual Interfaces (SVIs)

The last three steps of the process are optional. They call for the configuration of the SVIs, routed ports, and Layer 3 switching.

1. Configure switch management.
2. Configure VTP and VLANs and assign ports/interfaces to VLANs.
3. Configure connections between switches using EtherChannel, 802.1Q, and ISL encapsulations.
4. (Optional) Control STP and VLAN propagation.
5. (Optional) Configure SVIs.
6. (Optional) Configure routed ports.
7. (Optional) Configure Layer 3 switching.

Recollect that an SVI is a logical/virtual interface on the switch much like the management interface. It represents a VLAN as one interface to the routing or bridging functions of the switch. Only one SVI

associated with a VLAN. An SVI can be used to route between VLANs, as a fallback-bridge nonroute between VLANs, or to provide IP host connectivity to the switch for management.

By default, an SVI is created for the default VLAN (INT VLAN 1) for management. Other SVIs are created using the following global configuration command:

```
3550_switch(config)#interface vlan [1-4094]  
3550_switch(config-if)#ip addressIP_address subnet_mask
```

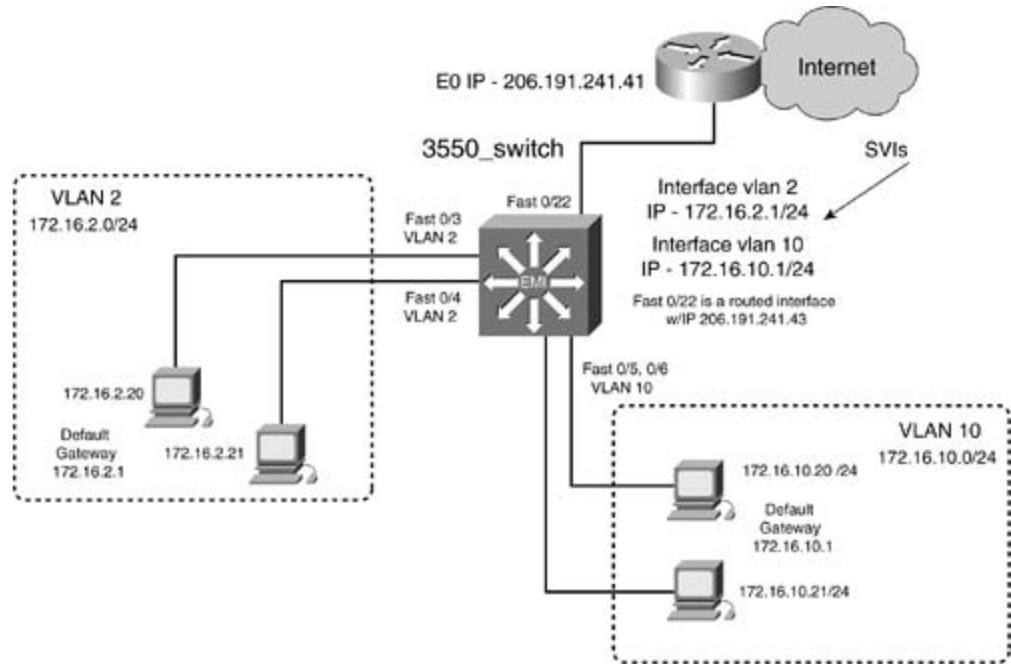
After creating the SVI, you can add an IP address to the interface and define features such as HSRP. Treat the SVI much like you would a Layer 3 interface on a router. The most common use of an SVI is for management and inter-VLAN routing.

NOTE

To use SVIs in Layer 3 mode or to "route" across SVIs, you must have the EMI image installed on the switch.

In [Figure 1-21](#), there exists a Cisco 3550 with the EMI software installed. Two VLANs exist on the switch: VLAN 10 and VLAN 20. VLAN 10 has workstations in the IP subnet of 172.16.10.0/24, and VLAN 20 has workstations in the IP subnet of 172.16.2.0/24. In this example, two SVIs are created (interface VLAN 2 and interface VLAN 10), each assigned IP addresses within the appropriate VLAN range.

Figure 1-21. SVI Configuration



[Example 1-30](#) demonstrates how to configure two SVIs and assign IP addresses.

Example 1-30. Configuring an SVI

```
3550_switch(config)#interface vlan 2
02:05:42: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan2, changed state to
3550_switch(config-if)#ip address 172.16.2.1  255.255.255.0
3550_switch(config-if)#exit
3550_switch(config)#interface vlan 10
02:06:17: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan10, changed state to
3550_switch(config-if)#ip address 172.16.10.1  255.255.255.0
```

If there is an interface in VLAN 2 or VLAN 10, or if a trunk is active, you will be able to ping the interface. You can also view the interface with the standard show interface command and subcommands.

Although the SVI is up and you can ping it, you do not have Internet and IP connectivity yet. For the workstations on the VLANs to be able to have Internet access, and access to one another, Layer 3 switching must be enabled. Enabling Layer 3 switching on a switch is accomplished through the global command `switch enable`. When routing is enabled, a routing protocol must still be configured for IP connectivity. [Example 1-31](#) shows the configuration that is needed for full IP reachability.

Example 1-31. Enabling Routing/Layer 3 Switching

```
3550_switch(config)#ip routing  
3550_switch(config)#router eigrp 2003  
3550_switch(config-router)#network 172.16.0.0  
3550_switch(config-router)#network 206.191.241.0  
3550_switch(config-router)#no auto-summary
```

Using the show ip route command, you can verify the status of the SVIs. The administrative distance is 0, appearing as a connected route. [Example 1-32](#) shows the route/forwarding table of the 3550 :

Example 1-32. Viewing SVI in the Route/Forwarding Table

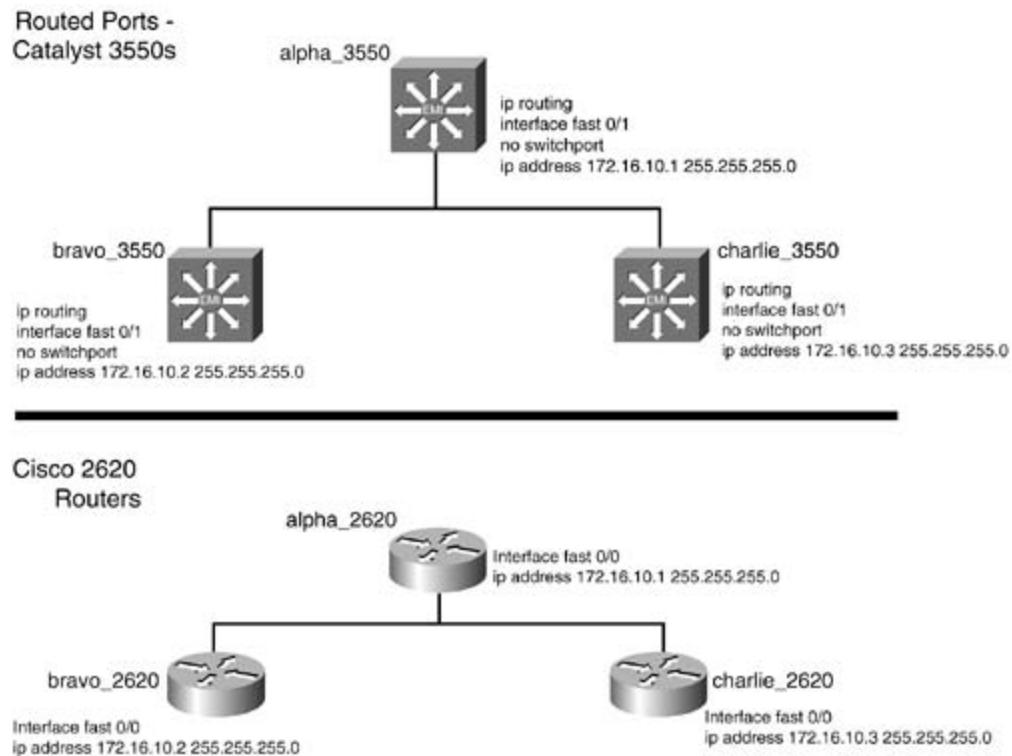
```
3550_switch#show ip route  
<<<text omitted>>>  
Gateway of last resort is 206.191.241.41 to network 0.0.0.0  
172.16.0.0/24 is subnetted, 4 subnets  
C        172.16.10.0 is directly connected, Vlan10  
C        172.16.2.0 is directly connected, Vlan2  
C        206.191.241.43 is directly connected, FastEthernet0/22  
D*EX 0.0.0.0/0 [170/537600] via 206.191.241.41, 1d04h, FastEthernet0/22  
3550_switch#
```

Step 6: (Optional) Configuring Routed Ports

A *routed port* is a physical port on the Catalyst 3550 switch that functions just like a physical interface on a router. This is the simplest way to view it. You can configure many of the same features on a routed port as you can on a router's physical interface, including IP address, ACL, and membership of an HSRP group. A routed port cannot have VLAN subinterfaces, however, or be configured as a trunk of any type. Configuring routed ports requires the EMI software image.

[Figure 1-22](#) illustrates two identical networks. The top network has three Catalyst 3550s with Fast Ethernet–routed ports connecting all three switches. The bottom network has three Cisco 2620 routers through the routers' Fast Ethernet interfaces.

Figure 1-22. Routed Port Comparison



A routed port is enabled by using the interface command `no switchport`. The `no switchport` command effectively disables switching functions for that interface.

The switch will use an internal VLAN to map the routed port. This internal VLAN will also be used for VLANs; be careful that they do not conflict. The internal VLAN ID the switch chooses can be viewed with the `show vlan internal usage` command. [Example 1-33](#) demonstrates the configuration of two routers followed by the `show vlan internal usage` command showing to which VLAN the switch will assign the port.

Example 1-33. Configuring a Routed Port

```

3550_switch(config)#interface fast 0/7
3550_switch(config-if)#no switchport
02:06:22: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/7, changed
02:06:23: %LINK-3-UPDOWN: Interface FastEthernet0/7, changed state to down

```

```

02:06:26: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/7, changed
3550_switch(config-if)#ip address 172.16.200.16 255.255.255.0

3550_switch(config-if)#interface fast 0/8

3550_switch(config-if)#no switchport

3550_switch(config-if)#

02:06:53: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/8, changed
02:06:23: %LINK-3-UPDOWN: Interface FastEthernet0/8, changed state to down
02:06:26: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/8, changed
3550_switch(config-if)#ip address 172.16.201.16 255.255.255.0

3550_switch(config-if)#^Z

3550_switch

3550_switch#show vlan internal usage

VLAN Usage
-----
1017 -
1025 FastEthernet0/7
! Internal VLANs used
1026 FastEthernet0/8

```

If you switch a port/interface from a *switch*port to a *routed*port by using the no switchport interface command, and you want to change the interface back to a *switched*interface, you must enter the interface switchport without subcommands.

Step 7: (Optional) Configuring Layer 3 Switching

Layer 3 switching is the capability to make Layer 3 decisions and forward Layer 3 packets at Layer 2. Layer 3 switching is, in actuality, *routing*. Another, and easier, way to define Layer 3 switching is to rapidly *route* and *switch* on the same hardware platform. When IP routing is enabled, the Catalyst effectively becomes a fast and sleek multiport router. Many of the IP features that are available in the suite are available when IP routing is enabled. Cisco has preserved the syntax of all IP configuration commands and smoothly integrated the traditional Cisco IOS Software. If you know how to configure a router, which you should at this point, configuring the Layer 3 or routing portion of the 3550 is just configuring the router. Because of the extensive IOS feature sets, not all IP features, such as data-link layer switching (DLSw), are supported on the 3550. See [Appendix A](#), "Cisco IOS Software Limitations and Restrictions" for more information.

of unsupported 3550 commands.

Seeing Isn't Always Believing

I'm a firm believer in using the question mark (?) for help. It has always helped guide me in syntax and show me some new available features. Be careful with the help on the 3550; many of the items that appear in the help cannot be configured. On IOS 12.1(9)EA1c, for example, you will see features such as Border Gateway Protocol (BGP) and On Demand Routing (ODR), but you will get an error if you try to configure them.

[Appendix A](#) includes a list of limitations and restrictions. For the most current list of new features, limitations, and restrictions, go to www.cisco.com.

To configure Layer 3 switching, follow these three steps:

Step 1. Configure one of the three supported Layer 3 interfaces and assign an IP address to Catalyst 3550 routing fabric recognizes three types of Layer 3 interfaces.

A routed port

An SVI

Layer 3 EtherChannel

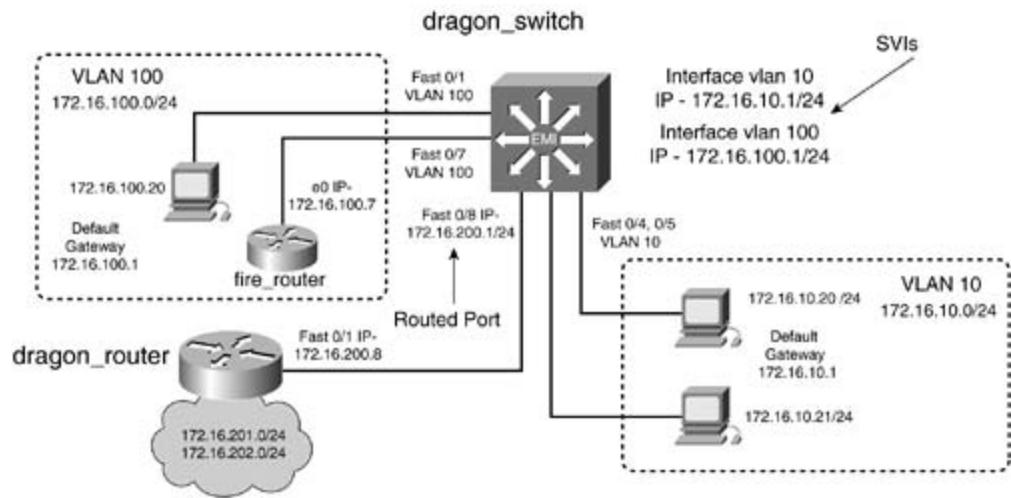
Step 2. Enable IP routing with the global configuration command ip routing.

Step 3. Configure Interior Gateway Protocols (IGPs) and other IP functionality. The IGPs support RIP v1 and v2, Interior Gateway Routing Protocol (IGRP), Enhanced IGRP, and Open Shortest Path First (OSPF). Interior routing protocols on the switch are configured in the same manner as they are on a router. For that reason, routing protocol specifics are not discussed here. For more information on configuring IGPs, refer to *CCIE PSV1*.

Practical Example: Configuring SVIs, Routed Ports, and Layer 3 Switching

The network model in [Figure 1-23](#) represents a Catalyst 3550, the dragon switch, serving as the central switch for the network. The dragon switch is using two SVIs for VLAN 10 and VLAN 100 for inter-VLAN traffic. The workstation ports such as Fast Ethernet 0/7 port are configured as *access ports* in a single VLAN. The Fa0/1 interface is serving as a routed port and attaches to the dragon router. The routed port has an IP address of 172.16.200.1/24. IP routing is enabled on the dragon switch with EIGRP, in autonomous system 20. The dragon switch is also connected to a server and a workstation.

Figure 1-23. Routed Port and SVI Configuration



[Example 1-34](#) lists the relevant portions of the dragon switch.

Example 1-34. Dragon Switch Configuration

```

hostname dragon_switch
!
ip subnet-zero
ip routing
! Routing enabled
!
spanning-tree extend system-id
! Extended System ID in use
!
interface FastEthernet0/1
switchport access vlan 100
! VLAN 100
no ip address
!
<<<text omitted>>>

```

```
!

interface FastEthernet0/4
    switchport access vlan 10
    ! VLAN 10
    no ip address

!

interface FastEthernet0/5
    switchport access vlan 10
    ! VLAN 10
    no ip address

!

interface FastEthernet0/6
    no ip address

!

interface FastEthernet0/7
    switchport access vlan 100
    ! VLAN 100
    no ip address

!

interface FastEthernet0/8
    no switchport
    ! Routed Port/interface
    ip address 172.16.200.1 255.255.255.0
    ! IP address

!

<<<text omitted>>>

!

interface Vlan1
```

```

! Default VLAN

no ip address

! not used!

shutdown

!

interface Vlan10

! SVI 10

ip address 172.16.10.1 255.255.255.0

! IP address

!

interface Vlan100

! SVI 100

ip address 172.16.100.1 255.255.255.0

! IP address

!

router eigrp 2003

! Routing Protocol

network 172.16.0.0

! EIGRP on networks 172.16.0.0/16

no auto-summary

no eigrp log-neighbor-changes

!

```

In this network, the dragon switch is routing for all VLANs via EIGRP. VLAN 10, VLAN 100, and IP s 172.16.200.0/24, 172.16.201.0/24, and 172.16.202.0/24 have full IP reachability to each other. T switch will have two EIGRP neighbors. One neighbor, the fire router, is formed via the access port using SVI VLAN 100. The other neighbor, the dragon router, is formed via the routed port Fast 0/8

[Example 1-35](#) lists the route/forwarding table of the dragon switch, followed by the show ip eigrp command.

Example 1-35. Dragon Switch Configuration

```
dragon_switch#show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

      172.16.0.0/24 is subnetted, 5 subnets

C        172.16.200.0 is directly connected, FastEthernet0/8
D        172.16.201.0 [90/156160] via 172.16.200.8, 00:00:16, FastEthernet0/8
D        172.16.202.0 [90/156160] via 172.16.200.8, 00:00:09, FastEthernet0/8
C        172.16.10.0 is directly connected, Vlan10
C        172.16.100.0 is directly connected, Vlan100

dragon_switch#
dragon_switch#show ip eigrp neighbors

IP-EIGRP neighbors for process 2003

      H   Address          Interface      Hold Uptime     SRTT      RTO    Q  Seq Type
                           ( sec )        ( ms )      Cnt Num
      2   172.16.100.7      Vl100        12 00:03:06      1    200  0  11
      1   172.16.200.8      Fa0/8        14 00:03:40      1    200  0  9

dragon_switch#
!
```

By now, you can see what a powerful and versatile platform the Catalyst 3550 Intelligent Ethernet

and why Cisco chooses to call it an intelligent switch. Because of the diversity of the Catalyst 3550 possible software configurations it can perform, one chapter could not possibly cover them. Instead mini-novel on the 3550, this chapter has laid the necessary groundwork for configuring some basic features of the 3550. Layer 3 functionality—such as routing protocols, HSRP, IP ACL, and so on—is identical in terms of configuration as on a Cisco router. The knowledge of routing protocols you have from other sources, such as *CCIE PSV1* and other references, can easily be transferred and applied to Catalyst 3550.

The remaining portion of this chapter covers some of the additional and optional features of the Catalyst 3550. Once again, due the vast array of configuration options available on the Catalyst 3550, it is impossible to cover all of them in a single chapter. To cover some topics, such as multicast, the way they deserve and should be covered would require 100 pages, which is simply beyond the scope of this text. (However, they are import worthy of study.) The following topic list includes other features on the Catalyst 3550 that make it one of the most versatile and powerful platforms available:

- Multicast Layer 2 and Layer 3, IGMPv2, Cisco Group Management Protocol (CGMP), and Multi-VLAN Registration (MVR)
- 802.1X port-based authentication
- Voice VLANs with 802.1Q and 802.1p
- SPAN and Remote SPAN (RSPAN)
- SNMP and RMON
- 802.1Q tunneling
- QoS

Configuring Advanced Features on a Catalyst 3550 Ethernet Switch

Spanning tree, after years of remaining the hidden backbone in many networks, finally has outgrown its critical role as STP plays, the 50-second convergence time—20 seconds of max age expiring followed by a 15-second listening and a 15-second learning state—is simply too long for convergence in many modern networks. Cisco provides many workarounds, some of which are discussed here, to help alleviate the convergence issues and stabilize STP. Some advanced features of the Catalyst 3550 include the following:

- PortFast and BPDU guard and BPDU filtering
- UplinkFast
- BackboneFast
- Root guard
- IEEE 802.1w Rapid Spanning Tree (RSTP)
- IEEE 802.1s Multiple Spanning Tree (MST)
- VLAN maps
- VLAN protected ports with unicast and multicast blocking

Examine these features in greater detail.

Configuring PortFast Spanning Tree and BPDU Guard

PortFast Spanning Tree should only be configured on edge switches. In this state, upon a local fail initialization, the 15-second listening state and the 15-second learning state are skipped. All ports permanent forwarding mode. For this reason, PortFast should only be used on end stations such as and servers. By default, STP PortFast is disabled; it can be enabled with the following interface con

```
3550_switch(config-if)#spanning-tree portfast [disable]
```

The keyword disable removes the PortFast configuration or disables it.

PortFast can also be enabled for all nontrunking ports with the following global configuration comr

```
3550_switch(config)#spanning-tree portfast default
```

Exercise extra caution that the proper end stations are connected to all ports before enabling PortF global level. You can verify PortFast configurations with the show spanning-tree interface<interfa portfast command.

CAUTION

PortFast should be used only when connecting a single end station to a switch port. If PortFast enabled on a port connected to another networking device, such as a switch, you can create S When you enable PortFast on the Catalyst 3550, you will get the following message:

%Warning: PortFast should only be enabled on ports connected to a single host.
Connecting hubs, concentrators, switches, bridges, etc. to this interface when
PortFast is enabled can cause temporary bridging loops.

Use with CAUTION

%Portfast has been configured on FastEthernet0/7 but will only have effect
when the interface is in a nontrunking mode.

PortFast-enabled ports are still able to participate in STP and are still able to send and receive BPDU. If a PortFast port is inadvertently connected to another switch, an STP loop could result. Cisco implements features that go hand in hand with PortFast to help prevent situations such as this: BPDU guard and BPDU filtering.

- BPDU guard— BPDU guard enforces the rule that PortFast-enabled ports should not receive a BPDU if one is received, that could indicate the port is connected to a switch and a possible STP loop could result. A BPDU guard-enabled port puts the port in an error-disabled state if it receives a BPDU. BPDU guard is disabled on all interfaces and should be enabled if PortFast is enabled. It can be enabled globally, or on a single interface, with the following command:

```
3550_switch(config)#spanning-tree portfast bpduguard default
```

To enable or disable BDPU guard on an interface, use the following interface command:

```
3550_switch(config-if)#spanning-tree bpduguard [enable | disable]
```

You can verify BPDU guard with the show spanning-tree summary command.

- BPDU filtering— BPDU filtering prevents PortFast-enabled ports from sending *or* receiving BPDUs one minor exception. During the link's initialization, a small number of BPDUs are sent before being filtered by the BPDU filtering. Once again, exercise *extreme caution* with this feature: By disabling sending and receiving of BPDUs, you effectively are disabling STP for that interface. Therefore, a warning stands as previously mentioned; be sure that no switches, hubs, bridges, and so on are connected to the interface. By default, BPDU filtering is disabled on all interfaces and should be enabled. It can be enabled globally, or on a single interface, with the following command:

```
3550_switch(config)#spanning-tree portfast bpdufilter default
```

To enable or disable BPDU filtering on an interface, use the following interface command:

```
3550_switch(config-if)#spanning-tree bpdufilter [enable | disable]
```

You can verify BPDU filtering by using the show spanning-tree detail command. At the end of the output, you will see the number of BPDUs sent and received. The number received should always be 0, and the number sent should be small and not increment if BPDU filtering is enabled. [Example 1-36](#) lists the output of the show spanning-tree detail command after enabling PortFast with BPDU guard and BPDU filtering on interface FastEthernet 0/7.

Example 1-36. Examining Spanning-Tree Details

```
3550_switch#show spanning-tree detail
<<<text omitted>>>
```

```
VLAN0100 is executing the ieee compatible Spanning Tree protocol

Bridge Identifier has priority 32768, sysid 100, address 000a.8a0e.ba80

Configured hello time 2, max age 20, forward delay 15

We are the root of the spanning tree

Topology change flag not set, detected flag not set

Number of topology changes 0 last change occurred 03:01:07 ago

Times: hold 1, topology change 35, notification 2

    hello 2, max age 20, forward delay 15

Timers: hello 0, topology change 0, notification 0, aging 300

Port 7 (FastEthernet0/7) of VLAN0100 is forwarding

    Port path cost 100, Port priority 128, Port Identifier 128.7.

    Designated root has priority 32868, address 000a.8a0e.ba80

    Designated bridge has priority 32868, address 000a.8a0e.ba80

    Designated Port id is 128.7, designated path cost 0

    Timers: message age 0, forward delay 0, hold 0

    Number of transitions to forwarding state: 1

    BPDU: sent 11, received 0

! no BPDUs received

    The port is in the portfast mode

! PortFast Enabled

3550_switch#
```

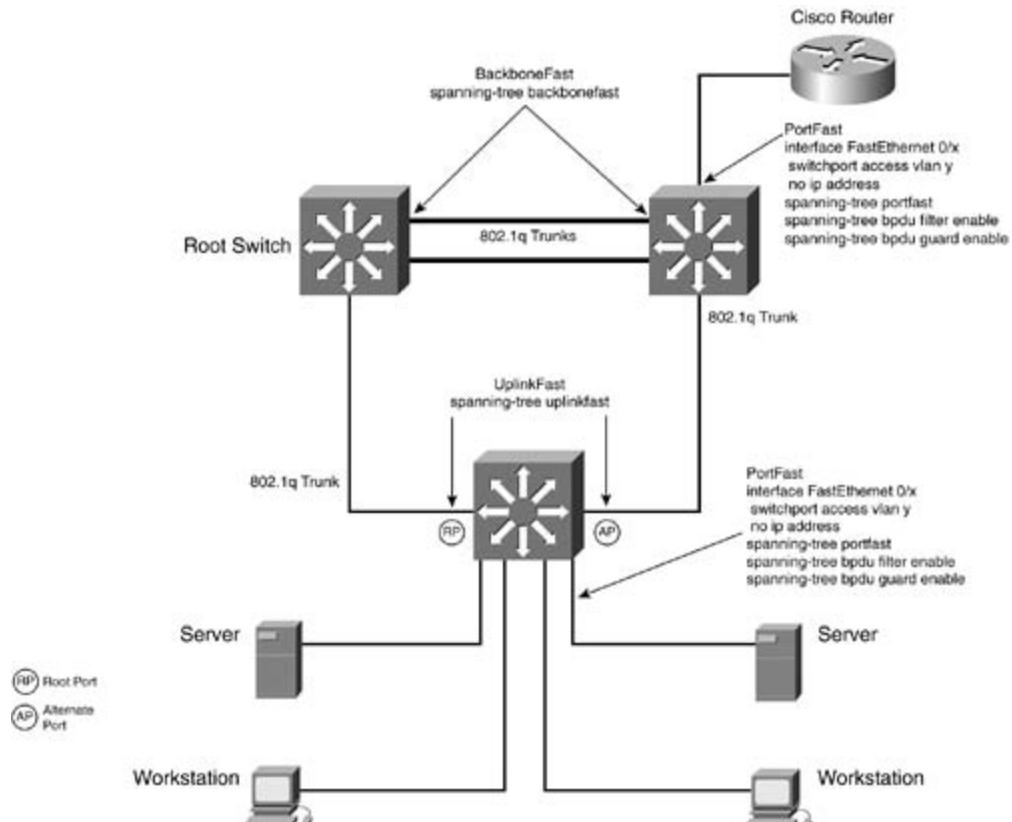
NOTE

PortFast, BPDU guard, and BPDU filtering can be used in a PVST+ or MST environment.

Configuring UplinkFast

Once again, spanning tree's Achilles' heel, the 50-second convergence time, plagues the modern L2 switch. Cisco has performed another enhancement with STP designed primarily for use in the wiring closet edge switches. It is designed to speed up the convergence speed between the edge and the core switches. Figure 1-24 illustrates where you would use PortFast along with UplinkFast and BackboneFast in a common switched network.

Figure 1-24. PortFast, UplinkFast, and BackboneFast Locations



UplinkFast works in the following manner. UplinkFast is enabled globally on the switch and affects all ports. When this happens, the VLAN priority is set to 49,152 for all VLANs on the switch. The path cost of all ports is increased by 3000 on interfaces with a path cost below 3000 to aid in preventing the switch from becoming root. The root port then immediately goes into forwarding state, bypassing the two 15-second listening and learning states. Ports within the VLAN create an uplink group. The uplink group consists of a single forwarding state, the root port, and the rest of the ports in blocking state, called *alternate ports*. When a switch with UplinkFast detects a local failure, it unblocks the blocked ports in the uplink group with the lowest path cost (next to the original root port), bypassing the two 15-second listening and learning states. As the switch transitions the alternate port to the forwarding state, the switch begins transmitting dummy frames on all forwarding ports, one for each entry in the local Encoded Address Recognition Logic (EARL) (except those entries associated with the failed root port). EARL is a centralized processing engine and forwarding packets based on MAC address. By default, approximately 15 dummy multicast frames are transmitted every 100 milliseconds. Each dummy multicast frame uses the station address in the EARL entry as its source MAC address and a dummy multicast address (01-00-0C-CD-CD-CD) as the destination address. Switches receiving these dummy multicast frames immediately update their EARL table for the source MAC address to use the new port, allowing the switches to begin using the new path virtually immediately.

If connectivity through the original root port is restored, the switch waits for a period equal to twice the delay time plus 5 seconds before transitioning the port to the forwarding state. This allows time for the port to transition through the listening and learning states.

To configure UplinkFast, use the following global configuration command:

```
3550_switch(config)#spanning-tree uplinkfast [max-update-ratepkts/seconds]
```

Before using the uplinkfast command, set the spanning-tree priority to the default value 32,768. If the priority has been modified, change it back to the default; otherwise, the uplinkfast command will have no effect. The uplinkfast command is a global command that will affect all VLANs on the switch. You cannot configure UplinkFast for an individual VLAN. The optional max-update-rate keyword is the rate at which spanning-tree updates are sent. The default rate is 150 packets per second.

NOTE

UplinkFast can only be used in a PVST+.

You can verify UplinkFast operation with the show spanning-tree uplinkfast command. This command displays whether UplinkFast is enabled on the interface. It also lists the default timers and statistics.

Configuring BackboneFast

BackboneFast is another Cisco innovation that continues to improve on the amount of time STP takes to converge. BackboneFast allows STP to detect an indirect link failure and use its alternative paths immediately. This time is significantly shorter than the default 50 seconds it takes STP to converge. BackboneFast accomplishes this by the use of inferior BPDUs and some intelligent and logical deductions based on the information contained in them. BackboneFast operates in the following manner.

A switch detects an indirect link failure when the switch receives inferior BPDUs from its designated root port or blocked ports. The previous four-step BPDU evaluation process determines whether BPDU is inferior. Inferior BPDUs could indicate that the designated bridge has lost its connection to the root bridge. An inferior BPDU identifies a single switch as both the root bridge and the designated bridge. Under normal spanning-tree rules, the switch ignores inferior BPDUs until the configured maximum aging time expires.

The switch also tries to determine whether it has an alternate path to the root bridge. If the inferior BPDU arrives on a blocked-port, root port, the switch deduces that it has alternative paths to the root bridge. If the inferior BPDU arrives on the root port, all blocked ports become alternative paths to the root bridge. If the switch finds alternative paths to the root bridge, it uses these alternate paths to transmit a new kind of PDU called a backbone-freeze message.

Link Query PDU. The switch sends the Root Link Query PDU out all alternate paths to the root bridge. If an inferior BPDU arrives on the root port and there are no blocked ports, the switch assumes that it has connectivity to the root bridge; this causes the max age timers to expire, and the switch becomes the root accordingly under normal spanning-tree standards.

If the switch has alternative paths to the root bridge, it transmits root link query (RLQ) PDUs out all alternate paths to the root bridge. If the switch determines that it still has an alternative path to the root, it maximum aging time on the ports on which it received the inferior BPDU to expire. If all the alternative paths to the root bridge indicate that the switch has lost connectivity to the root bridge, the switch causes the maximum aging times on the ports on which it received an inferior BPDU to expire. If one or more alternative paths to the root bridge connect to the root bridge, the switch makes all ports on which it received an inferior BPDU its desired root port and moves them out of the blocking state, if they were in blocking state, through the listening and learning states, and into the forwarding state.

NOTE

BackboneFast can only be used in a PVST+ and is not supported for Token Ring VLANs or third-party switches.

BackboneFast is enabled with the following global configuration command:

```
3550_switch(config)#spanning-tree backbonefast
```

You can verify BackboneFast operation with the show spanning-tree summary command, as demonstrated in [Example 1-37](#).

Example 1-37. Verifying STP UplinkFast and BackboneFast

```
3550_switch#show spanning-tree summary

Root Bridge for: VLAN0010, VLAN0100.

Extended system ID is enabled.

PortFast BPDU Guard is disabled

EtherChannel misconfiguration guard is enabled
```

```
UplinkFast is enabled
```

```
BackboneFast is enabled
```

```
Default pathcost method used is short
```

Name	Blocking	Listening	Learning	Forwarding	STP Active	Active
VLAN0001	1	0	0	4	5	
VLAN0010	0	0	0	1	1	
VLAN0100	0	0	0	1	1	
3 vlans	1	0	0	6	7	

```
Station update rate set to 150 packets/sec.
```

```
UplinkFast statistics
```

```
-----  
Number of transitions via uplinkFast (all VLANs) : 2
```

```
Number of proxy multicast addresses transmitted (all VLANs) : 0
```

```
BackboneFast statistics
```

```
-----  
Number of transition via backboneFast (all VLANs) : 0
```

```
Number of inferior BPDUs received (all VLANs) : 0
```

```
Number of RLQ request PDUs received (all VLANs) : 0
```

```
Number of RLQ response PDUs received (all VLANs) : 0
```

```
Number of RLQ request PDUs sent (all VLANs) : 0
```

```
Number of RLQ response PDUs sent (all VLANs) : 0
```

```
3550_switch#
```

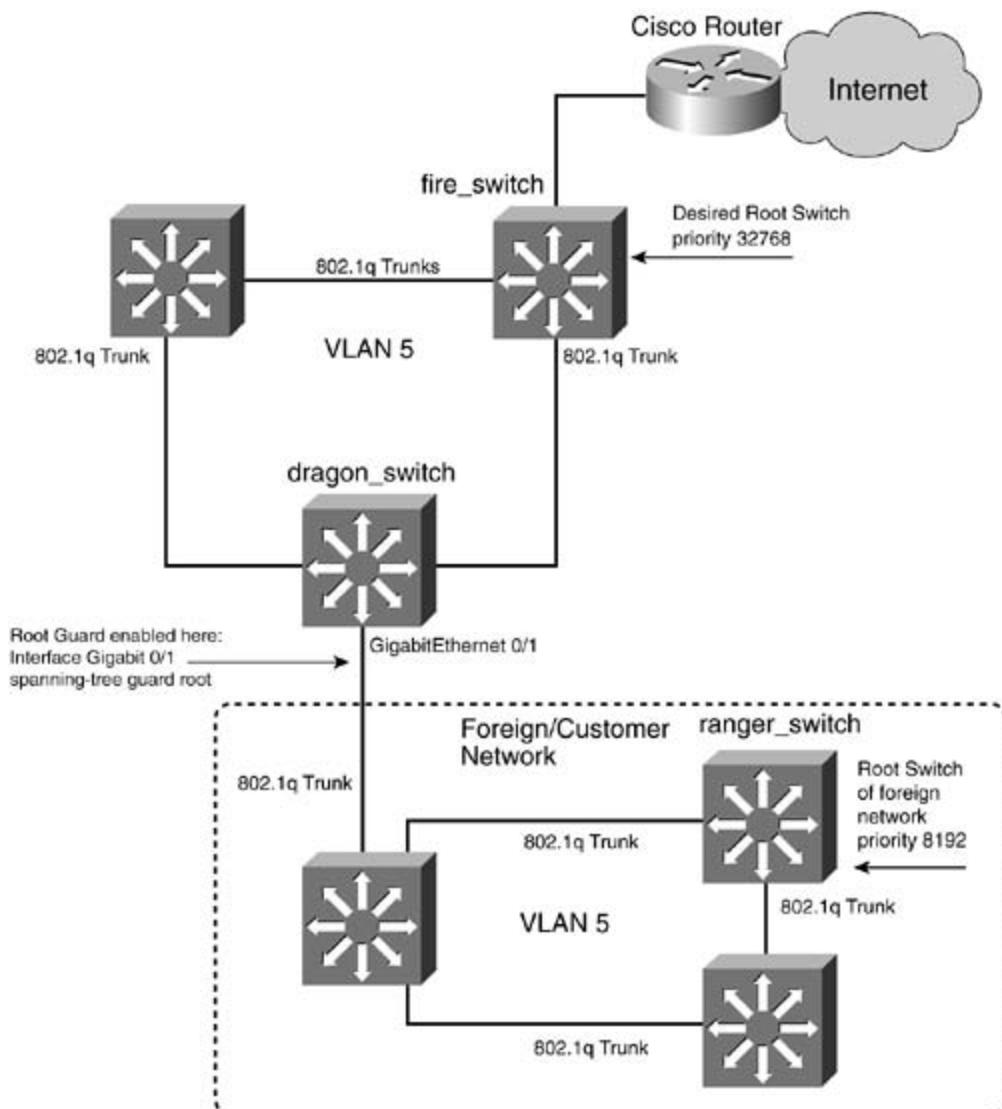
Configuring STP Root Guard

Root guard is a feature available in PVST+ and MST that protects the LAN from an undesired switch root. This feature can prove useful when integrating two LANs or VLANs and you want to preserve the original root switch.

root switch in one LAN or VLAN from another switch becoming root of the network. It may also be used in a service provider network for extra security to prevent a customer's network from becoming root over the provider.

Figure 1-25 illustrates where STP root guard would be used in VLAN 5. STP root guard will be applied to VLANs on the trunk or interface; for the purposes of this discussion, however, VLAN 5 is covered. If the fire switch is the desired root switch and has a priority of 32,768 for VLAN 5. The foreign network could also be a customer network, is connected through the dragon switch. The ranger switch has a priority of 8192 and is root for VLAN 5 in that network. To prevent the ranger switch from becoming root for VLAN 5, an interface command spanning-tree guard root was used on the GigabitEthernet 0/1 interface of the dragon switch.

Figure 1-25. Root Guard Placement



With root guard enabled on the GigabitEthernet 0/1 of the dragon switch, it will perform the following: if the dragon switch detects a switch with characteristics to become root for VLAN 5 (in this case, the ranger switch), it

port into an STP broken state with a reason of "Root Inconsistent." The port will then be put into a state, preventing the ranger switch from becoming root for the entire VLAN and preserving the current fire switch. The following interface command accomplishes this:

```
dragon_switch(config)interface gigabitethernet 0/1
dragon_switch(config-if)spanning-tree guard root
```

By default, root guard is disabled on all ports. Root guard should not be used with UplinkFast or LoadsharingFast. To verify root guard status with the show spanning-tree detail command, as listed in [Example 1-37](#), the following example shows the STP detail of the dragon switch after the ranger switch attempts to take over as root for VLAN 5.

Example 1-38. Root Guard Enabled and Active

```
3550_switch#show spanning-tree detail
<<<text omitted>>>
Port 25 (GigabitEthernet0/1) of VLAN0005 is broken (Root Inconsistent)
  Port path cost 4, Port priority 128, Port Identifier 128.25.
  Designated root has priority 32768, address 0004.275e.f5c4
  Designated bridge has priority 32773, address 000a.8a0e.ba80
  Designated Port id is 128.25, designated path cost 19
  Timers: message age 1, forward delay 0, hold 0
  Number of transitions to forwarding state: 1
  BPDU: sent 2077, received 3078
  Root guard is enabled
<<<text omitted>>>
```

Rapid Spanning Tree (802.1w) and Multiple Spanning Tree (802.1s)

802.1d spanning tree performed its job very well over the years. When 802.1d was conceived, it was primarily around bridges. In 802.1d, BPDUs are relayed from bridge to bridge with the sole intent of creating a loop-free topology with a single root bridge. Switches did not exist at the time and obviously neither did VLANs. LANs continued to evolve at a blistering pace, and switching was introduced along with the VLANs and VLAN trunks. For the most part, STP still continued to perform its role rather well.

Spanning tree's Achilles' heel has always been its long convergence time. The 50 seconds it requires from link failure is simply too long in today's Fast Ethernet and Gigabit Ethernet networks.

The IEEE has been very busy addressing many of the needs of the ever-changing Ethernet protocol. Systems once again pioneered the way by offering technologies such as PortFast and UplinkFast, added to the IEEE committee to use in 802.1w RSTP. Two standards developed by the IEEE will play an important role in large redundant Ethernet networks: IEEE 802.1w, called Rapid Spanning Tree Protocol (RSTP); and IEEE 802.1s, Multiple Spanning Tree (MST).

NOTE

RSTP was first implemented as part of MST in CAT OS 7.1 and native IOS 12.1.(11)EX and later became available as a standalone protocol, Rapid PVST mode, in Cisco IOS 12.1(13)E and in CAT C. At the time of this writing, you must configure MST for RSTP to work.

Quick Convergence with 802.1w Rapid Spanning Tree Protocol

IEEE 802.1w is called *Rapid Spanning Tree Protocol* (RSTP). RSTP could really be called *intelligent*. RSTP operates identically to STP in terms of root selection, STP cost, and STP priority. What makes RSTP different is that it can recognize a port's physical status and make logical deductions about the network topology based on the BPDUs received on that port. The *port type* or *port role* plays an important role. Because the bridging functions of the switch are now intelligent, RSTP can converge in a few hundred milliseconds rather than the 50 seconds of 802.1d. Now that's more like it! RSTP uses technologies such as PortFast, and some concepts from UplinkFast and BackboneFast. It can coexist with PVST+ and is fully compatible with 802.1d. The election of the root bridge/switch is identical to 802.1d.

Topology changes are marked with the same topology change (TC) flag but are handled differently in 802.1d. Topology changes in 802.1w occur only when a port transitions from the blocking to the forwarding state. Edge-port transitions do not generate topology changes. In 802.1d, TCs flow from where the root switch/bridge; from there, the root propagates the TC to all the leaves of the spanning tree. In other words, it works like a designated router in OSPF. In 802.1w networks, TCs are flooded out all ports where a topology change occurred, saving the time of having to go to the root switch first. This method aids in quick convergence for 802.1w networks and prevents unnecessary port transitions and BPDU flooding.

In addition to using *port roles*, RSTP uses a new BPDU format.

Updated and Improved BPDU Handling

IEEE 802.1w bridges/switches ensure backward compatibility with legacy 802.1d bridges/switches by using the same 802.1d BPDU and following the same spanning-tree rules for root, designated port, and non-root port election. 802.1w uses the same BPDU as 802.1d, but it is how it uses that BPDU that is different.

takes full advantage of the Flags field, using all 8 bits to aid in making intelligent forwarding decisions.

[Figure 1-26](#) shows the traditional IEEE 802.1d BPDU frame format compared to the new IEEE 802.1w Spanning Tree frame. 802.1d BPDDUs only use two flags, one of which is for TC, and the other for Tc acknowledgments. The remaining 6 bits, bits 2 through 7, are not used in 802.1d.

802.1w BPDDUs distinguish themselves by setting the BPDU type and version to 2. By setting the version type to 2, 802.1w can recognize legacy bridges easily on any link. Likewise, a legacy 802.1d bridge can recognize the version 2 BPDDUs and will drop them. When an 802.1w port detects an 802.1d BPDU, it automatically configures that port for PVST+ and sends normal 802.1d frames on that port. 802.1w generates BPDDUs every 2 seconds, equal to the hello timer. With 802.1d, a nonroot bridge only generates BPDDUs when it is one hop away from the root bridge. An 802.1w bridge is actually generating the BPDDUs rather than relaying them in a 802.1d environment. A bridge now sends a BPDU with its current information every hello-timer seconds (the default), even if it does not receive any from the root bridge.

If hellos are not received for three consecutive times, BPDU information is immediately aged out; the max age timer expires. BPDDUs are now used as a keepalive mechanism between bridges. A bridge considers that it has lost connectivity to its direct neighboring root or designated bridge if it misses three hellos in a row. This is referred to as *fast aging* and allows for quick failure detection.

802.1w bridges also accept inferior BPDDUs, much like backbone fast ports. 802.1w bridges will accept inferior BPDU information and replace the old information with it.

As shown in [Figure 1-26](#), other bits are now used in the 802.1w frame. Some of the more significant fields include the proposal bit and the port type.

- The *proposal bit* is just one method RSTP uses for rapid convergence. The proposal mechanism uses timers; therefore, it allows STP to converge very quickly. A proposal message is sent to the switches. The proposal is sent when a switch detects a change in root. Either the switch becomes the new root port or it remains the same. The new root port is selected from receiving a more desirable BPDU. When this happens, the switch sends a proposal message to adjacent switches on designated point-to-point ports. When the downstream switch receives the proposal, it sends an acknowledgment back to the switch that sent it. When it does so, it puts the port that received the proposal into forwarding mode. At the same time, all designated ports are moved into the blocking/discarding state; this helps prevent loops on the network. The designated ports generate a proposal message to any downstream switches. When the proposal is acknowledged, the designated port is put into the forwarding state. This synchronization process works its way up the switch, where it stops. The synchronization process does not happen if the port's prior state is edge. Edge ports are defined as an edge port. In [Figures 1-27](#) and [1-28](#), an 802.1w network goes through the synchronization process described.

Figure 1-27. IEEE 802.1w Synchronization

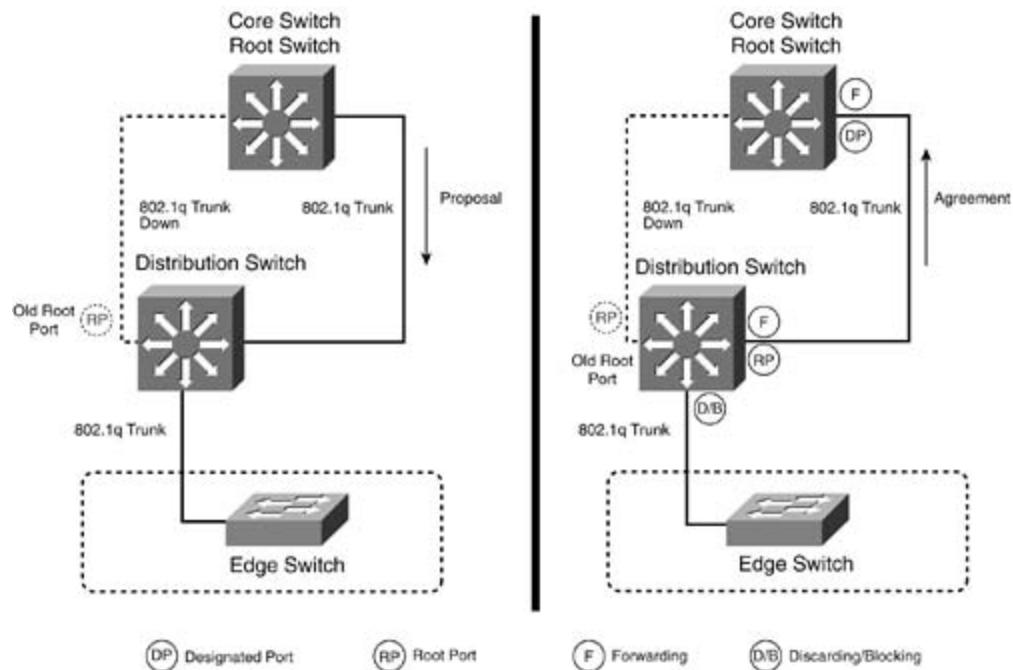
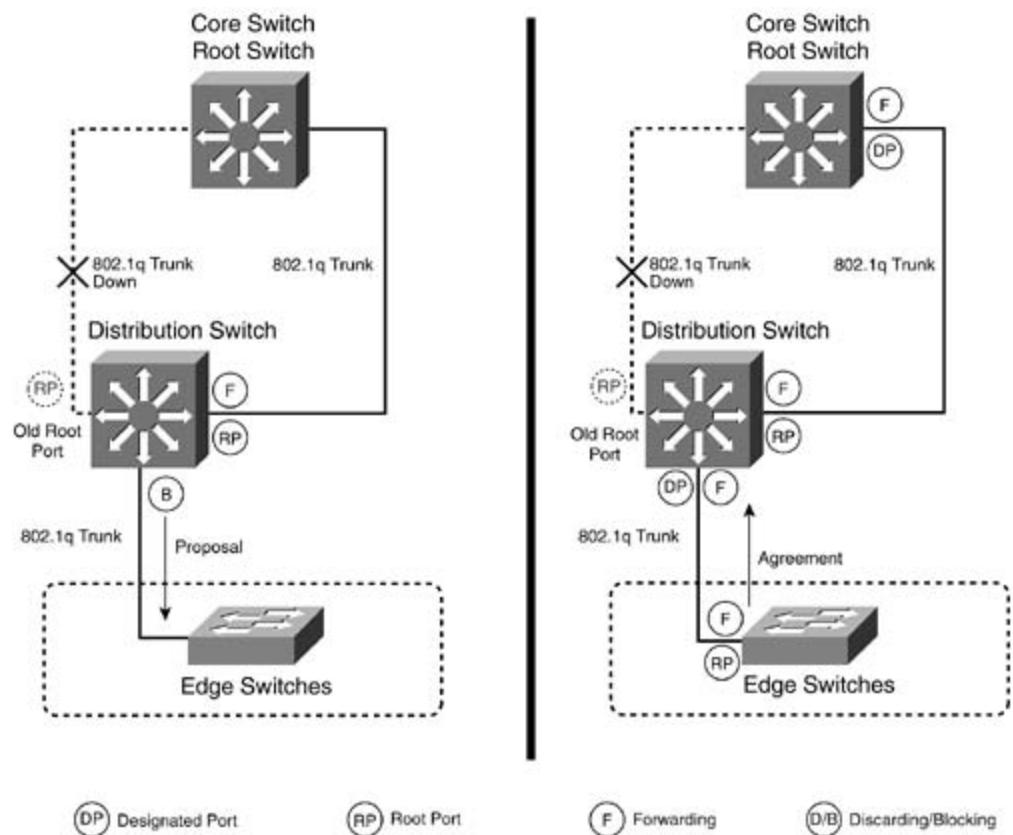


Figure 1-28. IEEE 802.1w Synchronization

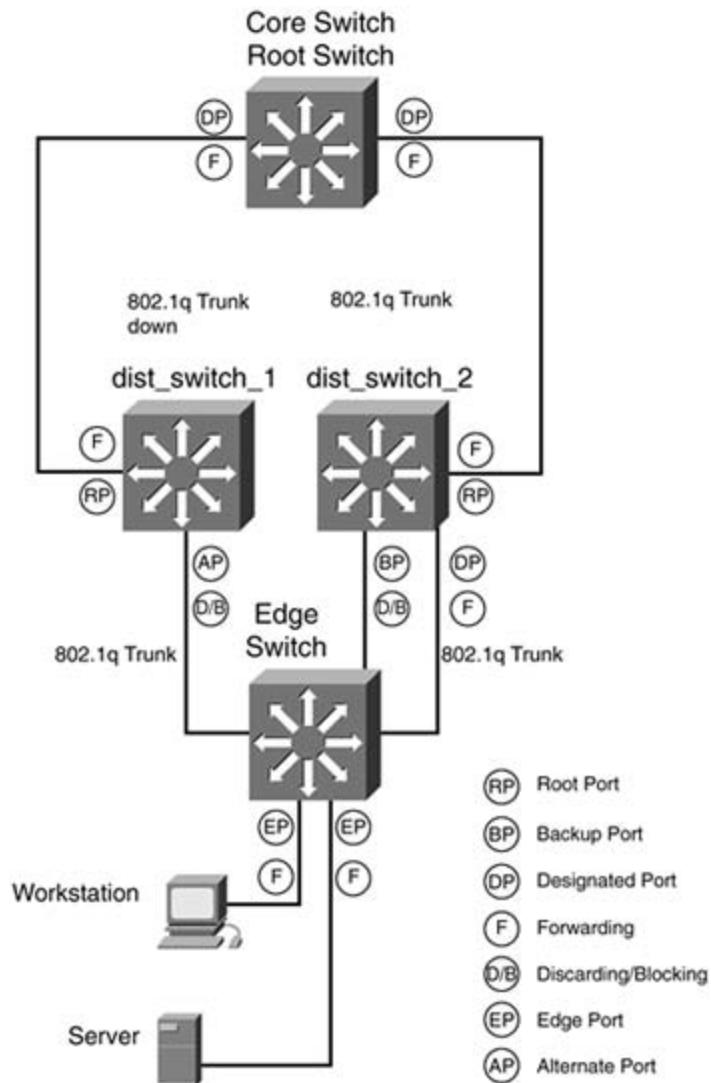


Port Status in RSTP/802.1w

Another way 802.1w dramatically increases the convergence rate is by assigning every port a specific role in the network. From [Figure 1-26](#), you see that 802.1w incorporates room in the BPDU for port status information. 802.1w not only classifies the port type, but it also classifies the link type. [Figure 1-29](#) shows the port roles in an 802.1w network.

- Link type (point-to-point versus shared)— 802.1w or RSTP assumes that a link operating in a point-to-point link. Convergence happens on a point-to-point link with the proposal/agreement mechanism previously mentioned. If a link is operating in half duplex, RSTP considers it a shared link and can override both of these settings with the spanning-tree link-type command.
- Edge ports— RSTP uses the same command, spanning-tree portfast, to define edge ports. This command smoothes the STP transition from 802.1d to 802.1w. All edge ports operate the same way as 802.1d; they skip the listening and learning states and are immediately put into permanent forwarding mode. In RSTP networks, if a BPDU is received on an edge port, it becomes a normal STP port with edge and PortFast status.
- Root ports— Root ports operate and are elected in the same manner as 802.1d STP. The root port provides the best, lowest-cost path to the root switch. Think of the root port as the port that leads away from the root. If RSTP selects a new root port, it blocks the old root port and immediately transitions the new port to forwarding.
- Designated ports— A designated port can be defined as the port that leads away from the root as the port that a LAN must go through to reach the root switch. There can only be one designated port per segment, and it is elected in the same way that it is in 802.1d: by the bridge sending the best BPDUs on the segment. Designated ports also use the proposal/agreement procedure for rapid convergence and are placed in the forwarding state.
- Alternate ports— Alternate ports are a new RSTP classification. Alternate ports are ports that receive more useful BPDUs from *another* bridge/switch on the same segment. These more useful BPDUs come from the designated port. Alternate ports are put into a new RSTP state called discarding. Discarding is discussed in the next section. Discarding is basically equivalent to the blocking state.
- Backup ports— Backup ports are ports that have received more useful BPDUs from the *same* bridge/switch that they are on. A backup port is really an UplinkFast port and functions in the same manner. It can be thought of as a backup for the designated port on the same switch. Backup ports are in discarding state. By having explicit alternate ports and backup ports, RSTP is able to make intelligent convergence decisions when it loses BPDUs or loses the root port. This is yet another way RSTP offers quick convergence.

Figure 1-29. IEEE 802.1w RSTP Port Status



[Figure 1-29](#) illustrates the new RSTP port status on a common network.

802.1w RSTP also uses a slightly different port state than 802.1d. Instead of blocking, a RSTP prot state of discarding. [Table 1-15](#) compares the old 802.1d STP state to the new 802.1Q RSTP state.

Configuring 802.1w RSTP on the Catalyst 3550, at this time, requires you to configure 802.1s MST, such as the Catalyst 4000, 6500, and other CAT OS systems, RSTP can be enabled separately from set spantree mode command.

[Table 1-15. STP and RSTP Port State Comparison](#)

802.1dSTPState	802.1wRSTPState	Port Included in Active Topology?
Blocking	Discarding	No
Listening	Discarding	No
Learning	Learning	Yes
Forwarding	Forwarding	Yes

Multiple Spanning Tree (802.1s)

Multiple Spanning Tree 802.1s enables you to group VLANs and their associated STP tree into comr instances. Members of the same STP instance have the same STP topology, such as root and which forwarding and so on. The VLANs that are members of one STP instance operate independently of another STP instance. MST enables network administrators to quickly configure load balancing acrc network, without having to set an individual root or priority for each VLAN on the switch. MST acco in part, by the use of MST regions.

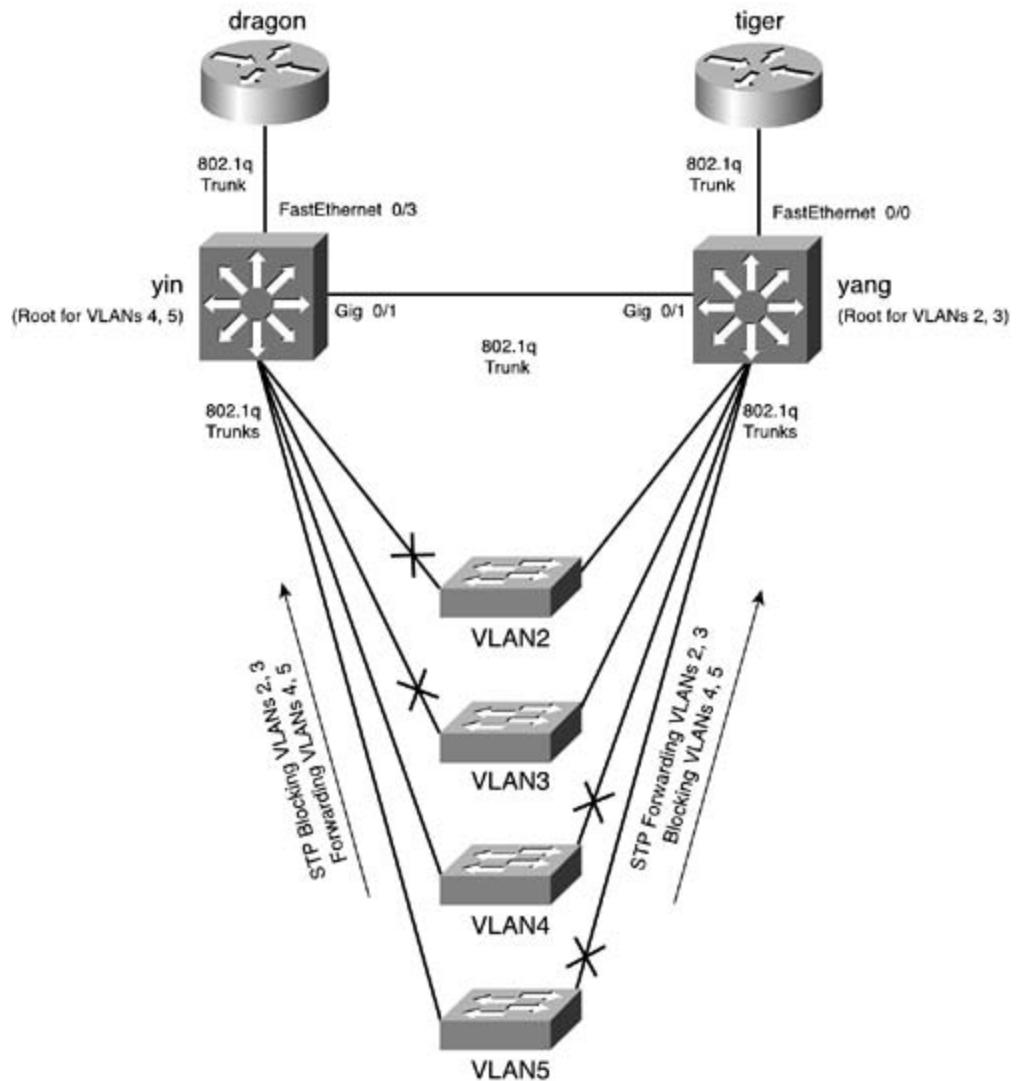
MSTregions are interconnected bridges that have the same MST configuration. The configuration in following:

- MST instance number and name
- Configuration revision
- 4096 element table used for VLAN association

The instance number, name, and configuration revision must match for the switches to be in the sa region.

This chapter previously covered VLAN load sharing. (Refer to [Figure 1-30](#).) With traditional 802.1d needed to define the root for VLANs 2 and 3 on the yang switch. You also had to manually assign t VLANs 4 and 5 on the yin switch. This procedure was necessary to load share over the links between yang switches. In large networks, this can lead to a lot of configuration (requiring you to manually priorities for each VLAN).

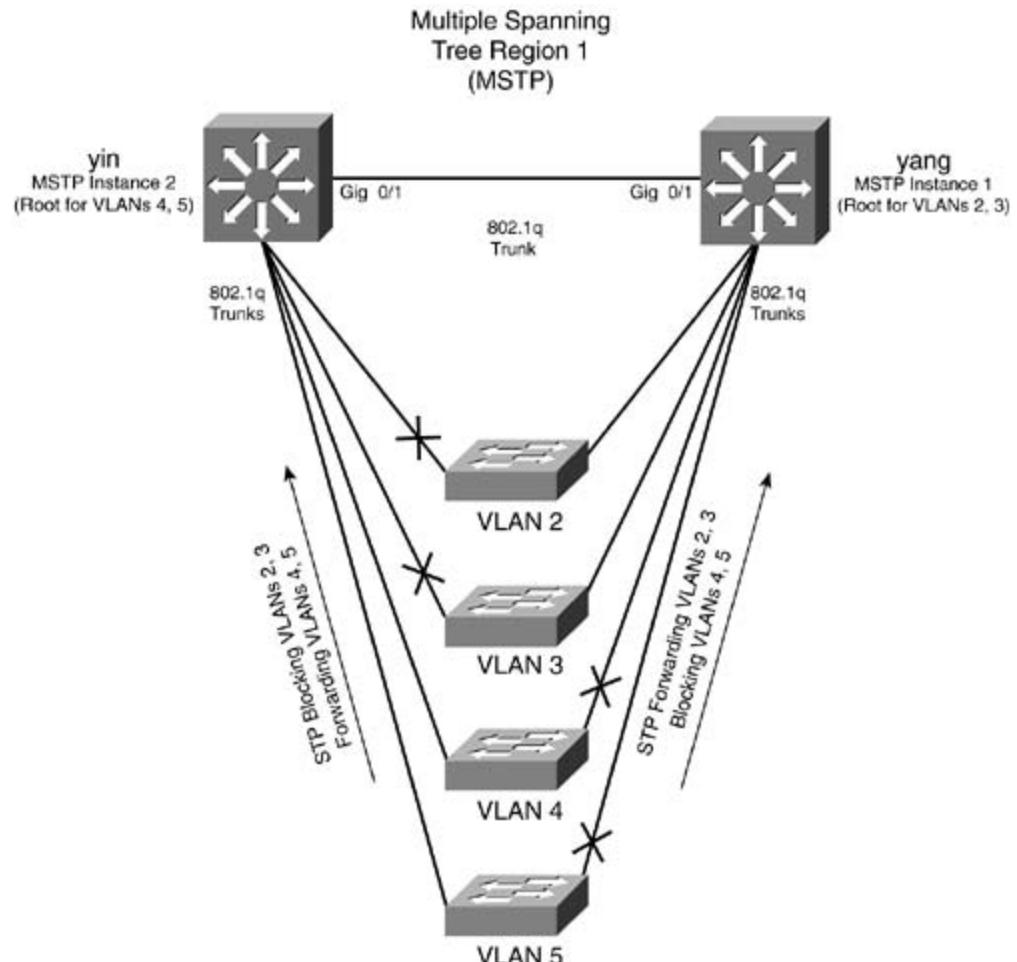
Figure 1-30. STP Load Sharing with 802.1d



If you were running MST 802.1s on this network, you would make just two MST instances. One instance would have VLANs 2 and 3 assigned to it, and the root would be the yang switch. The second MST instance would have VLANs 4 and 5 assigned to it, and the root would be the yin switch. If you needed to add more VLANs to the network, the new VLANs would just become a member of one of the two MST instances. With MST, you do not have to configure STP for two instances, instead of configuring STP and its associated parameters for every instance.

[Figure 1-31](#) illustrates the network with 802.1s configured.

Figure 1-31. STP Load Sharing with 802.1s



The Cisco implementation of MST defines the following characteristics:

- MST runs a variation of spanning tree called *Internal Spanning Tree* (IST). IST complements Spanning Tree (CST) information with internal information about the MST region. The MST region is a single bridge to adjacent 802.1d, or Single Spanning Tree (SST), and other MST regions. [1-32](#) and [1-33](#).

Figure 1-32. CST IST Relationship with 802.1s

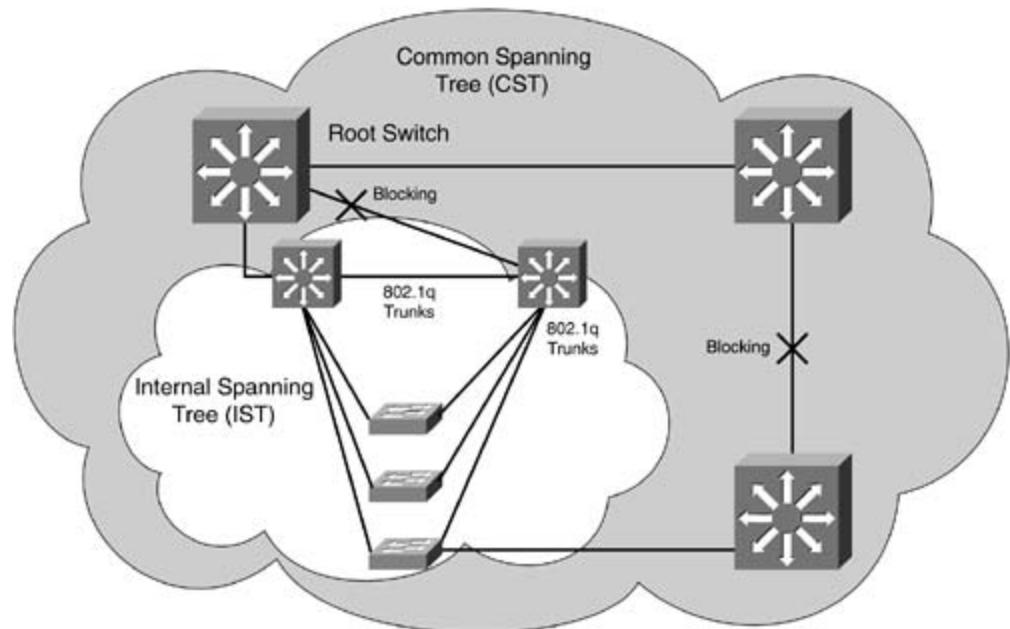
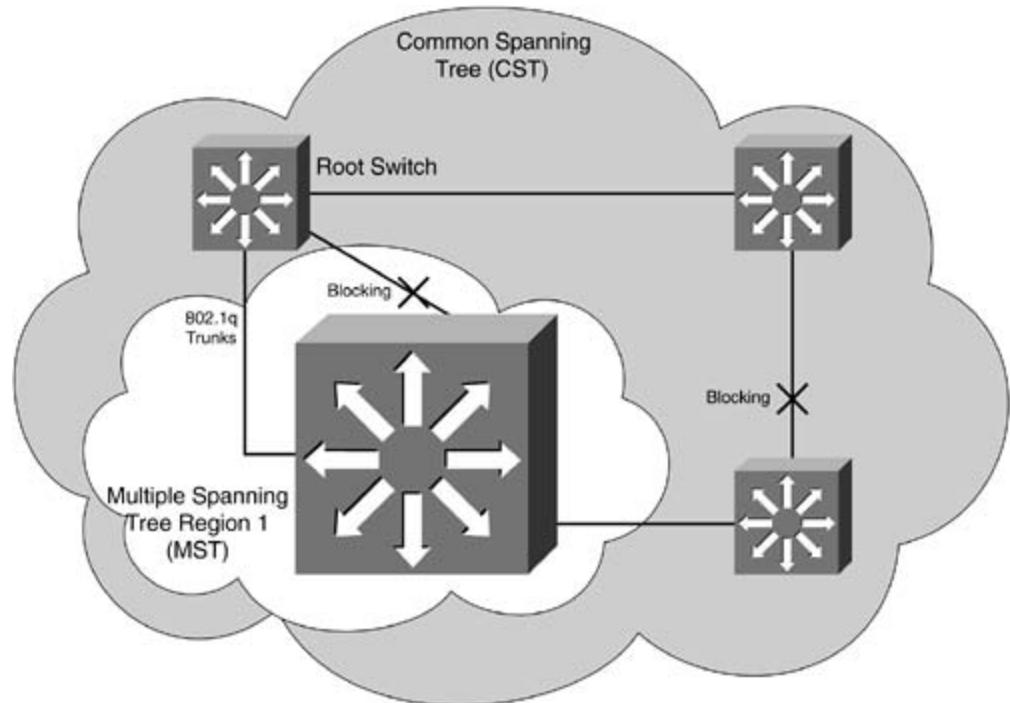


Figure 1-33. CST MST Relationship with 802.1s



- The *Common Internal Spanning Tree (CIST)* is the collection of the following: ISTs in each MST region, the CST that interconnects the MST regions, and the legacy 802.1d or SST bridges. CIST is identical inside an MST region and identical to a CST outside an MST region. The STP, RSTP, and MST are single bridge as the root of the CIST. The CIST can be thought of like the Mono Spanning Tree needed for 802.1Q.

- MST establishes and maintains additional spanning trees within each MST region. These spans are termed *MST Instances* (MSTIs). The IST is numbered 0, and the MSTIs are numbered 1, 2, 3, and so on. The MSTI is local to the MST region and is independent of MSTIs in another region, even if the regions are interconnected.
- Spanning tree information for an MSTI is contained in an MST record (M-record). M-records are encapsulated within MST BPDUs. The original spanning trees computed by MSTP are called M-trees. M-trees are active only within the MST.
- MST provides interoperability with PVST+ by generating PVST+ BPDUs for the non-CST VLANs.
- MST supports the following PVST+ extensions:
 - UplinkFast and BackboneFast are not configurable in MST mode; they are part of RSTP enabled by default when MST is enabled.
 - PortFast is supported and required for RSTP edge ports.
 - BPDU filter and BPDU guard are supported.
 - Loop guard and root guard are supported.
 - MST switches operate with an extended system ID.

[Figures 1-32](#) and [1-33](#) illustrate the relationship between the MST, IST, and CST functions. The two figures show different views of the same topology. The MST region is represented to the CST as a single bridge. The MST region appears as a virtual bridge to adjacent 802.1d SST bridges and MST regions. The IST master of the MST region is the bridge with the lowest BID and the lowest-cost path to the CST root. If an MST region is the root bridge for the CST, it is the IST master of that MST region. If the CST root is outside the MST region, one of the MST bridges at the boundary is selected as the IST master. This port is referred to as the *boundary port*. Other bridges on the boundary that belong to the same region eventually block all traffic from other regions except for the ports that lead to the root bridge.

Cisco defines the IST and CST relationship as follows:

IST connects all the MST bridges in the region and appears as an STP subtree in the CST domain. The MST region appears as a virtual bridge to adjacent 802.1d SST bridges and MST regions. The IST master of the MST region is the bridge with the lowest BID and the lowest-cost path to the CST root. If an MST region is the root bridge for the CST, it is the IST master of that MST region. If the CST root is outside the MST region, one of the MST bridges at the boundary is selected as the IST master. This port is referred to as the *boundary port*. Other bridges on the boundary that belong to the same region eventually block all traffic from other regions except for the ports that lead to the root bridge.

Special port statuses for 802.1s are as follows:

- Boundary ports are the port(s) that connect to a legacy 802.1d LAN, or a bridge/switch in a different region. Boundary ports can automatically configure themselves by examining an agreement with another MST or SST or legacy 802.1d bridge.
- ISTmaster is the bridge/switch with the lowest BID and the least-cost path to the CST root. If an MST region is the root bridge for the CST, it is the IST master of that particular MST region. If the CST root is outside the MST region, one of the MST bridges that is a boundary port is selected as the IST master.

NOTE

IST BPDUs for the IST are sent on MST instance 0. Only the first instance of MST actually sends IST BPDUs. The first instance in Cisco switches is instance 0; therefore, you should avoid mapping VLANs to instance 0.

instance. Treat it much as you would VLAN 1. It runs everywhere and is needed for the IST.

The previous information was meant to be a comprehensive overview of IEEE 802.1w and IEEE 802.1s. As many protocols, the technical details can be rather complex. For more detailed information on 802.1s, consult www.ieee.org/standards.ieee.org, and, of course, www.cisco.com.

Configuring IEEE 802.1w Rapid Spanning Tree (RSTP) and IEEE 802.1s Multiple Spanning Tree (MST)

Cisco has made the migration to 802.1s MST and 802.1w RSTP seamless. As a matter of fact, RSTP is automatically enabled when you select MST as the spanning-tree mode. On CAT OS platforms, you configure the two separately, but on the Catalyst 3550, the two are tightly integrated, and why not. The benefits from RSTP convergence are enormous, and they multiply themselves with the size of the network. Just like its predecessor 802.1d STP, configuring 802.1w and 802.1s is simpler than the concepts behind them.

To configure 802.1w RSTP, you need to configure 802.1s MST and enable spanning-tree PortFast on all edge ports. RSTP will automatically be enabled when MST is configured. Use the following process to configure MST on the Catalyst 3550. This configuration process assumes you have VLANs, VTP, and VLAN routing running.

Step 1. Configure spanning-tree PortFast on all edge ports. Use the interface command `spanning-tree portfast`.

Step 2. Configure the MST name and revision number. All switches within an MST region must have the same MST name and MST revision number. To configure MST, first enter the MST configuration mode using the following global configuration command:

```
3550_switch(config)#spanning-tree mst configuration
```

From this mode, you can configure the MST instance, name, and revision and show the current MST configuration. This mode works like the VLAN database, in that it has to be committed before changes take effect. Use the keyword `exit` to commit the changes or the keyword `abort` to clear any configuration entered in this period. To display pending configuration settings, use the MST configuration command `show pending`. Use the following MST configuration commands to configure MST parameters:

```

3550_switch(config-mst)#nameMST_region_name

3550_switch(config-mst)#revision revision_number_<0-65535>

3550_switch(config-mst)#exit

! Must commit changes for MST

3550_switch(config-mst)#abort

! optional Aborts MST config

```

Step 3. Divide the MST region into MST instances and assign VLANs to those instances. Rem VLANs in a single instance will follow the same path to root. Any VLANs not assigned to a spe will default to instance 0. All VLANs in use should be assigned to an instance. If you just wan RSTP, assign all VLANs to instance 1. If you want to load share, assign half the VLANs to one half to the other. Use the following MST configuration command to assign MST instances and VLANs:

```
3550_switch(config-mst)#instance <0-15> vlanlan,vlan-range
```

Step 4. Enable MST mode. Use the following global configuration command to enable MST or default mode of PVST. This command also enables RSTP 802.1w.

```
3550_switch(config)#spanning-tree mode mst
```

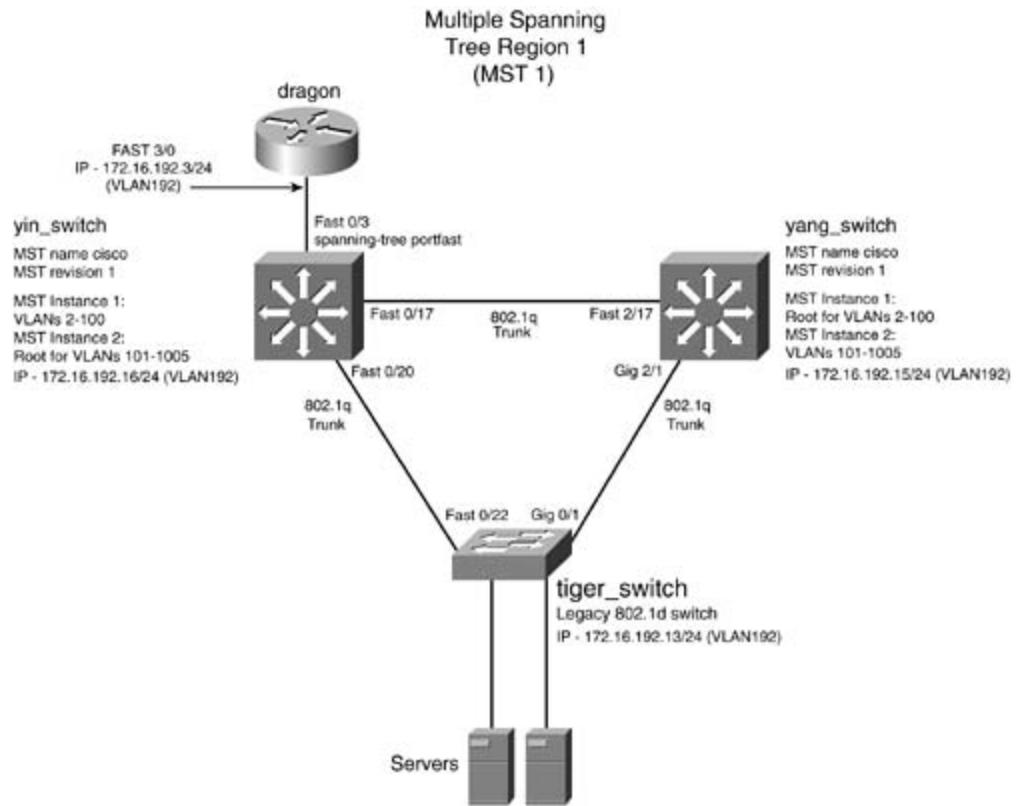
NOTE

The MST instance of 0 is used for the IST. As a design rule, assign VLAN 1 to MST instance 0 a VLANs not in use. This is a design option more than a functional requirement.

Practical Example: Configuring RSTP and MST Load Sharing

[Figure 1-34](#) shows a LAN network in which you want to configure MST load sharing between the yin switch. In this model, you configure RSTP and MST. You will make one MST instance, instance 1, fc through 100. The root for VLANs 2 through 100 will be the yang switch. MST instance 2 will contain VLANs 101 through 1005, and the yin switch will be the root for those VLANs. The MST name will be cisco, and revision number will be 1.

Figure 1-34. RSTP and MST Configuration



[Example 1-39](#) demonstrates the configuration of RSTP and MST on the yin switch.

Example 1-39. Configuration of RSTP and MST on the Yin Switch

```
yin_switch(config)#interface fast 0/3
yin_switch(config-if)#spanning-tree portfast
! enable portfast on the router port
```

```

yin_switch(config)#spanning-tree mst configuration

! Enter the MST configuration mode

yin_switch(config-mst)#name cisco

! MST region name

yin_switch(config-mst)#revision 1

! MST region revision

yin_switch(config-mst)#instance 1 vlan 2-100

! VLANs 2-100 assigned to Instance 1

yin_switch(config-mst)#instance 2 vlan 101-1005

! VLANs 2-100 assigned to Instance 2

yin_switch(config-mst)#show current

! view current MST changes

Current MST configuration

Name      [cisco]

Revision  1

Instance  Vlans mapped
----- -----
0        1,1006-4094
1        2-100
2        101-1005

yin_switch(config-mst)#exit

! commit current MST changes

yin_switch(config)#spanning-tree mode mst

! enable MST mode

yin_switch(config)#spanning-tree mst 2 root primary

! set MST instance 2 to root

% This switch is already the root bridge of the MST02 spanning tree

mst 2 bridge priority set to 24576

```

You can view and verify the MST status with the show spanning-tree mst 0-15[configuration | interface] command. This command displays detailed information about the MST instance, such as root priority, the MST interfaces, and the interface role; state and type are also listed. [Example 1-4](#) demonstrates the show spanning-tree mst command on the yin switch.

Example 1-40. show spanning-tree mst Command

```
yin_switch#show spanning-tree mst 2

##### MST02      vlans mapped: 101-1005

Bridge      address 000a.8a0e.ba80  priority 24578 (24576 sysid 2)

Root        this switch for MST02

Interface    role state cost      prio type

-----
Fa0/3        desg FWD   200000    128   edge P2P
Fa0/17       desg FWD   200000    128   P2P
Fa0/20       boun BLK   200000    128   P2P bound(PVST)
```

Notice that the port Fast 0/17 is a designated point-to-point port to a switch in the same region, while Fast 0/20 is a boundary point-to-point link to a PVST (802.1d) domain. Interface Fast 0/3 goes to the tiger switch. Notice that in [Example 1-40](#), the Fast 0/17 port to the yang switch is forwarding traffic; if you ping the yang switch, the interface 0/17 will be disconnected; as you will see, there is virtually no loss at all in the ping. This is really an incredible convergence improvement over 802.1d. Recall that an 802.1d network would take 30 seconds to converge!

Example 1-41. Rapid Spanning Tree in Action!

```
yin_switch#ping

Protocol [ip]: ip

Target IP address: 172.16.192.13

Repeat count [5]: 5000
```

```

Datagram size [100]:  

Timeout in seconds [2]:  

Extended commands [n]:  

Sweep range of sizes [n]:  

Type escape sequence to abort.  

Sending 5000, 100-byte ICMP Echos to 172.16.192.13, timeout is 2 seconds:  

!!!!!!  

!!!!!!  

!!!!!!  

<<<text omitted>>>  

!!  

00:53:53: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/17, change  

.!!  

!!!!!!  

!!!!!!  

!!!!!!  

<<<text omitted>>>  

Success rate is 99 percent (4999/5000), round-trip min/avg/max = 1/14/72 ms  

yin_switch#  

yin_switch#show spanning-tree mst 2  

##### MST02          vlans mapped: 101-1005  

Bridge      address 000a.8a0e.ba80  priority 24578 (24576 sysid 2)  

Root        this switch for MST02  

Interface    role state cost      prio type  

-----  

Fa0/3        desg FWD   200000    128   edge P2P  

Fa0/20       boun FWD   200000    128   P2P bound(PVST)  ←Fast 0/17 is gone!!

```

Variations of the same 802.1d spanning-tree commands are available in MST for setting STP root position, secondary, port priority, port cost, and STP priority. Functionally, they are identical to 802.1d commands. The syntax for changing these various values is as follows:

```
3550_switch(config)#spanning-tree mst instance_id [root {primary|secondary } |cost  
➥ 200000000 | priority 0-61440 | port-priority 0-255 ]
```

To adjust the MST timers, use the following syntax:

```
3550_switch(config)#spanning-tree mst instance_id [hello-time 1-10 | max-age 6-40 |  
➥ forward-time 6-40 | max-hops 1-40 ]
```

To change the MST link type to a point to point, use the following interface command:

```
3550_switch(config-if)#spanning-tree link-type point-to-point
```

You can verify the MST configuration with the following command:

```
show spanning-tree mst instance_id [configuration | detail | interface]
```

The `show spanning-tree mst` command shows all the MST instances and the associated STP status, and timers. [Example 1-42](#) lists the partial output of the `show spanning-tree mst detail` command on the `yin` switch. For more detailed information on various show commands, refer to the Cisco IOS command reference.

Example 1-42. `show mst detail` Command Output

```
yin_switch#show spanning-tree mst detail

##### MST00      vlans mapped: 1,1006-4094

Bridge      address 000a.8a0e.ba80  priority 32768 (32768 sysid 0)
Root        address 0004.275e.f0c0  priority 32768 (32768 sysid 0)

port       Fa0/17          path cost 20019

IST master  address 0030.1976.4d00  priority 32768 (32768 sysid 0)
                           path cost 200000    rem hops 19

Operational hello time 2, forward delay 15, max age 20, max hops 20
Configured   hello time 2, forward delay 15, max age 20, max hops 20
FastEthernet0/3 of MST00 is designated forwarding

Port info      port id      128.3  priority 128  cost 200000
Designated root  address 0004.275e.f0c0  priority 32768  cost 20019
Designated ist master address 0030.1976.4d00  priority 32768  cost 200000
Designated bridge  address 000a.8a0e.ba80  priority 32768  port id 128.3

Timers: message age 0, forward delay 0, transition to forwarding 0
Bpdus sent 5250, received 0

FastEthernet0/17 of MST00 is root forwarding

Port info      port id      128.13  priority 128  cost 200000
Designated root  address 0004.275e.f0c0  priority 32768  cost 20019
Designated ist master address 0030.1976.4d00  priority 32768  cost 0
```

```
Designated bridge      address 0030.1976.4d00  priority  32768  port id    32.81
<<<text omitted>>>
```

Controlling Traffic and Security with VLAN Maps

The Catalyst 3550 enables you to control all traffic within a VLAN with a specific route map type of *VLAN map*. This section briefly discusses how to configure and apply VLAN maps.

VLAN maps enable you to control all traffic within a VLAN that is local to the switch. VLAN maps apply to packets that are routed into or out of the VLAN, or are bridged within a VLAN that is local to the switch. A VLAN map does not have a direction (in or out) associated with it.

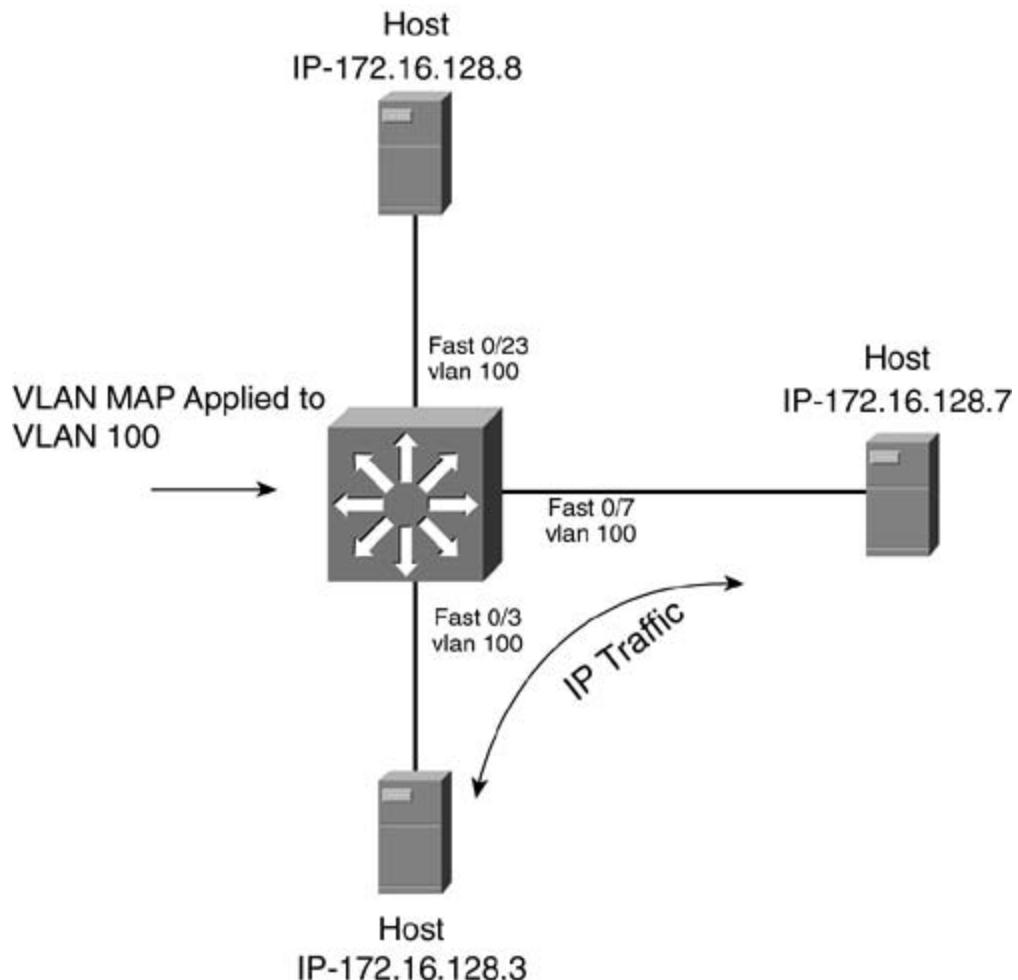
You can configure VLAN maps to work with a standard, extended, or named ACL. The Catalyst 3550 supports IP standard and IP extended ACLs, numbers 1 to 199 and 1300 to 2699. All non-IP protocols are controlled through MAC addresses and by using MAC VLAN maps. It is important to note that you can control traffic based on MAC. The MAC filters only apply to nonrouted traffic such as NetBIOS. You must use a standard or extended ACL to forward IP traffic.

A VLAN map works just like a route map. You may want to skip ahead to [Chapter 2](#), "Configuring IP and Policy-Based Routing," for more information about route maps if you are not already familiar with them.

To configure VLAN maps to control IP traffic, first configure the VLAN map, and then assign a sequence number to the map. VLAN maps are executed from the lowest instance to the highest. Use the global configuration command `vlan access-map map_name sequence_number`. Next, add a `match ip` statement, where you can call a named ACL for your match criteria. You then assign an action to the VLAN map; the valid actions are `forward` and `drop`. Based on the result of the ACL, the switch forwards or drops the packet. The MAC filter may also be applied to filter nonroutable traffic. To apply the VLAN map, use the `vlan filter map_name vlan-list vlangs` command.

In [Figure 1-35](#), three IP hosts are connected to the switch. In this example, IP traffic needs to be controlled so that hosts in VLAN 100 can talk to each other, but not to hosts in VLAN 200. For example, traffic from host 172.16.128.7 in VLAN 100 to host 172.16.128.3 in VLAN 100 needs to be forwarded, but traffic from host 172.16.128.7 in VLAN 100 to host 172.16.128.1 in VLAN 200 needs to be dropped.

Figure 1-35. VLAN Maps



[Example 1-43](#) demonstrates the configuration needed to control IP access with a VLAN map.

Example 1-43. Configuring a VLAN Map

```

3550_switch(config)#vlan access-map allow_ip 10
! Define the VLAN map 'allowip'

3550_s(config-access-map)#action forward
! Forward ACL permitip

3550_s(config-access-map)#match ip address permitip
! Call ACL permitip

3550_s(config-access-map)#exit

3550_switch(config)#

```

```

3550_switch(config)#ip access-list extended permitip
! ACL permitip

3550_swi(config-ext-nacl)#permit ip host 172.16.100.7 host 172.16.100.3
3550_swi(config-ext-nacl)#permit ip host 172.16.100.3 host 172.16.100.7
3550_swi(config-ext-nacl)#exit
3550_switch(config)#
3550_switch(config)#vlan filter allow_ip vlan-list 100
! Apply VLAN map to VLAN 100
3550_switch(config)#

```

To verify the VLAN map, use the show vlan access-map and the show access-list commands to configuration.

MAC filters can use VLAN maps to control nonroutable traffic such as NetBIOS or Systems Network (SNA). [Example 1-44](#) lists the configuration used to prevent nonsecure hosts from communicating with other via nonroutable protocols. Note that this only controls nonrouted traffic and will have no impact on routable traffic. This example allows nonroutable traffic between the two MAC addresses 00e0.1e58.e792 and 00e0.1e58.e793, but the rest of the network, but the two hosts cannot talk to each other.

Example 1-44. VLAN Map for MAC Addresses

```

vlan access-map allowed_macs 10
! define VLAN map 'allowed_macs'
action forward
! forward ACL valid_macs
match mac address valid_macs
! call mac ACL 'valid_macs'
!
vlan filter allowed_macs vlan-list 100
! Apply VLAN map to VLAN 100
!
```

```
mac access-list extended valid_macs  
  
! MAC ACL 'valid_macs'  
  
permit host 00e0.1e58.e792 any  
  
! Allow these two MAC addresses  
  
permit host 00e0.1e58.c112 any
```

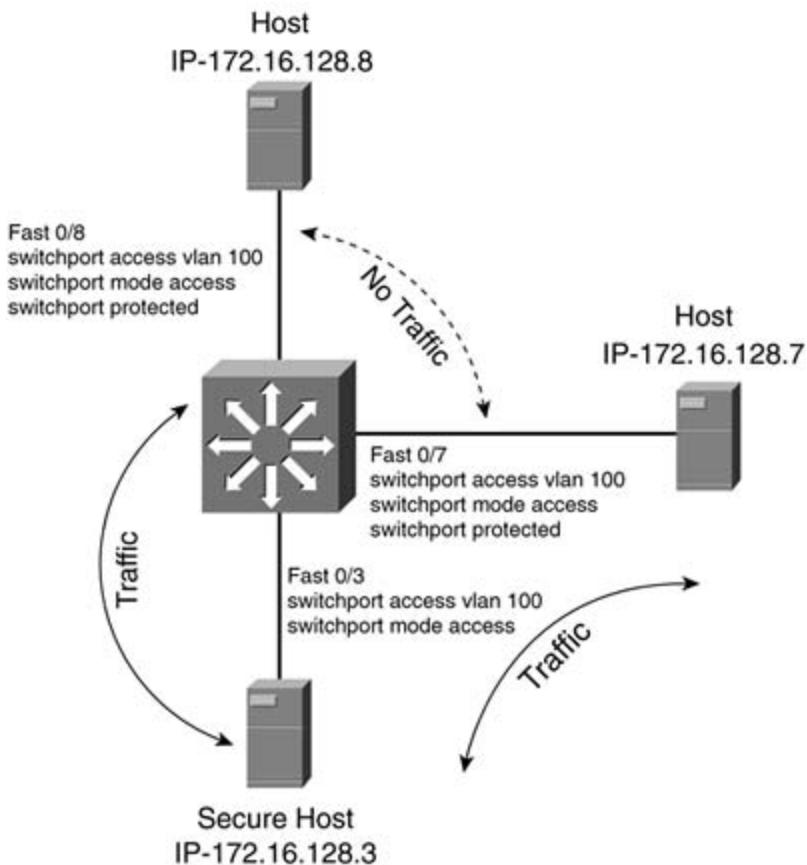
NOTE

The same rules that apply to ACLs and route maps apply to VLAN maps. Rules such as there is implicit deny any at the end of an ACL and so on all apply to VLAN maps. For more information on how to configure route maps and ACLs and for configuration tips, see those appropriate sections in the *CCIE PSV1* and *CCIE PSV2*.

Controlling VLAN Access and Security with Protected Ports

Yet another way you can control access or enhance security on the Catalyst 3550 is by using VLAN-protected ports. VLAN-protected ports can only talk to nonprotected ports. Traffic from one VLAN-protected port cannot reach another VLAN-protected port. In [Figure 1-36](#), Fast Ethernet 0/8 and 0/7 are VLAN-protected ports. Host 172.16.128.7 cannot ping 172.16.128.8, but it can ping 172.16.128.3. The host 172.16.128.3 can ping both 172.16.128.7 and 172.16.128.8.

Figure 1-36. VLAN-Protected Ports



To configure a port as a protected port, use the interface command `switchport protected`. You can verify protected ports with the `show interface fast 0/7 switchport` command, as in [Example 1-45](#).

Example 1-45. Verifying Protected Ports

```
3550_switch#show interfaces fast 0/7 switchport
Name: Fa0/7
Switchport: Enabled
Administrative Mode: static access
Operational Mode: static access
Administrative Trunking Encapsulation: negotiate
Operational Trunking Encapsulation: native
Negotiation of Trunking: Off
Access Mode VLAN: 100 (psv2_vlan100)
```

```
Trunking Native Mode VLAN: 1 (default)
```

```
Trunking VLANs Enabled: ALL
```

```
Pruning VLANs Enabled: 2-1001
```

```
Protected: true
```

```
Unknown unicast blocked: disabled
```

```
Unknown multicast blocked: disabled
```

```
Voice VLAN: none (Inactive)
```

```
Appliance trust: none
```

The Catalyst 3550 switch floods packets with unknown destination MAC addresses to all ports by default. If unknown unicast and multicast traffic is forwarded to a protected port, there could be security issues. To prevent unknown unicast or multicast traffic from being forwarded from one port to another, you can configure a port (protected or nonprotected) to block unknown unicast or multicast packets. Use the following interface commands to block unknown unicast and multicast traffic:

```
3550_switch(config-if)#switchport block unicast
```

```
3550_switch(config-if)#switchport block multicast
```

If unicast or multicast blocking is enabled, it would appear in the show switchport command as either listed in the preceding example.

Lab 1: Configuring EtherChannel, Layer 3 Switching, Router Ports, and SVIs—Part I

Practical Scenario

The world of Ethernet switching continues to evolve at a rapid pace. In the field, you will encounter many types of switches, and the Catalyst 3550 might be one of them. The Catalyst 3550 has many types of configurable interfaces. It is important to be able to configure these different types of interfaces because it gives you more flexibility in your design. Capabilities such as Fast/Gigabit EtherChannel provide better bandwidth and excellent redundancy for core switches.

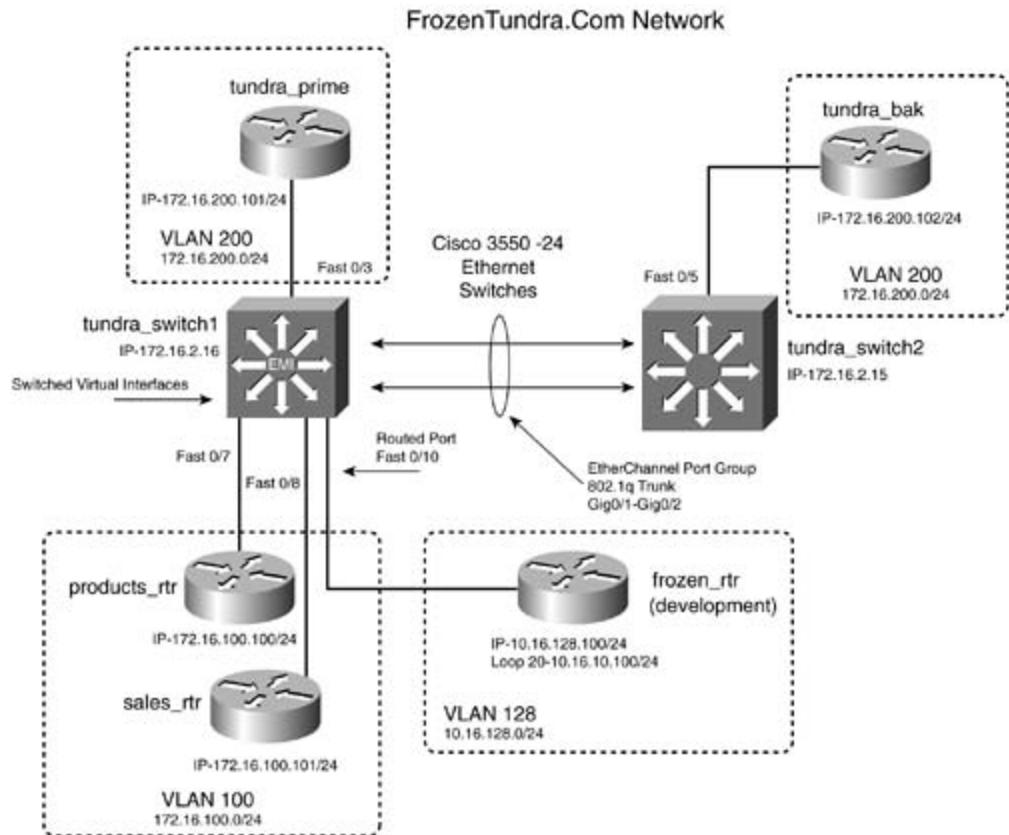
Lab Exercise

FrozenTundra.com is one of the few surviving dot.coms. It makes outdoor clothing and other products in the great wilderness of the Northwest and Canada. FrozenTundra.com is upgrading its backbone Ethernet and would like to use the two gigabit interface converter (GBIC) interfaces that come on the 3550-24 Ethernet switches. It also wants to perform Layer 3 switching on the 3550 switch, rather than routers.

Your task is to configure a working IP network and configure the Ethernet 3550 switch using the following strict design guidelines:

- Configure the FrozenTundra.com IP network as depicted in [Figure 1-37](#). Use EIGRP as the routing protocol and 2003 as the autonomous system ID on all routers.

Figure 1-37. Tundra.Net



- Configure all IP addresses as depicted in [Figure 1-37](#). All labeled interfaces should be able to other.
- See the "[Lab Objectives](#)" section for configuration specifics.

Lab Objectives

- Configure the EIGRP as the routing protocol, as depicted in [Figure 1-37](#). Use 2003 as the auto system ID.
- Configure the management interface of 172.16.2.16/24 on tundra_switch1, and 172.16.2.15/ tundra_switch2. These addresses should be reachable, and Telnet login should be supported f sessions on both switches. Use cisco as the login and enable password.
- Configure the two Gigabit Ethernet interfaces as a single Gigabit EtherChannel. You may use i Ethernet for this if you do not have Gigabit Ethernet.
- Configure the tundra_switch1 as the VTP server and the tundra_switch2 as the VTP client. Use domain of tundra and a VTP password of psv2.
- Configure the tundra_switch1 Fast 0/10, the port that goes to the frozen router, as a routed p IP address of 10.16.128.16 on this interface.
- Configure the other interfaces as access ports and assign VLANs as depicted in [Figure 1-37](#).
- Configure any SVIs needed for the tundra_switch1 to provide routing for all VLANs in the netw

- Configure HSRP between the tundra_prime router, tundra_switch1, and the tundra_bak route 200. The primary IP address should be 172.16.200.1/24, and the tundra_switch1 should be the primary. The tundra_prime router should be HSRP secondary.
- Configure tundra_switch1 as the STP root for VLANs 100 and 200.
- Enable VTP pruning on the EtherChannel link between the two switches.

Equipment Needed

- Five Cisco routers, one Catalyst 3550 with the EMI software image installed, and one other Catalyst switch. Only one switch needs to be a Catalyst 3550 with the EMI installed. You may simulate the switch with another Catalyst as long as it supports 802.1Q and EtherChannel.
- The switches need two back-to-back 100BASE-T links or a Gigabit Ethernet for the EtherChannel connection. The other routers should be set up with a Category 5 connection to the appropriate ports as depicted in [Figure 1-37](#).

Physical Layout and Prestaging

- Connect the switches to the routers, as shown in [Figure 1-37](#).
- This lab focuses on the configuration of the Ethernet switches.

Lab 1: Configuring EtherChannel, Layer 3 Switching, Routed Ports, and SVIs—Part II

Lab Walkthrough

Attach all the routers to the switch, as illustrated in [Figure 1-37](#). You can use either two Gigabit Ethernet connections between the two switches or 100-Mbps links. Your choice will not affect the operations of the lab.

Recall from earlier the seven-step process for configuring the 3550 Ethernet switch.

- Step 1. Configure switch management.
- Step 2. Configure VTP and VLANs and assign ports/interfaces to VLANs.
- Step 3. Configure connections between switches using EtherChannel, 802.1Q, and ISL encapsulation.
- Step 4. (Optional) Control STP and VLAN propagation.
- Step 5. (Optional) Configure SVIs.
- Step 6. (Optional) Configure routed ports.
- Step 7. (Optional) Configure Layer 3 switching.

The first step is to configure switch management. This includes setting a host name, a password, a management address on the switch. In this lab, you also make Telnet available by assigning a login line 0 through 4. [Example 1-46](#) lists the management portion of the tundra_switch1.

Example 1-46. Management Portion of tundras_switch1 Thus Far

```
hostname tundra_switch1

!
enable secret 5 $1$nt35$131XBSgKT6BmA1KHMqj1V1
! Enable Secret=cisco
!
<<<text omitted>>>
!
interface Vlan1
  no ip address
  shutdown
!
interface Vlan2
! MNGT VLAN and IP
  ip address 172.16.2.16 255.255.255.0
<<text omitted>>>
!
line con 0
line vty 0 4
  password cisco
! Telnet access allowed
  login
line vty 5 7
  login
```

The second step calls for you to configure VTP and VLANs. You need to configure a VLAN for any S1 ports, and management VLANs. In this model, you need to configure four VLANs: VLANs 2, 100, 120, and 200. On the 3550, you can do this from the global configuration mode with the command `vlan x`. A name can be entered, as well, after entering the VLAN number. The VTP mode of the `tundra_switch1` is server, and `tundra_switch2` will be the client. The VTP domain is called `tundra`, and the password is `psv2`. Ensure that the VTP domains are in the same case, along with the password. Domain name and password are case sensitive. Be sure that the VTP server's revision number is also higher than the VTP client's; otherwise, the two switches will not synchronize. The VTP domain and mode can be configured from the VLAN database or the VLAN configuration mode. [Example 1-47](#) demonstrates this being done on the `tundra_switch1`.

Example 1-47. Configuring VTP on `tundra_switch1`

```
tundra_switch1#vlan database
tundra_switch1(vlan)#vtp domain tundra
tundra_switch1(vlan)#vtp server
tundra_switch1(vlan)#vtp password psv2
```

This step also calls for you to configure the physical port properties and assign the ports to VLANs. [Example 1-48](#) illustrates the VLAN and port configuration of the `tundra_switch1` to this point.

Example 1-48. Configuring VLAN Port Membership

```
hostname tundra_switch1
!
<<<text omitted>>>
!
interface FastEthernet0/3
  switchport access vlan 200
  ! assigned to VLAN 200
  switchport mode access
  no ip address
```

```
!  
  
interface FastEthernet0/4  
    no ip address  
  
!  
  
interface FastEthernet0/5  
    no ip address  
  
!  
  
interface FastEthernet0/6  
    no ip address  
  
!  
  
interface FastEthernet0/7  
    switchport access vlan 100  
    ! assigned to VLAN 100  
    switchport mode access  
    no ip address  
  
!  
  
interface FastEthernet0/8  
    switchport access vlan 100  
    ! assigned to VLAN 100  
    switchport mode access  
    no ip address  
  
!
```

You can verify the VLANs and VTP with the `show vlan` command and the `show vtp status` command demonstrated in [Example 1-49](#).

Example 1-49. Verifying VTP and VLAN Status

```
tundra_switch1#show vlan
```

VLAN	Name	Status	Ports
1	default	active	Fa0/1, Fa0/2, Fa0/4, Fa0/5
			Fa0/6, Fa0/9, Fa0/11, Fa0/12
			Fa0/13, Fa0/14, Fa0/15, Fa0/16
			Fa0/17, Fa0/18, Fa0/19, Fa0/20
			Fa0/21, Fa0/22, Fa0/23, Fa0/24

2	psv2_vlan2	active	
100	psv2_vlan100	active	Fa0/7, Fa0/8
200	psv2_vlan200	active	Fa0/3
1002	fdmi-default	active	
1003	token-ring-default	active	
1004	fdnet-default	active	
1005	trnet-default	active	

VLAN	Type	SAID	MTU	Parent	RingNo	BridgeNo	Stp	BrdgMode	Trans1	Trans2
1	enet	100001	1500	-	-	-	-	-	0	0
2	enet	100002	1500	-	-	-	-	-	0	0
100	enet	100100	1500	-	-	-	-	-	0	0
128	enet	100128	1500	-	-	-	-	-	0	0
200	enet	100200	1500	-	-	-	-	-	0	0
1002	fdmi	101002	1500	-	-	-	-	-	0	0
1003	tr	101003	1500	-	-	-	-	srb	0	0
1004	fdnet	101004	1500	-	-	1	ieee	-	0	0
1005	trnet	101005	1500	-	-	1	ibm	-	0	0

tundra_switch1#

tundra_switch1#show vtp status

VTP Version : 2

```

Configuration Revision          : 15
Maximum VLANs supported locally : 1005
Number of existing VLANs       : 8
VTP Operating Mode            : Server
VTP Domain Name               : tundra
VTP Pruning Mode              : Disabled
VTP V2 Mode                   : Disabled
VTP Traps Generation          : Disabled
MD5 digest                    : 0xE6 0x6C 0xFD 0xDA 0x1B 0xCC 0x7B 0x8A
Configuration last modified by 172.16.2.16 at 3-1-93 04:03:13
Local updater ID is 172.16.2.16 on interface V12 (lowest numbered VLAN interface)
tundra_switch1#

```

Step 3 calls for you to configure EtherChannel and 802.1Q trunking between the switches. The configuration on both switches will be identical for the EtherChannel, as long as both are Catalyst 3550s. [Example 1-49](#) demonstrates the Gigabit EtherChannel configuration on the tundra_switch1.

Example 1-50. Configuring Gigabit EtherChannel with 802.1Q Encapsulation

```

tundra_switch(config)#interface gigabitEthernet 0/1
tundra_switch(config-if)#switchport trunk encapsulation dot1q
! 802.1q trunking
tundra switch(config-if)#switchport mode trunk
tundra switch(config-if)#channel-group 1 mode on
! EtherChannel Configuration

Creating a port-channel interface Port-channel1
tundra (config-if)#exit
00:23:18: %LINK-3-UPDOWN: Interface Port-channel1, changed state to up
00:23:19: %LINEPROTO-5-UPDOWN: Line protocol on Interface Port-channel1, changed s

```

```
tundra switch(config)#interface gigabitEthernet 0/2
tundra switch(config-if)#switchport trunk encapsulation dot1q
tundra switch(config-if)#switchport mode trunk
tundra switch(config-if)#channel-group 1 mode on
```

At this point of the configuration, VTP should be working between switches, and you should be able to local devices. You need to configure the SVIs and routing protocols for inter-VLAN connectivity. In this example, you were to set the root of spanning tree for VLANs 100 and 200 to the tundra_switch1. You can do this with the global configuration command spanning-tree vlan 100 root and spanning-tree vlan 200 root commands. This macro uses the extended system ID to set the priority of the VLANs to 24,576, which makes them root. VTP pruning should also be enabled for VLAN 200. VTP pruning is enabled with the VLAN configuration command vtp pruning. You can verify the status of STP with the show spanning-tree command, as demonstrated in [Example 1-51](#). At the bottom of this example is the show interface command, verifying that VTP pruning is enabled on the EtherChannel between the two switches.

Example 1-51. Verifying STP and VTP Pruning on the tundra_switch1

```
tundra_switch1#show spanning-tree root
          Root      Hello Max Fwd
Vlan           Root ID        Cost     Time   Age Dly  Root Port
-----  -----  -----  -----  -----  -----  -----
VLAN0001      32768 0004.275e.f0c0      3       2    20   15  Po1
VLAN0002      32768 0004.275e.f0c1      3       2    20   15  Po1
VLAN0100      24676 000a.8a0e.ba80      0       2    20   15
VLAN0200      24776 000a.8a0e.ba80      0       2    20   15

tundra_switch1#
tundra_switch1#show int port-channel 1 switchport
Name: Po1
Switchport: Enabled
Administrative Mode: trunk
Operational Mode: trunk
Administrative Trunking Encapsulation: dot1q
```

```
Operational Trunking Encapsulation: dot1q
Negotiation of Trunking: On
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
Trunking VLANs Enabled: ALL
Pruning VLANs Enabled: 2,100,200
<<<text omitted>>>
```

In the next two steps, you configure SVIs and the routed interface on the switch. You need three S' routed port for full IP connectivity on the tundra_switch1. One SVI, interface VLAN 2 is needed for management VLAN, whereas two more SVIs—interface VLAN 100 and interface VLAN 200—are nee other routers. The routed interface is configured by first enabling routing and then using the no sw interface command on the port you want to be a routed interface. [Example 1-52](#) shows the necessa configuration of the tundra_switch1.

Example 1-52. SVI and Routed Interface Configuration

```
!
ip routing
! IP routing must be enabled for routed INTs
!
interface FastEthernet0/10
no switchport
! Disable switching
ip address 10.16.128.16 255.255.255.0
! Assign an IP address
!
-----SVI CONFIG-----→
interface Vlan2
ip address 172.16.2.16 255.255.255.0
!
```

```

interface Vlan100
    ip address 172.16.100.16 255.255.255.0
!
interface Vlan200
    ip address 172.16.200.16 255.255.255.0
    no ip redirects

```

The final portion of the lab is to configure EIGRP as the routing protocol. IP was enabled during the step, so that is not necessary here. To configure the Layer 3 switching portion of the lab, you just re-configure EIGRP on the routers and the Ethernet switch. This is done identically as it would be on a router. HSRP can also be configured at this time. Once again, the syntax to configure HSRP on a switch is the same as on a router. *CCIE PSV1* has in-depth configurations of EIGRP and HSRP; therefore, they are listed here. The configurations listed here are the minimum required to complete the lab. If you have questions on the configuration options used, refer to *CCIE PSV1*. Example 1-53 lists the full configuration of the tundra_switch1 followed by the route table of the switch and the EIGRP neighbors. Notice that the switch has five EIGRP neighbors.

Example 1-53. Complete Configuration of the tundra_switch1 Switch

```

hostname tundra_switch1
!
enable secret 5 $1$nt35$131XBSgKT6BmA1KHMqj1V1
!
ip subnet-zero
ip routing
!
spanning-tree extend system-id
spanning-tree vlan 100 priority 24576
spanning-tree vlan 200 priority 24576
!
interface Port-channel1
    switchport trunk encapsulation dot1q

```

```
switchport trunk pruning vlan 2,100,128,200
switchport mode trunk
no ip address
!
<<<text omitted>>>
!
interface FastEthernet0/3
switchport access vlan 200
switchport mode access
no ip address
!
<<<text omitted>>>
!
interface FastEthernet0/7
switchport access vlan 100
switchport mode access
no ip address
!
interface FastEthernet0/8
switchport access vlan 100
switchport mode access
no ip address
!
interface FastEthernet0/9
no ip address
!
interface FastEthernet0/10
no switchport
```

```
ip address 10.16.128.16 255.255.255.0
!
<<<text omitted>>>
no ip address
!
interface GigabitEthernet0/1
switchport trunk encapsulation dot1q
switchport trunk pruning vlan 2,100,128,200
switchport mode trunk
no ip address
channel-group 1 mode on
!
interface GigabitEthernet0/2
switchport trunk encapsulation dot1q
switchport trunk pruning vlan 2,100,128,200
switchport mode trunk
no ip address
channel-group 1 mode on
!
interface Vlan1
no ip address
shutdown
!
interface Vlan2
ip address 172.16.2.16 255.255.255.0
!
interface Vlan100
ip address 172.16.100.16 255.255.255.0
```

```
!

interface Vlan200

    ip address 172.16.200.16 255.255.255.0

    no ip redirects

    standby 200 ip 172.16.200.1

    standby 200 priority 101

    standby 200 preempt

!

router eigrp 2003

    network 10.0.0.0

    network 172.16.0.0

    no auto-summary

    no eigrp log-neighbor-changes

!

ip classless

ip http server!

line con 0

line vty 0 4

password cisco

login

line vty 5 7

end

tundra_switch1#  
tundra_switch1#show ip route  
  
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP  
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area  
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2  
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
```

```

i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

172.16.0.0/24 is subnetted, 3 subnets

C      172.16.200.0 is directly connected, Vlan200
C      172.16.2.0 is directly connected, Vlan2
C      172.16.100.0 is directly connected, Vlan100

10.0.0.0/24 is subnetted, 2 subnets

D      10.16.10.0 [90/409600] via 10.16.128.100, 03:25:34, FastEthernet0/10
C      10.16.128.0 is directly connected, FastEthernet0/10

tundra_switch1#
tundra_switch1#show ip eigrp neighbors
IP-EIGRP neighbors for process 2003

H   Address           Interface     Hold Uptime    SRTT     RTO   Q   Seq Type
                                         (sec)        (ms)      Cnt Num
                                         (sec)        (ms)      Cnt Num
4   172.16.100.100     Vl100        13 03:22:58  1524    5000   0   6
3   172.16.100.101     Vl100        11 03:23:01  1488    5000   0   7
2   10.16.128.100      Fa0/10       10 03:30:33  1080    5000   0   5
1   172.16.200.102     Vl200        13 03:32:03  419     2514   0   5
0   172.16.200.101     Vl200        14 03:32:06  204     1224   0   8

tundra_switch1#

```

[Example 1-54](#) lists relevant configuration portions of the tundra_bak switch.

Example 1-54. tundra_bak Switch Configuration

```
hostname tundra_switch2
```

```
!  
enable secret 5 $1$nt35$131XBSgKT6BmA1KHMqj1V1  
!  
spanning-tree extend system-id  
!  
interface Port-channel1  
switchport trunk encapsulation dot1q  
switchport trunk pruning vlan 2,100,128,200  
switchport mode trunk  
no ip address  
!  
<<<text omitted>>>  
!  
interface FastEthernet0/5  
switchport access vlan 200  
!  
interface GigabitEthernet0/1  
switchport trunk encapsulation dot1q  
switchport trunk pruning vlan 2,100,128,200  
switchport mode trunk  
no ip address  
channel-group 1 mode on  
!  
interface GigabitEthernet0/2  
switchport trunk encapsulation dot1q  
switchport trunk pruning vlan 2,100,128,200  
switchport mode trunk  
no ip address
```

```

channel-group 1 mode on

!
interface Vlan1
no ip address
shutdown

!
interface VLAN2
ip address 172.16.2.15 255.255.255.0
no ip directed-broadcast
no ip route-cache

!
ip default-gateway 172.16.2.16

!
line con 0
line vty 0 4
password cisco
login
line vty 5 7
end

```

Example 1-55 shows the configuration of the tundra_prime router, the tundra_bak, and the frozen_EIGRP and IP configurations on the other routers are nearly identical, save for the IP address; ther the sake of brevity, not all of the configurations are listed here.

Example 1-55. Configurations of tundra_prime and frozen_rtr Routers

```

hostname tundra_prime
!
interface FastEthernet3/0

```

```
ip address 172.16.200.101 255.255.255.0
duplex auto
speed auto
standby 200 preempt
standby 200 ip 172.16.200.1
!
router eigrp 2003
network 172.16.0.0
no auto-summary
no eigrp log-neighbor-changes
!
```

```
hostname frozen_rtr
!
interface loopback 20
ip address 10.16.10.100 255.255.255.0
!
interface Ethernet0/0
ip address 10.16.128.100 255.255.255.0
!
router eigrp 2003
network 10.0.0.0
no auto-summary
!
```

```
hostname tundra_bak
!
interface Ethernet0/1
```

```
ip address 172.16.200.102 255.255.255.0
no ip redirects
no ip directed-broadcast
standby priority 95
standby preempt
standby 200 ip 172.16.200.1
!
router eigrp 2003
network 172.16.0.0
no auto-summary
!
```

```
hostname products
!
!
interface Ethernet0
ip address 172.16.100.100 255.255.255.0
no ip directed-broadcast
media-type 10BASE-T
!
router eigrp 2003
network 172.16.0.0
no auto-summary
!
```

Lab 2: Configuring 802.1w RSTP and 802.1s MST, Layer 3 Switching, and VLAN Maps—Part I

Practical Scenario

One area of switching that has made vast improvements is that of redundancy and failover recovery. With IEEE 802.1w RSTP and IEEE 802.1s MST, spanning tree can now converge in hundredths of a second rather than the 50 seconds that 802.1d requires. When configuring large production networks, customers pay thousands for redundancy and backup. Being able to provide excellent recovery times via new techniques helps you and your customer get the most for the money.

Lab Exercise

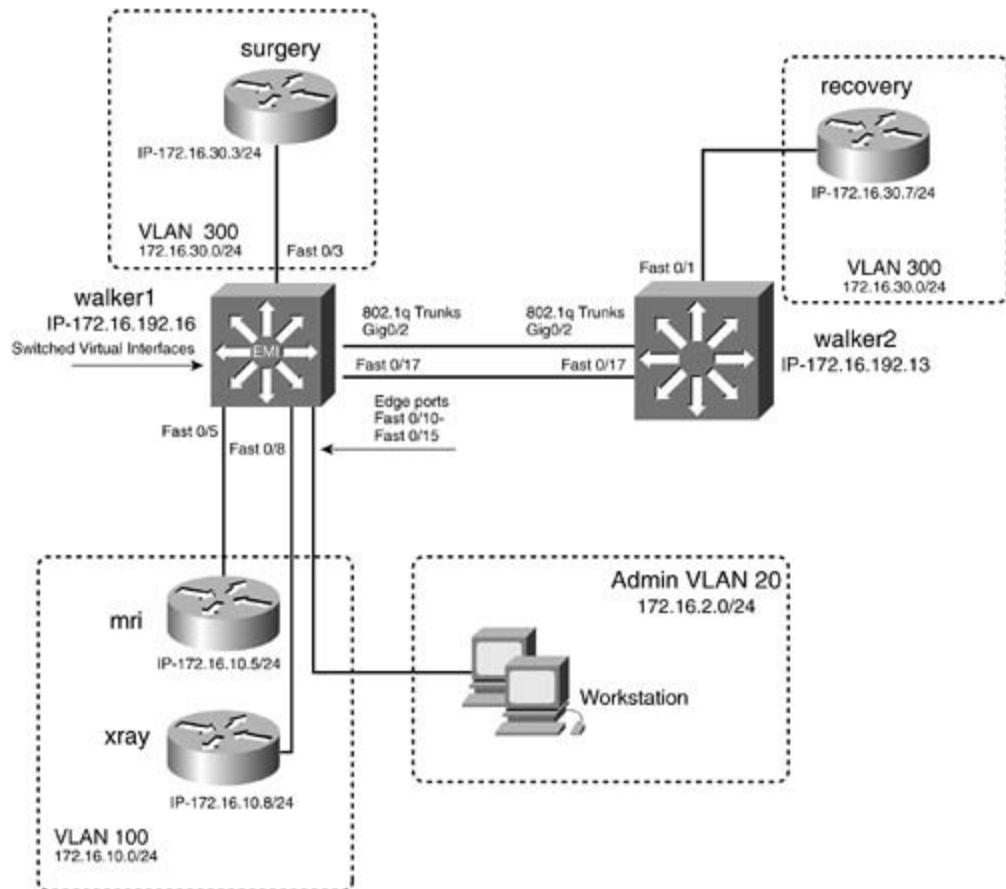
The famous Dr. Walker has established the Walker Children's Hospital, specializing in the care of young children who have leg and bone problems. The hospital network has been running under 802.1d STP for redundancy, but administrators have found that the recovery time is too long. Critical services between areas such as surgery and recovery need very fast convergence in the event of a failure.

Your task is to configure a working IP network and configure the Ethernet 3550 switch using the following strict design guidelines:

- Configure the Walker Children's Hospital network as depicted in [Figure 1-38](#). Use EIGRP as the routing protocol and 2003 as the autonomous system ID on all routers.

Figure 1-38. Walker Children's Hospital

Walker Children's Hospital



- Configure all IP addresses as depicted in [Figure 1-38](#). All labeled interfaces should be able to ping each other.
- See the "[Lab Objectives](#)" section for configuration specifics.

Lab Objectives

- Configure the EIGRP as the routing protocol, as depicted in [Figure 1-38](#). Use 2003 as the autonomous system ID.
- Configure the management interface of 172.16.192.16/24 on **walker1** and 172.16.192.13/24 on **walker2**. These addresses should be reachable.
- Configure the two interfaces between the **walker1** and **walker2** switches. Do not configure the interfaces as an EtherChannel group. In this model, you use one Gigabit Ethernet interface as one 100-Mpbs interface for backup.
- Configure the **walker1** as the VTP server and the **walker2** as the VTP client. Use the VTP domain of **walker** and a VTP password of **psv2**.
- Configure the other interfaces as access ports and assign VLANs as depicted in [Figure 1-38](#). Configure six interfaces into VLAN 20; these will be edge ports for the admin VLAN.

- Configure 802.1w RSTP and 802.1s MST. Configure all hosts as edge ports for rapid convergence. Use walker as the MST name.
- Configure the walker1 switch so that it will be the root for all VLANs in the range of 2 through 300.
- Configure any SVIs needed for the walker1 switch to provide routing for all VLANs in the network. There should be full IP connectivity across the LAN. All depicted IP addresses should be pingable.
- There have been problems with people sharing files and using unauthorized applications in the admin VLAN. Configure this VLAN such that users of this VLAN will no longer be able to share files or use network applications within that VLAN.

Equipment Needed

- One IP-based workstation, four Cisco routers, one Catalyst 3550 with the EMI software image installed, and one other Catalyst switch that supports MST and RSTP. Only one switch needs to be a Catalyst 3550 with the EMI installed. One router can be substituted for a workstation on VLAN 20. VLAN 20 should have at least one active IP device for testing.
- The switches need two back-to-back 100BASE-T links or a Gigabit Ethernet link for the connection between the two switches. The other routers should be set up with Category 5 connections to the appropriate switch, as depicted in [Figure 1-38](#).

Physical Layout and Prestaging

- Connect the switches to the routers as shown in [Figure 1-38](#).
- This lab focuses on the configuration of the Ethernet switches.

Lab 2: Configuring 802.1w RSTP and 802.1s MST, Layer 3 Switching, and VLAN Maps—[Part II](#)

Lab Walkthrough

Attach all the routers to the switch as illustrated in [Figure 1-38](#). You can use either two Gigabit Ethernet connections between the two switches or 100-Mbps links. Your choice will not affect the operational ability of the lab.

Recall from earlier the seven-step process for configuring the 3550 Ethernet switch.

- Step 1. Configure switch management.
- Step 2. Configure VTP and VLANs and assign ports/interfaces to VLANs.
- Step 3. Configure connections between switches using EtherChannel, 802.1Q, and ISL encapsulations.

Step 4. (Optional) Control STP and VLAN propagation.

Step 5. (Optional) Configure SVIs.

Step 6. (Optional) Configure routed ports.

Step 7. (Optional) Configure Layer 3 switching.

The first step is to configure switch management. This includes setting a host name, password, and management address on the switch. [Example 1-56](#) lists the management portion of walker1. The configuration of walker2 would be identical except for the IP address, which will be 172.16.192.13.

Example 1-56. Management Portion of walker1 Thus Far

```
hostname walker1
! Set the hostname
!
enable secret 5 $1$nt35$131XBSgKT6BmA1KHMqj1V1
! Enable Secret=cisco
!
<<<text omitted>>>
!
interface Vlan1
  no ip address
  shutdown
!
interface Vlan192
  ! MNGT VLAN and IP
  ip address 172.16.192.16 255.255.255.0
<<text omitted>>>
!
```

The second step calls for you to configure VTP and VLANs. You need to configure a VLAN for any S1 access ports, and management VLANs. In this model, you need to configure five VLANs: VLANs 20, 100, 192, 200, and 300. On the 3550, you can do this from the global configuration mode with the command `vlan x`. A name can be entered as well after entering the VLAN number. The VTP mode of walker1 is server, and walker2 will be the VTP client. The VTP domain is called walker, and the password is psv2. Ensure that the VTP domains are in the same case, along with the password. Domain name and password are case sensitive. Be sure that the VTP server's revision number is at higher than the VTP client's; otherwise, the two will not synchronize. The VTP domain and mode can be configured from the VLAN database or the VLAN configuration mode. [Example 1-57](#) demonstrates this being done on the walker1 switch.

Example 1-57. Configuring VTP on walker1

```
walker1#vlan database  
walker1(vlan)#vtp domain walker  
walker1(vlan)#vtp server  
walker1(vlan)#vtp password psv2
```

This step also calls for you to configure the physical port properties and assign the ports to VLANs. [Example 1-58](#) illustrates the VLAN and port configuration of walker1 to this point. Because you are configuring RSTP, you must configure edge ports with the interface command `spanning-tree portfast`.

Example 1-58. Configuring VLAN Port Membership

```
hostname walker1  
!  
<<<text omitted>>>  
!  
interface FastEthernet0/3  
switchport access vlan 300  
! assigned to VLAN 300  
switchport mode access  
spanning-tree portfast
```

```

! Portfast used in 802.1w

no ip address

!

interface FastEthernet0/5

switchport access vlan 100

! assigned to VLAN 100

switchport mode access

spanning-tree portfast

! Portfast used in 802.1w

no ip address

!

interface FastEthernet0/8

switchport access vlan 100

! assigned to VLAN 100

switchport mode access

spanning-tree portfast

! Portfast used in 802.1w

no ip address

!

```

When configuring a range of VLANs, it can be easier to use the range command. [Example 1-59](#) illustrates the use of the range command when configuring the six admin interfaces for VLAN 20.

Example 1-59. Configuring a VLAN Range

```

walker1(config)#interface range fastEthernet 0/10 - 15

walker1(config-if-range)#switchport mode access

walker1(config-if-range)#switchport access vlan 20

walker1(config-if-range)#spanning-tree portfast

```

```
%Warning: portfast should only be enabled on ports connected to a single host. Connecting hubs, concentrators, switches, bridges, etc... to this interface when portfast is enabled, can cause temporary bridging loops.
```

Use with CAUTION

```
%Portfast will be configured in 6 interfaces due to the range command but will only have effect when the interfaces are in a non-trunking mode.  
walker1(config-if-range)#exit
```

You can verify the VLANs and VTP with the show vlan command and the show vtp status command, as demonstrated in [Example 1-60](#).

Example 1-60. Verifying VTP and VLAN Status

```
walker1#show vlan
```

VLAN	Name	Status	Ports
1	default	active	Fa0/1, Fa0/2, Fa0/4, Fa0/6, Fa0/9, Fa0/16 Fa0/17, Fa0/18, Fa0/19, Fa0/20 Fa0/21, Fa0/22, Fa0/23, Fa0/24
20	psv2_vlan20	active	Fa0/10, Fa0/11, Fa0/12, Fa0/13 Fa0/14, Fa0/15
100	psv2_vlan100	active	Fa0/5, Fa0/8
192	psv2_vlan192	active	
300	psv2_vlan300	active	Fa0/3
1002	fddi-default	active	
1003	token-ring-default	active	
1004	fddinet-default	active	

```

1005 trnet-default           active

VLAN Type   SAID      MTU   Parent RingNo BridgeNo Stp   BrdgMode Trans1 Trans2
---- -----  -----  -----  -----  -----  -----  -----  -----  -----  -----
1   enet    100001   1500   -     -     -     -     -     -     0     0
20  enet    100020   1500   -     -     -     -     -     -     0     0
100 enet    100100   1500   -     -     -     -     -     -     0     0
192 enet    100192   1500   -     -     -     -     -     -     0     0
300 enet    100300   1500   -     -     -     -     -     -     0     0
1002 fddi   101002   1500   -     -     -     -     -     -     0     0
1003 tr     101003   1500   -     -     -     -     -     srb   0     0
1004 fdnet  101004   1500   -     -     1     ieee  -     0     0
1005 trnet  101005   1500   -     -     1     ibm   -     0     0

walker1#
walker1#show vtp status

VTP Version          : 2
Configuration Revision : 3
Maximum VLANs supported locally : 1005
Number of existing VLANs       : 9
VTP Operating Mode        : Server
VTP Domain Name          : walker
VTP Pruning Mode         : Enabled
VTP V2 Mode              : Disabled
VTP Traps Generation     : Disabled
MD5 digest               : 0xEF 0xD8 0x4D 0x0A 0x57 0x8F 0x7E 0x14
Configuration last modified by 172.16.192.16 at 3-1-93 01:10:51
Local updater ID is 172.16.192.16 on interface Vl192 (lowest numbered VLAN interface)
walker1#

```

Step 3 calls for you to configure 802.1Q trunking between the switches. The configuration on both switches will be identical, as long as both are in the Catalyst 35xxfamily. [Example 1-61](#) demonstra the 802.1Q trunk configuration on the walker1 switch for interfaces Gig 0/2 and Fast 0/17.

Example 1-61. Configuring Gigabit EtherChannel with 802.1Q Encapsulation

```
walker1(config)#interface gigabit 0/2
walker1(config-if)#switchport trunk encapsulation dot1q
walker1(config-if)#switchport mode trunk
walker1(config-if)#exit
walker1(config)#interface fast 0/17
walker1(config-if)#switchport trunk encapsulation dot1q
walker1(config-if)#switchport mode trunk
walker1(config-if)#exit
```

At this point of the configuration, VTP should be working between switches, and you should be able ping all local devices. Use the show vtp status command to verify VTP and ensure that both switc have the same VTP revision number and the same number of VLANs.

The next portion of the configuration requires you to enable 802.1s and 802.1w spanning tree. RS1 is partially enabled at this point from using the spanning-tree portfast command on all nontrunk interfaces. RSTP will be fully enabled when 802.1s or MST is enabled. The MST configuration on the walker1 and walker2 switches will be identical, except that the walker1 switch will use the spannir tree mst 1 root primary command to set root for VLANs 2 through 300. You will define a single S instance, MST 1, and assign VLANs 2 through 300 to this instance. The MST name will be walker, a the revision will be 1. [Example 1-62](#) demonstrates configuring MST and RSTP on the walker1 switch

Example 1-62. Configuring MST and RSTP on the walker1 Switch

```
walker1(config)#spanning-tree mst config           ← Enter MST configuration mode
walker1(config-mst)#name walker                   ← MST name
walker1(config-mst)#revision 1                  ← MST revision number
walker1(config-mst)#instance 1 vlan 2-300        ← assign VLANs 2-300 to instance 1
walker1(config-mst)#exit                         ← apply changes !important!
```

```
walker1(config)#spanning-tree mst 1 root primary ← Set root for instance 1
walker1(config)#spanning-tree mode mst ← enable MST
```

You can verify the status of MST with the show spanning-tree mst 1 and the show spanning-tree root commands, as demonstrated in [Example 1-63](#). You should see VLANs 2 through 300 in MST instance 1, and MST instance 1 should be the root for MST. In this model, the MAC address 000a.8a0e.ba80 is the root.

Example 1-63. Verifying MST

```
walker1#show spanning-tree mst 1

##### MST01      vlans mapped: 2-300
Bridge      address 000a.8a0e.ba80  priority 24577 (24576 sysid 1)
Root        this switch for MST01

Interface    role state cost      prio type
-----
Fa0/3        desg FWD  200000   128  edge P2P
Fa0/5        desg FWD  2000000  128  edge SHR
Fa0/8        desg FWD  200000   128  edge P2P
Fa0/10       desg FWD  2000000  128  edge SHR
Fa0/17       desg FWD  200000   128  P2P
Gi0/2        desg FWD  20000    128  P2P

walker1#show spanning-tree root

                                         Root      Hello Max Fwd
MST Instance          Root ID           Cost     Time  Age Dly  Root Port
-----
MST00                32768 0004.275e.f0c0  200000   2     20  15  Gi0/2
MST01                24577 000a.8a0e.ba80          0     2     20  15

walker1#
```

To test the functionality of MST and RSTP, perform the following test. Issue an extended ping from surgery router to the recovery router. Use a high number of pings, such as 10,000. While you are pinging the interfaces, disconnect the active trunk (in this model, the Gigabit Ethernet). You should see RSTP converge almost instantly, with a 99-percent success rate on the pings! [Example 1-64](#) shows the RSTP test being done.

Example 1-64. Testing MST and RSTP

```
surgery#ping

Protocol [ip]:
Target IP address: 172.16.30.7

Repeat count [5]: 10000

Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]:
Sweep range of sizes [n]:
Type escape sequence to abort.

Sending 10000, 100-byte ICMP Echos to 172.16.30.7, timeout is 2 seconds:
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!...! ←Gig 0/2 dropped
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Success rate is 99 percent (9998/10000), round-trip min/avg/max = 1/2/20 ms

surgery#
```

In the next two steps, you configure SVIs and enable routing on the walker1 switch. You need four SVIs—one for each VLAN and one for the management VLAN. One SVI, interface VLAN 192, is needed for the management VLAN. You also need three more SVIs: interface VLAN 20 for the admin, and

interface VLAN 100 and interface VLAN 300 for the routers. [Example 1-65](#) shows the necessary configuration of the walker1 switch.

Example 1-65. SVI Interface Configuration

```
interface Vlan20
    ip address 172.16.2.16 255.255.255.0
!
interface Vlan100
    ip address 172.16.10.16 255.255.255.0
!
interface Vlan192
    ip address 172.16.192.16 255.255.255.0
!
interface Vlan300
    ip address 172.16.30.16 255.255.255.0
```

The final portion of the lab is to configure EIGRP as the routing protocol. IP routing needs to be enabled with the global configuration command `ip routing`. To configure the Layer 3 switching portion of the lab, you just need to configure EIGRP on the routers and the Ethernet switch. This is done identically as it would be on a router. [Example 1-66](#) lists the full configuration of the walker1 switch followed by the EIGRP neighbors. Notice that the switch has four EIGRP neighbors.

Example 1-66. Complete Configuration of the walker1 Switch

```
hostname walker1
!
enable secret 5 $1$0TsK$C95mG2YeDzQ4w3ecs0Cks0
!
ip subnet-zero
ip routing
```

```
!  
spanning-tree mode mst  
spanning-tree extend system-id  
!  
spanning-tree mst configuration  
name walker  
revision 1  
instance 1 vlan 2-300  
!  
spanning-tree mst 1 priority 24576  
!  
<<<text omitted>>>  
!  
interface FastEthernet0/3  
switchport access vlan 300  
switchport mode access  
no ip address  
spanning-tree portfast  
!  
<<<text omitted>>>  
!  
interface FastEthernet0/5  
switchport access vlan 100  
switchport mode access  
no ip address  
spanning-tree portfast  
!  
<<<text omitted>>
```

```
!
!
interface FastEthernet0/8
    switchport access vlan 100
    switchport mode access
    no ip address
    spanning-tree portfast
!
<<<text omitted>>>
!
interface FastEthernet0/10
    switchport access vlan 20
    switchport mode access
    no ip address
    spanning-tree portfast
!
interface FastEthernet0/11
    switchport access vlan 20
    switchport mode access
    no ip address
    spanning-tree portfast
!
interface FastEthernet0/12
    switchport access vlan 20
    switchport mode access
    no ip address
    spanning-tree portfast
!
```

```
interface FastEthernet0/13
    switchport access vlan 20
    switchport mode access
    no ip address
    spanning-tree portfast
!
interface FastEthernet0/14
    switchport access vlan 20
    switchport mode access
    no ip address
    spanning-tree portfast
!
interface FastEthernet0/15
    switchport access vlan 20
    switchport mode access
    no ip address
    spanning-tree portfast
!
<<<text omitted>>>
!
interface FastEthernet0/17
    switchport trunk encapsulation dot1q
    switchport mode trunk
    no ip address
!
interface GigabitEthernet0/2
    switchport trunk encapsulation dot1q
    switchport mode trunk
```

```
no ip address

!
interface Vlan1
    no ip address
    shutdown
!

interface Vlan20
    ip address 172.16.2.16 255.255.255.0
!

interface Vlan100
    ip address 172.16.10.16 255.255.255.0
!

interface Vlan192
    ip address 172.16.192.16 255.255.255.0
!

interface Vlan300
    ip address 172.16.30.16 255.255.255.0
!

router eigrp 2003
    network 172.16.0.0
    auto-summary
    no eigrp log-neighbor-changes
!
    ip classless
    ip http server
!
line con 0
line vty 5 15
```

```
!
end
walker1#
walker1#show ip eigrp neighbors
IP-EIGRP neighbors for process 2003

H   Address           Interface      Hold Uptime    SRTT     RTO   Q   Seq Type
                           (sec)          (ms)       Cnt Num
3   172.16.10.5       Vl100        14 00:03:02  1048    5000   0   5
2   172.16.30.3       Vl300        12 00:03:04    1  3000   0   9
1   172.16.30.7       Vl300        13 00:03:06  1208    5000   0  10
0   172.16.10.8       Vl100        14 00:03:06  1516    5000   0   9
walker1#
```

[Example 1-67](#) lists relevant configuration portions of the walker2 switch.

Example 1-67. walker2 Switch Configuration

```
hostname walker2
!
enable secret 5 $1$0TsK$C95mG2YeDzQ4w3ecs0Cks0
!
spanning-tree mode mst
spanning-tree extend system-id
!
spanning-tree mst configuration
name walker
revision 1
instance 1 vlan 2-300
```

```
!

interface FastEthernet0/1
    switchport access vlan 300
    switchport mode access
    no ip address
    spanning-tree portfast

!
interface FastEthernet0/17
    switchport trunk encapsulation dot1q
    switchport mode trunk
    no ip address

!
interface GigabitEthernet0/2
    switchport trunk encapsulation dot1q
    switchport mode trunk
    no ip address

!
interface Vlan1
    no ip address
    shutdown

!
interface VLAN192
    ip address 172.16.192.13 255.255.255.0
    no ip directed-broadcast
    no ip route-cache

!
ip default-gateway 172.16.192.16
```

The final portion of the lab requires that you control access on VLAN 20. To prevent the administrative workstation from using IP services between them, you can define them as protected ports. Recall that a protected port prevents other ports that are protected from communicating with it. A protected port can still reach other nonprotected ports on the switch. [Example 1-68](#) demonstrates the configuration of the protected ports with the range command.

Example 1-68. Configuring Protected Ports on the walker1 Switch

```
walker1(config)#interface range fastEthernet 0/10 - 15
walker1(config-if-range)#switchport protected
walker1(config-if-range)#^z
walker1#
walker1#show interfaces fastEthernet 0/10 switchport
Name: Fa0/10
Switchport: Enabled
Administrative Mode: static access
Operational Mode: static access
Administrative Trunking Encapsulation: negotiate
Operational Trunking Encapsulation: native
Negotiation of Trunking: Off
Access Mode VLAN: 20 (psv2_vlan20)
Trunking Native Mode VLAN: 1 (default)
Trunking VLANs Enabled: ALL
Pruning VLANs Enabled: 2-1001
Protected: true
Unknown unicast blocked: disabled
Unknown multicast blocked: disabled
Voice VLAN: none (Inactive)
Appliance trust: none
```

```
walker1#
```

[Example 1-69](#) shows the configuration of the surgery, mri, xray, and recovery routers.

Example 1-69. Configurations of surgery, mri, xray, and recovery Routers

```
hostname surgery
```

```
!
```

```
interface FastEthernet3/0
```

```
  ip address 172.16.30.3 255.255.255.0
```

```
  duplex auto
```

```
  speed auto
```

```
!
```

```
router eigrp 2003
```

```
  network 172.16.0.0
```

```
  no auto-summary
```

```
  no eigrp log-neighbor-changes
```

```
!
```

```
hostname mri
```

```
!
```

```
interface Ethernet0/1
```

```
  ip address 172.16.10.5 255.255.255.0
```

```
!
```

```
router eigrp 2003
```

```
  network 172.16.0.0
```

```
  no auto-summary
```

```
!
```

```
hostname xray

!
interface Ethernet0/1
  ip address 172.16.10.8 255.255.255.0

!
router eigrp 2003
  network 172.16.0.0
  no auto-summary

!
```

```
hostname recovery

!
interface Ethernet5
  ip address 172.16.30.7 255.255.255.0
  no ip directed-broadcast
  media-type 10BASE-T

!
router eigrp 2003
  network 172.16.0.0
  no auto-summary

!
```

Part II: Controlling Network Propagation and Network Access

[Chapter 2](#) Configuring Route Maps and Policy-Based Routing

Chapter 2. Configuring Route Maps and Policy-Based Routing

Perhaps one of the most colorful descriptions for route maps is that route maps are like duct tape for the network—not necessarily because they can be used to fix or mend something broken, but because they can be applied to numerous situations to address many issues. At times, they may not be the most "pretty solutions," but they will be very effective. After you learn to configure and use route maps, you will soon see why some engineers refer to them as *route tape*. In policy-based routing (PBR), for instance, you may use a route map when traffic has to follow a particular path through the internetwork. This path may differ from the path the routing protocol wants to forward traffic on. PBR, along with route maps, enables the network engineer to essentially override the route table and influence which way traffic flows.

You also can apply route maps in a number of ways. The following list contains some of the more common and powerful applications of route maps:

- Route filtering during redistribution between routing protocols
- Route control and attribute modification on BGP neighbors
- Route metric modification or *tagging* during redistribution between routing protocols
- Policy-based routing (PBR)

After you have route maps in your engineering tool kit, you will have one of the most powerful and versatile configuration options available on Cisco routers. This chapter discusses how to configure and use route maps and how to configure PBR.

Route Map Overview

Route maps are much like the "If . . . Then . . ." statements of many programming languages. //a condition is true, *then* do something. Route maps enable you to define routing policy that will be executed before the router examines its forwarding table; therefore, you can define routing policy that takes precedence over the different route processes. This is why route maps are some of the most powerful commands you can use on a router. [Example 2-1](#) highlights route map logic.

Example 2-1. Route Map Logic

```
route-map route_map_name permit 10
  match criteria_1
  set perform_action_1
route-map route_map_name permit 20
  match criteria_2
  set perform_action_2
  set perform_action_3
route-map route_map_name permit 30
  match criteria_3 criteria_4 criteria_5
  set perform_action_2
  set perform_action_4
  set perform_action_5
route-map route_map_name deny 65536      ← implicit deny at the end
  match everything
```

In a nutshell, route maps work in the following manner:

1. Essentially, a process—whether it is a redistribution process, policy routing, or some other process such as Network Address Translation (NAT)—calls a route map by a text-based name.
1. The route map, in turn, has conditions or match statements, which are usually, but not always, access list or extended access list. Border Gateway Protocol (BGP), for instance, can match on autonomous system number (ASN) or different attributes. The match statement(s) can be followed by one or more set statements.

set statements.

If the match statement returns a true result, the set statement(s) are executed.

[Example 2-2](#) shows how a route map functions during redistribution.

Example 2-2. Route Map Function During Redistribution

```
router ospf 2001

 redistribute eigrp 65001 subnets route-map route_map_name      ← Call the route-map
                                                               ← and send EIGRP routes for comp

!

route-map route_map_name permit 10          ← Route-map with the lowest sequence numk
                                           gets executed first

  match ip address access_list             ← Call access-list, the IF of the route-m
                                           ← If access-list is true, THEN do somethi

  set condition                           ← If access-list is true, THEN do somethi

!

route-map route_map_name permit 20          ← Next highest sequence number
                                           gets executed

  match ip address access_list             ← Call access-list, the IF of the route-m
                                           ← If access-list is true, THEN do somethi

  set condition                           ← If access-list is true, THEN do somethi

!

route-map route_map_name deny 65536        ← Implicit deny at the end all route-maps
                                           This will not show up in the config

  match ip address all_routes
```

The next example is the syntax of an actual route map. [Example 2-3](#) demonstrates how a route map applied during redistribution.

Example 2-3. Route Map Application During Redistribution

```

router ospf 65

log-adjacency-changes

log-adjacency-changes

redistribute eigrp 65001 subnets route-map set_tag ← Call the route-map "set_tag"

network 10.10.3.0 0.0.0.255 area 0

default-metric 10

!

access-list 10 permit 172.16.32.0 0.0.0.255 ← Match the 172.16.32.0/24 subnet

access-list 11 permit 172.16.1.0 0.0.0.255 ← Match the 172.16.1.0/24 subnet

!

route-map set_tag permit 100 ← Route-map "set_tag"

match ip address 10 ← Call access-list 10, if this is true then...

set tag 10 ← If access-list is true set the tag of 10

!

route-map set_tag permit 200 ← If no match above, try and match the following

match ip address 11 ← access list 11

set metric-type type-1 ← If the ACL is true, set the OSPF metric type to 1

set tag 11 ← and set a tag of 11

!

route-map set_tag permit 300

set tag 300 ← All other routes get a tag of 300

!

```

In the preceding example, a route map is used to control and tag the routes from Enhanced Interior Gateway Routing Protocol (EIGRP) when they are redistributed into Open Shortest Path First (OSPF). During the OSPF redistribution process, a route map titled `set_tag` is called. The route map consists of three parts. The first part calls access control list (ACL) 10, which will permit the network 172.16.32.x and set a tag of 10. The second part calls ACL 11, which in turn matches IP address 172.16.1.x. If a match occurs, the OSPF metric will be set such that when the route is redistributed, it becomes an OSPF type 1 route; finally, the tag will be set to 11. The last part of the route map doesn't call an ACL, so all routes are matched, and the tag 300 is applied. In this example, the router is setting the tag to 300. You can set tags in this route map to help document the network, or you can use the tags to identify routes that you may want to filter or redistribute.

some other action on.

Route maps have the following common characteristics:

- Route maps are executed in the order of the lowest sequence number to the highest. You can modify maps by using the sequence number.
- If a match is found within a route map instance, execution of further route map instances stop.
- You can use route maps to permit or deny the information found true by the match statement.
- If multiple match statements are called within a single route map instance, all match statements must match for the route map instance to yield a true result.
- If route maps are applied in a policy-routing environment, packets that do not meet the match statement are then forwarded according to the route table.
- If there is no match statement in the route map instance, all routes and packets are matched.
- If there is not a corresponding ACL to the match statement in the route map instance, all routes are matched. The set statement, in turn, applies to all routes.
- As with ACLs, an implicit deny is included at the end of the route map policy.
- You can use route maps to create policies based on the following:
 - IP address
 - End-system ID
 - Application
 - Protocol
 - Packet size

Configuring Route Maps

The route map syntax is composed of roughly three separate Cisco commands, depending on what map is accomplishing and what type of process is calling it. This discussion covers the following components in detail as route maps are configured throughout this chapter:

- route-map commands
- match commands
- set commands

When configuring route maps, you can follow a basic five-step configuration process. Depending on the type of route map application, additional configuration may be needed, such as with BGP communities or F

Step 1. (Optional) Configure any ACLs, AS_PATH lists, or any other match criteria that the route map may be using on the match commands. This should be done first, so you do not call an empty

AS-PATH list.

Step 2. Configure the route map instance. This is accomplished with the `route-map name [permit | deny] sequence_number` command. Be sure to leave room in between the sequence numbers for future updates or modifications. The route map instance with the lowest sequence number is first.

Step 3. Define the match criteria and configure the match statements that will be used in the route map instance. You do this with the `route map configuration match` command. In the `any` match commands, all packets or routes are matched.

Step 4. (Optional) Define the set criteria and configure the set statements that will be used in a single route map instance. You can do so with the `route map configuration set` command.

Step 5. (Optional) Configure any ACLs, AS_PATH list, or any other match criteria that the router may be using on the match commands.

Step 6. Apply the route map. Once again, depending on the route map application, it can be applied in many ways. Some of the more common applications include route redistribution, PBR, and policy-based routing.

With this configuration process in mind, we will discuss in more detail the three primary commands used to configure route maps.

route-map Commands

The complete syntax for the `route-map` command is as follows:

```
route-map route_map_name [permit | deny] [sequence_number_1-65535]
```

The `route_map_name`, also called the *map tag*, is the text-based name of the route map. The name must be unique and logically groups and defines the entire route map policy. This is the name that you use when applying the route map during redistribution and other processes.

The `permit` and `deny` keywords are optional; the default keyword is `permit`. If the route map is called from a redistribution process, the keyword is set to `permit`, and the match criteria are met for the route(s), the route(s) are redistributed. If the keyword were set to `deny`, in the same scenario the route(s) would be denied.

If the route map is called from a policy-routing statement, the match criteria are met for the route(s). If the keyword is set to `permit`, the packet would be policy routed. Once again, `permit` is the default keyword. If the `deny` keyword is used, the packet is forwarded according to the normal route processing rules.

The `sequence-number` indicates in what order the route map statements will be executed. When a route map is applied to a route, the sequence numbers are compared, and the first matching route map is applied.

map is called, the route map with the lowest sequence number is executed first. If a match is not found, the route map with the next highest sequence number is executed. This process repeats itself until a match is found or no more route map statements exist. If no match is found, execution for that individual packet or route stops, and the next packet or route begins the process again starting with the route-map statement with the lowest sequence number. The default sequence number is 10.

NOTE

When creating route maps, leave room in between sequence numbers for future editing. Begin your first route map with a sequence of 10 or 100, depending on how big you expect the route map to be. By using increments of 10 or 100, you leave room for 65 to 650 route map instances. Starting at a higher sequence number and leaving space in between your sequence numbers will make editing your route maps easier. The maximum route map instance is 65,535.

match Commands

The `match` commands enable you to define the criteria of the route map. For instance, you can use the `match` command to call an ACL to compare routes against. The `match` statement could also match on a tag, a route type, or the length of a packet. BGP offers many exclusive match statements that are listed in [Chapters 4](#) and [5.Table 2-1](#). Table 2-1 lists the match parameters available in Cisco IOS Software Release 12.2.

Table 2-1. match Commands in Cisco IOS Software 12.2

Command	What It Matches
<code>as-path</code>	BGP AS_PATH list
<code>clns</code>	CLNS ^[*] information
<code>community</code>	BGP community list
<code>extcommunity</code>	BGP/VPN ^[**] extended community list
<code>interface</code>	First-hop interface of a route
<code>ip</code>	IP-specific information
<code>length</code>	Packet length
<code>metric</code>	Route metric
<code>route-type</code>	Route type
<code>tag</code>	Route tag

[*] CLNS = Connectionless Network Service

[**] VPN = virtual private network

The `match ip address` command is by far the most commonly used of the match commands. The `ip address` command enables you to call a standard, extended, or expanded-range ACL. You can use it during redistribution, with BGP, NAT, and during policy routing, as well as for other functions. The syntax for this match command is as follows:

```
match ip {address [access_list | prefix-list] | next-hop [access_list] | route-source [access_list | prefix-list]}
```

In IP networks, this command enables you to match routes that have a network address matching one in the specified ACL or prefix list. You can use a standard, extended, or expanded-range ACL.

The `next-hop` keyword enables you to match routes that have a next-hop address matching one or more in the specified ACL. This is primarily used in BGP.

The `route-source` keyword enables you to match the advertising router's IP address of the route/neighbor. You can use a standard, extended, or expanded-range ACL. For BGP, you may also use a prefix list.

NOTE

When using the `match ip address` command in BGP, you can use route maps only to filter outbound updates. The use of a `match ip address` route map is not supported on inbound BGP updates.

The `next-hop` keyword is used primarily in BGP, but it can also be used when redistributing routes on the next-hop IP address that correlates to the route. In this case, the router will examine the `NH` attribute for this comparison.

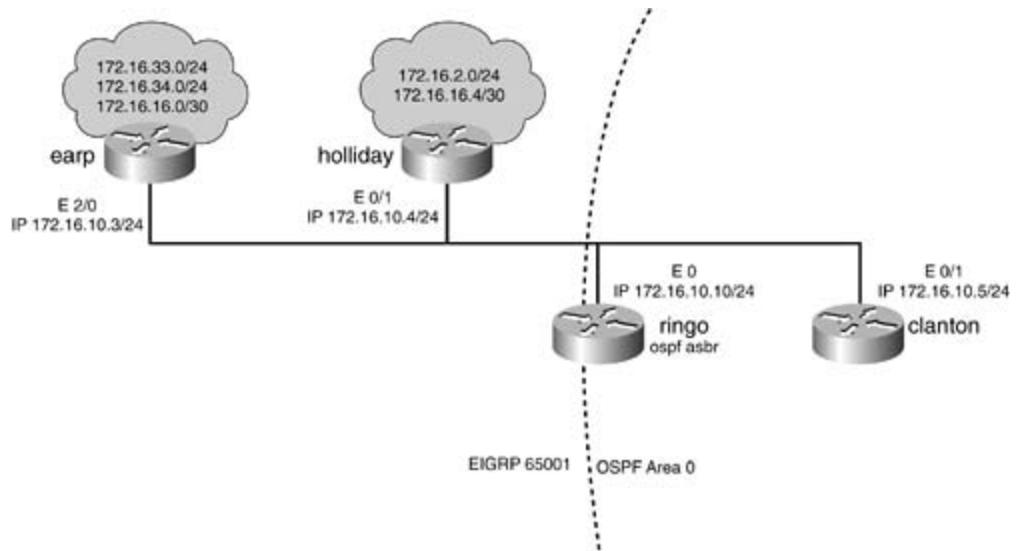
The `route-source` keyword enables you to match a router's advertising IP address. If you view the `ip route` table, and route 172.16.3.0/24 is advertised from the IP address of 172.16.2.1, for instance, the `route-source` keyword is used to match the advertising router's IP address of 172.16.2.1. In the next section, these commands are applied to practical examples to show you how they function.

Practical Example: Matching the Route Source and IP Address

In this model, four routers on a common LAN segment are running two routing protocols. The routers ringo and holliday are running EIGRP as the routing protocol, and the routers clanton and ricky are running OSPF. The router ringo is functioning as an OSPF autonomous system boundary router (ASBR) by redistributing between EIGRP and OSPF. The ringo router is receiving several routes from the earp

holliday routers, as depicted in [Figure 2-1](#).

Figure 2-1. Route Map Practical Example: Matching the Route Source a Address



In this practical example, a route map is applied during the redistribution of EIGRP into OSPF on the ringo router. The route map named set_tag3 is called on the redistribution process for OSPF on the ringo router. The first route map instance, route-map set_tag3 permit 100, will perform a match on the IP route source address 172.16.10.3. This statement will match only routes where the advertising IP address is found in ACL 5—in this case, 172.16.10.3. Not only will these routes be allowed for redistribution, but the tag of 3 will also be set.

NOTE

When using a route map with OSPF, the advertising OSPF router ID becomes the route source—the OSPF router ID for the IP address of the route source when using the route-source keyword with OSPF networks.

[Example 2-4](#) lists the forwarding/route table of the ringo router. Notice that routes 172.16.16.0/32, 172.16.33.0/24, and 172.16.34.0/24 are from the earp router, 172.16.10.3. The 172.16.2.0/24 and 172.16.16.4/30 routes are from the holliday router, 172.16.10.4.

Example 2-4. Forwarding/Route Table of the ringo Router

```
ringo#show ip route
```

```
<<<text omitted>>>

C      192.168.10.0/24 is directly connected, Loopback20

    172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks

D      172.16.33.0/24 [90/1812992] via 172.16.10.3, 00:07:13, Ethernet0

D      172.16.34.0/24 [90/1812992] via 172.16.10.3, 00:07:13, Ethernet0

D      172.16.16.4/30 [90/2195456] via 172.16.10.4, 00:07:13, Ethernet0

D      172.16.16.0/30 [90/1787392] via 172.16.10.3, 00:07:13, Ethernet0

C      172.16.10.0/24 is directly connected, Ethernet0

D      172.16.2.0/24 [90/307200] via 172.16.10.4, 00:07:14, Ethernet0

ringo#
```

[Example 2-5](#) lists the configuration of the route map on the ringo router.

Example 2-5. Configuration of the ringo Router

```
!

interface Loopback20

    ip address 192.168.10.10 255.255.255.0

!

interface Ethernet0

    ip address 172.16.10.10 255.255.255.0

!

<<<text omitted>>>

!

router eigrp 65001

    network 172.16.0.0

    network 192.168.10.0

    no auto-summary
```

```

no eigrp log-neighbor-changes

!
router ospf 7
log-adjacency-changes

redistribute eigrp 65001 subnets route-map set_tag3 ←Route-map called
network 172.16.10.10 0.0.0.0 area 0
default-metric 10
!

access-list 5 permit 172.16.10.3 ←Match route 172.16.10.3 only
access-list 50 permit any ←Match all remaining routes
!

route-map set_tag3 permit 100
match ip route-source 5 ←Match routes from 172.16.10.3 / ACL 5
set tag 3 ←set the tag to three
!

route-map set_tag3 permit 200 ←Second Route-map instance
match ip address 50 ←Call access-list 50 to match all routes
set metric-type type-1 ←Set OSPF route type to External Type-1
set tag 500 ←Set the tag to 500 for these routes

```

In the preceding example, the second instance of the route map calls ACL 50. Access list 50 will all remaining routes to be redistributed and will set a tag of 500 and the metric-type to an OSPF type-external.

By viewing the OSPF database, you can clearly see the tags and how redistribution is working. [Exa](#) demonstrates the show ip ospf database command on the ringo router.

Example 2-6. show ip ospf database Command

```
ringo#show ip ospf database
```

```
OSPF Router with ID (192.168.10.10) (Process ID 7)
```

```

        Router Link States (Area 0)

Link ID      ADV Router      Age       Seq#      Checksum Link count
172.16.10.5  172.16.10.5  1005      0x8000000B 0x18D8    1
192.168.10.10 192.168.10.10 1027      0x8000000A 0x7017    1

        Net Link States (Area 0)

Link ID      ADV Router      Age       Seq#      Checksum
172.16.10.5  172.16.10.5  1005      0x8000000A 0x75DA

        Type-5 AS External Link States

Link ID      ADV Router      Age       Seq#      Checksum Tag
172.16.2.0   192.168.10.10 1027      0x80000009 0x10E0    500
172.16.16.0  192.168.10.10 1027      0x80000009 0xD285    3
172.16.16.4  192.168.10.10 1027      0x80000009 0x3BA6    500
172.16.33.0  192.168.10.10 1027      0x80000009 0x291B    3
172.16.34.0  192.168.10.10 1027      0x80000009 0x1E25    3
192.168.10.0 192.168.10.10 1027      0x80000009 0x8BB0    500

ringo#

```

Examining the route table of a downstream OSPF router, such as clanton, you can see the effects of metric-type type-1 command. Notice in [Example 2-6](#) that the 172.16.2.0/24, 192.168.10.0/24, & 172.16.16.4/30 routes are OSPF external type 1 routes. Normally, or by default, the routes would be external type 2 routes. For more information on the different link-state advertisement (LSA) types used, refer to *CCIE Practical Studies, Volume 1*. You will learn more about the various set commands in the upcoming section. [Example 2-7](#) lists the forwarding table of the clanton router.

Example 2-7. Route Table of the clanton Router

```

clanton#show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2

```

```

E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
U - per-user static route, o - ODR

Gateway of last resort is not set

O E1 192.168.10.0/24 [110/20] via 172.16.10.10, 04:47:26, Ethernet0/0
    172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks
O E2      172.16.33.0/24 [110/10] via 172.16.10.10, 04:47:27, Ethernet0/0
O E2      172.16.34.0/24 [110/10] via 172.16.10.10, 04:47:27, Ethernet0/0
O E1      172.16.16.4/30 [110/20] via 172.16.10.10, 04:47:27, Ethernet0/0
O E2      172.16.16.0/30 [110/10] via 172.16.10.10, 04:47:27, Ethernet0/0
C        172.16.10.0/24 is directly connected, Ethernet0/0
O E1      172.16.2.0/24 [110/20] via 172.16.10.10, 04:47:27, Ethernet0/0

clanton#

```

BGP uses many specific match commands, as the next couple of examples show. BGP can use route maps to call an AS-Path rather than an ACL to control routing information. [Table 2-2](#) lists the syntax for the match as-path command.

Table 2-2. match as-path Command

Command	Description
match as-path/1-199/	Used in BGP to match an autonomous system list. The valid path list is

You can use this command in BGP to match the autonomous system path (AS_PATH) attribute.

Another BGP-specific match command is match community. You can use route maps to match all COMMUNITY attribute(s) in BGP.

The syntax for the match community command is as follows:

```
match [community|extcommunity|exactmatch]
```

The community keyword is used in BGP to call an IP community list. The valid range is 1 through 4294967295 for a standard community list, and 100 through 199 for an expanded community list; alternatively, you can use exact-match to perform precise matching of communities.

You can use route maps to base the selection of the global address pool on the output interface as an ACL match for NAT. The match interface command is used in NAT applications. You can also use match routes whose next-hop address is an interface, such as a static route pointing at an interface. [Table 2-3](#) shows the syntax for the match interface command.

Table 2-3. match interface Command

Command	Description
<code>match interface <i>interface_name</i></code>	Used in route maps for NAT to match the output interface, or routes that have an interface as the next-hop address rather than an IP address.

Tags very effectively enable you to control and track routes during redistribution. Cisco routers enable network engineer to mark certain routes with a numeric value. A tag value is an extra value that is transported along by the routing protocol. The tag value does not influence router forwarding decisions. The tag value has no intrinsic value to the routing protocol. The tag is used primarily during redistribution to *tagged* routes. After a route has been *tagged*, the tag value can be acted on during the redistribution process to control route redistribution. Tags are supported in RIPv2, OSPF, Integrated IS-IS, EIGRP, BGP, and CLNS. IGRP and RIPv1 do not support tags. To view tags, use the `show eigrp topology`/*ip_address subnet* and the `show ip ospf database` commands for EIGRP and OSPF, respectively. You can also view the tag value by using the extended `show ip route` command `show ip route`/*ip_address*. [Table 2-4](#) shows the syntax for the match tag command.

Table 2-4. match tag Command

Command	Description
<code>match tag [0-4294967295]</code>	Use the match tag command to match tag values in routing protocols such as RIPv2, IS-IS, OSPF, EIGRP, BGP, and CLNS.

You can also use route maps to match specific route types in Cisco IOS Software 12.0. For instance, you can use the match route-type key to match EIGRP external routes or OSPF external type 1 or type 2 routes. The match route-type key enables you to match the following route types:

- OSPF external type 1 (O E1) and type 2 routes (O E2), NSSA external type 1 (O N1) type 2 (C), intra-area routes (O), and interarea routes (O IA)
- EIGRP external routes (D EX)
- IS-IS level 1 routes (L1) and level 2 routes (L2)
- BGP external routes

The syntax for the match route-type command is as follows:

```
Match route-type {local|internal|external[type-1|type-2]|level-1|level2|nssa-exter
```

You can use the following keywords with the match route-type command:

External— External route (BGP, EIGRP, and OSPF type 1/2)

Internal— Internal route (including OSPF intra/interarea and EIGRP routes)

level-1— IS-IS level 1 route

level-2— IS-IS level 2 route

local— BGP locally generated route

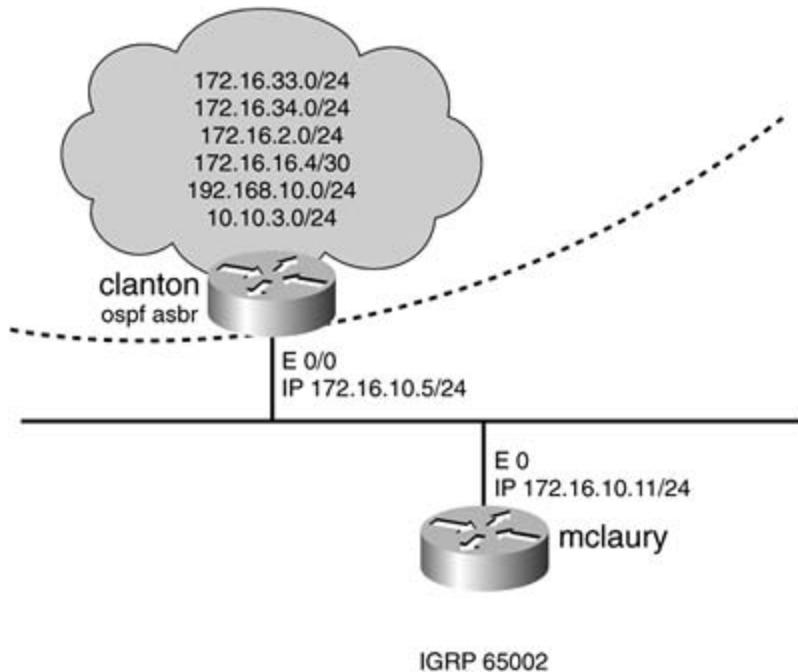
nssa-external— NSSA external route

Although you can use multiple match statements in a single line, you should use only one match c per line. This will make troubleshooting and modifying the route map easier.

Practical Example: Matching Tags

Manipulating the model from the preceding practical example, the following example has the route running OSPF and IGRP as the routing protocols. The clanton router will call a route map on redistribute. This route map will redistribute routes with a tag of 3 and OSPF external type 1 (O E1) routes into [Figure 2-2](#) shows the new network model.

Figure 2-2. Route Map Practical Example: Matching Tags



Example 2-8 lists the route table of the clanton router, with the OSPF external type-1 routes highlighted.

Example 2-9 lists the OSPF database on the clanton router, highlighting the routes that have a tag

Example 2-8. Route Table of the clanton Router

```
clanton#show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR

Gateway of last resort is not set

O E1 192.168.10.0/24 [110/20] via 172.16.10.10, 01:59:17, Ethernet0/0
    172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks
O E2      172.16.33.0/24 [110/10] via 172.16.10.10, 01:49:44, Ethernet0/0
O E2      172.16.34.0/24 [110/10] via 172.16.10.10, 01:49:44, Ethernet0/0
```

```

O E2      172.16.16.0/30 [110/10] via 172.16.10.10, 01:49:44, Ethernet0/0
C          172.16.10.0/24 is directly connected, Ethernet0/0
O E2      172.16.2.0/24 [110/10] via 172.16.10.10, 01:49:44, Ethernet0/0
               10.0.0.0/24 is subnetted, 1 subnets
O E1      10.10.3.0 [110/20] via 172.16.10.10, 01:59:18, Ethernet0/0
clanton#

```

Example 2-9. OSPF Database of the clanton Router

```

clanton#show ip ospf database
OSPF Router with ID (172.16.10.5) (Process ID 7)

```

Router Link States (Area 0)					
Link ID	ADV Router	Age	Seq#	Checksum	Link count
172.16.10.5	172.16.10.5	557	0x80000006	0x22D3	1
192.168.10.10	192.168.10.10	1642	0x80000005	0x7A12	1

Net Link States (Area 0)				
Link ID	ADV Router	Age	Seq#	Checksum
172.16.10.5	172.16.10.5	557	0x80000005	0x7FD5

Type-5 AS External Link States					
Link ID	ADV Router	Age	Seq#	Checksum	Tag
10.10.3.0	192.168.10.10	1642	0x80000004	0x9904	500
172.16.2.0	192.168.10.10	1133	0x80000005	0x87DF	3
172.16.16.4	192.168.10.10	1642	0x80000004	0x45A1	500
172.16.33.0	192.168.10.10	1133	0x80000005	0x3117	3
172.16.34.0	192.168.10.10	1133	0x80000005	0x2621	3
192.168.10.0	192.168.10.10	1643	0x80000004	0x95AB	500

```
clanton#
```

To control redistribution between OSPF and IGRP, use a route map on the redistribution process. The route map to accomplish this must have two route map instances. The first route map instance will match all OSPF routes that have a tag value of 3. The second route map instance will match OSPF external type 1 routes. [Example 2-10](#) lists the significant portions of the configuration on the clanton router.

Example 2-10. Route Map Configuration on the clanton Router

```
hostname clanton
!
router ospf 7
  network 172.16.10.5 0.0.0.0 area 0
!
router igrp 65002
  redistribute ospf 7 route-map match_me      ← Redistribute OSPF and call the route-
  network 172.16.0.0
  default-metric 10000 100 254 1 1500
!
route-map match_match_me permit 10
  match tag 3                                ← Match routes with a tag 3
!
route-map match_match_me permit 20
  match route-type external type-1           ← Match OSPF external type-1 routes
```

To verify redistribution and that the route maps worked properly, view the route table of the mclaury router. [Example 2-11](#) lists the route table of the mclaury router. Notice that routes with a tag value of 3 are present: 172.16.2.0/24, 172.16.33.0/24, and 172.16.34.0/24. Also, notice that the OSPF external routes are present: 192.168.10.0/24 and 10.0.0.0/8 as summarized subnets.

Example 2-11. Route Table of the mclaury Router

```
mclaury#show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

I      192.168.10.0/24 [100/1200] via 172.16.10.5, 00:00:50, Ethernet0
       172.16.0.0/24 is subnetted, 4 subnets
I      172.16.33.0 [100/1200] via 172.16.10.5, 00:00:50, Ethernet0
I      172.16.34.0 [100/1200] via 172.16.10.5, 00:00:50, Ethernet0
C      172.16.10.0 is directly connected, Ethernet0
I      172.16.2.0 [100/1200] via 172.16.10.5, 00:00:50, Ethernet0
I      10.0.0.0/8 [100/1200] via 172.16.10.5, 00:00:50, Ethernet0

mclaury#
```

You can also use route maps to match a route's metric. This is the metric for the route as it appears in the route/forwarding table. If an OSPF route has an associated metric of 20, for instance, match metric 20 would be used to match this route. [Table 2-5](#) lists the syntax used with the match metric command.

Table 2-5. match metric Command

Command	Description
match metric [0-4294967295]	Enter the metric value as it appears in the route/forwarding table on the router.

Using [Figure 2-1](#) as a guide, [Example 2-12](#) lists the route table of the clanton router followed by the command to match the route with metric 20.

map configuration used to match the OSPF routes with a metric of 20. This example redistributes C routes into EIGRP routes that have a metric of 20.

Example 2-12. Demonstration of the match metric Route Map

```
clanton#show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR

Gateway of last resort is not set

O E1 192.168.10.0/24 [110/20] via 172.16.10.10, 00:19:58, Ethernet0/0
    172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks
O E2      172.16.33.0/24 [110/10] via 172.16.10.10, 00:19:59, Ethernet0/0
O E2      172.16.34.0/24 [110/10] via 172.16.10.10, 00:19:59, Ethernet0/0
O E1      172.16.16.4/30 [110/20] via 172.16.10.10, 00:19:59, Ethernet0/0
O E2      172.16.16.0/30 [110/10] via 172.16.10.10, 00:19:59, Ethernet0/0
C        172.16.10.0/24 is directly connected, Ethernet0/0
O E2      172.16.2.0/24 [110/10] via 172.16.10.10, 00:19:59, Ethernet0/0
    10.0.0.0/24 is subnetted, 1 subnets
O E1      10.10.3.0 [110/20] via 172.16.10.10, 00:19:59, Ethernet0/0

hostname clanton
!
<<<text omitted>>>
!
router ospf 7
```

```

network 172.16.10.5 0.0.0.0 area 0
!
router eigrp 65002
  redistribute ospf 7 route-map match_metric_20
  network 172.16.0.0
    default-metric 10000 100 254 1 1500
  !
  ip classless
  !
  route-map match_metric_20 permit 10
    match metric 20
  !

```

In the preceding example, the routes 10.10.3.0/24, 172.16.16.4/30, and 192.168.10.0/24 were redistributed into EIGRP.

The `match clns` address command is used in ISO CLNS routing much in the same way that it is used in IP routing. The `match clns address` command calls a CLNS address list and compares the address being tested against it. The `next-hop` and `route-source` keywords are used to call an OSI filter set during routing. Use the CLNS commands in the same manner as their IP counterparts. The syntax of the `match clns` command is as follows:

```
match clns {address [name]|next-hop [filter set]|route-source [filter set]}
```

Use the `match clns address` command to match routes that have a network address matching one or more entries in the specified OSI filter set.

The `next-hop` keyword is used to match routes that have a next-hop address matching one or more entries in the specified OSI filter set.

The `route-source` keyword is used to match routes that have been advertised by routers matching

more in the specified OSI filter set.

The last match command discussed here is the match length command. This match statement is primarily in policy routing when ACLs are insufficient for proper traffic distribution. The match length command enables you to match the Layer 3 packet length in bytes, including headers and trailers. use a route map such as this to send little interactive packets, such as Telnet traffic, one way, and bulk-data transfers, such as a large FTP transfer, another way. [Table 2-6](#) lists the syntax for the match length command.

Table 2-6. match length Command

Command	Description
<i>Match length [min_packet_length_0-2147483647] [max_packet_length_0-2147483647]</i>	Used to match the Layer 3 packet length in bytes with associated headers and trailers included. You must specify the minimum and maximum packet length.

For an example of the match length command, see the later section "[Configuring Policy-Based Routing \(PBR\)](#)."

set Commands

These set commands are executed after a successful match has been made in the route map instance. The set command is optional and may be omitted. If you are using route maps on redistribution, or just to redistribute networks, for instance, there is no need to use a set command unless you want to tag or further in the route. If no match statements are present in the route map instance, all set commands are executed for all routes. You may also use multiple set commands in each route map instance. The set commands discussed here are supported in Cisco IOS Software Release 12.2 and are listed in [Table 2-7](#). The set commands have been divided into three categories: BGP-specific set commands, routing protocol/redistribution-specific set commands, and policy-routing specific set commands. The policy-routing specific set commands are covered in the upcoming section "[Configuring Policy-Based Routing \(PBR\)](#)."

Table 2-7. set Commands

set Command	Description
<i>BGP-specific set commands</i>	
as-path	Prepend string for a BGP AS_PATH attribute
community extcommunity	Set BGP COMMUNITY attributes
comm-list	BGP community list for deletion
dampening	Set BGP route flap dampening parameters
local-preference	Set BGP LOCAL_PREF path attribute
origin	Set BGP origin code
weight	Set BGP weight
<i>Routing protocol/redistribution-specific set commands</i>	
metric	Set metric value for destination routing protocol
metric-type	Type of metric for destination routing protocol
tag automatic-tag	Tag value for destination routing protocol
<i>Policy-routing specific set commands</i>	
default	Set default routing information
interface	Set the Output interface, used in point-to-point links
ip	IP-specific information

BGP-Specific set Commands

The first set commands covered here are the ones related to BGP. This section discusses the syntax of various set commands for BGP and their basic application. For more specific and detailed information on the application of the BGP-specific set commands, see [Chapter 8](#), "Introduction to BGP-4 Configuration" or [Chapter 9](#), "Advanced BGP Configuration."

The set as-path command is used in BGP to prepend one or more autonomous systems to the well-known mandatory transitive AS_PATH attribute. In BGP, this can be used to influence routing decisions. BGP routes that have one or more autonomous systems prepended to the current AS_PATH attribute are less desirable, which can prove useful in a multihomed BGP network.

CAUTION

The purpose of the prepend command is essentially to make the AS_PATH longer—thereby forming a less desirable path—not to completely change it. When using the set as-path prep command in production environments, always use the same ASN that the route is from. If a different ASN is used, and that autonomous system is encountered by the advertised route, the receiving autonomous system/router will not accept the route. Modifying the AS_PATH by prepending a different autonomous system directly affects the inherent loop prevention provided by the AS_PATH attribute. Some Cisco IOS Software levels will not even enable you to enter a AS_PATH different from your own. For educational purposes, some of the examples in this text show the prepending of different autonomous systems; this is done to highlight the placement

the prepended autonomous system only.

Note an important difference in how the prepend command works with inbound and outbound route maps. When the prepend command is used on outbound route maps, the prepended autonomous system number appears after the advertising router's autonomous system. This is because the prepended autonomous system number must be in place before the route update is sent. When the update is sent, the advertising router's autonomous system number is the first one on the list. If you prepend AS 10 10 to an outbound route map, for instance, and your router's autonomous system is 5, the receiving router/neighbor will have an AS_PATH of 5 10 10.

If you apply the prepend command on an inbound route map, the autonomous system that is prepended will actually precede the originating AS_PATH. This is because the autonomous system prepend is happening after the route has been received from its neighbor. If you prepend AS 10 10 on an inbound route map, and the router/neighbor you are receiving the route from has the AS_PATH of 5 500, for example, the AS_PATH to that route will be 10 10 5 500. The syntax for the set as-path command follows:

```
set as-path {prepend [as_path1|as_path2|as_path3]| [tag]}
```

Use the set as-path command in BGP networks to modify the AS_PATH attribute, by prepending one or more autonomous systems to it. You can use this command on inbound and outbound route maps.

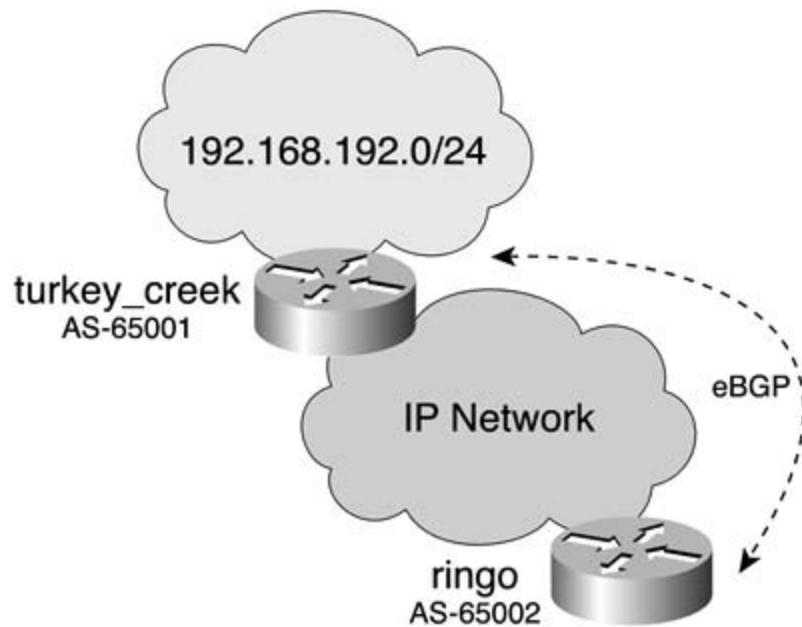
The tag keyword is used in BGP to recover the AS_PATH information from the tags of Interior Gateway Protocol (IGP)-redistributed routes.

The set as-path tag command is used in BGP when doing redistribution to preserve a consistent and correct AS_PATH across an IGP. The Cisco BGP implementation automatically conveys AS_PATH information in a tag when redistributing BGP into an IGP. When redistributing IGP routes into BGP, however, AS_PATH information is lost. To recover the AS_PATH information from the tag of a redistributed IGP, use the set as-path tag command.

Practical Example: Setting the AS_PATH

The network model shown in [Figure 2-3](#) has two routers running BGP between them. The turkey_creek router is in autonomous system 65001, and the ringo router is in autonomous system 65002. The router turkey_creek will advertise the network 192.168.192.0/24 via BGP. In this example, a route map named turkey_creek is used to prepend the AS_PATH with autonomous system 65001 2001 on outbound updates from the turkey_creek router.

Figure 2-3. Route Map Practical Example: Setting the AS_PATH



Example 2-13 lists the configuration to manipulate the AS_PATH attribute on the turkey_creek router.

Example 2-13. BGP Configuration of the turkey_creek Router

```
route-map set_as permit 10
  set as-path prepend 65001 2001
!
 $\leftarrow$ prepend AS-PATH with 65001 2001
```

You might be tempted to think that the AS_PATH for route 192.168.192.0/24 would read 65001 2C 65001; after all, the command says "prepend." Because this is an outbound route map, however, the prepended autonomous system will occur before the advertisement is sent. Therefore, the "prepended" AS_PATH will appear after the originating autonomous system to the downstream router. The AS_F value for the downstream router, the ringo router, will read 65001 65001 2001. [Example 2-14](#) demonstrates listing the output of the show ip bgp command on the ringo router.

Example 2-14. show ip bgp Command on the ringo Router

```
ringo#show ip bgp 192.168.192.0

BGP routing table entry for 192.168.192.0/24, version 4

Paths: (1 available, best #1, table Default-IP-Routing-Table)

Not advertised to any peer

65001 65001 2001

172.16.200.10 (metric 1915392) from 172.16.200.10 (192.168.192.7)

    Origin IGP, metric 0, localpref 100, valid, external, best

ringo#
```

Example 2-15. Configuration of the ringo Router, and the show ip bgp Command

Hostname ringo

```

<<<text omitted>>>

!

router bgp 65002

no synchronization

bgp log-neighbor-changes

neighbor 172.16.200.10 remote-as 65001

neighbor 172.16.200.10 ebgp-multipath 10

neighbor 172.16.200.10 update-source Loopback20

neighbor 172.16.200.10 route-map modify_as in      ←Route-map "modify_as" is cal

!

route-map modify_as permit 10

set as-path prepend 2001 65002 65001           ←Prepended AS

!



---


ringo#show ip bgp 192.168.192.0

BGP routing table entry for 192.168.192.0/24, version 2

Paths: (1 available, best #1, table Default-IP-Routing-Table)

    Not advertised to any peer

2001 65002 65001 65001

    172.16.200.10 (metric 1915392) from 172.16.200.10 (192.168.192.7)

        Origin IGP, metric 0, localpref 100, valid, external, best

ringo#

```

The `set community` command is used in BGP to set various community attributes. As discussed in chapters on BGP, communities can be a powerful and efficient way to apply policies to a group of routes. The `community` command enables you to form community membership. After routes become members of a community, they can be assigned policies, such as "do not export this route to any E-BGP neighbor or advertise this route to the Internet community." To send the community attribute in BGP, the `neighbor a.b.c.d send-community` command must be used.

The syntax for the `set community` command in Cisco IOS Software Release 12.2 is as follows:

```
set community {community-number_1-4294967200|AA|NN|no-export|no-advertise |internet|local-AS [additive]}}|none
```

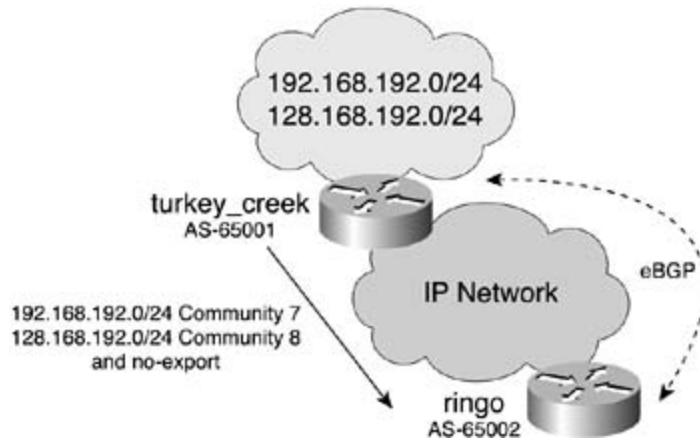
Use the `set community` command to designate or form communities from routes and to apply specific policies to those routes. The valid parameters and values are as follows:

- *Community number*—A valid number from 1 to 4,294,967,200; the routes will be designated by this community number.
- *AA:NN*—This format can also be used to designate communities. The *AA* is a 16-bit ASN between 1 and 65,535. *NN* is an arbitrary 16-bit number between 1 and 65,440.
- Internet—The Internet community. Advertise these routes to the Internet community and all routers belonging to it.
- no-export—Do not advertise these routes to an E-BGP peer. Routes with this community are not advertised to peers in other subautonomous systems within a confederation.
- local-as—Do not advertise these routes to peers outside the local autonomous system. These routes will not be advertised to other autonomous systems or subautonomous systems if confederations are present.
- no-advertise—Do not advertise these routes to any peer (internal or external). Used for I-BGP.
- Additive—(Optional) Adds the community to the already existing communities.
- None—Removes the COMMUNITY attribute from the prefixes that pass the route map.

Practical Example: Setting BGP Community Attributes

Consider the same network model from the preceding example, with the `turkey_creek` and the `ringo` routers running BGP between them. (See [Figure 2-4](#).) The `turkey_creek` router is in AS 65001, and the `ringo` router is in AS 65002. The `turkey_creek` router will advertise the network 192.168.192.0/24 via BGP and set the COMMUNITY attribute to 7. The `turkey_creek` router will also advertise another route, 128.168.192.0/24. The `turkey_creek` router will put this route in community 8 and set the COMMUNITY attribute to no-export. The no-export COMMUNITY attribute will instruct the `ringo` router not to advertise this route to E-BGP neighbors.

Figure 2-4. Route Map Practical Example: Setting Communities



[Example 2-16](#) lists the route map used to accomplish this.

Example 2-16. Route Map for Communities on turkey_creek

```

Hostname turkey_creek
!
<<<text omitted>>>
!
router bgp 65001
no synchronization
network 128.168.192.0 mask 255.255.255.0
network 192.168.192.0
neighbor 172.16.100.10 remote-as 65002
neighbor 172.16.100.10 ebgp-multipath 10
neighbor 172.16.100.10 update-source Loopback20
neighbor 172.16.100.10 send-community           ←send-community must be enabled
neighbor 172.16.100.10 route-map set_communities out ←route-map "set_communities"
!
<<<text omitted>>>
!
```

```

access-list 10 permit 192.168.192.0 0.0.0.255      ←allow network 192.168.192.0/24
access-list 11 permit 128.168.192.0 0.0.0.255      ←allow network 128.168.192.0/24
!
route-map set_communities permit 100
  match ip address 10                         ←Match ip access-list 10 or 192.168.192.
    set community 7                           ←set the community to 7
  !
route-map set_communities permit 200
  match ip address 11                         ←Match ip access-list 11 or 128.168.192.
    set community 8 no-export                  ←set the community to 8 and don't export
                                              future E-BGP peers

```

By observing the routes on the ringo router, you can see that route 192.168.192.0/24 is in community 7. Route 128.168.192.0/24 is in community 8 with the no-export option set. [Example 2-17](#) lists the output of the `show ip bgp` command on the ringo router.

Example 2-17. Routes with Communities Set on the ring Router

```

ringo#show ip bgp 192.168.192.0
BGP routing table entry for 192.168.192.0/24, version 3
Paths: (1 available, best #1, table Default-IP-Routing-Table)
  Not advertised to any peer
  65001
    172.16.200.10 (metric 1915392) from 172.16.200.10 (192.168.192.7)
      Origin IGP, metric 0, localpref 100, valid, external, best
      Community: 7

ringo#
ringo#show ip bgp 128.168.192.0
BGP routing table entry for 128.168.192.0/24, version 2

```

```
Paths: (1 available, best #1, table Default-IP-Routing-Table, not advertised to
EBGP peer)

Not advertised to any peer

65001

172.16.200.10 (metric 1915392) from 172.16.200.10 (192.168.192.7)

Origin IGP, metric 0, localpref 100, valid, external, best

Community: 8 no-export

ringo#
```

Use the set comm-list delete command to remove the COMMUNITY attribute of an inbound or outbound route update. The syntax is as follows:

```
set comm-list {[standard | extended community list]} delete
```

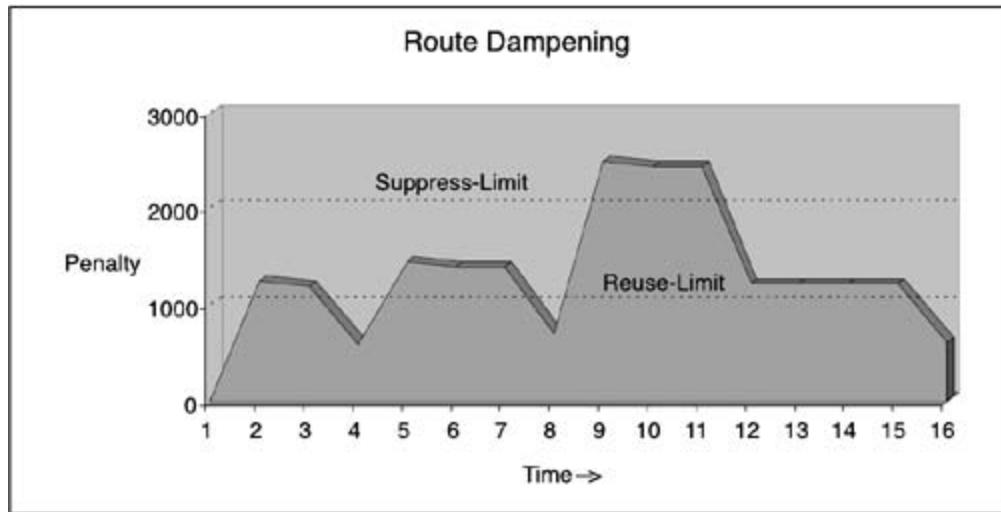
For more examples of the various set communities commands and how they function in BGP, see [7](#) through [9](#) on configuring BGP.

Another BGP-specific feature that you can set is dampening. Because of the long time it takes BGP to converge, an unstable route, or "route flapping," can have significant and detrimental impacts on BGP networks. If a route goes down, a WITHDRAWN message is sent via BGP requesting all peers to withdraw that route from their tables. An unstable route in your autonomous system will cause constant sending of withdrawal messages to other autonomous systems. This effect multiplied by the hundreds or thousands of routes that may be in an autonomous system can negatively affect BGP.

Dampening allows routers to categorize routes as either well behaved or ill behaved. Obviously, a *well-behaved* route should be very stable over an extended period of time. On the other end of the spectrum, an *ill-behaved* route could be a route that is unstable, or flapping. When route dampening is enabled with the BGP router command `bgp dampening`, the router will start a history file on how many times a route flaps. The route dampening feature will start to assign a penalty to a route each time it flaps. These penalties start to accumulate for each route, and when the penalty is greater than an arbitrary number called the *suppress value*, the route will no longer be advertised. The route will remain suppressed until the penalty falls below the reuse-limit or the max_suppress timer is exceeded. The penalty for a route can be decreased over time. The half-life timer is a timer, expressed in minutes, that must elapse before the penalty will be reduced by one-half. If the route remains stable, over time the penalty for that route will decrease. When the penalty is below another arbitrary timer called the reuse-limit, the route will be

unsuppressed and advertised once again. [Figure 2-5](#) illustrates the time and penalty relationship in dampening.

Figure 2-5. Route Dampening Timer Relationship



Note that this type of route map is called from the BGP router command `bgp dampening [route-map-name]`. A route map called on the neighbor statement will not work for route dampening. The set dampening command in Cisco IOS Software Release 12.2 is as follows:

```
set dampening {half-life_1-45 reuse_1-20000 suppress_1-20000 max_suppress_time_1-2
```

Use the set dampening command to influence how the router will react when it encounters unstable routes. The half-life parameter represents a time (in minutes) that must pass with a route being suppressed after which the penalty value is reduced by half. The default is 15 minutes, and the valid range is 1 to 45 minutes.

The reuse parameter enables you to mark a point, or a reuse, point that allows the route to be advertised again. When the penalty value falls below the reuse point, the route is unsuppressed and re-advertised. The default value is 750, and the valid ranges are 1 to 20,000.

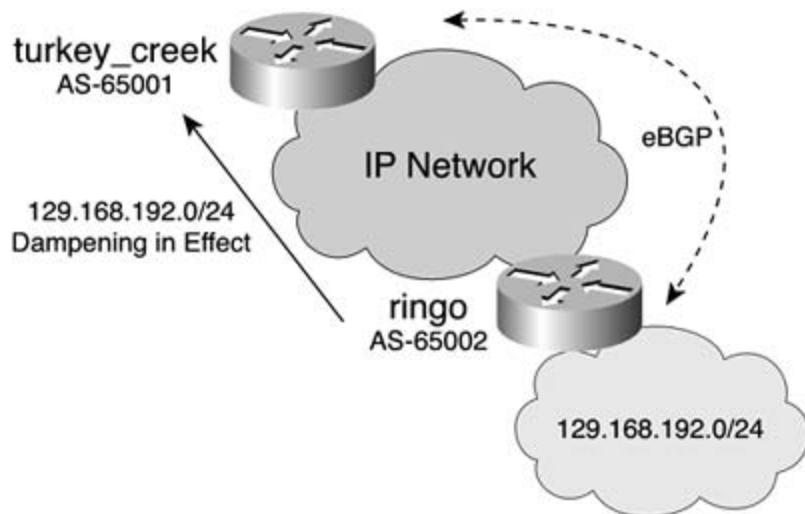
When the penalty exceeds the suppress parameter, the route is suppressed and no longer advertised. The valid range is from 1 to 20,000; the default is 2000.

The `max_suppress_time` is a value expressed in minutes that specifies how long a route should be suppressed by the dampening feature. The default value of this is 4 times the half-life timer, or 60. The valid range is from 1 to 255 minutes.

When a prefix is withdrawn, BGP considers the withdrawn prefix as a flap and increases the penalty by 1000. When BGP receives an attribute change, the penalty is increased by 500.

In [Figure 2-6](#), the router `ringo` is advertising 129.168.192.0/24 to the `turkey_creek` router via BGP.

Figure 2-6. Route Dampening



The `turkey_creek` router has route dampening enabled, with a route map to apply the dampening to 129.168.192.0/24. Use the `show ip bgp dampened-paths` command and the `show ip bgp a.b.c` command to view whether route dampening has occurred and to view what the current penalty code is. Note that information related to the dampening does not appear until the route has actually flapped. [Example 2-18](#) shows the penalty and dampening occurring on the `turkey_creek` router for route 129.168.192.0/24.

Example 2-18. Verifying Dampening

```
turkey_creek#show ip bgp dampened-paths

BGP table version is 9, local router ID is 192.168.192.7
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          From        Reuse     Path
*d 129.168.192.0/24 172.16.100.10    00:38:00 65002 i

turkey_creek#
```

```

turkey_creek#show ip bgp

BGP table version is 9, local router ID is 192.168.192.7

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          Next Hop            Metric LocPrf Weight Path
* > 128.168.192.0/24 0.0.0.0                  0          32768  i
*d 129.168.192.0/24 172.16.100.10           0          0 65002  i
*> 192.168.192.0     0.0.0.0                  0          32768  i

turkey_creek#

turkey_creek#show ip bgp 129.168.192.0

BGP routing table entry for 129.168.192.0/24, version 9

Paths: (1 available, no best path)

  Not advertised to any peer

  65002, (suppressed due to dampening)

    172.16.100.10 (metric 2323456) from 172.16.100.10 (172.16.100.10)
      Origin IGP, metric 0, localpref 100, valid, external, ref 2
      Dampinfo: penalty 3717, flapped 4 times in 00:04:36, reuse in 00:37:50

turkey_creek#

```

[Example 2-19](#) lists the BGP configuration for the preceding example and the associated route maps for the turkey_creek router.

Example 2-19. Configuration of the turkey_creek Router

```

hostname turkey_creek
!
<<<text omitted>>>
!

```

```

router bgp 65001

no synchronization

bgp dampening route-map set_dampening      ←Dampening enabled with route-map

network 128.168.192.0 mask 255.255.255.0

network 192.168.192.0

neighbor 172.16.100.10 remote-as 65002

neighbor 172.16.100.10 ebgp-multipath 10

neighbor 172.16.100.10 update-source Loopback20

!

access-list 11 permit 129.168.192.0 0.0.0.255

!

route-map set_dampening permit 100

match ip address 11                         ←Match network 129.168.192.0/24

set dampening 20 1000 2000 80                ←Set dampening parameters

```

For more information and examples on route dampening, see BGP [Chapters 7](#) through [9](#).

You can also use route maps in BGP to set the well-known discretionary LOCAL_PREF attribute. The LOCAL_PREF attribute is a numeric value ranging from 0 to 4,294,967,295, where the higher the value, the more preferred the route is. The default LOCAL_PREF value is 100. [Table 2-8](#) lists the syntax used for the LOCAL_PREF attribute.

Table 2-8. set local-preference Command in Cisco IOS Software Release 12.4(17)S

Command	Description
set local-preference { 0-4294967295 }	Use the set local-preference command to set the LOCAL_PREF of a route. The valid range is from 0 to 4,294,967,295. The default value is 100.

Another BGP attribute that you can set with route maps is the well known mandatory transitive ORIGIN attribute. The ORIGIN attribute is a well-known mandatory attribute. The ORIGIN attribute, as the name states, specifies the origin of the route with respect to the autonomous system that originated it. BGP supports three different types of origin:

- IGP(i)— The network layer reachability information (NLRI) is internal to the originating autonomous system.

system. This is a remote IGP system. The route originates from the network command.

- EGP(e)— The NLRI is learned via the EGP. This is a local EGP system. The route is redistributed by EGP.
- Incomplete(?)— The NLRI is learned from some other means. The route is redistributed from static or static.

[Table 2-9](#) lists the syntax used in setting the origin.

Table 2-9. set origin Command in Cisco IOS Software Release 12.2

Command	Description
set origin { igp egp [as_number] /incomplete}	Use the set origin command to set the ORIGIN attribute of a route/routes. The valid origin types are IGP, EGP, and incomplete.

The final BGP-specific set command discussed here is the set weight command. The WEIGHT attribute is a Cisco proprietary feature used to measure a route's preference. The WEIGHT attribute is local to the router and does not get exchanged between routers; therefore it is only effective on inbound route maps. The WEIGHT attribute can be used to influence routes from multiple service providers to a central location. Like LOCAL_PREF, assigning a higher weight to a route makes that route more preferred. The WEIGHT attribute also has the highest precedence of any BGP attribute. For more information on BGP, see [Chapters 9](#). [Table 2-10](#) lists the syntax used in setting the WEIGHT attribute.

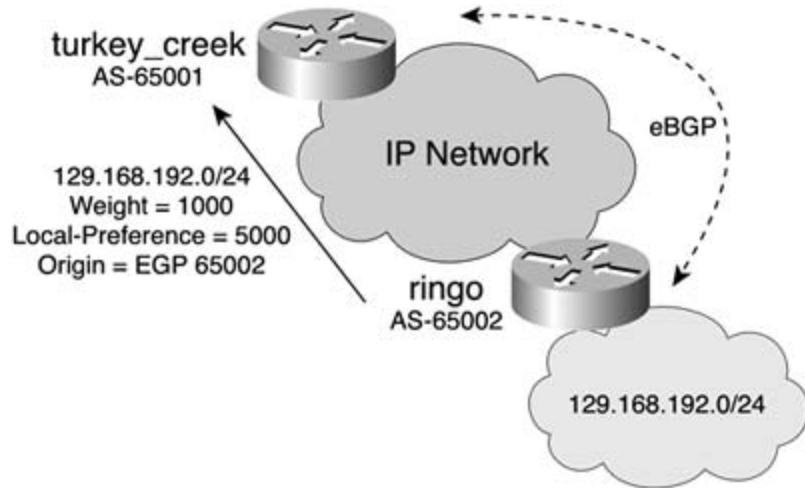
Table 2-10. set weight Command in Cisco IOS Software Release 12.

Command	Description
set weight { 0-65535}	Use the set weight command to set the weight of a route/routes. The valid weight range is from 0 to 65,535, and the default weight of a route is 32,768.

Practical Example: Configuring BGP Attributes

This practical example uses the same network model as in the previous examples and sets the BGP attributes of LOCAL_PREF, WEIGHT, and ORIGIN. [Figure 2-7](#) is the same network shown earlier. The example calls an inbound route map on the turkey_creek router. The route map set_attributes will set the following attributes: WEIGHT to 1000, LOCAL_PREF to 5000, and ORIGIN to be EGP from autonomous system 65002. In this example, the setting local-preference is for education purposes only. Normal local-preference would not be used or effective on E-BGP peers.

Figure 2-7. Configuring BGP Attributes



[Example 2-20](#) lists the BGP and route map configuration to accomplish this on the turkey_creek router.

Example 2-20. BGP Attribute Configuration

```

hostname turkey_creek
!
<<<text omitted>>>
!
router bgp 65001
  no synchronization
  network 128.168.192.0 mask 255.255.255.0
  network 192.168.192.0
  neighbor 172.16.100.10 remote-as 65002
  neighbor 172.16.100.10 ebgp-multipath 10
  neighbor 172.16.100.10 update-source Loopback20
  neighbor 172.16.100.10 route-map set_attributes in ←call route-map "set_attributes"
!
route-map set_attributes permit 100
  set local-preference 5000      ←Set local-preference to 5000
  set weight 1000               ←Set weight to 1000

```

```

set origin egp 65002           ← Set the ORIGIN to EGP in AS 65002
!
!                                     ← *note with no match parameter all routes are
                                matched from the neighbor 172.16.100.10

```

To verify the effectiveness of the route map, use the `show ip bgp` command, as demonstrated in [E-2-21](#).

Example 2-21. Verifying the Attributes

```

turkey_creek#show ip bgp

BGP table version is 4, local router ID is 192.168.192.7
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          Next Hop            Metric LocPrf Weight Path
* > 128.168.192.0/24 0.0.0.0          0          32768  i
* > 129.168.192.0/24 172.16.100.10   0      5000    1000  65002  e
* > 192.168.192.0     0.0.0.0          0          32768  i

turkey_creek#
turkey_creek#
turkey_creek#show ip bgp 129.168.192.0

BGP routing table entry for 129.168.192.0/24, version 2
Paths: (1 available, best #1)
Not advertised to any peer
65002
172.16.100.10 (metric 2323456) from 172.16.100.10 (172.16.100.10)
Origin EGP, metric 0, localpref 5000, weight 1000, valid, external, best,
ref 2

turkey_creek#

```

Configuring Routing Protocol/Redistribution-Specific set Commands

These set commands covered next relate primarily to IGP routing protocols and are used mostly during redistribution. The set metric, set metric-type and set tag commands can all be used to change metric or the tag of a route during redistribution. As mentioned previously, the metrics and tags can be matched and used for further route control during redistribution.

The most common use of the set metric command is to set the metric of the route for the destination routing protocol. If you are redistributing EIGRP routes into OSPF, for example, you can use a route map conjunction with the set metric command to set the new OSPF metric. If you are redistributing from EIGRP, the metric value you enter is the composite metric only. This differs slightly from setting the metric or the metric on redistribution without a route map, where you would set all five submetrics. The use of the set metric command is to set the BGP optional nontransitive MULTI_EXIT_DISC (MED). The syntax for the set metric command in Cisco IOS Software Release 12.2 is as follows:

set metric { [-/+ <0-4294967295>] | 1-4294967295]

The + and – keywords enable you to increase or decrease the current metric. To increase the metric for example, the command would be set metric +10. To set just the composite metric for EIGRP, command is set metric 4295. For more information on IGP routing protocol metrics, refer to *CCIE Studies, Volume 1*. You can find more information on the BGP MED attribute in [Chapters 7](#) through [9](#) book.

The `set metric-type` command is rather limited. It is used primarily in BGP, OSPF, and IS-IS. You can use it to set IS-IS external and internal metrics and OSPF type 1 and type 2 external metrics. The `set metric-type` command can also be used in BGP to use the IGP metric as the MED for BGP. The syntax for the `set metric-type` command in Cisco IOS Software Release 12.2 is as follows:

```
set metric-type [internal|external|type-1|type-2]
```

- external— IS-IS external metric.
 - internal— Use the metric of the IGP as the MED for BGP. Also used for setting IS-IS internal
 - type-1— Use to match the OSPF type 1 metric.
 - type-2— Use to match the OSPF external type 2 metric.

The final set command discussed in this section is the set tag command. The set tag command enables you to set the administrative tag of route. For IGPs, the tag value is usually set with a route map a set tag command. In BGP, when you redistribute BGP into an IGP, the ASN of BGP is automatically set as the tag value. BGP does this to preserve the AS_PATH attribute across an IGP domain. For IGPs, th

an administrative value that certain routing protocols carry within the routing update. The tag value impact on routing decisions. Instead, it is used to mark routes or flag routes or to track the AS_PATH in BGP. The tag value may also be acted upon during a redistribution process. When the automatic-tag command is used with the BGP table-map command, the tag value includes the ASN and the original syntax used to manipulate the tag value in Cisco IOS Software Release 12.2 is as follows:

```
set {tag [0-4294967295]}|automatic-tag}
```

Use the set tag *value* command to set the tag value. Use the set automatic-tag command when redistributing an IGP into BGP to recover the tag value as an AS_PATH attribute.

NOTE

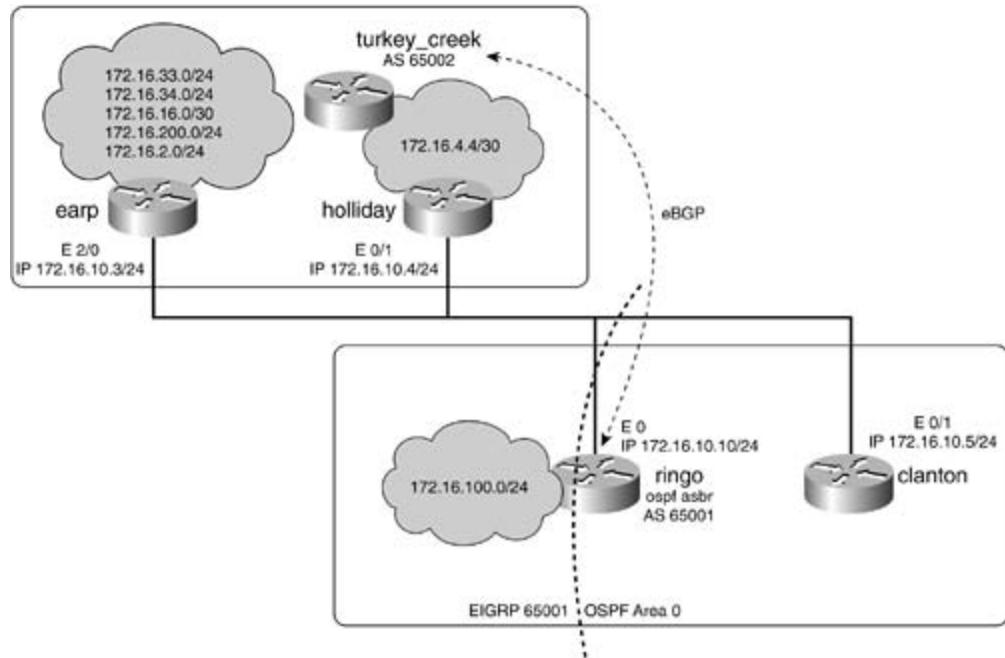
You can also use the tag value strictly for documentation purposes in an internetwork. If you have an OSPF domain, where RIP routes and EIGRP routes are redistributed, for example, you may want to tag the routes from EIGRP with a value of 100 and tag the routes from IGRP with a value of 110. When the OSPF database is viewed, it will be easy to determine the origin of specific routes. This can prove a handy documentation tool for troubleshooting route redistribution.

Tags are supported in RIPv2, OSPF, Integrated IS-IS, EIGRP, BGP, and CLNS. IGRP and RIPv1 do not support tags. To view tags, use the show ip eigrp topology */p_address subnet mask* command and the show ip ospf database command for EIGRP and OSPF, respectively. You can also view the tag values for other routing protocols by using the extended show ip route command, show ip route */p_address*.

Practical Example: Setting Route Tags and Metric Types

In the internetwork model in [Figure 2-8](#), the routers turkey_creek, earp, holliday, and ringo are running EIGRP. The ringo router also has a BGP peer to the turkey_creek router and is running OSPF and the clanton router.

Figure 2-8. Route Tagging and Metric Setting



To demonstrate route tagging and metric setting, the following example writes a route map on the router. The route map will be used on the ringo router when redistributing EIGRP routes into OSPF route map will first tag the routes from the earp router, 172.16.10.3, with a tag of 3. Next, the rou will tag all other routes with a tag of 500 while making these routes OSPF external type 1 routes. [E-222](#) lists the configuration to accomplish this on the ringo router.

Example 2-22. Configuration of the ringo Router

```

hostname ringo

!
<<<text omitted>>>
!

router eigrp 65001

 redistribute bgp 65002

 network 172.16.0.0

 network 192.168.10.0

 default-metric 10000 1000 254 1 1500

 no auto-summary

 eigrp log-neighbor-changes

```

```
!  
  
router ospf 7  
  
log-adjacency-changes  
  
redistribute eigrp 65001 subnets route-map set_tag3 ←Redistribute and call route  
redistribute bgp 65002  
  
network 172.16.10.10 0.0.0.0 area 0  
  
default-metric 10  
  
!  
  
router bgp 65002  
  
no synchronization  
  
bgp log-neighbor-changes  
  
neighbor 172.16.200.10 remote-as 65001  
  
neighbor 172.16.200.10 ebgp-multihop 10  
  
neighbor 172.16.200.10 update-source Loopback20  
  
!  
  
access-list 5 permit 172.16.10.3 ←Match routes from 172.16.10.3  
access-list 50 permit any ←Match all routes  
  
!  
  
route-map set_tag3 permit 100  
  
match ip route-source 5 ←Match routes from 172.16.10.3  
set tag 3 ←Set the TAG value to 3  
  
!  
  
route-map set_tag3 permit 200  
  
match ip address 50 ←Match all other routes  
set metric-type type-1 ←Set the OSPF metric to External Type-1  
set tag 500 ←Set the TAG value to 500  
  
!
```

By observing the route table of the ringo router followed by the OSPF database, you can see the effects of the route maps, as shown in [Example 2-23](#).

Example 2-23. Route Map Effects on the ringo Router

```
ringo#show ip route
```

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

B 192.168.192.0/24 [20/0] via 172.16.200.10, 01:07:04
 172.16.0.0/16 is variably subnetted, 8 subnets, 2 masks

D 172.16.200.0/24 [90/1915392] via 172.16.10.3, 01:07:08, Ethernet0

D 172.16.33.0/24 [90/1812992] via 172.16.10.3, 01:07:08, Ethernet0

D 172.16.34.0/24 [90/1812992] via 172.16.10.3, 01:07:08, Ethernet0

D 172.16.16.4/30 [90/2195456] via 172.16.10.4, 01:07:08, Ethernet0

D 172.16.16.0/30 [90/1787392] via 172.16.10.3, 01:07:08, Ethernet0

C 172.16.10.0/24 is directly connected, Ethernet0

D 172.16.2.0/24 [90/284160] via 172.16.10.3, 01:07:09, Ethernet0

C 172.16.100.0/24 is directly connected, Loopback20

```
ringo#
```

```
ringo#show ip ospf database
```

OSPF Router with ID (172.16.100.10) (Process ID 7)

Router Link States (Area 0)

Link ID	ADV Router	Age	Seq#	Checksum	Link count
---------	------------	-----	------	----------	------------

```

172.16.10.5      172.16.10.5      1151        0x80000015 0x4E2      1
172.16.100.10    172.16.100.10    1875        0x80000003 0xC969     1

          Net Link States (Area 0)

Link ID          ADV Router       Age        Seq#        Checksum
172.16.10.5      172.16.10.5      1151        0x80000003 0x1693

          Type-5 AS External Link States

Link ID          ADV Router       Age        Seq#        Checksum Tag
172.16.2.0        172.16.100.10    1875        0x80000002 0x8E2E      3
172.16.16.0        172.16.100.10    1875        0x80000002 0xE1CF      3
172.16.16.4        172.16.100.10    1875        0x80000002 0x4AF0    500
172.16.33.0        172.16.100.10    1875        0x80000002 0x3865      3
172.16.34.0        172.16.100.10    1875        0x80000002 0x2D6F      3
172.16.100.0       172.16.100.10    1875        0x80000002 0xE403    500
172.16.200.0       172.16.100.10    1875        0x80000002 0x4F1      3
192.168.192.0      172.16.100.10    1876        0x80000002 0x4A22    65001

ringo#

```

Notice that at the end of the OSPF database is the BGP route 192.168.192.0/24. This route has a tag value of 65001 because BGP will try to preserve the AS_PATH attribute when redistributing BGP into an IGP. BGP supports tags. BGP will use a tag value equal to its autonomous system ID.

You can also see the effects of the route map on the clanton router. [Example 2-24](#) lists the route table for the clanton router, highlighting the different OSPF route types. Notice how the 172.16.16.4/30 and 172.16.100.0/24 routes are not set as default OSPF external type 2 routes, but are external type 1 routes. This is due to the set route-type type-1 command in the route map on the ringo router.

Example 2-24. Route Table of the clanton Router

```

clanton#show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
      D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area

```

```

N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
U - per-user static route, o - ODR

Gateway of last resort is not set

O E2 192.168.192.0/24 [110/10] via 172.16.10.10, 01:00:14, Ethernet0/0
    172.16.0.0/16 is variably subnetted, 8 subnets, 2 masks
O E2      172.16.200.0/24 [110/10] via 172.16.10.10, 01:00:14, Ethernet0/0
O E2      172.16.33.0/24 [110/10] via 172.16.10.10, 01:00:14, Ethernet0/0
O E2      172.16.34.0/24 [110/10] via 172.16.10.10, 01:00:14, Ethernet0/0
O E1      172.16.16.4/30 [110/20] via 172.16.10.10, 01:00:14, Ethernet0/0
O E2      172.16.16.0/30 [110/10] via 172.16.10.10, 01:00:14, Ethernet0/0
C        172.16.10.0/24 is directly connected, Ethernet0/0
O E2      172.16.2.0/24 [110/10] via 172.16.10.10, 01:00:15, Ethernet0/0
O E1      172.16.100.0/24 [110/20] via 172.16.10.10, 01:00:15, Ethernet0/0

```

clanton#

Route Maps and Policy-Based Routing

Sometimes in the modern internetwork, the forwarding decisions of a router need to be more complex than the decision information offered by the routing protocols and route table. Routers for the most part make their forwarding decisions on the destination address of packet. Policy-based routing enables the network engineer to configure policies that selectively cause packets to take paths that differ from the next-hop specified by the route table. This section discusses the benefits and configuration of policy-based routing.

Policy-based routing offers the following benefits:

- Forwarding decision not based on the destination address— Policy routing enables the network engineer to define a path based on attributes of a packet, source/destination IP address, application port, and packet lengths, and to forward them according to a different policy. Policy routing can be configured to set the packet's next hop or the packet's default next hop/interface. Policy routing can also be used to route the packet to the null interface, essentially discarding them.
- Quality of service (QoS)— Route maps and PBR can provide QoS by enabling you to set the ToS values and the IP precedence values in the IP header. QoS configuration is performed on the edge routers. This improves performance by preventing additional configuration on the core devices.

- Cost saving by using alternative paths— IP traffic can be manipulated with PBR, for instance traffic such as large bulky batch file transfers can be sent over low-cost, low-bandwidth links, while more time-sensitive, user-interactive traffic is sent over higher-cost and higher-speed links.
- Multiple and unequal path load sharing based on traffic characteristics— Policy routing is used to load balance traffic across multiple and unequal paths based on traffic characteristics such as the route cost.

Assuming that PBR is enabled and configured on the router and interface, PBR operates in the following manner:

Step 1. All packets *received* on a PBR-enabled interface are considered for policy routing. Each packet *received* on that interface is passed through an associated route map.

Step 2. The match commands are called by the route map; if all match commands are met, the route map is marked as a permit or deny, and no further route maps instances are executed. If a match statement is not present, the route map and any set commands apply to all packets.

Step 3. If the route map has a permit statement, all set commands are applied and the packet is forwarded according to the new policy. You can use multiple set commands in a single route map instance. [Table 2-7](#) lists the set commands that are specific to PBR. If you use multiple set commands in conjunction with one another, they are applied in the same order as follows:

```
set ip {precedence [value_0-7 | name] | tos [value_0-8 | name]}
set ip next-hop ip_address
set interface interface_name
set ip default next-hop ip_address
set default interface interface_name
```

Each of these commands is covered in further detail later in this section.

Step 4. If the route map has a deny statement, normal forwarding is used, as specified in the route/forwarding table. The set statements will not be applied to the packet.

Step 5. At the end of all the route map instances, an implicit route map will deny all packets. If a packet has not found a match in the previous route map instances, the packet will hit the implicit route map instance. When this occurs, the packet will be forwarded by the router following the route table.

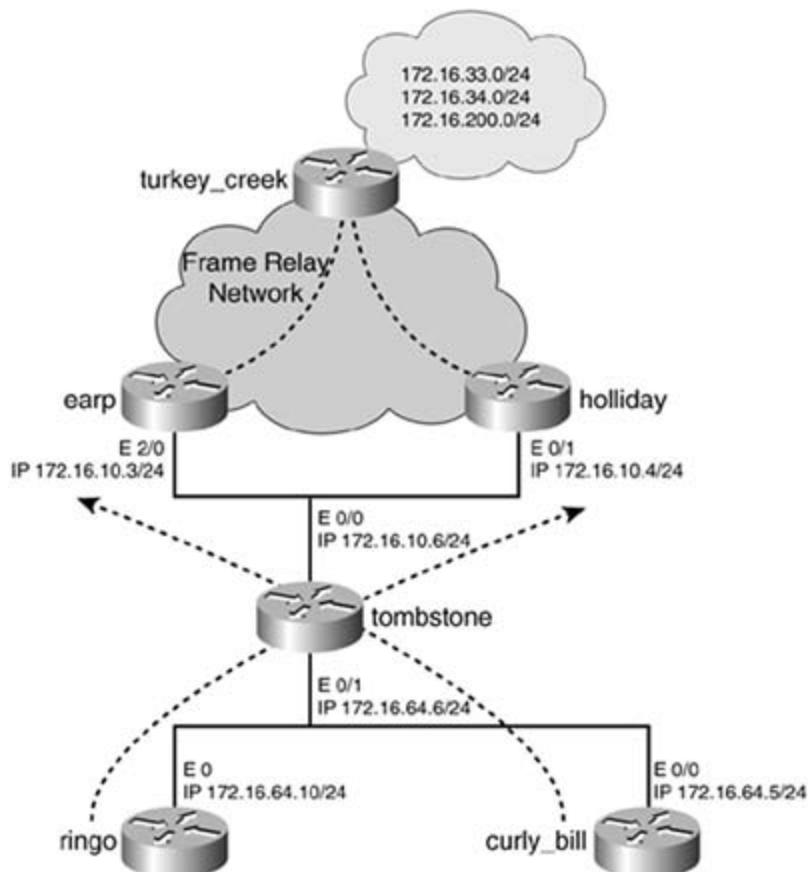
NOTE

Policy routing only works on inbound packets; therefore, it must be applied to the incoming traffic or to the interface receiving the traffic to be policy routed. To policy route local traffic, you must have local policy routing enabled.

Practical Example: Policy-Based Routing

This section examines how you may use policy routing to control traffic in the internetwork. In the model depicted in [Figure 2-9](#), a policy route exists on the tombstone router to control traffic from the ringo and curly_bill routers. The policy states that all IP traffic from the ringo router will be forwarded to the earp router, whereas all IP traffic from the curly_bill router will be forwarded to the holliday router. All other IP traffic will be handled by the normal routing procedure.

Figure 2-9. Policy-Based Routing



To control the traffic from the ringo and curly_bill routers, this example uses policy routing and route maps on the tombstone router. Policy routing will be enabled on the E0/1 interface of the tombstone router. This is the inbound interface, or the interface that will be receiving traffic from the ringo and curly_bill routers. The route map used in this model, policy_1, will have two route map instances. One will match packets from the ringo router, 172.16.64.10, and set the next hop to be 172.16.10.4, the holliday router. The other instance will match packets from the curly_bill router, 172.16.64.5, and set the next hop to be 172.16.33.0, the earp router.

map instance will match packets from the curly_bill router, 172.16.64.5, and set the next hop to be 172.16.10.3, the earp router.

The route/forwarding table on the tombstone router shows that there are two paths to the routes 172.16.33.0/24, 172.16.34.0/24, and 172.16.200.0/24 that reside on the turkey_creek router. One passes through the earp router, whereas the other one passes through the holliday router. [Example](#) lists the route table of the tombstone router.

Example 2-25. Route Table of the tombstone Router

```
tombstone#show ip route
```

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP

D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area

N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2

E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP

i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area

* - candidate default, U - per-user static route, o - ODR

P - periodic downloaded static route

Gateway of last resort is not set

172.16.0.0/16 is variably subnetted, 9 subnets, 2 masks

```
D      172.16.200.0/24 [90/40665600] via 172.16.10.3, 03:58:24, Ethernet0/0
                  [90/40665600] via 172.16.10.4, 03:58:24, Ethernet0/0
D      172.16.33.0/24 [90/40563200] via 172.16.10.3, 03:58:24, Ethernet0/0
                  [90/40563200] via 172.16.10.4, 03:58:24, Ethernet0/0
D      172.16.34.0/24 [90/40563200] via 172.16.10.3, 03:58:24, Ethernet0/0
                  [90/40563200] via 172.16.10.4, 03:58:24, Ethernet0/0
D      172.16.16.4/30 [90/40537600] via 172.16.10.4, 03:59:03, Ethernet0/0
D      172.16.16.0/30 [90/40537600] via 172.16.10.3, 04:56:26, Ethernet0/0
C      172.16.10.0/24 is directly connected, Ethernet0/0
D      172.16.2.0/24 [90/284160] via 172.16.10.3, 03:59:03, Ethernet0/0
D      172.16.100.0/24 [90/409600] via 172.16.64.10, 03:49:42, Ethernet0/1
C      172.16.64.0/24 is directly connected, Ethernet0/1
```

```
tombstone#
```

By issuing an extended traceroute command on the tombstone router from the address 172.16.6 to 172.16.200.10, you can see that EIGRP is using load sharing between the earp and holliday routers. Routing will override this process by sending IP traffic from the ringo router to holliday, and IP traffic curly_bill to earp, as shown in [Example 2-26](#).

Example 2-26. Extended Trace on the tombstone Router

```
tombstone#traceroute
```

```
Protocol [ip]:
```

```
Target IP address: 172.16.200.10
```

```
Source address: 172.16.64.6
```

```
Numeric display [n]:
```

```
Timeout in seconds [3]:
```

```
Probe count [3]: 4
```

```
Minimum Time to Live [1]:
```

```
Maximum Time to Live [30]:
```

```
Port Number [33434]:
```

```
Loose, Strict, Record, Timestamp, Verbose[none]:
```

```
Type escape sequence to abort.
```

```
Tracing the route to 172.16.200.10
```

```
1 172.16.10.4 0 msec
```

```
172.16.10.3 0 msec
```

```
172.16.10.4 0 msec
```

```
172.16.10.3 0 msec
```

```
2 172.16.16.5 8 msec
```

```
172.16.16.1 12 msec
```

```
172.16.16.5 8 msec
```

172.16.16.1 12 msec

tombstone#

The configuration needed for PBR on the tombstone router is listed in the next example, [Example 2](#).

Example 2-27. Policy-Based Routing Configuration on tombstone

```

route-map policy_1 permit 200
    ← next route map instance

    match ip address 101
        ← call ACL 101 for match crit

    set ip next-hop 172.16.10.3
        ← set IP next hop to the earp r

!

```

To test the new policy, issue the traceroute commands on the ringo and curly_bill routers to the IP of 172.16.200.10, which resides on the turkey_creek router. The traceroute from the ringo router shows that packets pass to the tombstone router, and then to holliday, and finally to turkey_creek. [Example 2-28](#) demonstrates the traceroute command on the ringo router with PBR enabled.

Example 2-28. traceroute Performed on the ringo Router

```

ringo#traceroute 172.16.200.10

Type escape sequence to abort.

Tracing the route to 172.16.200.10

 1 172.16.64.6 4 msec 4 msec 4 msec
 2 172.16.10.4 8 msec 4 msec 4 msec
 3 172.16.16.5 20 msec 8 msec *

ringo#

```

To test the new policy for the curly_bill router, issue the traceroute command on the curly_bill router with the IP address of 172.16.200.10. The packets will pass to the tombstone router, and then to earp, and finally to turkey_creek. [Example 2-29](#) demonstrates the traceroute command on the curly_bill router.

Example 2-29. traceroute Performed on the curly_bill Router

```

curly_bill#traceroute 172.16.200.10

Type escape sequence to abort.

Tracing the route to 172.16.200.10

 1 172.16.64.6 4 msec 4 msec 4 msec

```

```
2 172.16.10.3 4 msec 4 msec 0 msec
3 172.16.16.1 12 msec 9 msec *
curly_bill#
```

CAUTION

Whenever implementing policy routing, take care to consider the applications running on the network and the forward and return paths of the network traffic. In models such as this preceding example, you could implement policy routing on the turkey_creek router to avoid asymmetric routing. *Asymmetrical routing* refers to when IP packets are forwarded along one path toward a destination, but follow a different path back, which can lead to problems with some applications such as multicast.

Configuring Policy-Based Routing (PBR)

You can configure PBR by following these steps. Some of the steps may be omitted depending on your application for PBR.

Step 1. Define and configure the route map needed for the policy. This is accomplished with route-map command, as discussed previously.

Step 2. Define and configure the match statements the route map will use. The most common statements used are the following:

```
match ip address [access-list number]
```

The **match ip address** is used to call a standard, extended, or expanded-range ACL.

```
match length [min_packet_length_0-2147483647] [max_packet_length_0-2147483647]
```

The match length is used to match the Layer 3 packet length, in bytes, with all associated headers and trailers included. You must enter the minimum and maximum packet length. Use the match length command to policy route traffic based on packet size. You can deploy this to route traffic with large packet sizes to specific areas of the network.

Step 3. Configure and define the new routing policy with set commands. Multiple set commands can be used; if multiple commands are used, they are executed in the following order:

```
set ip {precedence [value_0-7 | name] | tos [value_0-8 | name]}

set ip next-hopip_address

set interfaceinterface_name

set ip default next-hopip_address

set default interfaceinterface_name

Set ip precedence {[1-7]|routine|critical|flash|flash-
override|immediate|internet|network|priority}
```

By setting the precedence, you are manipulating the first 3 bits, bits 0 through 2, of the 8-bit ToS field in the IP header. Earlier texts on TCP/IP state that this field is unused and ignored by routers, except for routing protocols. This may have been true in the past; however, with the advent of Voice over IP and newer QoS features, the Precedence field is finding new life and meaning. IP precedence becomes important during periods of congestion on an interface. By default, Cisco routers do not manipulate the precedence value in the IP header; it remains at its original setting as when it arrived at the router. When Weighted Fair Queuing (WFQ) is enabled and the precedence bits are set, the packets are ordered for transmission according to the precedence value. The higher the precedence value, the higher its place in the queue for transmission. For the router to act on precedence, the link must be congested, and queuing must be enabled; otherwise, the packets are transmitted in first in, first out (FIFO) order. When setting precedence, you may use the numeric value of the precedence or the name of the precedence. Precedence should be set such that downstream IP devices can take advantage of the settings you use. [Table 2-11](#) lists the various names and values for the set precedence command. For detailed information about the set precedence command, see [Chapter 5](#), "Integrated and Differentiated Services," and [Chapter 6](#), "QoS – Rate Limiting and Queuing Traffic."

Command	Function
routine	Set routine precedence (value = 0)
priority	Set priority precedence (value = 1)
immediate	Set immediate precedence (value = 2)
flash	Set Flash precedence (value = 3)
flash override	Set Flash override precedence (value = 4)
critical	Set critical precedence (value = 5)
internet	Set internetwork control precedence (value = 6)
network	Set network control precedence (value = 7)

NOTE

For a router's queuing mechanisms to act on the precedence bits, the following two conditions must be met:

- The outbound link must be congested.

The outbound link must be configured for WFQ or Weighted Random Early Detection (WRED).

```
set ip tos {[1-15] | [normal|min-delay|max-throughput|max-reliability|min-monetary-cost|priority]}
```

The `set ip tos` command enables you to set bits 3 through 6 in the IP header's 8-bit ToS field. These bits are composed of 4 bits. These bits are referred to as the following:

- D bit (bit 3)— Normal = off, low delay = on
- T bit (bit 4)— Normal = off, high throughput = on
- R bit (bit 5)— Normal = off, high reliability = on
- C bit (bit 6)— Unused in Cisco Routers. RFC 1349 calls it the *minimize monetary cost*. Some implementations ignore this bit or implement it differently.

Bit 7 in the ToS field is currently unused and is set to 0. If all 4 bits are set to 0, it implies normal service.

[Table 2-12](#) lists the recommended guidelines for setting ToS by protocol type.

Table 2-12. Recommended ToS Values by Protocol

Protocol	min-delay	max-throughput	max-reliability	min-monetary-cost
Telnet/Rlogin	1	0	0	0
HTTP	1	0	0	0
FTP control	1	0	0	0
FTP data	0	1	0	0
Any bulk data	0	1	0	0
TFTP	1	0	0	0
SMTP commands	1	0	0	0
SMTP data phase	0	1	0	0
DNS UDP query	1	0	0	0
DNS TCP query	0	0	0	0
DNS zone xfer	0	1	0	0
ICMP	0	0	0	0
IGPs	0	0	1	0
SNMP	0	0	1	0
BOOTP	0	0	0	0
NNTP	0	0	0	1

NOTE

Cisco IOS Software considers the precedence bits of the ToS field if there is traffic that is queued using WFQ, WRED, or Weighted Round Robin (WRR). The precedence bits are not considered when protocols such as routing, Priority Queuing (PQ), Custom Queuing (CQ), or Class-Based Weighted Fair Queuing (CBWFQ) are configured.

```
set ip next-hop {ip_address}
```

Use this command to set IP address of the next-hop router to which the packet will be forwarded. The address used must be an adjacent router.

```
set interface {interface_name}
```

Use this command to set the output interface for the matched packet.

```
set ip default next-hop {ip_address}
```

This command is used like the ip next-hop command. It specifies which IP address to forward packets to if there is not an explicit route to the destination in the route table. Think of this command as a default route for policy routing. The next-hop address must be an adjacent router.

```
set default interface {interface_name}
```

This command functions much like the ip default next-hop command; it specifies which interface to forward a matched packet to if there is not an explicit route to the destination. Used on point-to-point links.

NOTE

The `set ip next-hop` and `set ip default next-hop` commands are similar but function differently. The `set ip next-hop` command causes the router to use policy routing first and then use the route table. The `set ip default next-hop` command causes the router to use the route table first and then use the specified default next hop.

Step 4. (Optional) Define and configure any ACLs that will be used with the new routing policy. You can use standard or extended ACLs, for example, you can use policy to forward traffic based on traffic type (for instance, HTTP traffic one way, and FTP traffic another). You can also use ACLs to route traffic from specific source addresses. When you use standard ACLs, policy routing compares the source IP address in the packet to the ACL.

Step 5. Configure policy routing on the inbound interface. To configure policy routing for an interface, use the following interface command:

```
router(config-if)#ip policy route-map route-map_name
```

Step 6. (Optional) Enable fast switching for PBR. In Cisco IOS Software Release 12.0, PBR can only be processed in a process-switched environment. Prior to Cisco IOS Software Release 12.0, PBR could only be processed in a fast-switched environment. In a process-switched environment, the switching rate is approximately 1000 to 10,000 packets per second. This speed was not considered fast enough for many applications. You can enable fast switching of PBR with the following interface command:

```
router(config-if)#ip route-cache policy
```

PBR must be configured before you configure fast-switched PBR. Fast-switched PBR does not support the `set ip next-hop` and `set default-interface` commands. The `set interface` command is supported only over point-to-point links or with a static route cache entry equal to the interface specified in the `set interface` command.

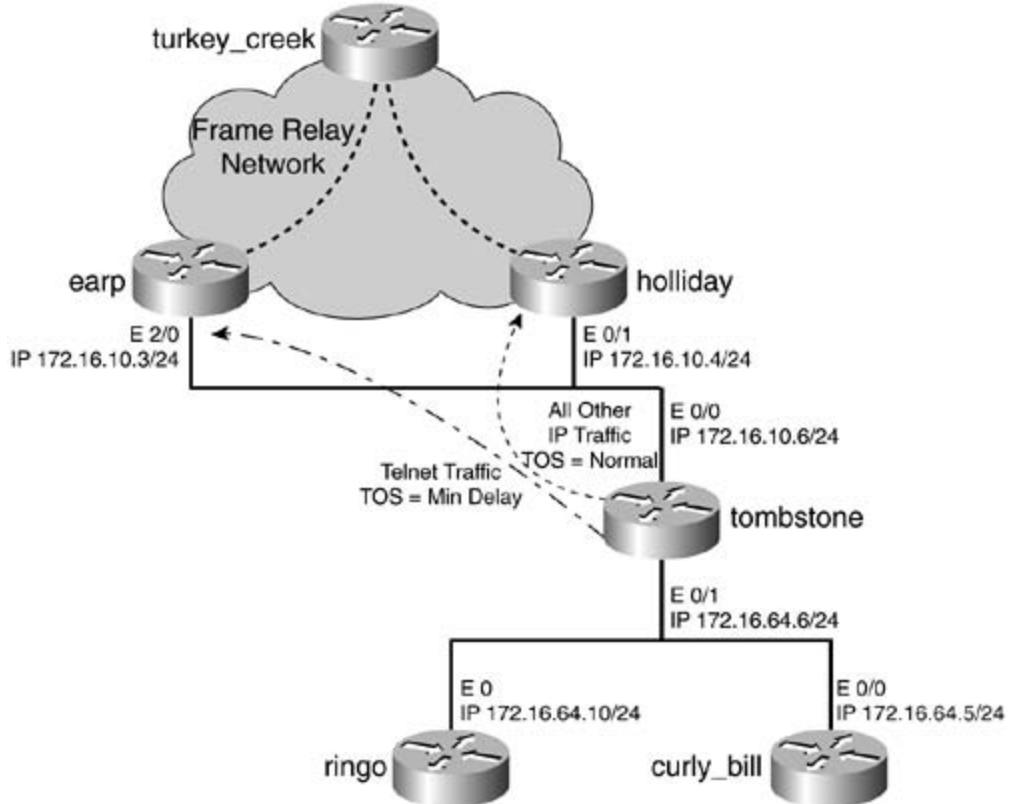
Step 7. (Optional) Configure local PBR. Packets generated by the router are not policy routes. If you want to policy route traffic generated by the router, you must enable it. To enable local PBR, enter the following global configuration command.

```
router(config)#ip local policy route-map route-map_name
```

Practical Example: Configuring PBR and Setting ToS

In this section, you apply a couple of these concepts to a practical example in policy routing. For the network depicted in [Figure 2-10](#), create a policy route that will forward Telnet traffic to the earp router, 172.16.10.3, while setting the ToS bit to minimum delay. All other IP traffic will be forwarded to the holliday router, 172.16.10.4.

Figure 2-10. Policy-Based Routing



Following the multistep process for configuring PBR, Steps 1 through 3 call for you to first configure a route map with the necessary match and set commands. The route map will call an ACL that matches Telnet traffic, and the set command will set the IP next hop to be the IP address of the earp router. [Step 12](#) specifies that Telnet traffic should have the ToS set to min-delay; therefore, the route map will set the bit for Telnet traffic in the ToS value to min-delay. Another route map instance will be used to match all other traffic and forward it to the holliday router. Because the route map instance will match all tra-

is no need to include a match command. [Example 2-30](#) lists the route map configuration on the tombstone router to accomplish this.

Example 2-30. Route Map Configuration on the tombstone Router

```
route-map policy_2 permit 100
  match ip address 101          ← Call access-list 101
  set ip next-hop 172.16.10.3   ← Set the next hop to 172.16.10.3/earp
  set ip tos min-delay         ← Set the TOS to min-delay
!
route-map policy_2 permit 200
  set ip next-hop 172.16.10.4   ← Match all routes and set the next hop
                                ← to 172.16.10.4/holliday
```

Now you must configure any ACLs the route map will need. In this case, configure a single ACL to route TCP telnet traffic from any IP address. The ACL you will use resembles the following:

```
access-list 101 permit tcp any any eq telnet
```

There is no need to write an ACL to catch all the regular traffic. As discussed earlier, the absence of a `any` statement, such as in the second route map instance, will match all routes or all packets.

The last two steps call for you to apply the policy route to an interface and to enable fast switching. This is accomplished with the interface commands `ip policy route-map` and `ip route-cache policy`. In this model, you will enable PBR on the E0/1 interface of the tombstone router. With PBR enabled on the E0/1 interface, all Telnet traffic will be forwarded to the earp router, whereas all other IP traffic will be forwarded to the holliday router. [Example 2-31](#) lists the complete PBR configuration of the tombstone router.

Example 2-31. PBR Configuration on the tombstone Router

```
hostname tombstone

!
interface Ethernet0/0
 ip address 172.16.10.6 255.255.255.0
!
interface Ethernet0/1
 ip address 172.16.64.6 255.255.255.0
 ip route-cache policy
 ip policy route-map policy_2
!
router eigrp 65001
 network 172.16.0.0
 no auto-summary
 no eigrp log-neighbor-changes
!
access-list 101 permit tcp any any eq telnet
!
priority-list 1 protocol ip high
priority-list 1 default low
!
route-map policy_2 permit 100
 match ip address 101
 set ip next-hop 172.16.10.3
 set ip tos min-delay
!
route-map policy_2 permit 200
 set ip next-hop 172.16.10.4
```

←enable PBR fast-switching
←Call route-map "policy_2" for PBR
←Match Telnet traffic
←Priority queuing for TOS enforcement
←call access-list 101 and match Telnet
←Set the next hop to earp/172.16.10.
←Set TOS min-delay bit
←Match all other traffic
←Set the next hop to holliday/172.16.

In this model, because you are setting ToS values, you need to configure WRED or WFQ on the output interface. WFQ is not the default queuing method on Ethernet interfaces. It is the default queuing method on serial interfaces with 2.048 Mbps or less of bandwidth. This portion of the configuration is not part of this example. For more information on configuring WRED and WFQ, see [Chapters 5](#) and [6](#).

Big Show for Route Maps

CCIE Practical Studies, Volume 1 introduced what was called the *Big Show* and *Big D*. These terms were used because the discussion focused on only a select few show and debug commands considered most useful.

The Big Show and Big D commands for route maps are rather limited in their use. The best way to understand the functionality of route maps and policy routing is to actually see how they are performing by viewing the route table and using traceroute commands. The show commands offered by Cisco are very good at showing where the route map is applied and the logical order in which it is operated. The Big Show commands discussed here are as follows:

- show route-map
- show ip policy
- show ip cache policy

The `show route-map` command enables you to determine the logical order and execution of the route map. If PBR is enabled, the command also shows the number of matches and the number of bytes that were processed by the policy. Working from the previous network models, [Example 2-32](#) demonstrates the `show route-map` command on the tombstone router.

Example 2-32. `show route-map` Command on the tombstone Router

```
tombstone#show route-map

route-map policy_2, permit, sequence 100
  Match clauses:
    ip address (access-lists): 101
  Set clauses:
    ip next-hop 172.16.10.3
    ip tos min-delay
  Policy routing matches: 264 packets, 15852 bytes

route-map policy_2, permit, sequence 200
```

```
Match clauses:  
  
Set clauses:  
  
    ip next-hop 172.16.10.4  
  
Policy routing matches: 60 packets, 4478 bytes  
  
route-map policy_1, permit, sequence 100  
  
Match clauses:  
  
    ip address (access-lists): 100  
  
Set clauses:  
  
    ip next-hop 172.16.10.4  
  
    ip tos max-throughput  
  
Policy routing matches: 85 packets, 6880 bytes  
  
route-map policy_1, permit, sequence 200  
  
Match clauses:  
  
    ip address (access-lists): 101  
  
Set clauses:  
  
    ip next-hop 172.16.10.3  
  
Policy routing matches: 43 packets, 3318 bytes  
  
tombstone#
```

Use the `show ip policy` command to verify which interfaces have PBR enabled and which route maps are currently using for PBR. [Example 2-33](#) demonstrates the `show ip policy` command on the tombstone router.

Example 2-33. `show ip policy` Command on the tombstone Router

```
tombstone#show ip policy  
  
Interface      Route map  
  
Ethernet0/1    policy_2
```

You can use the show ip cache policy command to verify whether fast switching is enabled for pc routing. This command shows the policy type, the route map in use, and the age of the cache entry. If the policy is a next-hop policy, the next hop also displays. [Example 2-34](#) lists the output of the show ip cache policy command on the tombstone router.

Example 2-34. show ip cache policy Command on the tombstone Router

```
tombstone#show ip cache policy

Total adds 4, total deletes 2

Type Routemap/sequence      Age          Interface      Next Hop
NH   policy_2/100           00:38:27    Ethernet0/0    172.16.10.3
NH   policy_2/200           00:43:56    Ethernet0/0    172.16.10.4

tombstone#
```

Lab 3: Configuring Complex Route Maps and Using Tags—Part I

Practical Scenario

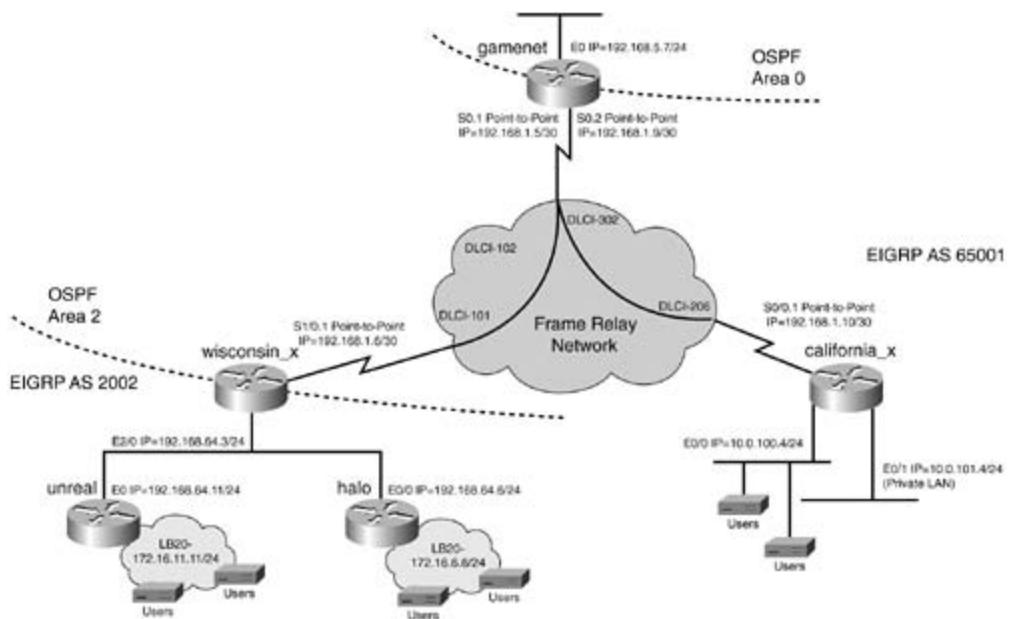
Route maps are one of most powerful features you can use on a router. You can use them during redistribution, in PBR, in BGP, and in many other scenarios. This lab gives you practice in configuring complex route maps that will be used during redistribution. You then practice setting and using route tags.

Lab Exercise

GameNetworks.com is an upstart company focusing on providing WAN and LAN connectivity for console games. GameNetworks.com enables its customers to play the latest and greatest console games online through its private network. GameNetworks.com has two new locations in Wisconsin and California. Your task is to configure an IP network using the following strict design guidelines:

- Configure the GameNetworks.com IP network as depicted in [Figure 2-11](#). Use EIGRP as the routing protocol and 2002 as the autonomous system ID on the wisconsin_x, unreal, and halo routers. Use EIGRP as the routing protocol on the california_x router and the gamenet router; the autonomous system of this router will be 65001.

Figure 2-11. GameNetworks.com



- Join the EIGRP routing domains with OSPF on the gamenet and wisconsin_x routers.
- Configure the Frame Relay network as depicted in [Figure 2-11](#).
- Configure all IP addresses as depicted in [Figure 2-11](#).
- Use the "[Lab Objectives](#)" section for configuration specifics.

Lab Objectives

- Configure the routing protocols as depicted in [Figure 2-11](#). The only interface on wisconsin_x broadcasting EIGRP updates should be the LAN interface.
- Configure OSPF on the wisconsin_x and gamenet routers. The serial interface of wisconsin_x will be in OSPF area 2. The serial s0.1 interface of the gamenet router is in OSPF area 2, and the LAN interface is in OSPF area 0.
- The s0.2 interface of the gamenet router will be configured for EIGRP, using AS 65001. All interfaces of the california_x router will be in the EIGRP domain.
- Configure a loopback interface on the unreal router with an IP address of 172.16.11.11/24, and on the halo router with an address of 172.16.6.6/24. Advertise these networks via EIGRP.
- Assign a tag value of 100 to all routes future and present advertised by the halo router. This includes all locally connected and LAN networks. In the future, other networks may be added to the halo router; ensure that these networks get a tag of 100, too.
- After a route is tagged with the value of 100, ensure that the tag value is preserved in the routing domain for EIGRP 65001.
- Routes advertised only by the halo router, and no other router, should appear as OSPF type 1 routes when they arrive on the gamenet router.
- Assign an OSPF tag value of 10 to the network 172.16.11.0/24 from the unreal router.
- When redistributing OSPF into EIGRP 65001 on the gamenet router, only redistribute those routes with a tag value of 100. The california_x router should be able to ping the halo network of 172.16.6.0/24, but not the network 172.16.11.0/24 on the unreal router.
- Do not allow the private LAN 10.0.101.0/24, on california_x, to be redistributed into the OSPF routing domain.

Equipment Needed

- Six Cisco routers; three will be connected via V.35 back-to-back cable or similar fashion to a single router serving as the Frame Relay switch.
- Four LAN segments, provided via hubs or switches. The figure shows the california_x router with two LAN interfaces; one of these interfaces may be substituted with a loopback interface.

Physical Layout and Prestaging

- Connect the hubs and serial cables to the routers as shown in [Figure 2-11](#).
- A Frame Relay switch with two PVCs is also required. [Example 2-35](#) lists the Frame Relay configuration used in this lab.

Example 2-35. Frame Relay Switch Configuration

```
hostname frame_switch
!
frame-relay switching
!
interface Serial0
no ip address
encapsulation frame-relay
no fair-queue
clockrate 2000000
frame-relay intf-type dce
frame-relay route 102 interface Serial1 101
frame-relay route 302 interface Serial4 206
!
interface Serial1
no ip address
encapsulation frame-relay
clockrate 2000000
frame-relay intf-type dce
frame-relay route 101 interface Serial0 102
!
<<<text omitted>>>
```

```
!  
  
interface Serial4  
  
no ip address  
  
encapsulation frame-relay  
  
clockrate 64000  
  
frame-relay intf-type dce  
  
frame-relay route 206 interface Serial0 302
```

Lab 3: Configuring Complex Route Maps and Using Tags—Part II

Lab Walkthrough

Configure the Frame Relay switch and attach the three routers in a back-to-back fashion to the frame relay switch. Use V.35 cables to connect the routers. Create the four Ethernet LANs by the use of switches and hubs, as illustrated in [Figure 2-11](#).

After the physical connections are complete, assign IP addresses to all LAN and WAN interfaces as depicted in [Figure 2-11](#). Configure a Frame Relay point-to-point network between the gamenet and wisconsin_x routers and between the gamenet and california_x routers. Use the data-link connection identifiers (DLCIs) from the diagram. [Example 2-36](#) lists the Frame Relay configuration of the gamenet, wisconsin_x, and california_x routers.

Example 2-36. Frame Relay Configurations for gamenet, wisconsin_x and california_x

```
hostname gamenet

!
interface Serial0
  no ip address
  no ip directed-broadcast
  encapsulation frame-relay
  no ip mroute-cache
  frame-relay lmi-type cisco
!
interface Serial0.1 point-to-point
  ip address 192.168.1.5 255.255.255.252
  no ip directed-broadcast
  frame-relay interface-dlci 102
!
interface Serial0.2 point-to-point
```

```
ip address 192.168.1.9 255.255.255.252
no ip directed-broadcast
frame-relay interface-dlci 302
```

```
hostname wisconsin_x
!
interface Serial1/0
no ip address
encapsulation frame-relay
frame-relay lmi-type cisco
!
interface Serial1/0.1 point-to-point
ip address 192.168.1.6 255.255.255.252
frame-relay interface-dlci 101
```

```
hostname california_x
!
interface Serial0/0
no ip address
no ip directed-broadcast
encapsulation frame-relay
!
interface Serial0/0.1 point-to-point
ip address 192.168.1.10 255.255.255.252
frame-relay interface-dlci 206
```

After configuring all the LAN and WAN interfaces, assign IP addresses and verify local connectivity. routers should be able to ping their adjacent routers. For instance, unreal, wisconsin_x, and halo should all be able to ping the others' Ethernet address. When local connectivity is verified, you can begin to configure routing protocols.

Before attempting to control routing updates and writing route maps, confirm that you have IP connectivity across the network, redistributing all routes freely without filters. By so confirming, yo can avoid troubleshooting route maps when the problem may be related to route redistribution or problems with the routing protocols.

Begin by configuring the EIGRP domain between the wisconsin_x, unreal, and halo routers. The configuration of EIGRP on these three routers is rather straightforward. On the wisconsin_x router, need a network statement and a default-metric because you need to redistribute OSPF into EIGP. [Example 2-37](#) lists the EIGRP configuration of the wisconsin_x router.

Example 2-37. EI GRP Configuration for wisonsin_x

```
hostname wisconsin_x
!
router eigrp 2002
 redistribute ospf 2002
 network 192.168.64.0
 default-metric 1000 100 254 1 1500
 no auto-summary
```

The EIGRP configuration on the unreal and halo routers will be identical. In [Example 2-38](#), the EIG configuration demonstrates the two ways to configure the network for EIGRP. In Cisco IOS Software Release 12.1, EIGRP supports a wildcard mask with the network statement. Network 172.16.11.0 using this method of configuration, and this example is following the standard way to configure EIG for the 192 networks. This is done purely for educational proposes.

Example 2-38. EI GRP Configuration of the unreal and halo Routers

```
!
hostname unreal
!
router eigrp 2002
```

```
network 172.16.11.0 0.0.0.255  
network 192.168.64.0  
no auto-summary  
eigrp log-neighbor-changes  
!
```

```
hostname halo  
!  
router eigrp 2002  
network 172.16.6.0 0.0.0.255  
network 192.168.64.0  
no auto-summary  
eigrp log-neighbor-changes
```

Then you configure OSPF and EIGRP on the gamenet router. The autonomous system ID used for EIGRP is 65001. The only interface sending EIGRP updates is interface s0.2, 192.168.1.9. The interface S0.1 is in OSPF area 2, and interface E0 is in OSPF area 0. [Example 2-39](#) lists the OSPF and EIGRP configuration on the gamenet router. At this time, no route maps have been configured on any router.

Example 2-39. EIGRP and OSPF Configuration of gamenet

```
hostname gamenet  
!  
router eigrp 65001  
redistribute ospf 2002  
passive-interface Ethernet0  
passive-interface Serial0.1  
network 192.168.1.0  
default-metric 1000 100 254 1 1500
```

```
no auto-summary

!
router ospf 2002
 redistribute eigrp 65001 subnets
 network 192.168.1.5 0.0.0.0 area 2
 network 192.168.5.0 0.0.0.255 area 0
 default-metric 100
!
```

The `california_x` router will be configured for EIGRP with an autonomous system ID of 65001. [Example 2-40](#) lists the EIGRP configuration of the `california_x` router.

Example 2-40. EIGRP Configuration of the `california_x` Router

```
hostname califorニア_x
!
router eigrp 65001
 network 10.0.0.0
 network 192.168.1.0
 no auto-summary
!
```

After configuring routing protocols on all the routers, verify IP connectivity with standard ping tests to ensure the `california_x` router can ping the `gamenet` LAN and the `halo` and `unreal` routers. Ensure that the loopback networks are advertised and reachable by the `unreal` and `halo` routers. Do not attempt to write route maps for filters and such without first verifying IP reachability.

The lab instructions call for you to write a route map to tag the routes from the `halo` router with a tag of 100, and to tag the routes from the `unreal` router with a tag of 10. You will also tag route 192.168.64.0/24 with a tag of 100. Therefore, on the `wisconsin_x` router, you will write a route map to accomplish this during redistribution.

Following the five-step process for configuring route maps, you will begin by first configuring the route map with its associated match and set commands. The route map, called `set_tag`, will match routes

using the `match ip route-source` command. Routes from the source IP address of 192.168.64.11 unreal router, will have the tag set to 10. Routes from the source IP address of 192.168.64.6, the I router, will have the tag set to 100. Routes from this source will also have the metric set to be an C type 1 metric. [Example 2-41](#) lists the syntax for the route map on the wisconsin_x router.

Example 2-41. Route-map set_tag Configuration on the wisconsin_x Router

```
hostname wisconsin_x

!
route-map set_tag permit 10      ←First route-map instance
  match ip route-source 1       ←Match ACL 1, 192.168.64.11
    set tag 10                  ←Set tag to 10
!
route-map set_tag permit 20      ←Second route-map instance
  match ip route-source 2       ←Match ACL 2, 192.168.64.6
    set metric-type type-1     ←Set route type to Ext OSPF type-1
    set tag 100                 ←Set tag to 100
!
route-map set_tag permit 30      ←Third route-map instance
  match ip address 10          ←Match ACL 10, all other routes
    set tag 100                 ←Set tag to 100
!
```

This now completes Steps 1 through 3 required to configure route maps. Now you apply the route maps. In this model, you apply the route map during redistribution of EIGRP into OSPF on the wisconsin_x router. [Example 2-42](#) lists the complete configuration of the wisconsin_x router, including the ACLs.

Example 2-42. Configuration of the wisconsin_x Router

```
hostname wisconsin_x
```

```
!  
<<<text omitted>>>  
!  
interface Serial0  
no ip address  
no ip directed-broadcast  
encapsulation frame-relay  
no ip mroute-cache  
frame-relay lmi-type cisco  
!  
interface Serial1/0.1 point-to-point  
ip address 192.168.1.6 255.255.255.252  
frame-relay interface-dlci 101  
!  
<<<text omitted>>>  
!  
interface Ethernet2/0  
ip address 192.168.64.3 255.255.255.0  
!  
router eigrp 2002  
redistribute ospf 2002 ← redistribute OSPF  
network 192.168.64.0  
default-metric 1000 100 254 1 1500 ← default metric  
no auto-summary  
!  
router ospf 2002  
redistribute eigrp 2002 subnets route-map set_tag ← Redistribute and call route-  
network 192.168.1.6 0.0.0.0 area 2
```

```
default-metric 10                                     ← default metric

!
access-list 1 permit 192.168.64.11                  ← match routes from 192.168.64

access-list 2 permit 192.168.64.6                   ← match routes from 192.168.64

access-list 10 permit any                           ← match all other routes/192.168.

!
route-map set_tag permit 10                         ← route-map "set_tag" begins

    match ip route-source 1

    set tag 10

!
route-map set_tag permit 20

    match ip route-source 2

    set metric-type type-1

    set tag 100

!
route-map set_tag permit 30

    match ip address 10

    set tag 100
```

Another requirement of this model is to only redistribute routes, on the gamenet router, into EGIRF 65001 from OSPF with a tag value of 100, and to preserve this tag. You can do this by creating and applying a route map to the redistribution process that matches only routes with a tag of 100. You use the `match tag` command for this purpose. Example 2-43 lists the required route map.

Example 2-43. Route Map match_tag100 on the gamenet Router

```
hostname gamenet

!
route-map match_tag100 permit 10      ← begin route-map "match_tag100"
    match tag 100                   ← match the tag value of 100
```

```
set tag 100           ←set the tag for EIGRP.  
!  
!
```

The route map will be applied during redistribution from OSPF into EIGRP. Before you apply this route map, however, configure the last route map needed in the model.

The last requirement is to also prevent the private LAN, 10.0.101.0/24, from being redistributed into OSPF from EIGRP on the gamenet router. You can prevent this with a route map applied during redistribution. The route map used to filter this subnet will call an ACL that matches network 10.0.101.0/24. [Example 2-44](#) lists the route map, called filter_net, used to filter network 10.0.101.0/24 and the associated ACL.

Example 2-44. Route Map filter_net on the gamenet Router

```
hostname gamenet  
!  
access-list 10 deny 10.0.101.0 0.0.0.255 ←deny network 10.0.101.0/24  
access-list 10 permit any ←Allow other networks to be redistributed  
route-map filter_net permit 10 ←begin route-map "filter_net"  
    match ip address 10 ←Match ACL 10
```

At this time, you can apply both route maps during the redistribution process. [Example 2-45](#) lists the final configuration of the gamenet router.

Example 2-45. Final Configuration of the gamenet Router

```
hostname gamenet  
!  
interface Ethernet0  
ip address 192.168.5.7 255.255.255.0  
no ip directed-broadcast  
media-type 10BaseT
```

```
!  
<<<text omitted>>>  
!  
interface Serial0  
  no ip address  
  no ip directed-broadcast  
  encapsulation frame-relay  
  no ip mroute-cache  
  frame-relay lmi-type cisco  
!  
interface Serial0.1 point-to-point  
  ip address 192.168.1.5 255.255.255.252  
  no ip directed-broadcast  
  frame-relay interface-dlci 102  
!  
interface Serial0.2 point-to-point  
  ip address 192.168.1.9 255.255.255.252  
  no ip directed-broadcast  
  frame-relay interface-dlci 302  
!  
router eigrp 65001  
  redistribute ospf 2002 route-map match_tag100      ←call route-map "match_tag100  
  passive-interface Ethernet0  
  passive-interface Serial0.1  
  network 192.168.1.0  
  default-metric 1000 100 254 1 1500      ←set default metric  
  no auto-summary  
!
```

```

router ospf 2002

 redistribute eigrp 65001 subnets route-map filter_net ←call route-map "filter_n
network 192.168.1.5 0.0.0.0 area 2
network 192.168.5.0 0.0.0.255 area 0
default-metric 100 ←set default metric
!
access-list 10 deny 10.0.101.0 0.0.0.255
access-list 10 permit any
route-map filter_net permit 10
match ip address 10
!
route-map match_tag100 permit 10
match tag 100
set tag 100

```

To verify the configuration, ensure that the `california_x` router sees only the routes with a tag of 10 and that it can ping the 172.16.6.0/24 subnet but not the 172.16.11.0/24 subnet. [Example 2-46](#) demonstrates the route table and the ping test on the `california_x` router.

Example 2-46. Verifying the Configuration on `california_x`

```

california_x#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
        D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
        N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
        E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
        i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
        U - per-user static route, o - ODR
Gateway of last resort is not set

```

```
172.16.0.0/24 is subnetted, 1 subnets
D EX      172.16.6.0 [170/3097600] via 192.168.1.9, 02:47:46, Serial0/0.1
D EX 192.168.64.0/24 [170/3097600] via 192.168.1.9, 02:48:50, Serial0/0.1
    10.0.0.0/24 is subnetted, 2 subnets
C       10.0.100.0 is directly connected, Ethernet0/0
C       10.0.101.0 is directly connected, Ethernet0/1
    192.168.1.0/30 is subnetted, 2 subnets
C       192.168.1.8 is directly connected, Serial0/0.1
D       192.168.1.4 [90/2681856] via 192.168.1.9, 02:58:26, Serial0/0.1
california_x#
california_x#show ip route 172.16.6.0
Routing entry for 172.16.6.0/24
    Known via "eigrp 65001", distance 170, metric 3097600
    Tag 100, type external
    Redistributing via eigrp 65001
    Last update from 192.168.1.9 on Serial0/0.1, 02:48:18 ago
    Routing Descriptor Blocks:
        * 192.168.1.9, from 192.168.1.9, 02:48:18 ago, via Serial0/0.1
            Route metric is 3097600, traffic share count is 1
            Total delay is 21000 microseconds, minimum bandwidth is 1000 Kbit
            Reliability 254/255, minimum MTU 1500 bytes
            Loading 1/255, Hops 1
california_x#
california_x#ping 172.16.6.6
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.6, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/34/36 ms
```

```
california_x#ping 172.16.11.11
Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 172.16.11.11, timeout is 2 seconds:
.....Success rate is 0 percent (0/5)

california_x#
```

To verify that the private subnet, 10.0.101.0/24, is filtered from OSPF, you can view the route table on the wisconsin_x router, as demonstrated in [Example 2-47](#).

Example 2-47. Final Route Table of the wisconsin_x Router

```
wisconsin_x#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
        D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
        N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
        E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
        i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
        * - candidate default, U - per-user static route, o - ODR
        P - periodic downloaded static route

Gateway of last resort is not set

172.16.0.0/24 is subnetted, 2 subnets
D      172.16.11.0 [90/409600] via 192.168.64.11, 03:00:27, Ethernet2/0
D      172.16.6.0 [90/409600] via 192.168.64.6, 03:00:27, Ethernet2/0
C      192.168.64.0/24 is directly connected, Ethernet2/0
O IA 192.168.5.0/24 [110/58] via 192.168.1.5, 03:01:39, Serial1/0.1
        10.0.0.0/24 is subnetted, 1 subnets
O E2    10.0.100.0 [110/100] via 192.168.1.5, 03:01:03, Serial1/0.1
        192.168.1.0/30 is subnetted, 2 subnets
```

O E2 192.168.1.8 [110/100] via 192.168.1.5, 03:01:44, Serial1/0.1

C 192.168.1.4 is directly connected, Serial1/0.1

wisconsin_x#

Lab 4: Configuring Policy-Based Routing—Part I

Practical Scenario

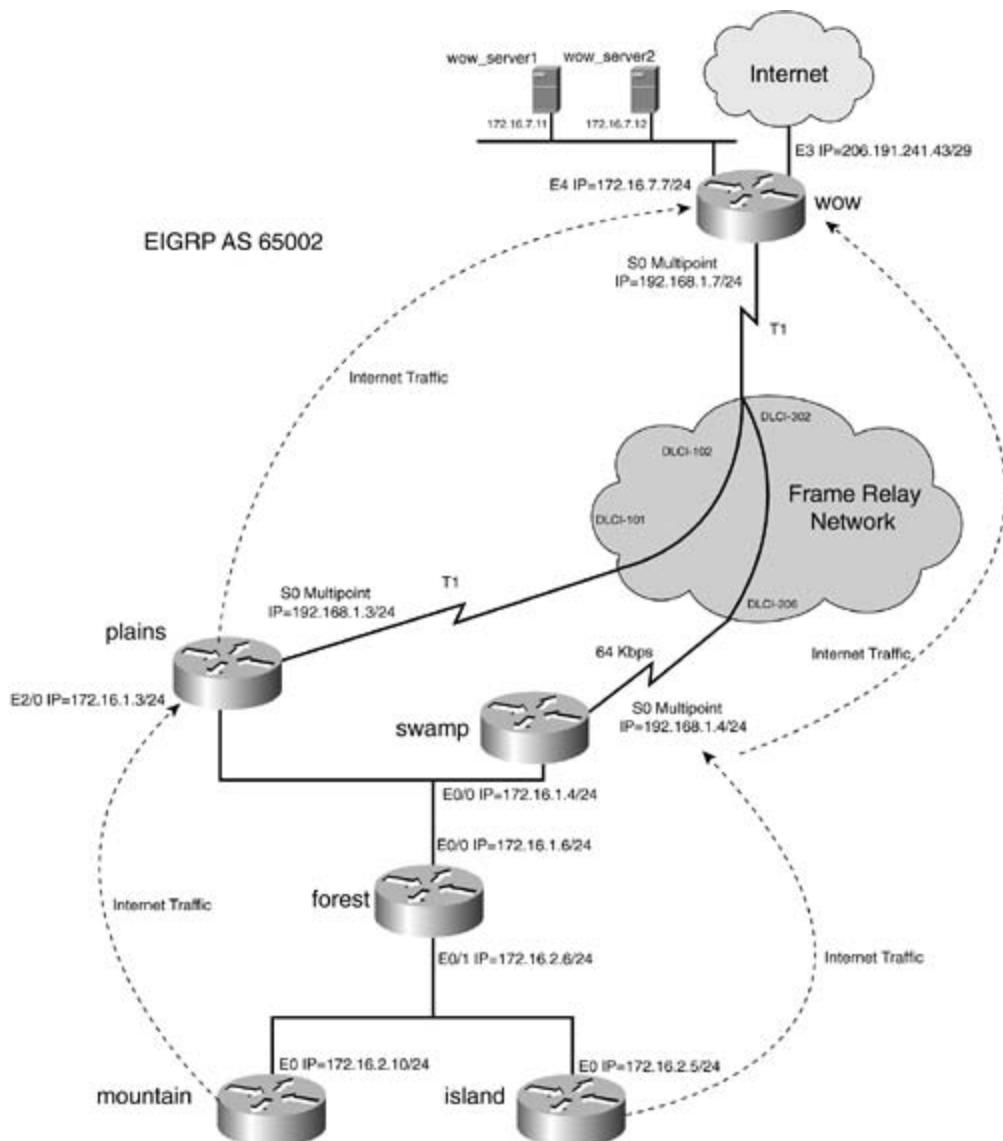
Route maps are also used for PBR. You can use PBR to force traffic to paths that are different from the ones in the normal forwarding/route table. You can use PBR to control traffic based on ToS, packet size and type, and source address, among others. This lab gives you practice in configuring complex PBR route maps using packet size and in controlling default routes.

Lab Exercise

Wizards of the Woods is the leading manufacturer of fantasy card games, fantasy role-playing games, and computer games. Wizards of the Woods has organized its divisions by geographic locations. To each division, there are two Frame Relay PVCs from the headquarters router, called the wow router. One PVC operates at T1 speeds; this runs between the wow and plains router. The other is a low-speed PVC, 64 kbps, between the wow and swamp router. The wow router also provides Internet service to the division. Wizards want to control and streamline traffic through the WAN and to the wow servers by using PBR. Your task is to configure an IP network and PBR using the following strict design guidelines:

- Configure the Wizards of the Woods IP network as depicted in [Figure 2-12](#). Use EIGRP as the routing protocol and 65002 as the autonomous system ID on all routers.

Figure 2-12. Wizards of the Woods



- Configure the Frame Relay network as depicted in [Figure 2-12](#).
- Configure all IP addresses as depicted in [Figure 2-12](#).
- Use the "[Lab Objectives](#)" section for configuration specifics.

Lab Objectives

- Configure EIGRP as the routing protocol, as depicted in [Figure 2-12](#). Use 65002 as the autonomous system ID.
- Configure EIGRP such that the routing protocol will prefer the higher-bandwidth link between the plains and wow routers over the swamp and wow routers for traffic that comes from the forest router. EIGRP should prefer this path when routing traffic for the forest, mountain, and island routers. (Hint: Set the bandwidth properly on the serial interfaces.)

- The testing and functionality of this lab will be greatly enhanced if there is an available connection to the Internet. The wow router will be configured to advertise a default route for Internet traffic. If an Internet connection is not available, you may simulate it with a loopback address or another router.
- Configure PBR using the following guidelines:
 - IP traffic from the mountain and island routers with a small packet size, 0 to 1199 bytes, destined for the wow servers should use the high-speed link between the plains and the wow routers.
 - IP traffic from the mountain and island routers with a large packet size, 1200 to 1544 bytes, destined for the wow servers should use the low-speed link between the swamp and wow routers.
 - Internet traffic from the mountain router should use the high-speed link through the plains router.
 - Internet traffic from the island router should use the low-speed link through the swamp router.
 - Configure fast switching for PBR.
 - For the purposes of the lab, do not worry about the return route of the traffic. EIGRP will load share for return traffic.
- (Optional) If you have access to the Internet, enhance the lab and your practice by making this model as close as you can to the real thing. Configure NAT on the wow router, such that all routers including the mountain and island routers can reach the Internet.

Equipment Needed

- Seven Cisco routers; three will be connected via V.35 back-to-back cable or a similar fashion to a single router serving as the Frame Relay switch.
- Four LAN segments, provided via hubs or switches. [Figure 2-12](#) shows the wow router with two LAN interfaces; one of these interfaces may be substituted with a loopback interface or another router to simulate the Internet, if a real Internet connection is not available.
- You may want to use IP workstations or servers to simulate response for the wow servers.

Physical Layout and Prestaging

- Connect the hubs and serial cables to the routers as shown in [Figure 2-12](#).
- A Frame Relay switch with two PVCs is also required. [Example 2-48](#) lists the Frame Relay configuration used in this lab.

Example 2-48. Frame Relay Switch Configuration

```
hostname frame_switch
!
frame-relay switching
!
interface Serial0
no ip address
encapsulation frame-relay
no fair-queue
clockrate 2000000
frame-relay intf-type dce
frame-relay route 102 interface Serial1 101
frame-relay route 302 interface Serial4 206
!
interface Serial1
no ip address
encapsulation frame-relay
clockrate 2000000
frame-relay intf-type dce
frame-relay route 101 interface Serial0 102
!
<<<text omitted>>>
!
interface Serial4
no ip address
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 206 interface Serial0 302
```


Lab 4: Configuring Policy-Based Routing—Part II

Lab Walkthrough

Configure the Frame Relay switch and attach the three routers in a back-to-back fashion to the Frame Relay switch. Use V.35 cables to connect the routers. Create the four Ethernet LANs by the use of switches or hubs, as illustrated in [Figure 2-12](#).

After the physical connections are complete, assign IP addresses to all LAN and WAN interfaces as depicted in [Figure 2-12](#). Configure a Frame Relay network as a single multipoint network between the routers on the WAN. Use the DLCIs from the diagram. Because the Frame Relay network is a multipoint, keep in mind that you will need to disable EIGRP split horizon at some point. At this time you will also want to set the bandwidth statements so that EIGRP chooses the best possible path through the network. [Example 2-49](#) lists the Frame Relay configuration of all the routers.

Example 2-49. Frame Relay Configurations for the wow, plains, and swamp Routers

```
hostname wow
!
interface Serial0
bandwidth 1544                                ←BW for EIGRP
ip address 192.168.1.7 255.255.255.0
encapsulation frame-relay
no ip split-horizon eigrp 65002                ←used to disable split-horiz
no ip mroute-cache
frame-relay map ip 192.168.1.3 102 broadcast   ←Map statement to plains
frame-relay map ip 192.168.1.4 302 broadcast    ←Map statement to swamp
frame-relay lmi-type cisco
!


---


hostname plains
!
```

```

interface Serial1/0

bandwidth 1544                                ←BW for EIGRP

ip address 192.168.1.3 255.255.255.0

encapsulation frame-relay

frame-relay map ip 192.168.1.4 101 broadcast   ←Map statement to swamp

frame-relay map ip 192.168.1.7 101 broadcast   ←Map statement to wow

frame-relay lmi-type cisco

!

```

```

hostname swamp

!

interface Serial0/0

bandwidth 64                                    ←BW for EIGRP

ip address 192.168.1.4 255.255.255.0

encapsulation frame-relay

no ip mroute-cache

frame-relay map ip 192.168.1.3 206 broadcast   ←Map statement to plains

frame-relay map ip 192.168.1.7 206 broadcast   ←Map statement to wow

frame-relay lmi-type cisco

!

```

After configuring all the LAN and WAN interfaces, assign IP addresses and verify local connectivity. routers should be able to ping their adjacent routers. For instance, plains, swamp, and forest shoul all be able to ping the others' Ethernet address. When local connectivity is verified, you can begin t configure routing protocols.

Begin by configuring the EIGRP domain between all the routers, starting with the wow router. On t wow router, you need two network statements, one for network 172.16.0.0 and one for 192.168.1. This router also needs to generate a default route for Internet traffic. To generate a default route, configure a default static route to the address 206.191.241.41 with the command ip route 0.0.0.0 0.0.0.0 206.191.241.41. For the wow router to advertise this route, it needs to be redistributed i EIGRP.[Example 2-50](#) lists the configuration of EIGRP on the wow router.

Example 2-50. EIGRP Configuration for wisonsin_x

```
hostname wow

!
router eigrp 65002
    redistribute static           ← redistribute the default route
    network 172.16.0.0
    network 192.168.1.0
    default-metric 10000 100 254 1 1500   ← default metric
    no auto-summary
!
ip classless
ip route 0.0.0.0 0.0.0.0 206.191.241.41   ← default route
```

NOTE

Packets will only follow a default route when ip classless is enabled.

Because the Frame Relay network is a multipoint, you should disable split horizon for EIGRP on the serial interface with the command no ip split-horizon eigrp 65002. Without disabling EIGRP split horizon, if the Ethernet link between the plains and swamp routers were broken, routes from the swamp router would not reach the plains router, and routing would be broken. Another important part of the EIGRP configuration, listed in the preceding example, is the configuration of the bandwidth statements on the serial interface. The configuration of the bandwidth statements will allow EIGRP to pick the best possible path for routing.

The EIGRP configurations on the plains and swamp routers resemble that of the wow router. [Example 2-51](#) lists the configurations.

Example 2-51. EIGRP Configuration of the plains and swamp Routers

```
hostname plains
!
hostname swamp
!
router eigrp 65002
    redistribute static
    network 172.16.0.0
    network 192.168.1.0
    default-metric 10000 100 254 1 1500
    no auto-summary
!
ip classless
ip route 0.0.0.0 0.0.0.0 206.191.241.41
```

```
router eigrp 65002
network 172.16.0.0
network 192.168.1.0
no auto-summary
!
```

```
hostname swamp
!
router eigrp 65002
network 172.16.0.0
network 192.168.1.0
no auto-summary
```

The EIGRP configurations on the forest, mountain, and island routers are pretty straightforward, as shown in [Example 2-52](#).

Example 2-52. EIGRP Configuration of the forest, mountain, and island Routers

```
hostname forest
!
router eigrp 65002
network 172.16.0.0
no auto-summary
!
```

```
hostname mountain
!
router eigrp 65002
```

```
network 172.16.0.0
```

```
no auto-summary
```

```
!
```

```
hostname island
```

```
!
```

```
router eigrp 65002
```

```
network 172.16.0.0
```

```
no auto-summary
```

After configuring all the routers for EIGRP, you should have IP end-to-end connectivity. The island mountain routers should be able to reach the wow servers. A default route should also be advertised by EIGRP. [Example 2-53](#) lists the route table of the island router.

Example 2-53. Route Table of the island Router

```
island#show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
```

```
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
```

```
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
```

```
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
```

```
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
```

```
U - per-user static route, o - ODR
```

```
Gateway of last resort is 172.16.2.6 to network 0.0.0.0
```

```
    172.16.0.0/24 is subnetted, 3 subnets
```

```
D      172.16.7.0 [90/2246656] via 172.16.2.6, 01:07:24, Ethernet0/0
```

```
D      172.16.1.0 [90/307200] via 172.16.2.6, 02:10:57, Ethernet0/0
```

```
C      172.16.2.0 is directly connected, Ethernet0/0
```

```
D      192.168.1.0/24 [90/2221056] via 172.16.2.6, 02:10:57, Ethernet0/0
```

```
D*EX 0.0.0.0/0 [170/2246656] via 172.16.2.6, 01:07:24, Ethernet0/0  
island#
```

The *optional*/portion of this lab calls for you to configure NAT on the wow router for reachability to the Internet. Having actual IP hosts for testing will help you verify whether the route maps and policy routing are working properly. Actual IP hosts may be substituted by loopback interfaces and by enabling local policy routing. When configuring NAT, configure the serial 0 and E4 interfaces of the wow router as NAT inside interfaces. The E3 interface will be the NAT outside interface. Because you have only a single IP address, you will be using Port Address Translation (PAT), sometimes referred to as the Overload feature. The NAT/PAT configuration used in this model is listed in [Example 2-54](#). For more detailed information on configuring NAT, refer to *CCIE Practical Studies, Volume 1*.

Example 2-54. NAT/PAT Configuration on the wow Router

```
hostname wow  
!  
interface Ethernet3  
ip address 206.191.241.43 255.255.255.248  
no ip directed-broadcast  
ip nat outside                                     ←NAT outside interface/Internet  
media-type 10BaseT  
!  
interface Ethernet4  
ip address 172.16.7.7 255.255.255.0  
no ip directed-broadcast  
ip nat inside                                     ←NAT inside interface  
media-type 10BaseT  
!  
interface Serial0  
bandwidth 1544  
ip address 192.168.1.7 255.255.255.0
```

```

no ip directed-broadcast

ip nat inside                                     ←NAT inside interface

encapsulation frame-relay

no ip split-horizon eigrp 65002

no ip mroute-cache

frame-relay map ip 192.168.1.3 102 broadcast
frame-relay map ip 192.168.1.4 302 broadcast
frame-relay lmi-type cisco

!

ip nat inside source list 101 interface Ethernet3 overload ←PAT enabled for E3

!

access-list 101 permit ip any any                 ←translate all traffic

```

To configure the routing policy specified by the lab, you need to configure policy routing on the forest routers. This lab does not require traffic to take the same return path as which it originated, however for extra practice, you may want to configure PBR on the wow router, such that traffic does follow the same return path.

The lab objectives call for you to configure PBR with the following guidelines:

- IP traffic from the mountain and island routers with a small packet size, 0 to 1199 bytes, destined for the wow servers should use the high-speed link between the plains and wow routers.
- IP traffic from the mountain and island routers with a large packet size, 1200 to 1544 bytes, destined for the wow servers should use the low-speed link between the swamp and wow routers.
- Internet traffic from the mountain router should use the high-speed link through the plains router.
- Internet traffic from the island router should use the low-speed link through the swamp router.
- Configure fast switching for PBR.

The route map for policy routing on the forest router will have four route map instances. The first instance will match traffic from the router mountain, 172.16.2.10, and island, 172.16.2.5. After traffic is verified from these sources, a match on small packet length, 0 to 1199, will be performed. Traffic that passes both of these criteria will have a next hop set to 172.16.1.3, to use the high-speed link to the plains router. The second route map instance will match the same addresses, but this instance will match large packet lengths, 1200 to 1544. Traffic that passes both of these matches will be forwarded to the next hop of 172.16.1.4, to the lower-speed link of the swamp router.

The final two route map instances are for Internet traffic. One instance will match traffic from the mountain router, 172.16.2.10, and set the IP default next hop to the plains router, 172.16.1.3. The other instance will match traffic from the island router, 172.16.2.5, and set the IP default next hop to the swamp router, 172.16.1.4. Recall that the IP default next-hop address will be used when the router does not have the destination address of the packet in its forwarding/route table.

Recalling the steps to configure PBR, you have the following:

- Step 1. Configure ACLs.
- Step 2. Configure route map instances.
- Step 3. Configure match commands.
- Step 4. Configure set commands.
- Step 5. Configure PBR on the interface.
- Step 6. Configure fast switching.
- Step 7. (Optional) Configure local PBR.

[Example 2-55](#) covers the configuration of Steps 1 through 4 on the forest router.

Example 2-55. Route Map and ACL Configuration on the forest Router

```
Hostname forest

!
access-list 110 permit ip host 172.16.2.10 172.16.7.0 0.0.0.255
access-list 110 permit ip host 172.16.2.5 172.16.7.0 0.0.0.255
!
access-list 130 deny   ip any 172.16.0.0 0.0.255.255
access-list 130 deny   ip any 192.168.1.0 0.0.0.255
access-list 130 permit ip host 172.16.2.10 any
!
access-list 140 deny   ip any 172.16.0.0 0.0.255.255
access-list 140 deny   ip any 192.168.1.0 0.0.0.255
access-list 140 permit ip host 172.16.2.5 any
!
```

```

route-map policy_1 permit 10           ←PBR small packets
  match ip address 110
  match length 0 1199
  set ip next-hop 172.16.1.3
!
route-map policy_1 permit 20           ←PBR large packets
  match ip address 110
  match length 1200 1544
  set ip next-hop 172.16.1.4
!
route-map policy_1 permit 30           ←PBR for default routing
  match ip address 130
  set ip default next-hop 172.16.1.3
!
route-map policy_1 permit 40           ←PBR for default routing
  match ip address 140
  set ip default next-hop 172.16.1.4
!
```

The last part of the configuration, Steps 5 and 6, calls for you to apply the PBR and to enable fast switching for PBR. This is accomplished with the interface commands `ip policy route-map` and `ip route-cache policy`. [Example 2-56](#) lists the entire configuration of the forest router.

Example 2-56. Configuration of the forest Router

```

hostname forest
!
<<<text omitted>>>
!
```

```
interface Ethernet0/0
    ip address 172.16.1.6 255.255.255.0
!
interface Ethernet0/1
    ip address 172.16.2.6 255.255.255.0
    ip route-cache policy
    ip policy route-map policy_1
!
router eigrp 65002
    network 172.16.0.0
    no auto-summary
    no eigrp log-neighbor-changes
!
ip classless
no ip http server
!
access-list 110 permit ip host 172.16.2.10 172.16.7.0 0.0.0.255
access-list 110 permit ip host 172.16.2.5 172.16.7.0 0.0.0.255
access-list 130 deny   ip any 172.16.0.0 0.0.255.255
access-list 130 deny   ip any 192.168.1.0 0.0.0.255
access-list 130 permit ip host 172.16.2.10 any
access-list 140 deny   ip any 172.16.0.0 0.0.255.255
access-list 140 deny   ip any 192.168.1.0 0.0.0.255
access-list 140 permit ip host 172.16.2.5 any
route-map policy_1 permit 10
    match ip address 110
    match length 0 1199
    set ip next-hop 172.16.1.3
```

```
!  
  
route-map policy_1 permit 20  
  
    match ip address 110  
  
    match length 1200 1544  
  
    set ip next-hop 172.16.1.4  
  
!  
  
route-map policy_1 permit 30  
  
    match ip address 130  
  
    set ip default next-hop 172.16.1.3  
  
!  
  
route-map policy_1 permit 40  
  
    match ip address 140  
  
    set ip default next-hop 172.16.1.4
```

[Example 2-57](#) lists the PBR configuration of the wow router.

Example 2-57. PBR Configuration of the wow Router

```
hostname wow  
  
!  
  
ip subnet-zero  
  
ip name-server 206.191.193.1  
  
!  
  
<<<text omitted>>>  
  
!  
  
interface Ethernet3  
  
    ip address 206.191.241.43 255.255.255.248  
  
    no ip directed-broadcast
```

```
ip nat outside
media-type 10BaseT
!
interface Ethernet4
  ip address 172.16.7.7 255.255.255.0
  no ip directed-broadcast
  ip nat inside
  media-type 10BaseT
!
interface Serial0
  bandwidth 1544
  ip address 192.168.1.7 255.255.255.0
  no ip directed-broadcast
  ip nat inside
  encapsulation frame-relay
  no ip split-horizon eigrp 65002
  no ip mroute-cache
  frame-relay map ip 192.168.1.3 102 broadcast
  frame-relay map ip 192.168.1.4 302 broadcast
  frame-relay lmi-type cisco
!
router eigrp 65002
  redistribute static
  network 172.16.0.0
  network 192.168.1.0
  default-metric 10000 100 254 1 1500
  no auto-summary
!
```

```
ip nat inside source list 101 interface Ethernet3 overload  
ip classless  
ip route 0.0.0.0 0.0.0.0 206.191.241.41  
no ip http server  
!  
access-list 101 permit ip any any
```

To test the policy, issue several extended pings from the mountain and island routers. By using the show route-map command on the forest router, you will be able to determine whether packets are being policy routed. [Example 2-58](#) demonstrates two pings on the mountain router—one ping to the wow server and one to www.cisco.com (on the Internet).

Example 2-58. Testing and Verifying PBR

```
mountain#ping  
Protocol [ip]:  
Target IP address: 172.16.7.11  
Repeat count [5]: 50  
Datagram size [100]: 100  
Timeout in seconds [2]:  
Extended commands [n]:  
Sweep range of sizes [n]:  
Type escape sequence to abort.  
Sending 50, 100-byte ICMP Echos to 172.16.7.11, timeout is 2 seconds:  
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!  
Success rate is 100 percent (50/50), round-trip min/avg/max = 8/8/12 ms  
mountain#  
mountain#ping www.cisco.com  
Type escape sequence to abort.  
Sending 5, 100-byte ICMP Echos to 198.133.219.25, timeout is 2 seconds:
```

!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 136/700/1116 ms

mountain#

forest#**show route-map**

route-map policy_1, permit, sequence 10 ← small packets matched

Match clauses:

 ip address (access-lists): 110

 length 0 1199

Set clauses:

 ip next-hop 172.16.1.3

Policy routing matches: 51 packets, 5814 bytes

route-map policy_1, permit, sequence 20

Match clauses:

 ip address (access-lists): 110

 length 1200 1544

Set clauses:

 ip next-hop 172.16.1.4

Policy routing matches: 0 packets, 0 bytes

route-map policy_1, permit, sequence 30 ← Internet traffic

Match clauses:

 ip address (access-lists): 130

Set clauses:

 ip default next-hop 172.16.1.3

Policy routing matches: 10 packets, 1140 bytes

route-map policy_1, permit, sequence 40

Match clauses:

 ip address (access-lists): 140

```
Set clauses:  
  ip default next-hop 172.16.1.4  
  
Policy routing matches: 0 packets, 0 bytes  
  
forest#
```

By performing the same test on the island router, with the exception of making the ping packet size 1500 bytes, you can observe the policy routing working on the forest router. [Example 2-59](#) lists the output of the show route-map command performed on the forest router, after running the test from the island router.

Example 2-59. show route-map Command on the wow and forest Router:

```
forest#show route-map  
  
route-map policy_1, permit, sequence 10  
  
Match clauses:  
  ip address (access-lists): 110  
    length 0 1199  
  
Set clauses:  
  ip next-hop 172.16.1.3  
  
Policy routing matches: 51 packets, 5814 bytes  
  
route-map policy_1, permit, sequence 20          ← Large packets matched  
  
Match clauses:  
  ip address (access-lists): 110  
    length 1200 1544  
  
Set clauses:  
  ip next-hop 172.16.1.4  
  
Policy routing matches: 101 packets, 152914 bytes  
  
route-map policy_1, permit, sequence 30  
  
Match clauses:
```

```
ip address (access-lists): 130
```

Set clauses:

```
ip default next-hop 172.16.1.3
```

Policy routing matches: 10 packets, 1140 bytes

```
route-map policy_1, permit, sequence 40
```

← Internet traffic

Match clauses:

```
ip address (access-lists): 140
```

Set clauses:

```
ip default next-hop 172.16.1.4
```

Policy routing matches: 12 packets, 1286 bytes

```
forest#
```

Part III: Multicast Routing

[Chapter 3](#) Configuring Multicast Routing

Chapter 3. Configuring Multicast Routing

Multicast has been used for different purposes for many years. Saying "multicast" these days typically conjures up the idea of streaming video or audio from a particular event. At a much more basic level, however, multicast is a technology that allows one host to send a single stream of traffic to reach any number of destination hosts.

Without multicast, the only options available are

- Unicast streams— A number of specific copies equal to the number of destination hosts.
- Broadcast streams— Although only one stream from the source, this replicates to all stations regardless of their intent to receive.

In the early days of media streaming, unicast was actually the method used to receive the streams over the Internet. This led to a huge amount of wasted bandwidth on the senders' part, the receivers' networks, and virtually everything in between.

As with many things in the real world, changes, fixes, and new RFCs quickly emerged as a way to deal with the growing demand for online multimedia of this nature. Multicast Backbone (MBONE) was one of the original methods of distributing multicast transmissions across the Internet and between providers.

The purpose of this chapter is not to educate you on all the nuances of multicast network design and maintenance. It is to serve as a refresher—and then as a series of examples on how to configure things, particularly in reference to the CCIE lab exam!

Multicast Basics

Thinking about the idea of a single stream sent out to multiple destinations, but not all destinations, leads you to the concept of multicast groups. Destination stations must maintain membership in a particular multicast group to receive the information. Without the membership, the multicast stream cannot be delivered to stations on the network.

To understand the efficiency of multicasting, consider a video server offering a single channel of content, as shown in [Figure 3-1](#). For full-motion, full-screen viewing, a video stream requires approximately 1.5 Mbps of server-to-client bandwidth. In a unicast environment, the server must send a separate video stream to the network for each client. (This consumes $1.5 * n$ Mbps of link bandwidth, where n = number of client viewers.) With a 10-Mbps Ethernet interface on the server, it takes only six or seven server-to-client streams to completely saturate the network interface. Even with a highly intelligent Gigabit Ethernet interface on a high-performance server, the practical limit would be from 250 to 300 1.5-Mbps video streams. Therefore, the server interface capacity can be a significant bottleneck, limiting the number of unicast video streams per video server. Replicated unicast transmissions consume a lot of bandwidth within the network, which is another significant limitation. If the path between server and client traverses h_3 router hops and h_2 switch hops, the "multi-unicast" video consumes $1.5 * n * h_3$ Mbps of router bandwidth, plus $1.5 * n * h_2$ Mbps of switch bandwidth. With 100 clients separated from the server by 2 router hops, and 2 switch hops (as shown in [Figure 3-2](#)), a single multi-unicast channel consumes 300 Mbps of router bandwidth and 300 Mbps of switch bandwidth. Even if you scale back the video stream bandwidth to 100 kbps (which provides acceptable quality in smaller windows on the screen), the multiple unicast streams consume 20 Mbps of both router and switch bandwidth.

Figure 3-1. Object of Multicast: One-to-Many Routing

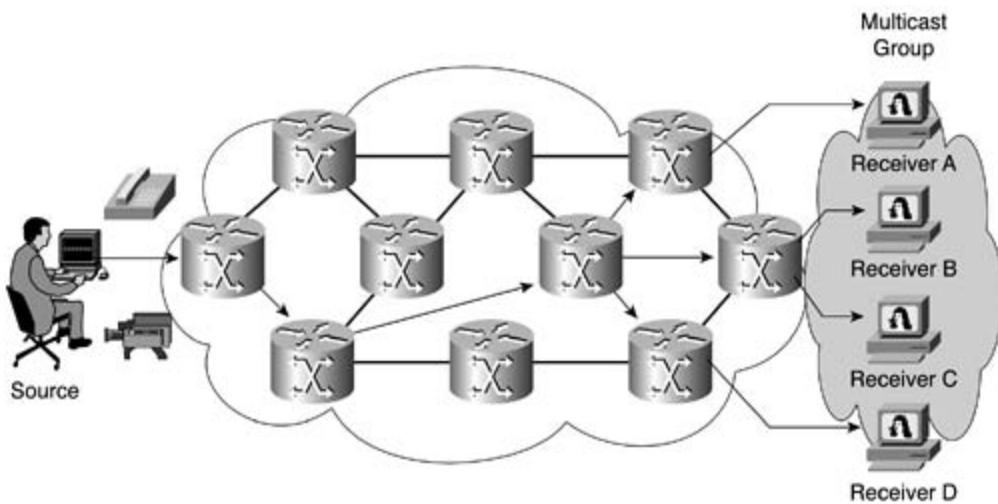
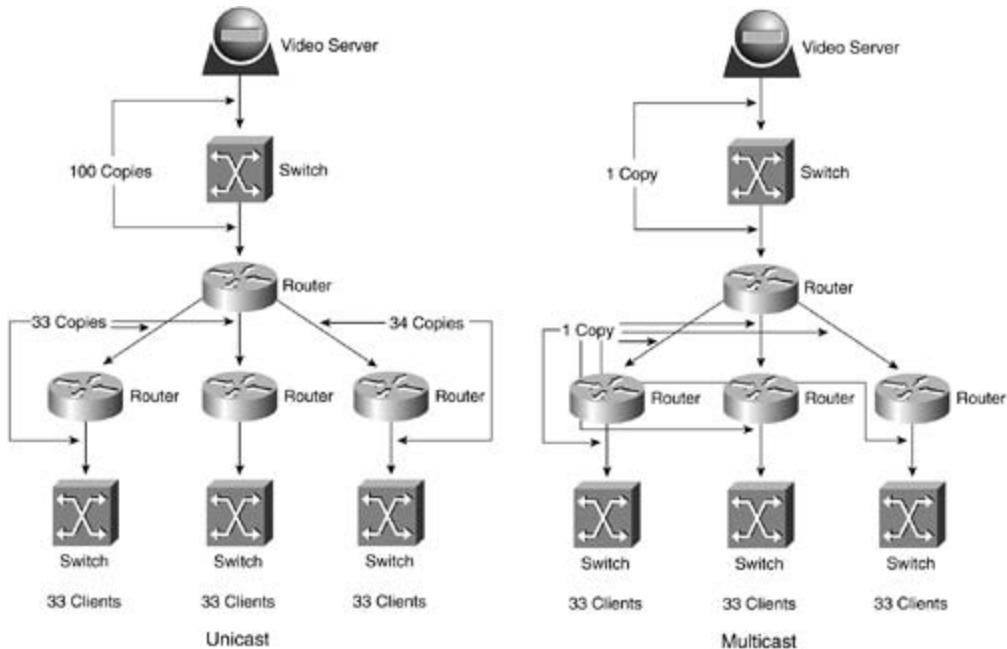


Figure 3-2. Multicast Versus Unicast Efficiency



Multicast packets are replicated down appropriate paths in the network with Protocol Independent Multicast (PIM), Internet Group Management Protocol (IGMP), and other associated protocols to create the most efficient routing mechanism possible.

Multicast provides a tremendous advantage: the potential to save overall bandwidth and conserve processing power. However, there are disadvantages as well. Multicast traffic is mostly UDP in nature. Although this makes perfect sense for how to treat a video stream, or audio stream, consider what this actually means. UDP traffic, by definition, is "best delivery," which, of course, means "if you get it, you get it. If you don't, it's okay."

UDP inherently has more dropped packets throughout a transmission. UDP offers no congestion control mechanisms, such as windowing or retransmission. Sequencing is another possible problem with UDP-based transmissions. You can expect to see degradation of the video or sound quality as packets are missed. Playing them back out of order would make no sense. The same holds true for duplicate packets.

IP Multicast Addressing

IP addresses represent a specific set of the IPv4 address space known as *Class D addresses*. In a specific binary method, all the class addresses are laid out. [Table 3-1](#) shows a listing of IPv4 class addressing.

Table 3-1. IPv4 Class Addressing

Address Class	Binary Representation	Decimal Notation
A	0xxxxxxx	First octet 1–126
B	10xxxxxx	First octet 128–191
C	110xxxxx	First octet 192–223
D	1110xxxx	First octet 224–239
E	1111xxxx	First octet 240–255

Note that certain restrictions apply to the address values listed in [Table 3-1](#). For instance, the 127.0.0.0/8 address is reserved for loopback testing of various sorts. In addition, the Class E addresses are reserved for future or research purposes. The Class D address space, as it relates to multicast, is the focus here.

Class D addresses differ from any other preceding class. Typically, an IP address is thought of as a value representing a single, particular host that resides on the network (source address). In Class D addresses, the address denotes the recipient group, wherever it is. The multicast group has no geographic or location boundaries in most cases. The source for multicast packets is always noted as the unicast source address (Class A, B, or C).

Class D addresses are further broken down into some manageable segments along the way. The Internet Assigned Numbers Authority (IANA) controls the assignment of IPv4 address space, including multicast addresses. IANA has broken the Class D space down into some specific groups for easy assignment.

Note that addresses are assigned globally and given out one at a time, instead of in binary ranges like other IPv4 addresses. [Table 3-2](#) shows a breakdown of the Class D address space.

Table 3-2. Class D Multicast Address Allocations

Description	IPv4 Address Range
Local-link address (reserved)	224.0.0.0/24
Globally scoped address (Assigned)	224.0.1.0 to 238.255.255.255
(Subset) Source-specific multicast	232.0.0.0/8
(Subset) GLOP addresses	233.0.0.0/8
Administratively scoped addresses (local)	239.0.0.0/8

Local-Link Addresses

The range of 224.0.0.0 through 224.0.0.255 has been reserved by IANA for use by network protocols on local network segments (subnets). Local-link address multicast packets have a Time-To-Live (TTL) of 1, so they are not forwarded by other routers onto different segments.

Many routing protocols use multicast addresses to maximize their efficiency. [Table 3-3](#) lists some examples of local addresses.

Table 3-3. Well-Known Multicast Groups

IP Multicast Address	Protocol Usage
224.0.0.1	All systems
224.0.0.2	All routers
224.0.0.5	All OSPF routers
224.0.0.6	All OSPF designated routers
224.0.0.9	All RIPv2 routers
224.0.0.10	All Cisco Enhanced IGRP routers
224.0.0.12	DHCP server and relay agent
224.0.0.13	All multicast PIM routers

This is not an exhaustive list of the local multicast addresses that have been assigned but more of a common representation thereof.

Globally Scoped Addresses

The majority of the Class D multicast address space is known as the *globally scoped addresses*. IANA controls and assigns these addresses for specific multicast applications and uses. These addresses again represent the groups listening to a particular packet flow and do not represent the source of the information.

These addresses are also individually assigned without the concept of ranges or subnets. [Table 3-4](#) shows some examples.

Table 3-4. Globally Scoped Addresses for Common Applications

IPMulticast Address	Protocol Usage
224.0.1.1	All systems (Network Time Protocol)
224.0.1.39	Cisco RP announce (auto-RP)
224.0.1.40	Cisco RP discovery (auto-RP)

This range of multicast address assignment is further defined in RFC 1112, *Host Extensions for IP Multicasting*. In addition, you can research all current assignments at <http://www.iana.org/assignments/multicast-addresses>. Some further addresses are reserved in RFC 1112.

Source-Specific Addresses

The addresses that fall within the 232.0.0.0/8 range are reserved for source-specific multicast. This is a type of multicast that allows some features of the multicast network, such as a rendezvous point (RP)—discussed later—to be bypassed after learning specific source information through a directory service.

Source-specific multicast might also remove the requirement of Multicast Source Discovery Protocol (MSDP) or other inter-autonomous system multicast shared tree arrangements. As an extension of the PIM protocol, other machines than the RP can provide "out-of-band" multicast services.

Typically, a receiver must issue a join command to a multicast group address. If multiple recipients join the same multicast group, even if information is sent from different source servers, both applications receive traffic from both sending servers. This solution yields extra traffic throughout the network.

In a source-specific multicast implementation, the router sees the join message specific to a particular multicast source. This is accomplished through the "include" mode within IGMP version 3. The router then sends the request directly to the source instead of sending it to the RP typically used.

There are no shared trees when dealing with source-specific multicast; everything is handled through source trees.

GLOP Addresses

Multicast addresses falling in the 233.0.0.0/8 range are reserved by RFC 2770 for GLOP. As an interesting note, GLOP does not stand for anything as an acronym; however, it is an interesting word! This is where any holder of an autonomous system number is automatically granted multicast addresses that route throughout the Internet.

An autonomous system number is a 16-bit number (1–65,535) used to signify separate systems of Border Gateway Protocol (BGP) speakers on the Internet. Fitting nicely into the equation here,

taking those 16 bits and fitting them into the two middle octets yields 256 multicast addresses per octet.

For example, AS 22222 is represented by 01010110 11001110 in binary—or 86.206 split into two octets and converted back to decimal. So AS 22222 is automatically granted 233.86.206.0/24 multicast addresses to use as it sees fit throughout the Internet.

Administratively Scoped Addresses

Also known as *limited-scope addresses*, administratively scoped addresses fall within the range of 239.0.0.0/8. RFC 2365 sets these addresses aside to be used within a company or organization. Private companies, campuses, or other networks can use these addresses to run multicast applications that will not be forwarded outside their autonomous system.

Service provider routers are typically configured to filter this type of multicast traffic to be sure applications do not flow outside the appropriate multicast domain. Large organizations might also separate these into scopes (the multicast theory of subnetting) to separate them across smaller multicast domains.

Layer 2 Multicast Addresses

Typically, a network interface card (NIC) on a system is capable of recognizing only frames destined for their burned-in MAC address (BIA) or the broadcast MAC address (all Fs). In the networks using IP multicast, multiple hosts need to be able to receive a single data stream with a common address. The 802.3 standards actually allowed this to occur by using the least significant bit (bit 0) of the most significant byte (far-left byte). When this bit is set to 0, it represents an individual address to which the NIC registers only its BIA. When this bit is set to a 1, it represents a group address encompassing broadcasts and multicasts.

For those who remember back to their CCIE written exam, this is the bit that was referred to as the I/G bit in an Ethernet MAC address.

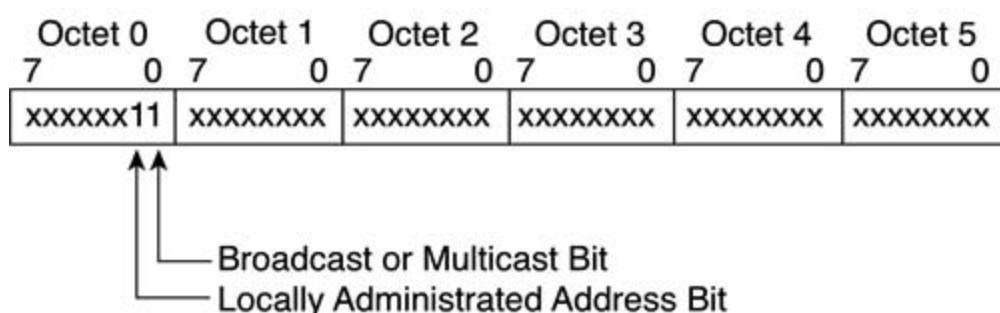
As an example of Layer 2 multicast addresses, consider the Intermediate System-to-Intermediate System (IS-IS) routing protocol. A derivation of the OSI Connectionless Network Service (CLNS) protocol suite, IP IS-IS uses a Layer 2 multicast address when it talks to neighbors:

Level 1 IS-IS routers talk with 01-80-C2-00-00-14.

Level 2 IS-IS routers talk with 01-80-C2-00-00-15.

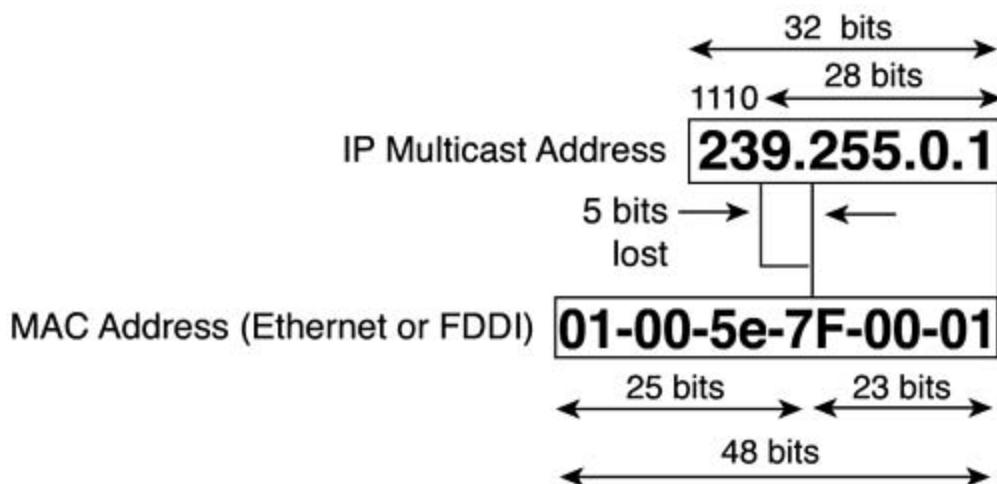
As a side note, the next least significant bit (bit 1) of that same byte represents a locally assigned MAC address (LAA), which allows multiple individual addresses to be received. This is a common occurrence on Token Ring networks where "functional addresses" are used for devices assuming necessary roles in network operation. [Figure 3-3](#) shows a MAC address bit layout.

Figure 3-3. MAC Address Bit Layout



Again, as you might remember from those days of the CCIE written exam and other Ethernet-related trivia, the first three octets in a MAC address represent the OUI code. The IANA has been allocated an organizational unique identifier (OUI) code for Ethernet multicast MAC addresses. This OUI code is 01:00:5E. One additional bit is allocated and forced to be a 0 value. This adds up to 25 bits out of 48 total pre-allocated, leaving 23 bits to vary, as shown in [Figure 3-4](#)..

Figure 3-4. IP Multicast-to-MAC Addressing



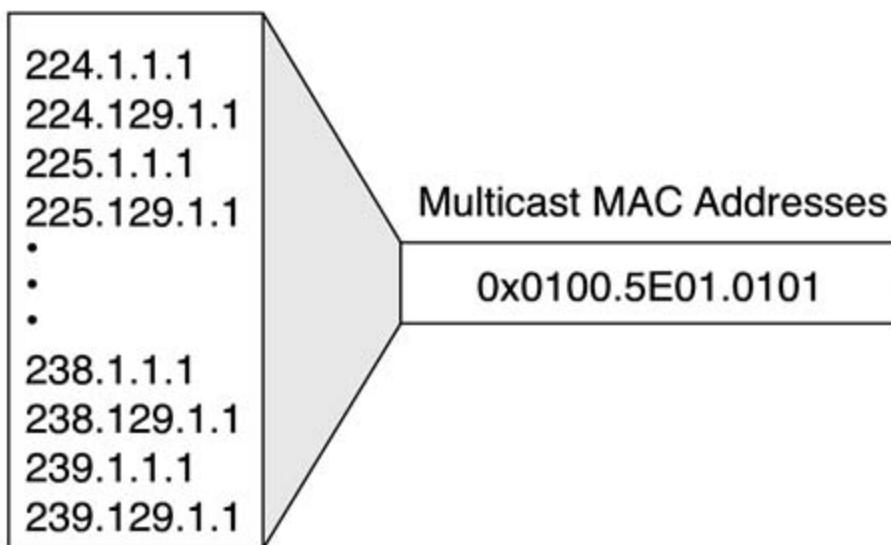
Now, for some interesting trivia to go with the mapping values, look at the binary values shown here by the OUI allocation code—the E value in particular. E in hexadecimal is 1110 in binary. All Class D IP addresses begin with binary values of 11100000 (224) through 11101111 (239). The first nibble of all multicast addresses is 1110 (E in hex).

This means that out of the 32 binary bits in all multicast addresses, at least 4 of them are always the same and statically represented in the OUI allocation representing multicast IP on an Ethernet network.

Regarding the mapping of IP multicast addresses into MAC addresses, however, you can see that this still leaves you with 23 bits to remap. The lower 23 bits of a 32-bit multicast IP address are mapped in here. Because the leading 4 bits are already represented by the E, this leaves 5 bits unmapped as shown in [Figure 3-5](#).

Figure 3-5. Overlap of Multicast MAC Addresses

32 IP Multicast Addresses



An Ethernet multicast MAC address has some overlap—the same MAC address is assigned to 32 different multicast groups. If one user on an Ethernet segment subscribes to multicast group 225.1.1.1, and another user subscribes to 225.129.1.1, both users receive both multicast streams. In engineering multicast networks on LAN segments, this overlap needs to be specifically watched for and engineered to avoid the problem.

With Token Ring networks, the overlap is even greater. As mentioned earlier, Token Ring uses the concept of functional addresses. Also, remember that Token Ring uses noncanonical addressing, so the bits are swapped on a byte level. Layer 3 IP multicast addresses are mapped to a single functional address, leaving just a little bit of overlap. Subtracting the first 4 bits that all IP multicast addresses have in common leaves 28 bits of overlap, or approximately 268,435,200 multicast addresses mapped into a single MAC address.

Needless to say, the best way to engineer multicast on Layer 2 is to *not use* Token Ring. Within Cisco configuration, the default mechanism is to map multicast packets into broadcast frames (FFFF.FFFF.FFFF).

If you want to use the Token Ring functional address, use the `ip multicast use-functional` command on the Token Ring interface. This uses C000.0004.0000 to map the multicast IP packets.

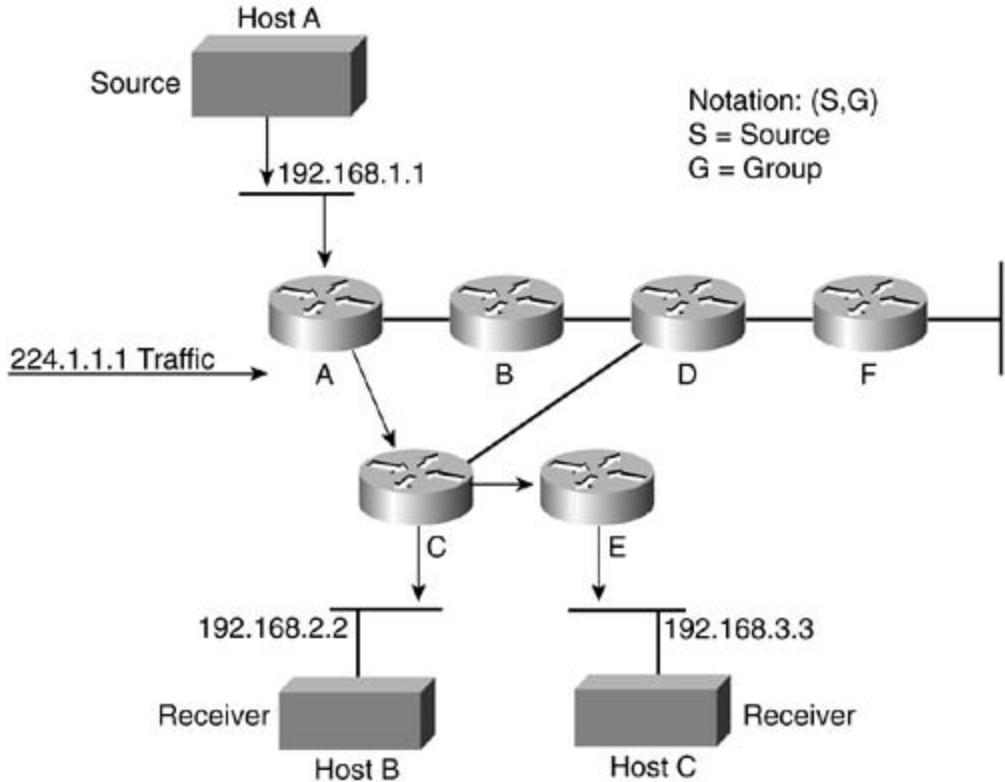
Multicast Distribution Trees

Multicast routers create distribution trees to control the path that multicast traffic takes throughout a network infrastructure to deliver traffic. Distribution trees consist of two basic types: source trees and shared trees.

Source Trees

The *source distribution tree* is also known as the shortest-path tree, and just like it sounds, it is a small spanning tree with the shortest path from the root (source) of the tree to each of the leaves (recipients). [Figure 3-6](#) shows an example of a multicast source tree.

Figure 3-6. Multicast Source Tree



The notation of S,G represents a pairing of the source (unicast) address and the group (multicast) address; this pair discovers the shortest-path tree. In [Figure 3-6](#), the S,G noted is (192.168.1.1, 224.1.1.1).

This S,G notation is used for each source tree. Every individual source sending to each specific group results in a separate S,G tree being noted. In large networks, this can lead to an inordinate number of S,G trees being planted in a network. This inefficiency necessitated shared trees and encouraged their use.

Shared Trees

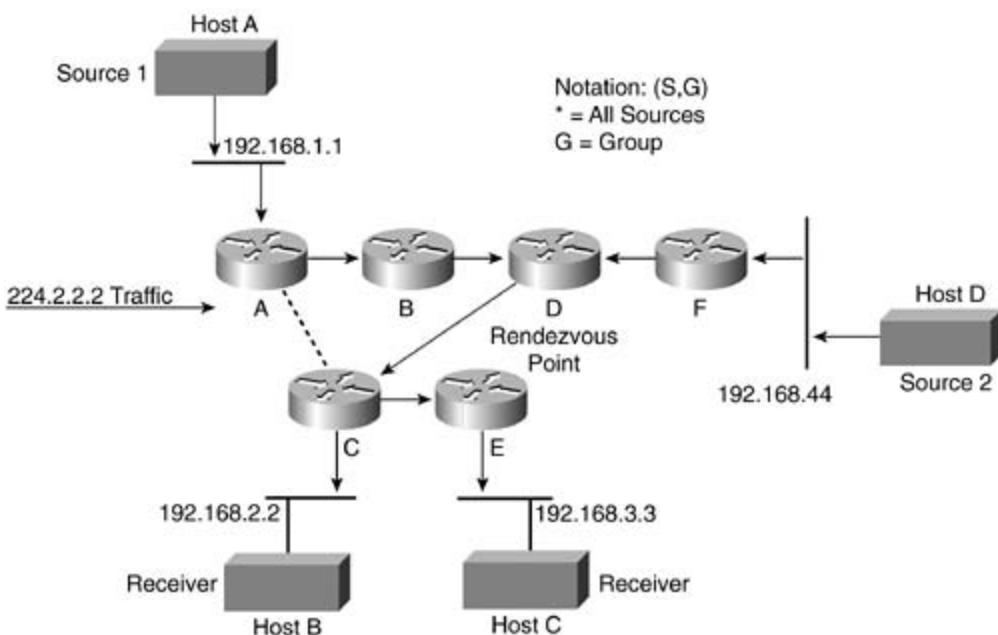
Unlike source trees, all multicast groups have a common root, regardless of source. The shared root in all these trees is known as the *rendezvous point (RP)*. Unlike the S,G mappings that you see with source trees, with shared trees, you see *,G mappings because the source is not specifically noted; therefore, the asterisk (*) represents any source.

The shared tree is unidirectional in nature; all traffic is sent from the source to the RP. Traffic is then forwarded down from the shared tree and RP to reach each of the receivers; however, exceptions to this rule do apply. If the receiver is located between the source and RP, for instance, the receiver is handled through a source tree directly.

After working within the shared tree and communicating with the RP, any intermediate multicast router might determine that it is a shorter path to the multicast source rather than through the RP shared tree. In this instance, a multicast router joins a source tree (S,G) and prunes from the shared tree. The shortest path is determined by the routing tables.

[Figure 3-7](#) shows a multicast network with an RP. Because all sources in the multicast group use the same tree, the multicast *,G tree maps as (*,224.2.2.2). One of the difficulties with this shared tree concept is that all multicast routers do not automatically learn of new multicast groups. With PIM sparse mode, all sources register with a registration message to the RP indicating a new multicast source. All other multicast routers know to inquire of the RP as clients join various multicast groups.

Figure 3-7. Rendezvous Point in Multicast Network



Both shared trees and source trees are loop free. Throughout the topology, multicast packets are sent only down active tree branches, as client systems join or leave multicast groups. When all receivers on a branch leave a group, the routers prune back the tree. If more clients join, the routers dynamically modify the tree.

Routers keep path information for each source. In large networks, with hundreds or thousands of groups being monitored, you need to consider the memory consumption on the router and the size of the multicast routing table in the multicast design. Shared trees inherently require less memory because of the common path to the RP. Similarly, in network design, consider the placement of the RP with respect to the position of multicast sources and the size of the share tree.

Multicast Forwarding

In a normal unicast network, all decisions are based on the destination address of a packet. In a multicast network, paths are determined in a more arbitrary fashion that varies based on which branches within a tree have active clients and which ones do not.

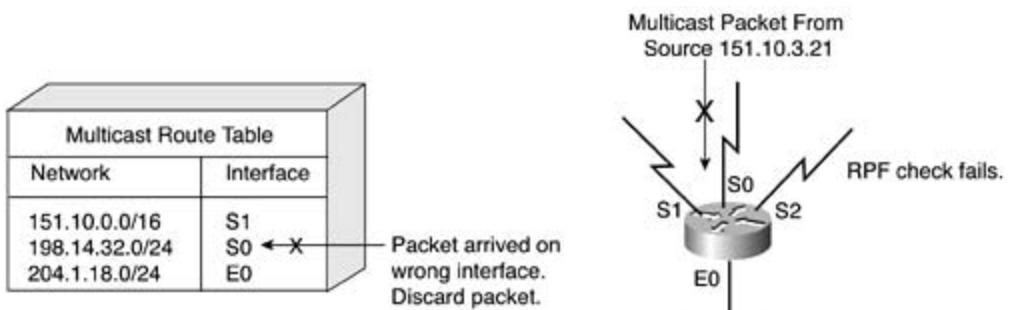
In source trees, traffic is forwarded based on the source address among other factors. In general, traffic is viewed as moving away from the source rather than toward the receivers.

Reverse Path Forwarding

The unicast routing database creates a multicast distribution tree. PIM selects the reverse path from the receivers toward the source to set this up. PIM uses the routing table to determine both the upstream and downstream interface. Depending on which PIM mode you use (sparse or dense), the reverse path forward (RPF) check might be based on a distribution tree toward the RP or toward the multicast source. The following section discusses PIM trees in more detail. The RPF check helps guarantee that a multicast distribution tree is loop free.

When a multicast packet comes through a router, as [Figure 3-8](#) shows, the router performs an RPF check on the packet. If the RPF check succeeds, the packet is forwarded. If the RPF check fails, the packet is dropped.

Figure 3-8. Reverse Path Forwarding Decision



The router first looks up the source address in the unicast routing table to see whether the packet that arrived on the same interface would be the reverse path back to the source. If the packet arrives on the correct interface leading back to the source, the check succeeds and the packet is forwarded. As [Figure 3-8](#) shows, if it arrives on any other interface, the RPF check fails and the packet is dropped.

Protocol Independent Multicasting

Protocol Independent Multicasting (PIM) is a routing protocol-independent method of moving multicast packets throughout an internetwork. Regardless of which routing protocol you use, including everything from static routes to OSPF and BGP, PIM uses the information from the Routing Information Base (RIB) to perform multicast routing. Although PIM uses the unicast routing table for the RPF check, it does not send and receive routing updates like other routing protocols do. All PIM modes are configured on a per-interface basis.

For the CCIE exam, you need to know about the following three PIM forwarding modes:

- PIM dense mode
- PIM sparse mode
- Bidirectional PIM

PIM Dense Mode

PIM dense mode uses a push method to move multicast packets through a network. In simple terms, a multicast router sends all multicast traffic out on all interfaces until another device tells it to be quiet (pruning).

Dense mode is persistent, however. It resets this flooding behavior every 3 minutes and must be re-pruned. PIM dense mode supports only source trees and cannot be used to build a shared multicast tree. (Note the importance of the wording here regarding tree types.)

To configure PIM dense mode, use the following command in interface configuration mode:

```
Router(config-if)#ip pim dense-mode
```

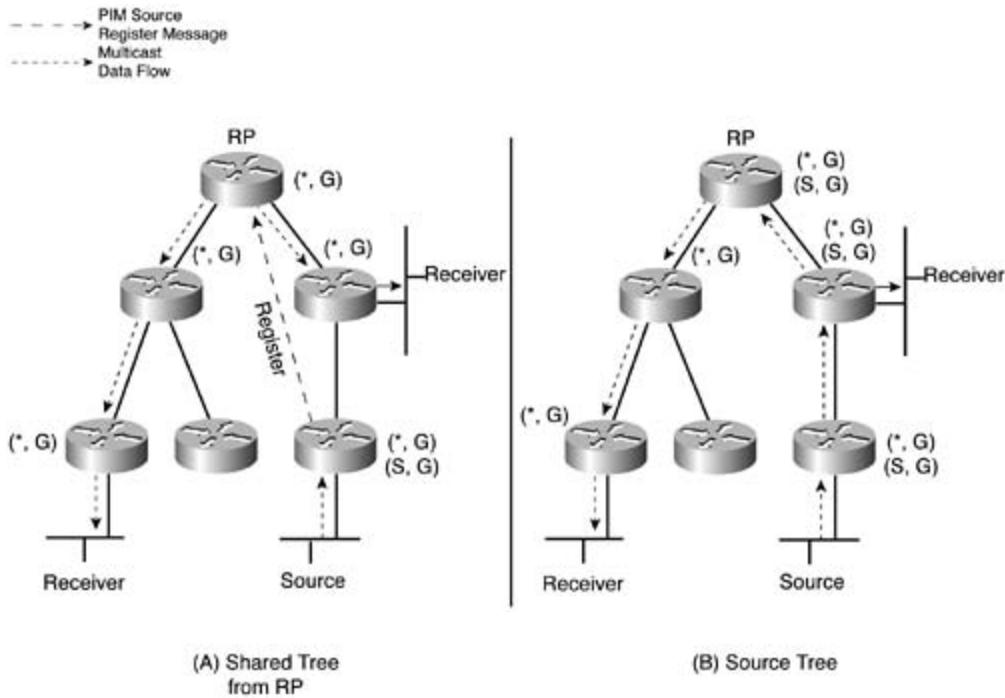
PIM Sparse Mode

PIM sparse mode uses a pull method to move multicast packets through the network. Network branches with active receivers are the only segments to receive multicast traffic. The various multicast routers paying attention to joins and leaves of a multicast group activate or prune traffic as necessary.

PIM sparse mode requires an RP. After receivers register, the data is sent down the shared tree toward the receivers. Each multicast router compares the metric of the RP address to the metric

of the source address of the multicast group. If the metric for the source is better (highlighting the location of the RP in the network), the S,G tree is built. The trees might take the same path for a short time and , therefore, are considered congruent paths, as demonstrated in [Figure 3-9](#).

Figure 3-9. Differences in Shared Tree and Source Tree



To configure PIM sparse mode, use the following command in interface configuration mode:

```
Router(config-if)#ip pim sparse-dense-mode
```

This is the typical way of representing PIM sparse mode, allowing it to also work in dense mode for certain operations or compatibility. If your design states that you are not allowed to use dense mode, you can issue the following command:

```
Router(config-if)#ip pim sparse-mode
```

You can configure RPs manually on each multicast router, telling them where communication needs to flow to, as in the following example:

```
Router(config)#ip pim rp-address (ip#) [(acl#)]
```

The optional access list limits which particular multicast groups the RP listed serves.

If your design scenario disallows the use of source trees in sparse mode, you must not use the `pim sparse-dense` command; instead, use the following:

```
Router(config-if)#ip pim spt-threshold infinity
```

SPT is the shortest-path tree algorithm, which compares the paths between source-specific multicast trees and shared multicast trees to the RP. This command disables the cost comparison between the source and the RP for the shortest-path algorithm.

Bidirectional PIM

Bidirectional PIM expands on the previously learned methods of tree creation. In forwarding packets downstream (RP to receivers), there is not much difference between sparse mode and bidirectional PIM. To forward packets in an upstream direction, however, there are significant differences.

PIM sparse mode cannot move packets in an upstream direction. This would violate the RPF

check that all multicast routers perform. All join traffic is contained in a register message toward the RP only while all other significant traffic flows downstream from the RP in a shared tree.

Bidirectional PIM elects a designated forwarder (DF) router to keep the multicast topology loop free. Every network segment and point-to-point link elects a DF. The DF is responsible for forwarding appropriate multicast traffic upstream. The router with the best route toward the RP becomes the DF for the network segment.

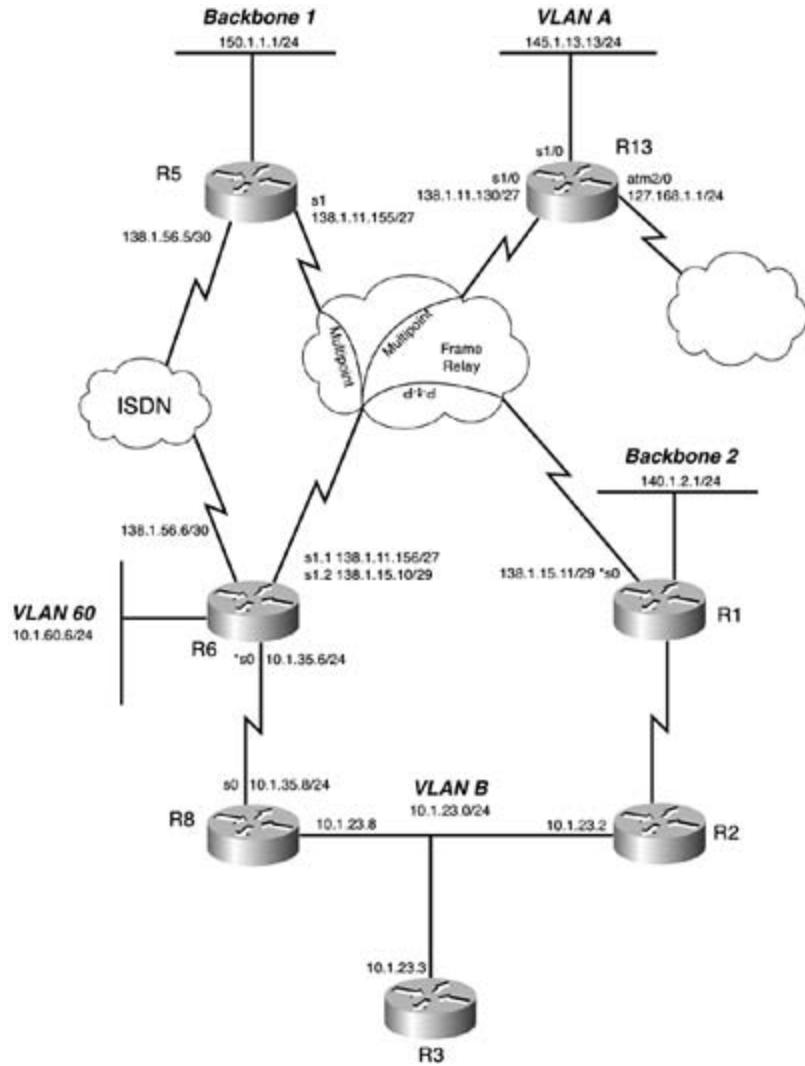
A DF is elected for each RP on a network. Because the election takes place based on routing metrics toward an RP, there might actually be multiple DF routers per segment when dealing with multiple RPs per network.

Most multicast functions are handled in the same way that they are in a sparse mode PIM network. There are more technical improvements in protocol handling, but for the scope of this chapter, be aware that the DF election is important.

Lab 5: Set Up Basic Multicasting

Given the topology in [Figure 3-10](#), configure all routers within VLAN B and VLAN 60 so that they join to multicast group 239.42.42.42. There should be no unnecessary multicast traffic exchanged between the routers.

Figure 3-10. Multicast Lab Network Diagram



Lab 5: Solution

The wording is key when considering this type of scenario. The fact that the scenario did not want unnecessary traffic to be exchanged indicates that you should not use the PIM dense mode.

The next issue in the configuration is where you should place the pim statements and who

should be the RP. Obviously, all routers need the ip multicast-routing command configured in global mode. In addition, all interfaces between the most distant endpoints participating in multicast groups must be configured with the ip pim sparse-mode interface command.

Which router chosen to be the RP in this example is negligible? No preference is indicated by the scenario question, and the topology is not large enough to make any difference as to which router is chosen. In live multicast networks, the placement of the RP can prove critical when viewing functional choices such as the SPT algorithm and designing overall traffic flow.

The next step is to configure all other routers with the ip pim rp-address command. A common question arising from this is whether the rp-address command must be placed on the actual router that is the RP. The answer is that it does not matter. If explicitly configured, the router knows. If not configured, as other routers send PIM join and prune messages, the router knows to assume the RP role automatically.

NOTE

Check the Cisco IOS Software release notes regarding this concept. Newer versions of Cisco IOS Software actually require you to configure the rp-address command on the RP itself.

To test the scenario and complete the joins, you must select some interfaces in both VLANs and issue the ip igmp join-group 239.42.42.42 interface command. After issuing these commands, you can ping the multicast group and receive responses from each joining router.

Lab 5: Configurations

Example 3-1. Command Entries Edited from show running-configuration on Routers

```
R2

ip multicast-routing

!

interface ethernet 0

  ip pim sparse-mode

  ip igmp join-group 239.42.42.42

!

ip pim rp-address 10.1.23.3
```

R3

```
ip multicast-routing
!
interface ethernet 0
  ip pim sparse-mode
```

R6

```
ip multicast-routing
!
interface ethernet 0
  ip pim sparse-mode
  ip igmp join-group 239.42.42.42
!
interface serial 0
  ip pim sparse-mode
!
ip pim rp-address 10.1.23.3
```

R8

```
ip multicast-routing
!
interface ethernet 0
  ip pim sparse-mode
  ip igmp join-group 239.42.42.42
```

```
!  
interface serial 0  
  ip pim sparse-mode  
!  
ip pim rp-address 10.1.23.3
```

Multicast Frame Relay

Running multicast over Frame Relay networks is similar to running it over any other network, except for some distinct differences that you might actually notice in real-life networks. With point-to-point Frame Relay interfaces, things such as routing protocols and other options tend to work "normally."

In multipoint interfaces, consider the differences. Frame Relay is a nonbroadcast multiaccess network. The word "broadcast," much like in Ethernet MAC marking, indicates multicast packets as well. To make routing protocols work, you use frame-relay map commands with the broadcast parameter.

You also need to also consider how the Frame Relay interface handles multicast traffic. On a physical interface, there are two interface queues—one handles normal traffic, and the other handles broadcast traffic. The broadcast queue is a strict-priority queue and is typically used for important items, such as routing protocol updates. The Frame Relay interface does not have a way to differentiate multicast traffic flows such as video or audio streaming from other multicast items such as OSPF routing protocols.

Traffic traversing the broadcast queue is also process switched by default, not fast switched.

In the lab networks, nobody cares. In real life, having a bandwidth-intensive video stream monopolize a strict-priority queue and starving out other "normal" traffic is a much more important event. To remedy this problem, you must instruct the router to deal with nonrouting multicast traffic, just as it would with any other "normal" traffic on the interface.

Frame Relay handling of multicast might raise other issues, too. Typically, PIM works on an interface basis. In a normal multipoint Frame Relay environment, there might be many paths out the same actual interface. When it comes to properly processing join and prune messages, this can lead to difficulties where one router's prune message cuts off traffic for every other router.

Much of the technical differences involved are beyond the scope of this book. (You can consult some of the reference material listed at the end of this chapter for further reading.)

For lab-based scenarios as well as most real-life scenarios, you need to address the different handling of Frame Relay interfaces with regard to multicast traffic.

The `ip pim nbma-mode` interface command enables you to do this. This command works only with PIM sparse mode because it relies on PIM join messages to indicate traffic types. This command is issued in addition to the `ip pim sparse-mode` command. This command, among other functions, allows multicast traffic to be fast switched over Frame Relay network interfaces. Watch the wording and topology within your CCIE lab scenarios.

Multicast TTL

As multicast packets traverse a router, the TTL is decremented. If the TTL is less than or equal to 0, the packet is dropped. If the TTL is greater than 0, it might be compared to the TTL threshold manually configured on the router. If the packet's TTL is greater than the threshold, it is forwarded.

Typically, TTL thresholds are set only on multicast or autonomous system boundary routers to make sure traffic does not cross where it should not.

To set a TTL threshold, use the `ip multicast ttl-threshold ttl-value` interface command.

Multicast Boundary

As a more stringent control, if multicast traffic is not desired to cross an imaginary line in a router, you can set up a multicast boundary. You can restrict this to certain multicast groups through a standard IP access list.

The `ip multicast boundary` (acl#) interface command enables you to create multicast boundaries. Multicast boundaries are bidirectional in nature. You can also add a parameter of `filter-autorp` to the command to filter multicast range announcements within the auto-RP messages. Auto-RP is discussed next.

```
Router(config-if)#ip multicast boundary 1  
Router(config)#access-list 1 deny 239.0.0.0 0.255.255.255  
Router(config)#access-list 1 permit 224.0.0.0 15.255.255.255
```

PIM Auto-RP

Instead of manually configuring the RP to each multicast router, the RP can announce itself. This proves especially useful in large network environments.

Auto-RP uses 224.0.1.39 and 224.0.1.40 multicast groups to send information. Auto-RP floods this information through PIM dense mode. For auto-RP to work properly, the routers must use the `ip pim sparse-dense-mode` interface command. Without the dense mode capability, the RP will never be learned.

The auto-RP functionality also includes mapping agents. Mapping agents hear about RPs (via the 224.0.1.39 multicast group) and send RP-to-group mappings in a discovery statement via 224.0.1.40.

The mapping agents receive messages from candidate RPs throughout the network. The mapping agent is responsible for creating consistent multicast group-to-RP mappings and sending these announcements to all multicast routers by dense mode flooding.

In a Frame Relay environment using auto-RP, you must address a few considerations. All candidate RPs must have a map statement or otherwise connect to the mapping agents. All mapping agents must connect to all multicast routers.

To configure the router as the RP and announce so that other multicast routers can automatically learn, use the `ip pim send-rp-announce source int$ scope ttl-value` global command.

To function as a mapping agent, use the `ip pim send-rp-discovery scope ttl-value` global command.

Typically, loopbacks are used for the RP addresses (source interface). The loopback interface must be reachable with an Interior Gateway Protocol (IGP) and must have PIM enabled on the interface. Select loopback interfaces because they will be an "always up" interface, and, therefore, are reachable through any other "up" interface.

Anycast RP

A newer method of controlling multicast RP stability throughout an internetwork is called *anycast RP*. Some new concepts and protocols relate to this approach. The gist behind anycast RP is that a single IP address is statically configured as the RP throughout a network. (See [Example 3-2](#).)

This IP address can exist on multiple routers simultaneously. (This concept is one that causes many people to have a puzzled expression.) Yes, you can configure the same IP address on multiple routers. One of the interesting things about IP addresses, particularly for a /32 route, is that routing tables all across a network could care less where an IP exists. All routing tables pull information from RIBs, which are exchanged through routing protocols. Routing protocols differentiate IP reachability based on metrics. If multiple routers advertise the same IP network, the best path is chosen based on metric value. No router actually knows where a route exists or compares information beyond that. Multicast senders and receivers join their closest RP based on routing metrics.

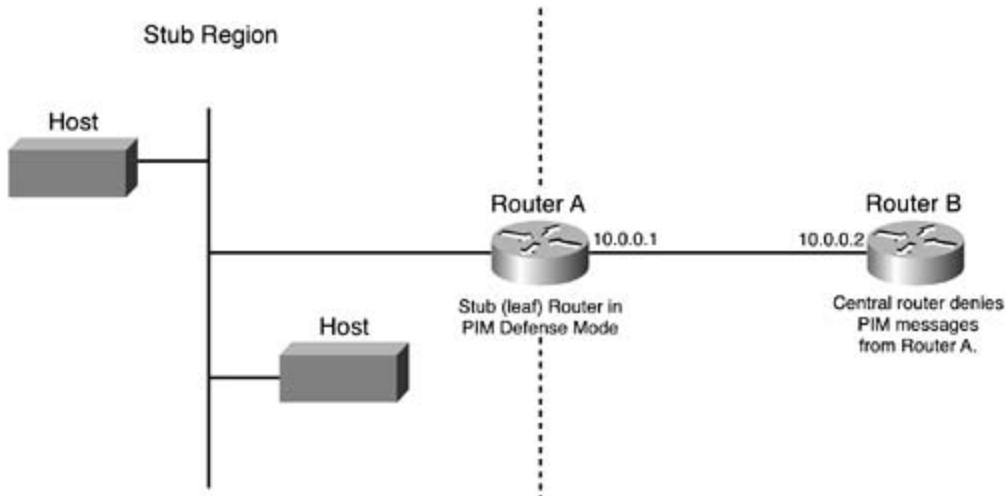
Working with this general concept, you need to understand how basic routing functionality and multiple IP address existence can help. You need to consider an additional protocol.

Typically designed for service provider types of interdomain multicast, the Multicast Source

Discovery Protocol (MSDP) is in this scenario to make sure that all the configured RPs contain the same basic information about multicast sources and multicast groups.

MSDP sessions run between all RP routers. As shown in [Figure 3-11](#), an IP network can have multiple RPs present. Each multicast router throughout the network has the RP address statically configured.

Figure 3-11. Anycast RP Diagram



Each of the RP routers has a loopback configured with the IP address that is considered the RP. In addition, each router has some other IP address to uniquely identify it. This second IP address peers with MSDP. In larger environments, you can configure MSDP as a full mesh between peers.

Example 3-2. Configuration of MSDP on Anycast RP Routers

```
RP1
interface loopback 0
  ip address 10.1.1.1 255.255.255.255
!
interface loopback 1
  ip address 10.0.0.101 255.255.255.255
!
ip msdp peer 10.0.0.102 connect-source loopback 1
ip msdp originator-id loopback 1
```

RP2

```
interface loopback 0
    ip address 10.1.1.1 255.255.255.255
!
interface loopback 1
    ip address 10.0.0.102 255.255.255.255
!
ip msdp peer 10.0.0.101 connect-source loopback 1
ip msdp originator-id loopback 1
```

MSDP peers with a TCP session and exchanges any new source active (SA) messages with all other peers. The commands listed are the minimum necessary to make MSDP operational. This minimum is listed here not to belittle the technology but because this theory is commonly oriented toward service providers and not toward typical enterprises. This topic, however, has come under increasing scrutiny to those preparing for the CCIE Routing and Switching lab.

The commands listed in [Example 3-2](#) establish a shared (10.1.1.1) and unique (10.0.0.101 and 10.0.0.102) IP address on each RP. The ip msdp commands specify the peering RP, as well as which interface is the connect source and originator ID for all messages. This avoids confusion and obvious difference in each router's routing table.

Lab 6: Set Up Frame Relay Multicast Routing

Using the same network from [Figure 3-10](#), configure VLAN A and Backbone 1 to participate in multicast group 225.3.3.3. R13 needs to be the RP for all multicast groups, except administratively scoped addresses, but should not be explicitly configured on any other routers. R5 needs to be the RP for the administratively scoped addresses.

Make sure that multicast packets do not cross back into VLAN B or other networks. These other networks might be running separate multicast groups.

Lab 6 Solution

For all CCIE scenarios, everything is in the wording. Running multicast on VLAN A and Backbone 1 tells you that R5, R6, and R13 must be involved in the multicast network, which, of course, is a Frame Relay multipoint network interface.

Therefore, in addition to the ip multicast-routing commands on these three routers, the Frame Relay interfaces must also run the ip pim nbma-mode command.

Next, you realize PIM sparse mode will be used because there is an RP. Because you must use auto-RP commands, however, PIM dense mode is needed, too. Each Frame Relay interface (the links between each of the multicast routers) will be configured with IP PIM sparse mode.

You must create access lists to filter certain multicast networks. On R13, administratively scoped addresses are not served as RP.

```
access-list 13 deny 239.0.0.0 0.255.255.255  
access-list 13 permit 224.0.0.0 15.255.255.255
```

That access list denies administratively scoped addresses but permits all the other addresses. On R5, just the opposite takes place:

```
access-list 5 permit 239.0.0.0 0.255.255.255
```

The access list implicitly denies all other multicast addresses.

Each router then uses the ip pim send-rp-announce *src-int* scope 16 group-list *ac#* global command to begin advertising itself as the RP for the multicast groups in the access lists.

R6 is the multipoint Frame Relay interface that all traffic between R5 and R13 must join. With that in mind, it is the best choice for the mapping agent (multicast RP relay). Use the ip pim send-rp-discovery scope 16 global command to make it the mapping agent.

Finally, the scenario requires that you set up a boundary between the Frame Relay cloud multicast network and any other network below.

```
access-list 6 deny any  
ip multicast boundary 6
```

The question is, where do you place the multicast boundary? The answer is wherever you need to, ensuring that no line will be crossed. Three other interfaces on R6 serve other networks: the Ethernet interface, the serial link to R8, and another Frame Relay subinterface to R1. You need to place the multicast boundary command on each of these interfaces.

Lab 6: Configurations

To configure a router with command entries, refer to [Example 3-3](#) to see how the show running-configuration works on a router.

Example 3-3. Command Entries Edited from show running-configuration on Routers

R5

```
ip multicast-routing  
!
```

```
access-list 5 permit 239.0.0.0 0.255.255.255
!
ip pim send-rp-announce ethernet 0 scope 16 group-list 5
!
interface ethernet 0
  ip pim sparse-dense-mode
  ip igmp join-group 225.3.3.3
!
interface serial 1
  ip pim sparse-dense-mode
  ip pim nbma-mode
!
```

```
R6
ip multicast-routing
!
ip pim send-rp-discovery scope 16
!
access-list 6 deny any
!
interface serial 1.1 multipoint
  ip pim sparse-dense-mode
  ip pim nbma-mode
!
interface serial 1.2 point-to-point
  ip multicast boundary 6
!
interface ethernet 0
```

```
ip multicast boundary 6

!
interface serial 0
ip multicast boundary 6
```

R13

```
ip multicast-routing
!
access-list 13 deny 239.0.0.0 0.255.255.255
access-list 13 permit 224.0.0.0 15.255.255.255
!
ip pim send-rp-announce ethernet 1/0 scope 16 group-list 13
!
interface ethernet 1/0
ip pim sparse-dense-mode
ip igmp join-group 225.3.3.3
!
interface serial 1/0
ip pim sparse-dense-mode
ip pim nbma-mode
```

Multicast Joining

From the solution for Lab 5 (and from the implications of Lab 6), you are aware of the `ip igmp join-group mcast#interface` command. To make your router (lab) actually respond to multicast and join the group, you must type in an IGMP command like this. What else is it used for, however?

In real life, you can use it to supply multicast groups to a LAN segment, enabling clients to interpret multicast but not enabling them to initiate group membership through IGMP. With the interface participating in the group, multicast traffic is forwarded to that LAN segment. Be aware of this functionality when it comes to paying attention to the wording of a CCIE lab scenario.

There is a downside—in real life—to this. Because the packets are processed by the router before being sent out, they are only process switched. This can degrade the performance of your router overall and is not necessarily a good thing to do. In the lab, however, you do not have those same concerns.

But wait—there's a better way to accomplish this! As you consider the wording of a CCIE lab scenario, look for the concept wording about forwarding multicast traffic on to a LAN segment without receiving IGMP messages from clients. In addition, watch for references to ensure that the router does not process the multicast packets; optimize the processing speed of the router while doing this.

What does this mean?

If you use the `ip igmp static-group mcast#interface` command, it accomplishes exactly that. Therefore, watch for the wording in the lab scenario to tell you what you need to know.

With the `ip igmp static-group` command, multicast packets are automatically fast switched without interaction with the RP.

Another scenario to watch out for deals with converting incoming multicast traffic into some other type of packet, such as broadcasts. This is used for clients who are not properly capable of receiving multicasts. The downside, of course, is that when converting to broadcast packets, many more stations might receive (and process) the multicast traffic than actually want it.

This conversion process uses multicast helper addresses and "bouncing" through a UDP port. The whole operation is similar to how Dynamic Host Configuration Protocol (DHCP) relay works. First, the unique, high UDP port is selected and a filtering access list is created, using the following commands:

```
Router(config)#ip forward-protocol udp 4400
```

```
Router(config)#access-list 101 permit udp any any eq 4400
```

```
Router(config)#access-list 101 deny udp any any
```

Next, these are bound to the conversion process on a LAN segment interface. To flood things out, you must use PIM dense mode as specified in the following commands:

```
Router(config-if)#ip pim dense-mode  
Router(config-if)#ip directed-broadcast  
Router(config-if)#ip multicast helper-map broadcast 225.4.4.4 101
```

These commands bind multicast group 225.4.4.4 to the UDP port specified in access list 101 and handle the conversion process of that group into broadcast packets for the interface. Note the ip directed-broadcast command here. The default in Cisco IOS Software 12.0 or later is to not allow subnet-level broadcasts to come in to the interface.

You might potentially open up a security flaw by working this scenario. But again, in the CCIE lab, you are not always concerned with these things.

Lab 7: Multicast Joining

Consider the network topology from [Figure 3-10](#) again. Clients on Backbone 2 cannot send IGMP join messages but need to listen to a multicast stream 225.9.13.5 from source 10.1.60.6. No multicast traffic should run over the Frame Relay cloud. R1 should be optimized to handle the multicast traffic because it is already an overtaxed router.

Lab 7: Solution

A few things going on here are important. Isolate the provided information. The source is 10.1.60.6 (VLAN 60 from R6) running over multicast group 225.9.13.5. The destination is clients on Backbone 2 (off of R1).

Remember that multicast trees follow the unicast best-route mentality when traversing a network. This tells you that the Frame Relay line between R6 and R1 is the preferred path. However, it is not allowed to work that way. Who said the CCIE lab was easy?

All routers run the ip multicast-routing global command.

Handle the scenario one step at a time. You can set up R6 as the RP, and E0/0 can join the IGMP group 225.9.13.5 at this point. In a scenario such as this, where no preference is given to sparse-only versus sparse-dense PIM, the latter is typically chosen. (See [Example 3-4](#).)

Example 3-4. Command Entries Edited from show running-configuration of Routers

```
R6(config-if)#ip pim sparse-dense-mode  
R6(config-if)#ip igmp join-group 225.9.13.5
```

Globally, you need to define the RP on each router:

```
R6(config)#ip pim rp-address 10.1.60.6
```

All routers between R6 and R1 (not through the Frame Relay cloud) need to have multicast and PIM enabled.

enabled to forward the traffic.

R1 needs to join the multicast group on its Ethernet segment but needs to be optimized as well. A nonoptimized router spends a lot of time processing packets and using memory that it should not use. This leads you to using the static-group rather than the join-group command. The fact that clients were unable to use IGMP joins should have also told you this. (See [Example 3-5](#).)

Example 3-5. Command Entries Edited from show running-configuration of Routers

```
R1(config-if)#ip pim dense-mode  
R1(config-if)#ip igmp static-group 225.9.13.5
```

The final thing you must consider is the routing of the multicast packets. This chapter has not yet addressed the concept of overriding the multicast routes; however, you need to think of these things and consider how to address issues that you might not have faced prior to seeing them on the CCIE.

Multicast packets are automatically checked for RPF based on the anticipated interface back to the source of the multicast sender. If a multicast packet arrives on an interface that is not the direction back to the sender's IP, the packet is dropped. Because you move multicast packets around, all the interfaces need to be multicast-capable in this scenario, too.

You definitely need to "adjust" R1 for routing. Whether you need to do so with other routers depends on what the IP routing table demands for next hop. On R1, you can adjust the choice manually with a static multicast route as follows:

```
R6(config)#ip mroute 10.1.60.6 255.255.255.255 [protocol-as-number] {rpf IP# | intf  
[(admin. Distance)]}
```

On R1, the RPF IP is the address on R2; or like IP static routes, you can route to the interface itself. The ip mroute command enables you to denote multicast source IP addresses in the address portion of the command.

Lab 7: Configuration

This section presents the router configuration for this lab solution. (See [Example 3-6](#).)

Example 3-6. Command Entries Edited from show running-configuration Routers

```
R6
ip multicast-routing
!
interface ethernet 0
  ip pim sparse-dense-mode
!
interface serial 0
  ip pim sparse-dense-mode
!
!
```

```
R8
ip multicast-routing
ip pim rp-address 10.1.60.6
!
interface serial 0
  ip pim sparse-dense-mode
!
interface ethernet 0
  ip pim sparse-dense-mode
!
```

R2

```
ip multicast-routing
ip pim rp-address 10.1.60.6
!
interface ethernet 0
  ip pim sparse-dense-mode
!
interface serial 1
  ip pim sparse-dense-mode
!
```

R1

```
ip multicast-routing
ip pim rp-address 10.1.60.6
!
interface serial 1
  ip pim sparse-dense-mode
!
interface ethernet 0
  ip pim dense-mode
  ip igmp static-group 225.9.13.5
!
ip mroute 225.9.13.5 255.255.255.255 serial 1
!
```

Controlling Multicast

When it comes to controlling multicast in networks, you face several issues and have several points at which you can control it. Such control is of particular concern when it comes to rate limiting. How can you rate limit multicast traffic? The short answer is, in several ways depending on the device performing the rate limiting.

On the Catalyst 3550, you can rate limit on a per-port basis with a function known as *storm control*. To make sure that multicast traffic occupies no more than 10 percent of a particular port (or EtherChannel group), issue the following command:

```
Cat3550(config-if)#storm-control multicast level 10
```

On a router, inclusive of WAN links, you can rate limit by issuing the `ip multicast rate-limit (in | out) [group-list (acl#)] [source-list (acl#)] interface kbps` command. If this command is not present, no rate limiting is being performed. If this command is present but no bandwidth is set, the default is 0, meaning no multicast is allowed.

Fast Switching

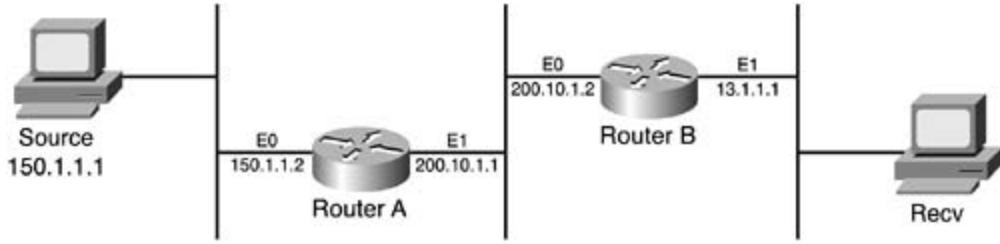
As you might recall, special care was taken with the `ip igmp static-group` command to ensure that multicast packets would be fast switched through a router. Now, consider what you need to do if the scenario calls for the disabling of fast switching.

The process is similar to what you use for unicast forwarding. Fast switching involves the use of a route cache to store recently used route choices and speed up subsequent path selection. To disable this in unicast, use the `no ip route-cache interface` command. In multicast, the logic is the same. The `no ip mroute-cache interface` command handles this.

Multicast Stub

When building a PIM tree, you can have branches (segments) with only one possible way to go in each direction. Similar to a stub network in the unicast world, you can limit the amount of control traffic in and out of the stub area because there is actually no path choice to be made. [Figure 3-12](#) shows a multicast stub network.

Figure 3-12. Multicast Stub Network



On the stub router (Router A), the outward-facing link uses the `ip igmp helper-address 10.0.0.2` interface command. This forwards all IGMP messages to the central router, without processing the typical IGMP report and query messages necessary itself, to make PIM work.

On the central router (Router B), the link facing the stub would have a filter command calling an access list to stop the PIM mechanism between Router A and Router B.

```
RouterB(config)#access-list 11 deny host 10.0.0.1
```

```
RouterB(config-if)#ip pim neighbor-filter 11
```

After these configuration steps, the IGMP messages from any hosts behind Router A forward on to Router B. Router A does participate in any PIM trees and does not participate based on the filter command.

Load Balancing or Disconnected Multicast Networks

Multicast does not offer load balancing or load sharing (in any sense). It performs an RPF check, and the answer is either yes or no, with no gray area. How do you share between equal-cost paths? How do you run multicast between two routers when the network in the middle does not support multicast? Like many things in the CCIE world, you need to think outside the box.

One simple word: *tunnel*. Do not forget about tunnels as part of the solution. Tunnels provide a simple way to encapsulate otherwise nonroutable traffic and deliver it from point A to point B. By encapsulating multicast (or any other) traffic into an IP unicast generic routing encapsulation (GRE) packet, the encapsulated packet takes on unicast properties. With that, the routers in the middle see only an IP packet destined for some place. The unicast IP packet can be load balanced because the router is concerned only with destination now and not source or group information as in the multicast world.

Lab 8: Advanced Multicast Delivery

Working from the network shown in [Figure 3-10](#), enable multicast traffic for group 226.7.6.5 between VLAN A, VLAN B, and source on VLAN 60. The WAN cannot directly carry multicast traffic. Make sure that VLAN B does not use more than 2 Mbps of traffic for multicast.

Lab 8: Solution

As with any other configuration, you must issue the ip multicast-routing global command on all appropriate routers. All Ethernet interfaces need the appropriate ip pim sparse-dense-mode command, too.

To allow multicast through the Frame Relay cloud indirectly, create a tunnel on both R13 and R6, using the following commands:

```
R13(config)#interface Tunnel 0
R13(config-if)#ip unnumbered Serial 1/0
R13(config-if)#ip pim sparse-dense-mode
R13(config-if)#tunnel source Serial 1/0
R13(config-if)#tunnel destination 138.1.11.156
```

This creates the tunnel and allows the encapsulation of multicast packets.

You must complete another step, however, to override the typical RPF check (which looks to Serial 1/0 directly as the path), as follows:

```
R13(config)#ip mroute 10.1.60.0 255.255.255.0 Tunnel 0
```

With the source on VLAN 60, it is not necessary to override multicast routing (RPF) on R6.

For VLAN B's limiting, you must make configuration changes on the Catalyst 3550. Of course, the numbers you pick depend on whether the interface is 10 Mbps or 100 Mbps! Remember that storm control is a percentage-based algorithm.

```
Cat3550(config)#interfaceintf  
! Note: 10 megabit Ethernet interface  
Cat3550(config-if)#storm-control multicast level 2
```

Or

```
Cat3550(config)#interfaceintf  
! Note: 100 megabit Ethernet interface  
Cat3550(config-if)#storm-control multicast level 20
```

If your lab scenario specifies a multicast source, you can place rate limiting on a router with a specific source IP listing instead. The semantics of your lab scenario dictate which way to configure.

Lab 8: Configurations

This lab also demonstrates how to use command entries edited from the show running-configuration on routers. (See [Example 3-7](#).)

Example 3-7. Command Entries Edited from show running-configuration on Routers

R8

```
ip multicast-routing
!
interface ethernet 0
  ip pim sparse-dense-mode
  ip igmp join-group 226.7.6.5
!
interface serial 0
  ip pim sparse-dense-mode
```

R6

```
ip multicast-routing
!
interface ethernet 0
  ip pim sparse-dense-mode
  ip igmp join-group 226.7.6.5
!
interface serial 0
  ip pim sparse-dense-mode
!
interface tunnel 0
  ip unnumbered serial 1.1
  ip pim sparse-dense-mode
  tunnel source serial 1
  tunnel destination 138.1.11.130
```

!

R13

```
ip multicast-routing
!
interface ethernet 1/0
  ip pim sparse-dense-mode
  ip igmp join-group 226.7.6.5
!
interface tunnel 0
  ip unnumbered serial 1/0
  ip pim sparse-dense-mode
  tunnel source serial 1/0
  tunnel destination 138.1.11.156
!
ip mroute 10.1.60.0 255.255.255.0 tunnel 0
```

Cat3550

```
interface 0/8
  description Link to R8-VLAN B
  storm-control multicast level 20
```

NOTE

You do not need to add other VLAN B routers because they will not route multicast traffic anywhere according to the diagram.

DVMRP Multicast Routing

Because multicast routing and unicast routing deal with separate topologies, policy requires that PIM follow the multicast topology to build loop-free distribution trees. PIM can use any unicast routing protocol to reference for RPF checks, but multicast-specific protocols might be better for tree building.

Using Distance Vector Multicast Routing Protocol (DVMRP), Cisco routers can exchange DVMRP unicast routes with other routers or mrouted-based machines. PIM can also use this for RPF information. The important note here is that DVMRP is a routing protocol for unicast routes that are used within the multicast routing topology. It is not a method for routing multicast through a network directly, nor is it a better path mechanism for normal unicast routing.

Cisco routers can exchange DVMRP routes but will not actually route multicast via decisions reached through DVMRP. Running DVMRP allows PIM to use the multicast topology, however, which allows sparse mode PIM throughout the Internet topology. MBONE is another application of this type, where participants use a multicast routing protocol to build efficient multicast topologies over otherwise discontiguous networks.

After DVMRP unicast routing is engaged, learned routes are cached in a separate RIB for DVMRP. PIM prefers routes in the DVMRP RIB to routes in other RIBs learned by other unicast routing protocols.

The DVMRP unicast routing can run on any interface type. With GRE tunnels, a special operating mode exists to dictate the tunnel be used for PIM topology building. Under the tunnel interface, issue the following command:

```
Router(config)#interface tunnel 0  
Router(config-if)#tunnel mode dvmrp
```

As noted earlier, this does not enable true multicast routing decisions but allows PIM to make tree-building decisions based on a more streamlined multicast topology. Overall, the router must know which interfaces to cache DVMRP information for to build a multicast topology. You can accomplish this by issuing the following command:

```
Router(config)#interface intf
! Any interface
Router(config-if)#ip dvmrp unicast-routing
```

By default, only 7000 DVMRP routes are exchanged over any single interface. These interfaces are ones where DVMRP is specifically enabled, or DVMRP tunnels where DVMRP neighbors are discovered. You can change this default number by using the `ip dvmrp route-limit /limit-value` global command. In addition, you can enhance the routing topology by summarizing the address. This is an interface-specific command:

```
Router(config)#interface intf
! Any interface
Router(config-if)#ip dvmrp summary-address net-addr net-mask [metricvalue]
```

DVMRP automatically summarizes to classful boundaries; however, the `ip dvmrp summary-address (mcast-net#)(mask)` interface command enables you to override this. Alternatively, the `no ip dvmrp auto-summary` interface command enables you to turn it off.

Remember about potentially needing to use the `multicast static route` command to override and further manipulate this routing table. Like other routing protocols, you can also apply offset lists to the metric values in more complicated scenarios with the `ip dvmrp metric-offset [in | out] /increment` command.

You might run into increasingly complicated scenarios on the CCIE lab. Just remember unicast routing and processing concepts. After all, multicast routing and processing mirrors unicast to a great extent. Other important points to remember include that you can allow a default route into the PIM unicast topology with the `ip dvmrp default-information originate` command, and you can specifically filter or change routes with the `ip dvmrp accept-filter access-list [distance | ip neighbor-list access-list]` command.

PIM Version 2

Much of the basic multicast operation discussed so far, particularly with the RP, worked with PIM version 1. PIM version 1 had an interesting way of building trees and routing multicast through the unicast routing structure. PIM version 2 made some enhancements to this. Remember the auto-RP feature discussed earlier? That is a Cisco proprietary feature. It is a nice feature, and everyone likes it, but Cisco devices are the only ones that understand it. PIMv2 has a bootstrap router (BSR) that provides the same type of functionality and announcement features. PIMv2 and PIMv1 are not automatically compatible with each other.

PIMv1 worked with RPs in an active mode. In the topology, there could be one or more RPs, but all of them were in an active state and processing messages and tree and routing information. With PIMv2, there is now a concept of backup BSR (RP). With the presence of a backup, the messages that are needed to keep the topology running are fewer than before. Much of the detail, although nice to know, is beyond the scope of this chapter.

If you have PIMv1 routers, do not use a BSR. Use the auto-RP (if all Cisco) feature or manual RP assignments instead. With the BSRs, you can configure multiple BSR candidates within a multicast domain. The one with the highest priority takes over, but this design allows failover concepts within the network.

The BSR handles the announcement features that auto-RP did. A discovery-like feature is also present, in that the BSR does not necessarily need to be the RP within a network.

To configure the PIM version on a router, use the `ip pim version (1 | 2)` global command.

When selecting the BSR, use the `ip pim bsr-candidate src_intf hash-length# priority#` global command. The hash-length value relates to the length used in the hash of exchanged messages. Although not required, it is recommended that this value be the same between all BSR candidates. The higher priority value becomes the BSR.

To make sure PIMv1 and PIMv2 networks do not interfere with one another, or to have two separate PIMv2 domains, set up multicast boundaries. This works both ways. For PIMv2, use the `ip pim border interface` command so that BSR messages do not cross. For PIMv1, use the `ip multicast boundary interface` command and associate it to an access list matching 224.0.1.39 and 224.0.1.40 to prevent the auto-RP multicast groups from traversing that interface.

Beyond that, set up routers to become candidates for acting as RP to some or all multicast groups. Use the `ip pim rp-candidate (src_intf) (ttl#) [group-list (acl#)]` global command to set up a router as an RP candidate.

Lab 9: PIM

Again, using the network described in [Figure 3-10](#), set up Backbone 1 and VLAN A to use PIMv1. R5 needs to automatically announce itself as the RP. Set up VLAN 60 and VLAN B to use PIMv2. All PIMv2 routers need to be BSR candidates, although R3 should win this election. R2 should be RP for the first half of the multicast group range, and R8 should be RP for the second half.

Lab 9: Solution

More complicated labs take some more time to set up. This lab requires a little thinking and tweaking along the way.

VLAN A and Backbone 1 are represented by R5 and R13. To talk to each other, however, Serial 1.1 of R6 must also participate in this version of multicast routing. All routers need IP multicast routing enabled. With this half of the multicast network, working in the Frame Relay cloud, R5 needs to be the RP and announce itself.

This alerts you to a few different requirements. First, PIM sparse dense mode is necessary. Second, because the Frame Relay between R5 and R13 is a multipoint interface on R6, you also need to set up a mapping agent to forward the RP announcements on to R13.

Being a Frame Relay cloud as well, you should have the `ip pim nbma-mode` command on serial interfaces, too.

Although not required, you can also specify IP PIMv1 on R5 and R13. R6 should not have this command because the second portion of this scenario specifically requires version 2.

Looking at the second half of this network and scenario, you can see that multicast is called for on VLAN 60 and VLAN B. There are a number of routers therein. Obviously, each needs IP multicast routing enabled.

The scenario states that all routers here should be BSR candidates; therefore, each needs the `ip pim bsr-candidate` commands, although R3 should have a higher weight than the others to actually be elected the bootstrap router.

After you take care of the BSR, it is time to look at the RPs in this part of the network. R2 and R8 both need to be RPs, although for different groups. Therefore, use the `ip pim rp-candidate` command with a group list calling an access control list on each router.

This exercise calls for a little knowledge of binary to create an access list covering half of the multicast range. Remember that the overall range is 224.0.0.0/4. Therefore, 224.0.0.0/5 is needed for one, and the rest (232.0.0.0/5) goes to the other side. Binary—it makes life exciting!

Lab 9: Configurations

This lab demonstrates another use of command entries and how you can edit them from the `show running-configuration` on routers. (See [Example 3-8](#).)

Example 3-8. Command Entries Edited from `show running-configuration` on Routers

R13

```
ip multicast-routing
ip pim version 1
!
interface ethernet 1/0
  ip pim sparse-dense-mode
!
interface serial 1/0
  ip pim sparse-dense-mode
  ip pim nbma-mode
!
```

R5

```
ip multicast-routing
ip pim version 1
!
interface ethernet 0
  ip pim sparse-dense-mode
!
interface serial 1
  ip pim sparse-dense-mode
  ip pim nbma-mode
!
ip pim send-rp-announce ethernet 0 scope 16
```

R6

```
ip multicast-routing

ip pim bsr-candidate ethernet 0 30 10

ip pim send-rp-discovery scope 16

!

interface serial 1.1

ip pim sparse-dense-mode

ip pim nbma-mode

!

interface ethernet 0

ip pim sparse-dense-mode

!

interface serial 0

ip pim sparse-dense-mode

!
```

R8

```
ip multicast-routing

ip pim bsr-candidate ethernet 0 30 10

!

interface serial 0

ip pim sparse-dense-mode

!

interface ethernet 0

ip pim sparse-dense-mode

!

access-list 8 permit 232.0.0.0 7.255.255.255
```

```
ip pim rp-candidate ethernet 0 group-list 2
```

R3

```
ip multicast-routing
ip pim bsr-candidate ethernet 0 30 20
!
interface ethernet 0
ip pim sparse-dense-mode
!
```

R2

```
ip multicast-routing
ip pim bsr-candidate ethernet 0 30 10
!
interface ethernet 0
ip pim sparse-dense-mode
!
access-list 2 permit 224.0.0.0 7.255.255.255
ip pim rp-candidate ethernet 0 group-list 2
```

Monitoring and Testing

After you configure multicast routing on devices throughout your network topology, it is always good to test the full functionality. In the CCIE lab, the object in any scenario is to think like the router—be the router.

To that end, a number of commands enable you to "see" what the router sees and attempt to think like the router thinks.

show and debug Commands

A variety of show and debug commands enable you to troubleshoot and monitor a multicast network. The basics of troubleshooting multicast networks are similar to those for troubleshooting unicast networks because of the reliance of multicast on the unicast routing table for its decisions.

When troubleshooting multicast, you must consider two primary areas:

- The flow of the packets themselves (for example, comparing the unicast routing table to the configuration commands used)
- The signaling of multicast, RP selection and use, and associated configurations there

Some commands to use are as follows:

```
show ip pim neighbor  
show ip pim interface  
show ip pim rp  
show ip mroute  
show ip mroute summary  
show ip igmp groups  
show ip igmp interface  
show ip rpf (/ip#)  
debug ip pim (multicast#)  
debug ip igmp  
debug ip mroute (multicast#)  
debug ip mpacket
```

mtrace, mrinfo, and mstat Commands

The mtrace, mrinfo, and mstat commands are built in to Cisco IOS Software and provide some useful features.

The mtrace command enables you to perform an RPF check and trace from the multicast source through a multicast tree to a particular destination or what a group might see. The basic command syntax for this command is as follows:

```
mtrace source-addr [destination-addr] [group-addr]
```

Example 3-9 shows some sample output from this command.

Example 3-9. mtrace Command Output

```
Router>mtrace 172.16.0.0 172.16.0.10 239.254.254.254
Type escape sequence to abort.

Mtrace from 172.16.0.0 to 172.16.0.10 via group 239.254.254.254
From source (?) to destination (?)
Querying full reverse path...
0 172.16.0.10
-1 172.16.0.8 PIM thresh^ 0 0 ms
-2 172.16.0.6 PIM thresh^ 0 2 ms
-3 172.16.0.5 PIM thresh^ 0 894 ms
-4 172.16.0.3 PIM thresh^ 0 893 ms
-5 172.16.0.2 PIM thresh^ 0 894 ms
-6 172.16.0.1 PIM thresh^ 0 893 ms
```

The mrinfo command enables you to determine which other routers exchange PIM information with the router currently tested. Use flags to discuss particular capabilities of the multicast

routers, too. The basic command syntax for this command is as follows:

```
mrinfo [mcast-neighbor#] [interface]
```

[Example 3-10](#) shows some sample output from this command.

Example 3-10. mrinfo Command Output

```
Router#mrinfo
```

```
172.31.7.37 (r8.lab.emanon.com) [version cisco 12.1] [flags: PMSA]:  
172.31.7.37 -> 172.31.7.34 (r4.lab.emanon.com) [1/0/pim]  
172.31.7.37 -> 172.31.7.47 (r7.lab.emanon.com) [1/0/pim]  
172.31.7.37 -> 172.31.7.44 (r14.lab.emanon.com) [1/0/pim]  
10.11.26.10 -> 10.11.26.9 (routera.lab.emanon.com) [1/32/pim]
```

The flags included in this output indicate the following:

- P— Prune capable
- M— Mtrace capable
- S— SNMP capable
- A— Auto-RP capable

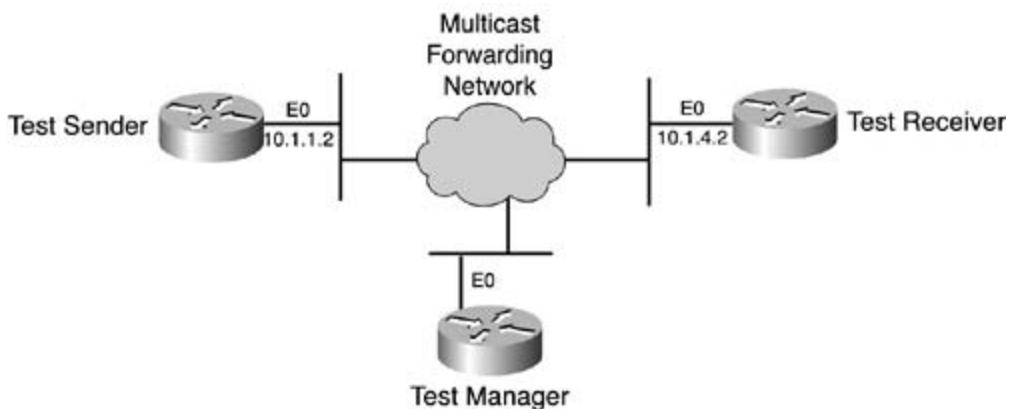
The `show themstat` EXEC command enables you to view the IP multicast packet rates and loss information for a multicast source, destination, or group address. The basic command syntax for this command is as follows:

```
mstat source-addr [destination-addr] [group-addr]
```

Multicast Troubleshooting Example

As you can see from the multicast network in [Figure 3-13](#), multicast packets come into E0 of Router A from source 150.1.1.1 and send to group 225.3.3.3. This yields an S,G of (150.1.1.1, 225.3.3.3).

Figure 3-13. Troubleshooting Multicast Networks



Hosts connected to Router A correctly receive the multicast feed, but those connected to Router B do not. Your first step should be to look at the multicast routing table on both routers. [Example 3-11](#) shows the configuration for Router A.

Example 3-11. Configuration for Router A

```
RouterA#show ip mroute 225.3.3.3

IP Multicast Routing table

Flags: D - Dense, S - Sparse, C - Connected, L - Local, P - Pruned
      R - RP-bit set, F - Register flag, T - SPT-bit set, J - Join SPT
      M - MSDP created entry, X - Proxy Join Timer Running
      A - Advertised via MSDP
```

```

Timers: Uptime/Expires

Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 225.3.3.3), 00:01:23/00:02:59, RP 0.0.0.0, flags: D

    Incoming interface: Null, RPF nbr 0.0.0.0

Outgoing interface list:

    Ethernet1, Forward/Sparse-Dense, 00:01:23/00:00:00

(150.1.1.1, 225.3.3.3), 00:01:23/00:03:00, flags: TA

    Incoming interface: Ethernet0, RPF nbr 0.0.0.0

Outgoing interface list:

    Ethernet1, Forward/Sparse-Dense, 00:01:23/00:00:00

```

Because the router runs in PIM dense mode, the *,G route is not important. The flag showing D denotes dense mode. The S,G route indicates incoming and outgoing interfaces that should be expected. Router A appears to be working correctly. [Example 3-12](#) shows the configuration for Router B.

Example 3-12. Multicast show Commands for Validation

```

RouterB#show ip mroute 225.3.3.3

IP Multicast Routing table

Flags: D - Dense, S - Sparse, C - Connected, L - Local, P - Pruned
      R - RP-bit set, F - Register flag, T - SPT-bit set, J - Join SPT
      M - MSDP created entry, X - Proxy Join Timer Running
      A - Advertised via MSDP

Timers: Uptime/Expires

Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 225.3.3.3), 00:05:36/00:02:19, RP 0.0.0.0, flags: DJC

    Incoming interface: Null, RPF nbr 0.0.0.0

Outgoing interface list:

    Ethernet0, Forward/Sparse-Dense, 00:05:36/00:00:00

```

```
Ethernet1, Forward/Sparse-Dense, 00:05:37/00:00:00
```

The multicast routing table in [Example 3-12](#) does not show the S,G group, which means that Router B is not forwarding the multicast packets. Refer to [Example 3-13](#) to see the show ip pim neighbor command used in validation work.

Example 3-13. Multicast show Commands for Validation

```
RouterB#show ip pim neighbor
```

```
PIM Neighbor Table
```

Neighbor Address	Interface	Uptime	Expires	Ver	Mode
200.10.1.1	Ethernet0	2d00h	00:01:15	v2	

Router A is shown as a PIM neighbor, as expected. [Example 3-14](#) shows the show ip rpf 150.1.1 command used to provide validation.

Example 3-14. Multicast show Commands for Validation

```
RouterB#show ip rpf 150.1.1.1
```

```
RPF information for ? (150.1.1.1)
```

```
RPF interface: Ethernet2
```

```
RPF neighbor: ? (4.1.1.2)
```

```
RPF route/mask: 150.1.1.1/32
```

```
RPF type: unicast (static)
```

```
RPF recursion count: 1
```

```
Doing distance-preferred lookups across tables
```

This shows the IP route to 150.1.1.1 comes up as the Ethernet2 interface of Router B as expected. Based on the figure, E0 should be expected, but you never know what else in a scenario affects the IP routing table. [Example 3-15](#) shows how the multicast debug output for

validation works.

Example 3-15. Multicast debug Output for Validation

```
RouterB#debug ip mpacket

*Jan 14 09:45:32.972: IP: s=150.1.1.1 (Ethernet0)
d=225.3.3.3 len 60, not RPF interface

*Jan 14 09:45:33.020: IP: s=150.1.1.1 (Ethernet0)
d=225.3.3.3 len 60, not RPF interface

*Jan 14 09:45:33.072: IP: s=150.1.1.1 (Ethernet0)
d=225.3.3.3 len 60, not RPF interface

*Jan 14 09:45:33.120: IP: s=150.1.1.1 (Ethernet0)
d=225.3.3.3 len 60, not RPF interface
```

Based on the debug, you see what was determined with the RPF check. The multicast packets arrive on an interface that is not associated with the RPF check; therefore, the interface drops the multicast packets.

The simplest fix to this problem, assuming that the unicast routing table is the way that it is based on other scenario questions or good reasons, is to set a static multicast route for the 225.3.3.3 group's source to reset the expected interface to Ethernet0. The following ip mroute command might assist in fixing this dilemma.

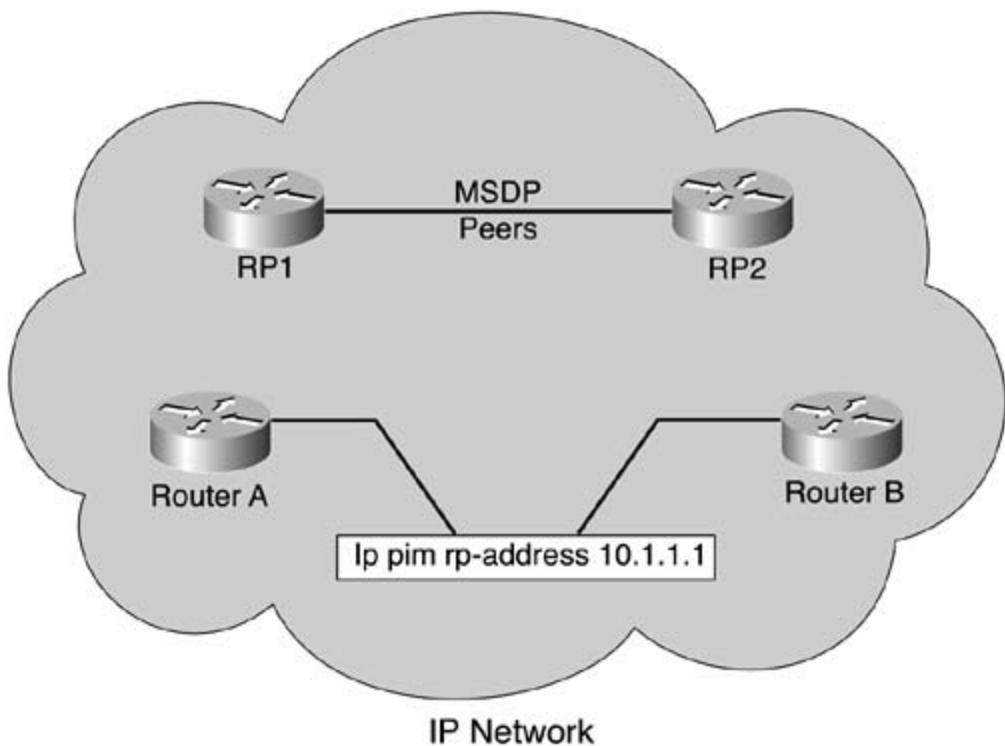
```
Router(config)#ip mroute 150.1.1.1 255.255.255.255 ethernet0
```

Multicast Routing Manager (MRM)

The MRM is a great tool to use on multicast networks and on any routers therein. Three pieces are necessary to perform a "live" multicast test: a test sender (multicast source), test receiver (multicast receiver), and test manager.

The network in [Figure 3-14](#) shows how an MRM test can be laid out.

Figure 3-14. Multicast Testing



The number of multicast routers within the Multicast Forwarding Network is irrelevant. Place the test sender and test receiver appropriately to test and troubleshoot different parts of the network.

The test sender, on its Ethernet0 interface, will use the ip mrm test-sender interface command. Likewise, the test receiver, on its Ethernet0 interface, will use the ip mrm test-receiver interface command.

The test manager will require more configuration steps. First, you must configure access lists delineating the senders and receivers on a network. A standard access list delineates specific hosts. ACL 1 is the sender list and ACL 2 is the receiver list:

```
Manager(config)#access-list 1 permit 10.1.1.2
```

```
Manager(config)#access-list 2 permit 10.1.4.2
```

Next, configure an MRM test and denote the senders and receiver within that test. Notice that the senders' and receivers' lines call the access lists to specify the senders and receivers. You can set more than one concurrent test on the manager:

```
Manager(config)#ip mrm manager mynettest  
Manager(config-mrm)#manager ethernet0 group 239.2.3.4  
Manager(config-mrm)#senders 1  
Manager(config-mrm)#receivers 2 sender-list 1
```

After completing configuration, you can start the test from the EXEC mode using the `mrm test-name start` command.

MRM is a complete test of the multicast network. Senders and receivers must join a specific multicast group (224.0.1.111) to talk with the manager. Control messages are passed through this multicast group. Also, a series of UDP messages and RTP messages test procedures (in addition to the desired group).

After a test begins, the MRM sends unicast control messages to the sender and receivers, after which the manager begins to send test beacons. The sender and receivers send acknowledgments to the beacons and initiate the testing of the configured multicast group. Report information is sent to the manager to determine the success or failure throughout the test.

While the test is in progress, the sender sends RTP packets to the configured multicast group address every 200 milliseconds (default). The receivers expect to receive packets within the same window, thus giving reportable statistics to the manager. If the receivers detect packet loss within a 5-second window, a report is sent to the manager:

```
Manager#mrm mynettest start  
*Mar 20 10:29:51.798: IP MRM test mynettest starts .....
```

```
Manager#
```

No updates automatically appear on the screen. To display a status report at the manager router, enter the following command:

```
Manager#show ip mrm status
```

IP MRM status report cache:

Timestamp	Manager	Test Receiver	Pkt Loss/Dup (%)	Ehsr
*Mar 20 14:12:46	10.1.2.2	10.1.4.2	1 (4%)	29
*Mar 20 18:29:54	10.1.2.2	10.1.4.2	1 (4%)	15

```
Manager#
```

The report shows that the receiver (10.1.4.2) sent two separate status reports (one line each). Each report contains one packet loss during the interval window (default of 1 second). The Ehsr value shows the estimated next sequence number value from the MRM sender. If the MRM receiver sees duplicate packets, it shows a negative number in the Pkt Loss/Dup column.

To stop the test, enter the following command:

```
Manager#mrm mynettest stop
```

```
*Mar 20 10:31:32.018: IP MRM test mynettest stops
```

```
Manager#
```

CCIE Multicast Lab Scenario

When studying multicast for the CCIE lab, think about the wording of things. This chapter provided a number of examples from which you can understand the importance of isolating the key words. You must ascertain exactly how the CCIE lab wants you to perform the work.

When comparing the multicast routing table with the unicast routing table, you might encounter "gotchas," as outlined previously in the "[Multicast Troubleshooting Example](#)" section. You might encounter other unforeseen difficulties. Know where the "IP Multicast" section is on the "Configuration Guide" section of the Documentation CD-ROM. This section is crucial to your research of unknown or unforeseen difficulties. In it, you might also come across small hints that jog your memory.

Further Reading

RFC 2362, *Protocol Independent Multicast-Sparse Mode*

RFC 1075, *Distance Vector Multicast Routing Protocol*

Developing IP Multicast Networks: The Definitive Guide to Designing and Deploying Cisco IP Multicast Networks, Volume I, by Beau Williamson (Cisco Press, 2000)

Cisco Connection Online—Documentation CD—Configuring IP Multicast Guides

Part IV: Performance Management and Quality of Service

[Chapter 4](#) Router Performance Management

[Chapter 5](#) Integrated and Differentiated Services

[Chapter 6](#) QoS — Rate Limiting and Queuing Traffic

Chapter 4. Router Performance Management

At some point in the life cycle of almost every network, some type of quality mechanism must be implemented to provide a level of service. With some networks, it may only be necessary to perform simple hardware or software upgrades every few years. Other networks may require the use of *Service Level Agreements (SLAs)*, either as customer or as service provider, to guarantee a certain level of service. A number of methods can be used to establish a certain level of quality of service (QoS); the method that you choose will be determined by the availability of the solution, the cost, and the value that it presents to your organization. When determining your required level of service, you must decide whether you require a "best effort" level of quality, or whether you require a certain level of guaranteed QoS. For instance, your network may only require a guaranteed amount of bandwidth availability during certain peak hours of operation, a certain data transfer rate over the transmission medium, or you may have applications on your network that have very specific requirements that must be met. In each of these situations, you can use a QoS method to ensure that your network is performing within the established limits. You must also consider that to achieve guaranteed levels of service, redundant links and hardware may be required, costing more money to implement and support.

In many cases, network quality issues result from issues that cannot be fixed using QoS. Before designing or applying Cisco IOS QoS techniques, verify that your network is already operating at its best. For instance, I am sure everyone has seen at least one instance where a certain router is constantly causing network delays. Users on the network commonly complain that the network is slow, but no one can determine why until someone takes a good look at the router's Ethernet interface and notices a high number of errors. The type of errors found on the interface indicates a bad Ethernet cable, and after the cable is replaced, everything works great. The following simple quality-control issues are not addressed with Cisco IOS QoS:

- Router resource limitations— Routers dropping packets because their resources are exhausted
- Router hardware problems— Bad interfaces causing performance problems
- Layer 1 network problems— Bad cabling or cables that exceed specifications

Router resource limitations generally occur when routers are no longer able to support traffic characteristics, or features that are currently used in today's networks are still in use. These issues can usually be fixed by adding memory or replacing outdated equipment. Router hardware problems, which tend to be harder to find, but easiest to fix, tend to disappear when you start taking a good look at your network. And Layer 1 cabling problems can cause myriad strange and complicated problems that are difficult to trace.

The beginning of this chapter covers quality-control issues, and includes several quick troubleshooting exercises that lead to a speedy problem diagnosis and resolution. An entire book could be dedicated to quality-control issues; this chapter just identifies tools that already exist within Cisco IOS Software, and shows how the output from these tools can provide valuable troubleshooting data. The output from the commands covered in this section is referred to throughout the rest of this book.

After this discussion, the chapter takes over where the first edition left off by exploring ATM QoS technologies. The ATM section begins by providing a quick ATM review before diving directly into ATM QoS. This chapter then explores the different Cisco IOS switching methods, and how they

can be used to improve network interface performance. This chapter ends with an in-depth look at interface compression, exploring how you can use it to improve network performance by sending more packets over existing interfaces without costly network bandwidth upgrades.

Determining Router Performance

Before attempting to determine the types of QoS that are required on your network, accomplish the following few tasks first:

- Verify that your network hardware is properly configured and in good working order.
- Perform a network baseline to determine whether your hardware is adequate to support your requirements, and whether you have sufficient bandwidth to support your network applications. The baseline also shows whether any of the applications on your network have certain link speed or quality requirements.
- Interview key network stakeholders. Determine who needs to be involved in network planning activities, and make sure that you know their current and future network requirements.

Verifying Cisco IOS Software and Memory Configuration

A number of key commands help you determine whether a router running Cisco IOS Software is working properly. Gather and record information over a period of time, taking into consideration how your network performs under peak- and low-utilization periods. How long you gather and record information depends on the size and scale of your network. To begin, determine which version of Cisco IOS Software your routers are currently running and check the amounts of Flash memory and DRAM on your router. Verify that the version of software and amount of memory are adequate to support the features that you currently have and will require in the near future. On a Cisco router, to find the version of Cisco IOS Software and the amount of installed memory, use the `show version` command, as shown in [Example 4-1](#).

Example 4-1. `show version` Command

```
Router#show version

Cisco Internetwork Operating System Software
IOS (tm) C2600 Software (C2600-JS-M), Version 12.0(3)T3, RELEASE SOFTWARE (fc1)
Copyright (c) 1986-1999 by cisco Systems, Inc.

Compiled Thu 15-Apr-99 17:05 by kpma

Image text-base: 0x80008088, data-base: 0x80C2D514

ROM: System Bootstrap, Version 11.3(2)XA4, RELEASE SOFTWARE (fc1)

2610 uptime is 2 hours, 21 minutes

System restarted by reload
```

```
System image file is "flash:c2600-js-mz.120-3.T3.bin"

cisco 2610 (MPC860) processor (revision 0x203) with 24576K/8192K bytes of memory.

Processor board ID JAD04180ETY (2670216847)

M860 processor: part number 0, mask 49

Bridging software.

X.25 software, Version 3.0.0.

SuperLAT software copyright 1990 by Meridian Technology Corp).

TN3270 Emulation software.

1 Ethernet/IEEE 802.3 interface(s)

2 Serial network interface(s)

16 terminal line(s)

32K bytes of non-volatile configuration memory.

8192K bytes of processor board System flash (Read/Write)

Configuration register is 0x2102

Router#
```

In this example, the router is running Cisco IOS Release 12.0(3), image name c2600-js-mz.120-3.T3.bin stored in 8 MB of Flash memory; this router also has 32 MB of DRAM, 25 MB of system memory, and 8 MB shared packet memory. Cisco IOS Software versions and quantities of Flash memory and random-access memory should be tracked and recorded for reference purposes. You can use this information to track software bugs, track features, and prepare for upgrades. At this time, it is also useful to note how the router was started; in the example, this router was restarted by reload. It is always good to note when the router has an error, and if so, remember the error and watch for future recurrences:

```
System restarted by error - a SegV exception, PC 0x808da564
```

Logging unexpected system restarts can save troubleshooting time and provide valuable

information that you can use to find the source of the router restarts. You can find this information by searching for the error at Cisco.com, or opening a case with the Cisco Technical Assistance Center (TAC). You may find the following tools useful when diagnosing router restarts:

- Bug Tracker
- Searching the TAC website
- Error Message Decoder

If you find that your routers frequently experience real hardware or software problems, concentrate on fixing the problems first; after you have fixed the problems, you can approach your network application's requirements and find solutions to enhance application performance.

Determining Network Application Requirements

If possible, try to obtain information on new network applications that will be deployed in your network. Try to find out what their network use requirements will be, how many computers will use the new applications, where they are located, and whether there are any bandwidth or link quality requirements. If you cannot increase the amount of bandwidth on your network, you may still be able to increase network performance by the use of Cisco IOS Software QoS features, including the following:

- Simple queuing and traffic prioritization
- Advanced switching methods
- Compression
- Congestion avoidance
- Advanced queuing and congestion management
- Traffic shaping
- Traffic policing
- Applying ATM QoS
- Low Latency Queuing
- Classifying traffic to provide QoS at various network points

The battle to learn and understand the effects of new applications and technologies will always drive the need for network quality enhancements. For instance, you may find that branch routers with smaller WAN links require compression to support the network applications that have been or are going to be deployed. After determining that the router will require the applications of compression techniques, you may find that the compression algorithm is very demanding on the router's processor or memory. After you have decided to move forward with the plan to implement compression, you may have to increase the amount of memory or, in some cases, replace older equipment to support other technologies.

To check the processor use and process CPU allocation, use the show processes cpu command, as shown in [Example 4-2](#).

Example 4-2. show processes cpu Command

```
Router#show processes cpu
```

```
CPU utilization for five seconds: 1%/0%; one minute: 0%; five minutes: 0%
```

PID	Runtime(ms)	Invoked	uSecs	5Sec	1Min	5Min	TTY	Process
1	4	1650	2	0.00%	0.00%	0.00%	0	Load Meter
2	1573	2653	592	1.31%	0.49%	0.34%	0	Exec
3	5701	990	5758	0.00%	0.04%	0.05%	0	Check heaps
4	0	1	0	0.00%	0.00%	0.00%	0	Pool Manager
5	0	2	0	0.00%	0.00%	0.00%	0	Timers
6	4	61	65	0.00%	0.00%	0.00%	0	Serial Backgroun
7	0	276	0	0.00%	0.00%	0.00%	0	Environmental mo
8	0	143	0	0.00%	0.00%	0.00%	0	ARP Input
9	5	6	833	0.00%	0.00%	0.00%	0	DDR Timers
10	0	2	0	0.00%	0.00%	0.00%	0	Dialer event
11	8	2	4000	0.00%	0.00%	0.00%	0	Entity MIB API
12	0	1	0	0.00%	0.00%	0.00%	0	SERIAL A'detect
13	0	1	0	0.00%	0.00%	0.00%	0	Critical Bkgnd
14	52	992	52	0.00%	0.00%	0.00%	0	Net Background
15	4	59	67	0.00%	0.00%	0.00%	0	Logger
16	48	8228	5	0.00%	0.00%	0.00%	0	TTY Background
17	8	8380	0	0.00%	0.00%	0.00%	0	Per-Second Jobs
18	16	8312	1	0.00%	0.00%	0.00%	0	Partition Check
19	88	725	121	0.00%	0.00%	0.00%	0	Net Input
20	12	1651	7	0.00%	0.00%	0.00%	0	Compute load avg
21	3915	141	27765	0.00%	0.05%	0.00%	0	Per-minute Jobs

The first line is often the most important part of the show processes cpu command: CPU utilization for five seconds: 1% /0% ; one minute: 0% ; five minutes: 0% . This one line displays the CPU utilization in 5-second, 1-minute, and 5-minute increments. This data can be displayed locally on the router by repeatedly issuing the command for immediate use, or you can use data collection software to collect data over a period of time and use it to find network trends, and determine future network requirements. The router shown in the preceding example is running at 0-percent utilization. If you notice a router that constantly runs at or more than 75-percent utilization, you may have to consider a router upgrade, or, in the case of the previous compression example, you may consider upgrading the smaller WAN circuit and disabling compression.

To gather performance trend information from a router, the output of the show processes cpu command is most valuable when gathered over a period of time, including peak- and low-traffic times. If processor utilization is high, log the process IDs from the PID column that are consuming the most time. You might be able to disable some processes to save resources.

While gathering processor utilization, you can gather memory utilization as well. Although sometimes difficult to read or understand, the show memory commands display quite a bit of information about the system utilization. There are many variations of the show memory command, one of the most useful of which is the show memory dead command.

As shown in [Example 4-3](#), the show memory dead command displays a summary of the memory use, total, used, and free memory statistics, and then goes on to display all the dead processes that still have memory allocated for their use. If this number is large, you may need to find the dead process and work with the Cisco TAC and fix the problem.

Example 4-3. show memory dead Command

```
Router#show memory dead
```

	Head	Total(b)	Used(b)	Free(b)	Lowest(b)	Largest(b)			
Processor	811E15FC	6416900	3884876	2532024	2495784	2508960			
I/O	1800000	8388608	1566808	6821800	6819308	6821756			
Processor memory									
Address	Bytes	Prev.	Next	Ref	PrevF	NextF	Alloc	PC	What
8120E740	64	8120E6E8	8120E7AC	1			808AF3AC		CEF process
812A3F44	92	812A3EB0	812A3FCC	1			801D4870		TTY timer block
812A8C00	24	812A8BBC	812A8C44	1			808AF3AC		CEF process
812A8DDC	24	812A8D98	812A8E20	1			808AF3A0		CEF process

In addition to displaying the memory summary and memory allocated for dead processes, it is also helpful to check for memory allocation failures, using the show memory failures alloc

command. This command displays any memory allocation failures, which, when gathered over a period of time, might indicate a need to increase the amount of memory. Under normal circumstances, this command should not have any output.

As a rule, routers should never run at a constant high processor or memory load. There are a number of beliefs about how one should judge the processor and memory utilization of their routers. Generally, as a precautionary method, before performing any QoS feature additions, make sure that your routers can handle the additional load added by the new QoS techniques. If your router's memory utilization is already high, adding new features, even those as simple as a change in switching modes, such as Cisco Express Forwarding (CEF) switching, may push the router over its limits. After you have verified that the router has the basic capabilities to perform the functions that you require, using the processor and memory commands just shown, or you have identified the need for a router upgrade or replacement, next verify that the router has enough interface capacity to handle the proposed traffic load. The next section covers router interface performance evaluation. This section shows you how to identify interface hardware and cable faults, traffic bottlenecks, and the efficiency of the route switch-mode selection.

Verifying Router Interface Performance

One of the most useful performance management show commands is the show interface command. The show interface commands display information about interface hardware, configuration, utilization, errors, and queuing. [Example 4-4](#) shows the output for the show interface serial command, and [Table 4-1](#) shows the show interface serial command output descriptions.

Example 4-4. show interface Output

```
Router#show interface serial s 0/1

Serial0/1 is up, line protocol is up

Hardware is PowerQUICC Serial

Internet address is 175.25.33.98/24

MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
      reliability 255/255, txload 1/255, rxload 1/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input 00:00:02, output 00:00:03, output hang never

Last clearing of "show interface" counters never

Input queue: 0/75/0 (size/max/drops); Total output drops: 0

Queueing strategy: weighted fair
```

```

Output queue: 0/1000/64/0 (size/max total/threshold/drops)
  Conversations 0/2/256 (active/max active/max total)
  Reserved Conversations 0/0 (allocated/max allocated)

5 minute input rate 0 bits/sec, 0 packets/sec

5 minute output rate 0 bits/sec, 0 packets/sec

  179 packets input, 12647 bytes, 0 no buffer
  Received 70 broadcasts, 0 runts, 0 giants, 0 throttles
  1 input errors, 0 CRC, 1 frame, 0 overrun, 0 ignored, 0 abort
  173 packets output, 17321 bytes, 0 underruns
  0 output errors, 0 collisions, 78 interface resets
  0 output buffer failures, 0 output buffers swapped out
  106 carrier transitions

  DCD=up  DSR=up  DTR=up  RTS=up  CTS=up

```

Table 4-1. show interface serial Output Description

Item	Description
Hardware is PowerQUICC Serial	Describes the hardware name for the interface specified. In this case, the hardware is a PowerQUICC WIC-1T Serial module. A more detailed hardware type description and interface specific troubleshooting counters can be found using the show controllers command.
Internet address is 175.25.33.98/24	The IP address assigned to the interface. This information only appears on IP interfaces.
MTU 1500 bytes	MTU size for this interface. You can change the MTU size for an interface by using the mtu command in interface configuration mode. The no mtu command sets the MTU size to default.

BW 1544 Kbit	<p>Displays the bandwidth for this interface. The bandwidth value does not actually change the bandwidth available for the interface. This command just provides a metric that is used to limit Hello traffic for the EIGRP or IGRP routing protocols.</p> <p>The default bandwidth value will be that of the interface, or another more precise value that can be manually entered using the bandwidth command in interface configuration mode.</p>
DLY 20000 usec	<p>The average interface delay of the interface in microseconds. Also, note that the Delay value shown here is only a metric that is to be used for EIGRP or IGRP routing protocols.</p> <p>You can change the delay for an interface by using the delay command in interface configuration mode.</p>
reliability 255/255	<p>The average reliability of the link over a period of 5 minutes.</p> <p>255/255 refers to 100 percent.</p> <p>127/255 would be 50 percent.</p> <p>1/255 would be 0 percent.</p>
txload 1/255	The transmit load for the interface over a 5-minute period. A load of 255/255 is 100-percent interface utilization.
rxload 1/255	The receive load for the interface over a 5-minute period. A load of 255/255 is 100-percent interface utilization.
Encapsulation HDLC	The interface encapsulation type.
loopback not set	Shows whether a loopback has been configured. Interface loopbacks can be used to test physical connectivity problems by transmitting a signal to a remote destination, sometimes referred to as "looping an interface" to a service provider. To configure an interface loopback, use the loopback command in interface configuration mode.
Keepalive set (10 sec)	<p>Displays the keepalive for the interface. The standard keepalive for a serial interface is 10 seconds.</p> <p>To change the interface keepalive, use the keepalive command under interface configuration mode.</p>
Last input 00:00:02	Displays the last time input was received on this interface.
output 00:00:03	Displays the last time output was transmitted on this interface.
output hang never	Displays the last time the interface was reset because a transmission took too long.
Last clearing of show interface counters never	<p>Displays the last time the counters for this interface were cleared.</p> <p>You can clear the interface counters by using the clear interface command from enable mode.</p>

Input queue: 0/75/0 (size/max/drops)	Displays the input queue size for the interface. size shows the current input queue size. max shows the maximum size of the queue. drops displays the number of packets dropped when the maximum queue size is exceeded.
Total output drops: 0	Displays the total number of output drops. Output drops occur when the router is attempting to transmit data and has no available buffers and so the packet is dropped.
Queuing strategy: weighted fair	Displays the queuing strategy for the interface. The default queuing type for a serial interface under 2 Mb (E1) is Weighted Fair. If no queuing type has been configured, or Weighted Fair Queuing has been disabled, the default queuing type is FIFO.
Output queue: 0/1000/64/0 (size/max total/threshold/drops)	Displays the output queue size for the interface. size shows the current size of the queue. max total shows the maximum size of the queue. threshold shows the number of packets that can be stored in the queue before new packets are discarded. drops shows the number of dropped packets.
Conversations 0/2/256 (active/max active/max total)	Displays the Weighted Fair Queuing settings for the interface. Weighted Fair Queuing is covered in detail in the next chapter. active displays the current number of Weighted Fair Queuing conversation queues. max active displays the maximum number of Weighted Fair Queuing queues that can concurrently be active. max total displays the total number of dynamic Weighted Fair Queuing queues.
Reserved Conversations 0/0 (allocated/max allocated)	When RSVP has been enabled, the current number of RSVP resource allocations and maximum number of RSVP resource allocations are displayed.
5 minute input rate 0 bits/sec, 0 packets/sec	Displays the 5-minute average input rate for the interface.
5 minute output rate 0 bits/sec, 0 packets/sec	Displays the 5-minute average output rate for the interface.

235 packets input	These counters display the following:
15967 bytes	The number of packets received.
0 no buffer	The number of bytes received on the interface. The number of times the router ran out of buffer space.
Received 126 broadcasts	These counters display the following: The number of broadcasts received.
0 runts	The number of runts received. A runt is a packet that is smaller than the minimum packet size for the interface.
0 giants	The number of giants received. A giant is a packet that exceeds the MTU size for the interface.
0 throttles	The number of throttles received. A throttle occurs when the router runs out of buffer or processor resources, and as a result, the interface's receiver is disabled.
2 input errors	These counters display the following: The combined number of all input errors. An input error is any packet that arrives at the interface with any error type. Packets with more than one error type are only counted once.
0 CRC	The number of CRC errors received. This number should be less than 0.0001 percent of the total bytes received on the interface using the formula $(\text{CRC errors}/\text{total bytes}) \times 100 = \text{Percentage CRC errors}$. High errors could indicate Layer 1 problems. The number of incoming framing errors received.
2 frame	The number of buffer overruns occurring on incoming packets. An overrun occurs when the interface is receiving data faster than the system buffers can process it.
0 overrun	
0 ignored	The number of ignored packets. Packets are ignored when the interface runs out of buffer space and has to ignore new packets until resources become available.
0 abort	The abort counter indicates the number of times the interface received an illegal series of 1s. Interface aborts usually indicate a clocking error.
236 packets output	These counters display the following: The number of packets transmitted.
22838 bytes	The number of bytes transmitted.
0 underruns	The number of times that the router detects that the data sender is sending faster than the router can receive.
0 output errors	These counters display the following:

0 collisions	The number of output errors. The number of packets retransmitted because of collisions—serial interfaces should not have collisions.
80 interface resets	The number of times the interface has reset itself. These counters display the following:
0 output buffer failures	The number of times the router received a no resource error upon output.
0 output buffers swapped out	The number of times the router swapped packets to DRAM.
106 carrier transitions	The number of carrier transitions sensed on this interface. A carrier transition occurs when the carrier detect signal changes state.
DCD=up	DCD(Data Carrier Detect)— Signal sent by DCE indicating that the carrier detect signal has been received from the DTE.
DSR=up	DSR(Data Set Ready)— Signal sent by the DCE to notify the DTE that the DCE is ready.
DTR=up	DTR(Data Terminal Ready)— Signal sent by the DTE to the DCE for new connections or to maintain an existing connection.
RTS=up	RTS(Request to Send)— Signal sent by the DTE to notify the DCE that the DTE is ready to transmit.
CTS=up	CTS(Clear to Send)— Sent by the DCE indicating that the DCE is ready to receive data from the DTE.

[Example 4-5](#) shows the output from the show interface fastethernet command, and [Table 4-2](#) shows the command output descriptions.

Example 4-5. show interface fastethernet Command

```
1750a>show interface fastethernet 0

FastEthernet0 is administratively down, line protocol is down

Hardware is PQUICC_FEC, address is 0004.2722.81d8 (bia 0004.2722.81d8)
MTU 1500 bytes, BW 100000 Kbit, DLY 100 usec,
      reliability 255/255, txload 1/255, rxload 1/255
Encapsulation ARPA, loopback not set
Keepalive set (10 sec)

Auto-duplex, 10Mb/s, 100BaseTX/FX
```

```

ARP type: ARPA, ARP Timeout 04:00:00

Last input never, output 01:03:50, output hang never

Last clearing of "show interface" counters never

Queueing strategy: fifo

Output queue 0/40, 0 drops; input queue 0/75, 0 drops

5 minute input rate 0 bits/sec, 0 packets/sec

5 minute output rate 0 bits/sec, 0 packets/sec

0 packets input, 0 bytes

Received 0 broadcasts, 0 runts, 0 giants, 0 throttles

0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored

0 watchdog

0 input packets with dribble condition detected

177 packets output, 35436 bytes, 0 underruns

0 output errors, 0 collisions, 0 interface resets

0 babbles, 0 late collision, 0 deferred

0 lost carrier, 0 no carrier

0 output buffer failures, 0 output buffers swapped out

```

Table 4-2. Ethernet-Specific show interface Output

Item	Description
FastEthernet0 is administratively down, line protocol is down.	<p>Displays the current interface and line protocol states; the possible states for Fast Ethernet interfaces are administratively up or down.</p> <p>up</p> <p>down</p> <p>administratively down</p> <p>For an interface to be in an up state, it must have received a keepalive within the amount of time configured.</p>

Hardware is PQUICC_FEC	Displays the type of hardware installed.
address is 0004.2722.81d8 (bia 0004.2722.81d8)	Displays the current MAC address and the burned-in address (BIA). You can change the MAC address by using the mac-address command in interface configuration mode.
MTU 1500 bytes	MTU.
BW 100000 Kbit	Bandwidth.
DLY 100 usec	Delay of the interface in microseconds. These values are usually best left at their intended values; changing the bandwidth or delay of an interface delay or bandwidth does not change the actual value; however, MTU values are sometimes changed to provide interoperability between different vendors' hardware. These values do not change on a dynamic basis.
Auto-duplex	Duplex mode for the interface. The duplex mode for the interface can be changed using either the full-duplex or half-duplex commands in interface configuration mode.
10Mb/s	Displays the speed of the interface. For Fast Ethernet interfaces or greater, you can change the interface speed by using the speed command in interface configuration mode. The speed can either be forced to a specific speed, or if the speed has been changed, it can be set back to automatic by specifying auto.
100BaseTX/FX	Displays the Ethernet media type.
ARP type: ARPA	Displays the ARP type. You can change the ARP type by using the arp type command in interface configuration mode. The default ARP type is ARPA.
ARP Timeout 04:00:00	Displays the ARP timeout [more]. You can change the ARP timeout by using the arp timeout command in interface configuration mode.
Queuing strategy: fifo	Displays the queuing strategy for the interface; on Ethernet interfaces, the default queuing type is FIFO.
0 watchdog	Displays the number of times the watchdog timer has expired. The watchdog timer usually expires when packet sizes exceed 2048 bytes.
0 input packets with dribble condition detected	Displays the number of frames that are oversized but still forwarded.
0 interface resets	Displays the number of times the interface has reset itself.

0 collisions	Indicates the number of collisions received on an interface. Collisions do not typically occur on Fast Ethernet interfaces.
0 babbles	These counters display the following: The number of times the transmit jabber timer expired.
0 late collision	The number of late collisions, when a collision occurs after the frame preamble has been transmitted.
0 deferred	The number of packets that have been deferred because the carrier was asserted.
0 lost carrier	Displays the number of times the interface lost the carrier during transmission.
0 no carrier	Displays the number of times the interface found no carrier during transmission.

After verifying the state of the interface over a period of time, you will be able to determine the type of problem that the router in question is displaying. At this point, you should see a clear trend pointing you in one of three directions. Perhaps the router is out of resources and dropping packets. Or, the router has a physical layer quality problem. Neither of these problems can be fixed with QoS. Alternatively, perhaps the router is under a load of traffic that requires additional tuning, and the network quality may be improved using QoS:

- A router resource problem— Indicated by a large number of throttles or buffer failures. This may be fixed with buffer tuning, but will, most likely, eventually require a router or memory upgrade depending on the situation.
- A physical layer problem— Indicated by a large number of errors, which can be fixed using good old-fashioned troubleshooting.
- A high traffic load on the router— Indicated by a high txload, rxload, a high number of dropped packets, underruns, and buffer errors.

To further isolate a problem with the quality of interface performance, you can take a few more steps. You can take a more detailed look at the interface controllers or, if the interface has an integrated channel service unit/data service unit (CSU/DSU), you can monitor any alarm conditions. When troubleshooting link-quality problems, one of the first places to look is the show controllers command. The show controllers command displays information about the interface hardware, as well as cable type and clocking information. The last few lines of the show controllers command also display hardware-specific errors. [Example 4-6](#) shows the show controllers serial command.

Example 4-6. show controllers serial Command Output

```
Router#show controller s 0/1
```

```
Interface Serial0/1
```

```
Hardware is PowerQUICC MPC860
```

DTE V.35 TX and RX clocks detected.

edb at 0x8129D3E8, driver data structure at 0x812A2958

SCC Registers:

General [GSMR]=0x2:0x00000030, Protocol-specific [PSMR]=0x8

Events [SCCE]=0x0000, Mask [SCCM]=0x001F, Status [SCCS]=0x06

Transmit on Demand [TODR]=0x0, Data Sync [DSR]=0x7E7E

Interrupt Registers:

Config [CICR]=0x00367F80, Pending [CIPR]=0x00000800

Mask [CIMR]=0x20200400, In-srv [CISR]=0x00000000

Command register [CR]=0x640

Port A [PADIR]=0x0000, [PAPAR]=0xFFFF

[PAODR]=0x0000, [PADAT]=0xF0F7

Port B [PBDIR]=0x03A0F, [PBPAR]=0x0C00E

[PBODR]=0x0000E, [PBDAT]=0x31DDD

Port C [PCDIR]=0x00C, [PCPAR]=0x000

[PCSO]=0x0A0, [PCDAT]=0xF30, [PCINT]=0x00F

Receive Ring

rmd(68012330): status 9000 length 18 address 1935788

rmd(68012338): status 9000 length 11D address 1932388

rmd(68012340): status 9000 length 18 address 1938508

rmd(68012348): status 9000 length 18 address 1937E88

rmd(68012350): status 9000 length 18 address 1933D88

rmd(68012358): status 9000 length 18 address 1937808

rmd(68012360): status 9000 length 18 address 1937188

rmd(68012368): status 9000 length 18 address 1934A88

rmd(68012370): status 9000 length 11D address 1936488

rmd(68012378): status 9000 length 18 address 1935E08

rmd(68012380): status 9000 length 11D address 1934408

```
rmd(68012388): status 9000 length 18 address 1933088  
rmd(68012390): status 9000 length 18 address 1936B08  
rmd(68012398): status 9000 length 18 address 1933708  
rmd(680123A0): status 9000 length 18 address 1932A08  
rmd(680123A8): status B000 length 18 address 1938B88
```

Transmit Ring

```
tmd(680123B0): status 5C00 length 18 address 193A158  
tmd(680123B8): status 5C00 length 18 address 193A158  
tmd(680123C0): status 5C00 length 18 address 193A158  
tmd(680123C8): status 5C00 length 18 address 193A158  
tmd(680123D0): status 5C00 length 18 address 193A158  
tmd(680123D8): status 5C00 length 123 address 1950098  
tmd(680123E0): status 5C00 length 123 address 194DE38  
tmd(680123E8): status 5C00 length 18 address 193A158  
tmd(680123F0): status 5C00 length 18 address 193A158  
tmd(680123F8): status 5C00 length 18 address 193A158  
tmd(68012400): status 5C00 length 18 address 193A158  
tmd(68012408): status 5C00 length 18 address 193A158  
tmd(68012410): status 5C00 length 18 address 193A158  
tmd(68012418): status 5C00 length 123 address 194F2D8  
tmd(68012420): status 5C00 length 123 address 1950098  
tmd(68012428): status 7C00 length 18 address 193A158
```

SCC GENERAL PARAMETER RAM (at 0x68013D00)

Rx BD Base [RBASE]=0x2330, Fn Code [RFCR]=0x18

Tx BD Base [TBASE]=0x23B0, Fn Code [TFCR]=0x18

Max Rx Buff Len [MRBLR]=1548

Rx State [RSTATE]=0x18008440, BD Ptr [RBPTR]=0x2380

Tx State [TSTATE]=0x18000548, BD Ptr [TBPTR]=0x23B8

```
SCC HDLC PARAMETER RAM (at 0x68013D38)

CRC Preset [C_PRES]=0xFFFF, Mask [C_MASK]=0xF0B8

Errors: CRC [CRCEC]=0, Aborts [ABTSC]=0, Discards [DISFC]=0

Nonmatch Addr Cntr [NMARC]=0

Retry Count [RETRC]=0

Max Frame Length [MFLR]=1608

Rx Int Threshold [RFTHR]=0, Frame Cnt [RFCNT]=65046

User-defined Address 0000/0000/0000/0000

User-defined Address Mask 0x0000
```

buffer size 1524

PowerQUICC SCC specific errors:

```
0 input aborts on receiving flag sequence
0 throttles, 0 enables
0 overruns
0 transmitter underruns
0 transmitter CTS losts
```

Another command that comes in handy when troubleshooting WAN interface card (WIC) modules with integrated CSU/DSU controller's link quality is the show service-module serial command. As shown in [Example 4-7](#), this command displays information about the internal CSU/DSU, such as the alarm status and self-test information. You should note and track CSU/DSU alarms over time. [Example 4-7](#) shows the show service-module serial command output, and [Table 4-3](#) describes the output.

Example 4-7. show service module serial Command Output

```
Router#show service-module serial 0/0

Module type is 4-wire Switched 56

Hardware revision is B, Software revision is 1.00,
Image checksum is 0x42364436, Protocol revision is 1.0
```

Receiver has no alarms.

CSU/DSU Alarm mask is 0

Current line rate is 56 Kbits/sec

Last module self-test (done at startup): Passed

Last clearing of alarm counters 02:13:56

oos/oof	:	0,
loss of signal	:	0,
loss of frame	:	0,
rate adaptation attempt:	:	0,

Table 4-3. show service-module serial *Command Output*

Item	Description
Module type is 4-wire Switched 56	Type of CSU/DSU module.
Hardware revision is B, Software revision is 1.00	
Image checksum is 0x42364436, Protocol revision is 1.0	
Receiver has no alarms, CSU/DSU Alarm mask is 0	This area shows any alarms that are currently being detected by the CSU/DSU.
Current line rate is 56 Kbits/sec	Displays the current rate of line.
Last module self-test (done at startup): Passed	Displays the status of the last module self-test.
Last clearing of alarm counters 02:13:56	Displays the last time the CSU/DSU alarm counters were cleared.
oos/oof: 0,	The out-of-synchronization (OOS) alarm indicates a clocking synchronization problem. An out-of-frame (OOF) alarm indicates about one-fourth of the framing bits have been missed.
Loss of signal: 0,	A loss-of-signal (LOS) alarm indicates that no physical signal is detected.
Loss of frame: 0,	A loss-of-frame (LOF) alarm indicates missing framing bits.

Rate adaptation attempt: 0,

Indicates that the receiver attempted rate adaptation.

After you have either fixed a router interface problem, or verified that the router does not have any hardware or software problems that may be causing link-quality issues, you can address two more issues before moving on to QoS configuration. First, you can verify that the router is using the most efficient switching mode possible; and then, if the interface is still too congested, you may need to consider compression or QoS.

ATM: The Other WAN Technology

One of the obstacles network professionals encounter on a regular basis is the introduction of new Although Asynchronous Transfer Mode (ATM) is not a new technology—the first ATM specifications developed in the early 1990s, and ATM hardware appeared soon after—and although most network have plenty of experience with other WAN protocols such as High-Level Data Link Controller (HDLC Relay, and X.25, many people are not as familiar with the newer ATM technologies. The goal of this not to repeat the ATM information from Volume I of this series; this section is designed to provide understanding of ATM router performance and QoS technologies. This section explores the following topics:

- Understanding basic ATM concepts
- Comparing ATM and Frame Relay technologies
- ATM performance management (displaying interface data, and basic troubleshooting of ATM)
- Basic ATM QoS on Cisco routers (concepts, application, and troubleshooting)

The Similarities and Differences of ATM and Frame Relay

All the Layer 2 WAN technologies mentioned earlier in this section share several similarities. For instance, [Table 4-4](#) shows, HDLC, PPP, ISDN, X.25, and Frame Relay all have similar Layer 2 frame formats based on similar framing Layer 2 standards. Link Access Procedure, Balanced (LAPB); Link Access Procedure for D channel (LAPD); Link Access Procedure for Frame Relay (LAPF), and Synchronous Data Link Control (SDLC). These use similar frame formats containing Flag, Address, Control, Information, FCS, and Flag field. Each of these technologies was originally intended for use with low-bandwidth interfaces, such as T1, PRI, or DS3. The frames that these technologies use were designed to handle variable-length packets, but the protocols were designed to work primarily with variable-length Layer 3 data units.

Table 4-4. Layer 2 WAN Protocols

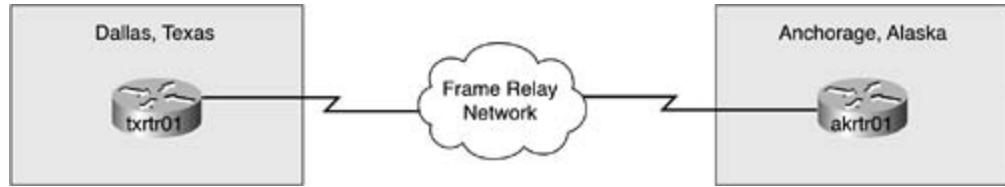
Layer 2 Protocol	Interface Encapsulation Type
LAPB	X.25
LAPF, LAPD	Frame Relay
SDLC	HDLC
LAPD	ISDN
B-ISDN ^[*]	ATM

[*] B-ISDN = broadband ISDN

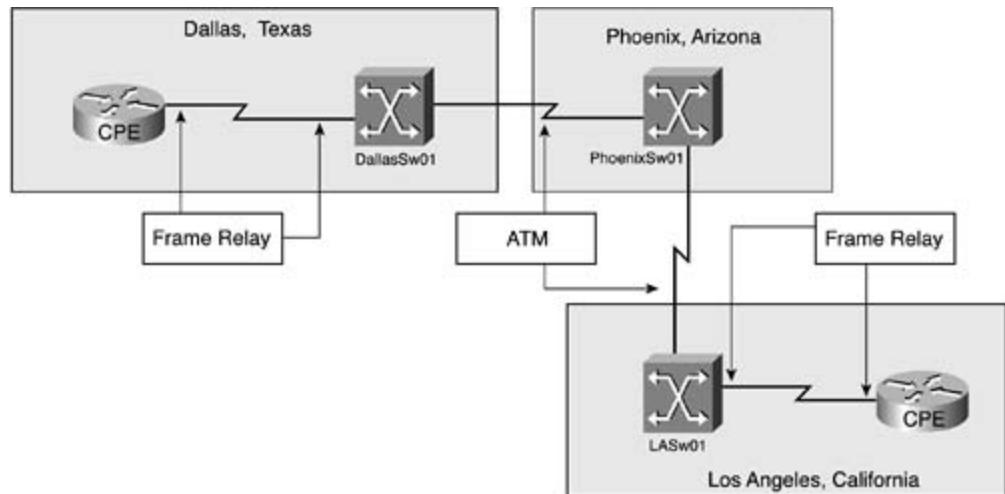
ATM was created to use much-higher-bandwidth interfaces, at consistent data rates. From the beginning, the ATM protocol was designed to be able to support voice, data, and video traffic, commonly referred to as *multiservice traffic*. This is accomplished by the use of fixed-length ATM cells. ATM switches provide

core, similar to the core provided by Frame Relay switches that provides CPE devices, such as routers, circuits using virtual paths and virtual channels. In fact, when you lease a Frame Relay circuit from provider, they will, most likely, provision your Frame Relay circuit on an ATM switch, such as a Cisco switch. When you document your network, you will show routers connected to a Frame Relay cloud shown in [Figure 4-1](#), because your service provider will probably not provide detailed network info for their network. The Frame Relay traffic is encapsulated in ATM cells, sent through the ATM core network, and translated back into Frame Relay at the edge ATM switch, as shown in [Figure 4-2](#). Because Frame Relay is primarily focused on routing and switching technologies, ATM switching is not covered in any detail.

[Figure 4-1. Customer Perception of Frame Relay Networks](#)



[Figure 4-2. Frame Relay over ATM Networks](#)



What makes the two technologies so similar is the fact that they both use virtual circuits to provide connectivity of service. Frame Relay virtual circuits are identified using locally significant *Data-Link Connection Identifiers (DLCIs)*. Generally speaking, Frame Relay circuits are provisioned with certain levels of service; a *Committed Information Rate (CIR)*, which dictates the guaranteed access rate. It is possible to order less-expensive Frame Relay service. With Zero CIR service, the switch only forwards Frame Relay traffic during no congestion; the term is not necessarily referring to the connection between your routers. At some point, congestion within your service provider's network may affect traffic that you cannot see from your router. Frame Relay also supports bursting, or the transmission of excess frames during periods of low utilization. Frame Relay traffic can be controlled, or shaped, using the *Sustained Burst Rate (Bc)* and *Excess Burst Size (EBS)* to perform traffic shaping on the edge router.

With Frame Relay, low-priority traffic is marked for discard eligibility using the *Discard Eligible (DE)* bit. When a Frame Relay switch receives a frame containing a DE=1 bit during a period of congestion, it considers

frame low priority and it is discarded. Unfortunately, in most cases, when the DE bit is not changed default value, and the network is congested, all frames leaving the router are considered discard el the Frame Relay switches in a congested network path may indiscriminately drop any of those fram Frame Relay is a connectionless protocol, it relies on upper-layer protocols, such as TCP, to retrans from those lost frames.

Frame Relay networks also have a QoS congestion notification system. This system uses forward *e. congestion notification (FECN)* and backward *explicit congestion notification (BECN)* frames to notif downstream neighbors of congested network paths. Because the use of the FECN and BECN frames explicitly be configured throughout the network on customer and service provider equipment, howe congestion notification is not configured, it does not offer much value. When devices are not config upon congestion notification frames, the only benefit they provide is a historical reference of netwo by means of the Frame Relay counters. So, during periods of congestion, Frame Relay networks th. configured to use traffic shaping and congestion notification may prove to be very unreliable.

ATM was designed to support many of the same technologies that were originally created for Fram networks. When Frame Relay was originally designed, most of the QoS features were left for vend implementation, so the use of these features depends on the Frame Relay hardware/software vend Relay implementation, and the service provider's Frame Relay network design and configuration. B a newer technology and it was designed after the technical community had experience with older X Frame Relay technologies, however, ATM networks inherently support QoS by use of the ATM Adop (AAL) types and ATM classes of service, shown in [Table 4-5](#).

Table 4-5. AAL Types and Their Intended Uses

AAL Type	AAL Description	Intended Use
AAL-1	<i>Constant bit rate (CBR)</i> — Designed to support applications requiring a low cell loss requirement and minimal <i>cell delay variation (CDV)</i> . CBR circuits are designed to mimic classic circuits by providing and enforcing a hard limit on cell rates like a real TDM circuit.	Voice and video traffic such as videoconferencing
AAL-2	This AAL type is designed to support connection-oriented applications with variable-rate, delay-sensitive traffic.	Voice and video traffic such as videoconferencing
AAL-3/4	AAL-3/4 was originally intended to support <i>Switched Multimegabit Data Service (SMDS)</i> traffic.	Legacy SMDS traffic
AAL-5	AAL-5 was specifically designed to support bursty, variable-rate data traffic. AAL-5 does not work well with delay-sensitive applications.	Data traffic

Unlike Frame Relay, which was originally designed as a baseband technology, ATM was designed a technology and was designed to run over high-speed networks. Most ATM interfaces have built-in A are designed specifically for ATM networks that are not interchangeable with other serial interfaces is very important to plan ATM networks carefully. Because the ATM specification was designed for k networks, ATM interfaces are usually available in DS3 or greater data rates, and for this reason, th use of ATM interfaces should be planned in advance.

NOTE

There are a few types of interfaces (ATM-Data Exchange Interface [ATM-DXI], Digital Subscribers Line [DSL], and inverse multiplexing over ATM [IMA]) that support ATM at rates lower than DS3. These type of networks are not covered in this book.

When configuring an ATM subinterface, you also have different AAL-5 encapsulation types from which to choose. *AAL-5 Subnetwork Access Protocol (SNAP) encapsulation* is the default encapsulation type for ATM interfaces and is appropriate for most data traffic. [Table 4-6](#) shows the AAL encapsulation types, their descriptions, and their recommended traffic type.

Table 4-6. AAL-5 Encapsulation Types

AAL-5 Encapsulation Type	Description	Recommended Type
aal5ciscopp	Cisco PPP over AAL-5 encapsulation	PPP traffic over ATM
aal5mux	AAL-5 MUX encapsulation for multiplexing different AAL types on different permanent virtual circuits (PVCs) running on a single physical circuit	IP or voice traffic
aal5nlpid	AAL-5 network layer protocol identification (NLPIID) encapsulation	RFC 1483 multiprotocol data traffic
aal5snap	AAL-5 <i>logical link control</i> (LLC)/SNAP encapsulation	The default, RFC 1483 multiprotocol traffic

Cisco IOS Software's atm commands have greatly matured over the past few major releases. Currently, you will encounter three different ATM configuration types. In later Cisco IOS Software releases, ATM AAL types are referred to as encapsulation types on Cisco routers, and can be configured in VC configuration mode.

As a quick review, let's go over the steps required for building a standard ATM PVC on a Cisco router. We will compare ATM to Frame Relay configuration. In this example, we will use the latest Cisco IOS Software configuration commands.

Step 1. Enable the physical interface and configure global interface properties.

Frame Relay	ATM
Enable the serial interface.	Enable the physical ATM interface.
<pre>interface Serial0/0 no shutdown</pre>	<pre>interface ATM0 no shutdown</pre>
Configure Frame Relay encapsulation type.	
<pre>encapsulation frame-relay IETF</pre>	
Optionally, configure Local Management Interface (LMI) type.	
<pre>frame-relay lmi-type ansi</pre>	
Optionally, configure interface clocking or CSU/DSU.	
<pre>clockrate 1300000</pre>	

Step 2. Create a multipoint subinterface.

Frame Relay	ATM
<p>Create a multipoint subinterface; as a best practice, you may consider using a subinterface number that relates to the PVC's DLCI number.</p> <pre>interface Serial0/0.651 multipoint</pre>	<p>Create a multipoint subinterface; as a best practice, you may consider using a subinterface number that relates to the PVC's virtual path identifier/virtual channel identifier (VPI/VCI) numbers.</p> <pre>interface ATM0.4 multipoint</pre>

Step 3. Assign an IP address to the subinterface.

```
interface Serial0/0.651 multipoint
ip address 192.168.26.1 255.255.255.252
```

or

```
interface ATM0.4 multipoint
ip address 192.168.25.2 255.255.255.252
```

Step 4. Assign a Layer 2 address to the subinterface.

Frame Relay	ATM
<p>Assign a DLCI to the Frame Relay subinterface.</p> <pre>interface Serial0/0.651 multipoint ip address 192.168.26.1 255.255.255.252 frame-relay map ip 192.168.26.2 651 broadcast</pre> <p>or on a physical interface</p> <pre>interface Serial0/0 ip address 192.168.26.1 255.255.255.252 frame-relay interface-dlci 651</pre>	<p>Assign a VPI/VCI pair and an optional Circuit Descriptor (VCD) name or route subinterface using the pvc [vcd-n] command.</p> <pre>interface ATM0.4 multipoint ip address 192.168.25.2 255.255.255.252 pvc 4/482</pre>

NOTE

With Frame Relay networks, you can either use the frame relay map command or the frame-interface dlci command, but not both.

Step 5. With ATM only, choose an ATM encapsulation type based on the ATM AAL provisioned by your service provider:

```
interface ATM0.4 multipoint
  ip address 192.168.25.2 255.255.255.252
  pvc 4/482
  encapsulation aal5snap
```

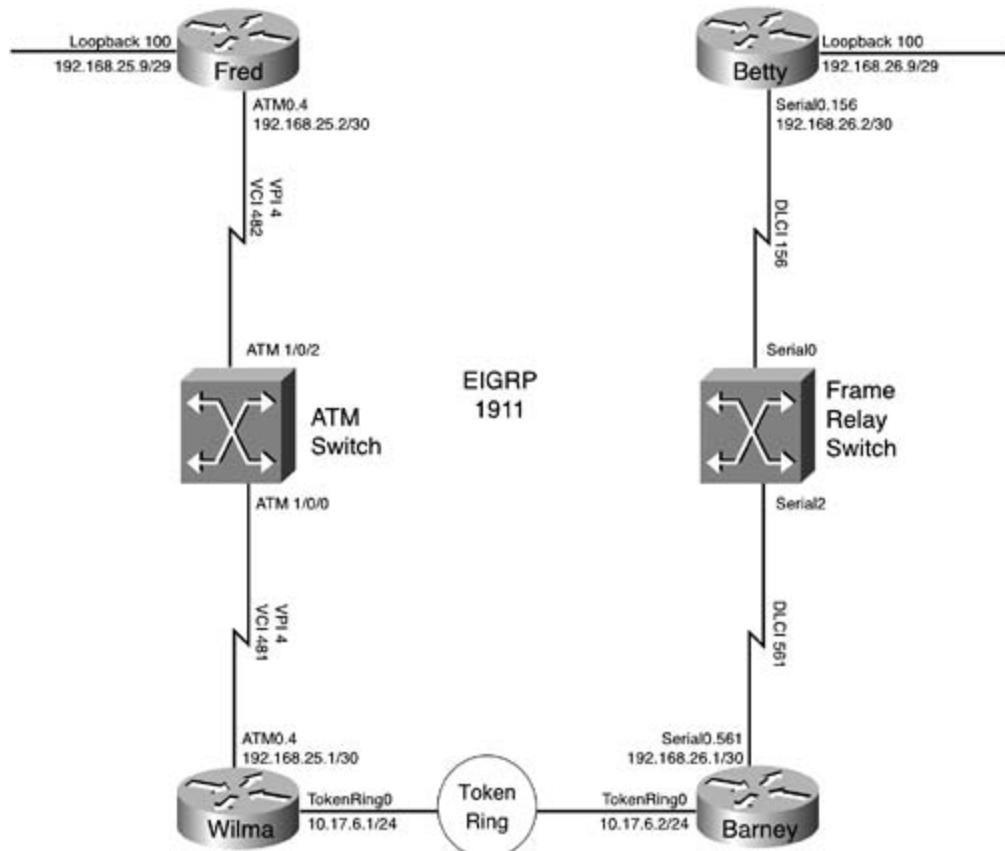
Map the Layer 2 identifier to the Layer 3 IP address of the remote nonbroadcast multiaccess (NBM) and, optionally, enable pseudo-broadcast replication.

Frame Relay	ATM
If you have not already done so, map the DLCI to an IP address and enable broadcast replication. <pre>interface Serial0/0.651 multipoint ip address 192.168.26.1 255.255.255.252 frame-relay map ip 192.168.26.2 651 broadcast</pre>	Map the VCD and VPI/VCI pair to an IP address and enable broadcast replication. <pre>interface ATM0.4 multipoint ip address 192.168.25.2 255.255.255.252 pvc 4/482 protocol ip 192.168.25.1 broadcast encapsulation aal5snap</pre>

Step 6. Optionally, configure ATM QoS parameters. This is covered later in this section.

Look at the complete ATM and Frame Relay network that was used for the examples shown in the configuration steps. [Figure 4-3](#) shows the complete ATM/Frame Relay networks, including all Layer 3 addressing.

Figure 4-3. The Complete ATM/Frame Relay Networks



In this example, the Fred and Wilma routers belong to the ATM network, and the Betty and Barney belong to the Frame Relay network, and a Token Ring LAN interconnects both networks. This example shows the similarities and differences between Frame Relay and ATM networks. [Example 4-8](#) shows the configuration for the Fred router.

Example 4-8. Configuration for the Fred ATM Router

```

hostname Fred
!
interface Loopback100
  ip address 192.168.25.9 255.255.255.248
!
interface ATM0
  no ip address
  no atm ilmi-keepalive

```

```

!
interface ATM0.4 multipoint
  ip address 192.168.25.2 255.255.255.252
pvc 4/482
  protocol ip 192.168.25.1 broadcast
  encapsulation aal5snap
!
router eigrp 1911
  network 192.168.25.0 0.0.0.3
  network 192.168.25.8 0.0.0.7
  no auto-summary
  no eigrp log-neighbor-changes

```

Three commands were used to configure and enable the ATM interface and then configure Enhance Gateway Routing Protocol (EIGRP) routing over the ATM interface in this preceding example. First, 4/482 command was used to create a PVC on the ATM0.4 multipoint ATM interface. This PVC was the IP address on the subinterface using the protocol ip 192.168.25.1 broadcast command. The broadcast option allows EIGRP to function over the NBMA network ATM network. And the encapsulation aal5snap command enables AAL-5 SNAP adaptation on the subinterface. [Example 4-9](#) shows the configuration of the ATM circuit configuration on the Wilma router.

Example 4-9. Configuration for the Wilma Router

```

hostname Wilma
!
interface TokenRing0
  ip address 10.17.6.1 255.255.255.0
  ring-speed 16
!
interface ATM0
  no ip address

```

```

no atm ilmi-keepalive

!
interface ATM0.4 multipoint
  ip address 192.168.25.1 255.255.255.252
  pvc 4/481
    protocol ip 192.168.25.2 broadcast
    encapsulation aal5snap
!
router eigrp 1911
  network 10.17.6.0 0.0.0.255
  network 192.168.25.0 0.0.0.3
  no auto-summary

```

As you can see, the Fred and Wilma routers both have very similar ATM configurations. These configurations can also be tested using one of several `atm show` commands. For instance, the `show atm interface atm 0.4` command displays information about the type and number of packets that have been transmitted on a specific ATM interface, as shown in [Example 4-10](#).

Example 4-10. `show atm interface atm0.4` Command on the Fred Router

```

Fred#show atm interface atm 0.4

Interface ATM0.4:
  AAL enabled: AAL5  AAL3/4, Maximum VCs: 1023, Current VCCs: 1
  Maximum Transmit Channels: 0
  Max. Datagram Size: 4528, MIDs/VC: 1024
  PLIM Type: SONET - 155000Kbps, TX clocking: LINE
  1981 input, 1986 output, 0 IN fast, 0 OUT fastUBR+ : 4
  Avail bw = 154996
  Rate-Queue 0 set to 56Kbps, reg=0x0 DYNAMIC, 1 VCC
  Config. is ACTIVE

```

When troubleshooting an ATM interface, it is helpful to be able to see the protocol mappings. The `show atm map` command displays the Layer 2-to-Layer 3 protocol mapping information for all VCs on a router. The `show frame-relay map` command on Frame Relay networks. [Example 4-11](#) shows the `show atm map` command output from the Fred router.

Example 4-11. `show atm map` Command on the Fred Router

```
Fred#show atm map

Map list ATM0.4pvcl : PERMANENT

ip 192.168.25.1 maps to VC 1, VPI 4, VCI 482, ATM0.4

, broadcast
```

The preceding example shows that ATM interface 0.4 has a permanent PVC mapping for the IP address 192.168.25.1 to VPI 4 and VCI 482. VPI/VCI 4/482 belongs to VC 1, and this VC supports pseudo-1 which was configured earlier using the `ip 192.168.25.2 broadcast` command under the subinterface. The `show atm vc` command shows the VC configuration for an ATM router, similar to the `show frame-relay pvc` command on Frame Relay networks, as shown in [Example 4-12](#).

Example 4-12. `show atm vc` Command on the Fred Router

```
Fred#show atm vc

VCD /
Peak Avg/Min Burst

Interface Name      VPI   VCI   Type    Encaps   SC     Kbps   Kbps   Cells  Sts
0.4       1          4     482   PVC     SNAP    UBR   155000
                                         UP
```

The `show atm vc` command displays the interface the VC exists under, the VCD name, VPI and VCI, the VC type, encapsulation, ATM class of service, the peak cell rate, the average cell rate (both in kilobits/second), the burst rate in cells, and the VC status. Each of these parameters should match the information provided by the service provider or ATM switch configuration. Therefore, in this example, the ATM 0.4 interface is an unspecified bit rate (UBR) circuit with a peak cell rate of 155,000 kbytes per second, a line rate, and the circuit is up. [Example 4-13](#) shows the configuration from the ATM switch.

Example 4-13. Configuration for the ATM Switch

```
interface ATM1/0/0
  no ip address
  logging event subif-link-status
  no atm ilmi-keepalive
!
interface ATM1/0/2
  no ip address
  logging event subif-link-status
  no atm ilmi-keepalive
atm pvc 4 482 interface ATM1/0/0 4 481
```

[Example 4-14](#) shows the configuration for the Barney and Betty Frame Relay routers, highlighting the Frame Relay configuration. You can compare this information to the ATM configuration shown earlier in [Example 4-13](#) to determine the differences and similarities between the ATM and Frame Relay configuration methods.

Example 4-14. Configuration for the Barney and Betty Router

```
hostname Barney
!
interface Serial0/0
  no ip address
  encapsulation frame-relay IETF
  clockrate 1300000
  frame-relay lmi-type ansi
!
interface Serial0/0.651 multipoint
```

```
ip address 192.168.26.1 255.255.255.252
frame-relay map ip 192.168.26.2 651 broadcast
!
interface TokenRing0/0
ip address 10.17.6.2 255.255.255.0
ring-speed 16
ip rsvp bandwidth 822 24
!
router eigrp 1911
network 10.17.6.0 0.0.0.255
network 192.168.26.0 0.0.0.3
no auto-summary
no eigrp log-neighbor-changes
```

```
hostname Betty
!
interface Loopback100
ip address 192.168.26.9 255.255.255.252
no ip directed-broadcast
!
interface Serial0/1
no ip address
encapsulation frame-relay IETF
clockrate 1300000
frame-relay lmi-type ansi
!
interface Serial0/1.156 multipoint
ip address 192.168.26.2 255.255.255.252
```

```

frame-relay map ip 192.168.26.1 156 broadcast
!
router eigrp 1911
network 192.168.26.8 0.0.0.3
network 192.168.26.0 0.0.0.3
no auto-summary

```

Table 4-7 lists some of the ATM and Frame Relay similarities and differences.

Table 4-7. ATM and Frame Relay Comparison

Frame Relay Technology	Technology Description	ATM Technology	Technology Description
DLCI	Identifies Frame Relay VCs.	VPI/VCI	Identifies ATM VCs.
LMI	Used to communicate Layer 2 signaling information from Frame Relay switch to FRAD.	ILMI	Communicates ATM signaling information between ATM switch and ATM CPE interface.
Serial sub-interfaces	Used to create logical point-to-point or point-to-multipoint Frame Relay circuit interfaces.	ATM subinterfaces	Used to create logical point or point-to-multipoint circuit interfaces.
Frame Relay Map Statements	Maps Frame Relay DLCI to Layer 3 IP address and, optionally, enables the use of NBMA pseudo-broadcast.	Map lists or protocol mappings (depending on Cisco IOS Software version or configuration preference)	Maps ATM VCD, and VPI/VCI to Layer 3 IP address, and enables the use of NBMA pseudo-broadcast.
Frame Relay encapsulation on a serial interface	One of the 11 encapsulation types available on a serial interface.	ATM interface encapsulation	The only type of encapsulation available on an ATM interface. ATM interfaces have ATM header support built in. Other encapsulation types can be selected and applied on a per-VC basis.

CIR and optionally Be, Bc	The Frame Relay QoS SLA for a virtual circuit.	CBR, ABR, UBR, VBR.	The ATM circuit QoS types switches, VCs are built the following ATM classes service: CBR ABR UBR VBR-rt VBR-nrt
DE	Frame Relay DE bit— Used to mark frames as discard eligible, or low priority. DE=0 priority DE=1 low priority	CLP	ATM cell loss priority (Used to mark cells with for use to determine d eligibility on congested CLP=0 priority CLP=1 low priority
FECN/BECN	Forward and backward congestion notification frames, sent by Frame Relay switches to indicate congestion.	EFCI and ER	A mode of congestion used with the ATM ABR service. Explicit forward indication (EFCI) is a forward notification, a rate (ER) mode is used backward congestion r
FRTS	Frame Relay traffic shaping (FRTS) uses Frame Relay CIR, Be, and Bc to shape Frame Relay traffic on a Frame Relay egress interface to control Frame Relay frame loss during times of congestion.	Inherent ATM QoS	ATM circuits inherently some mode of ATM QoS circuit type determines QoS supported, and the QoS provided by the A interface is partially dependent configuration.

Now that you have seen some of the ways that ATM and Frame Relay technologies contrast, the next section introduces you to the ATM QoS mechanisms and how they are implemented using Cisco IOS Software.

ATM QoS

Unlike Frame Relay networks that either forward or drop frames based on discard eligibility, ATM has four main classes of service that can be provisioned on ATM switches: constant bit rate (CBR), variable bit rate (VBR), unspecified bit rate (UBR), and available bit rate (ABR). Two of these main classes also have two subtypes. There are two forms of VBR circuits: VBR real-time (VBR-rt) and VBR non-real-time (VBR-nrt), and UBR+. All of these choices are usually provisioned at the ATM switch and the CPE devices. The routers will use matching QoS parameters that allow the routers to comply with the switch configurations. The type of QoS provisioned will depend on the SLA, and the pricing for the circuit will depend on the required level of service. Each class of service has different behaviors during periods of congestion, and will provide very different levels of service, so it is always best to plan ATM networks for the type of traffic that the network will support. The following table shows the ATM classes of service and traffic types that they support.

Table 4-8. ATM Classes of Service

ATM Class of Service	Service Level Traffic Characteristics
CBR	<p>Provides a constant bit rate similar to that of a physical circuit. Like physical circuits, do not allow for traffic bursts; when the bit rate has been exceeded, any excess traffic is discarded.</p> <p>CBR circuits are best suited for traffic that requires a constant bit rate and does not tolerate delay—such as constant-use voice or video traffic on service provider networks. For these reasons, CBR circuits are usually not provisioned for data networks.</p>
VBR-rt	<p>VBR real-time is recommended for traffic that has real-time data requirements and does not tolerate delay or jitter.</p> <p>VBR-rt circuits are usually provisioned for voice or video networks that do not require bandwidth all the time, and are more suitable for VoIP networks or videoconferencing that are not used on a constant basis.</p>
VBR-nrt	<p>VBR non-real-time circuits provide varying rates of service that support traffic bursts seen on data networks.</p> <p>VBR-nrt is frequently deployed in enterprise networks for use by bursty data applications. These circuits tolerate varying rates of delay, either by protocol retransmission or network application-level retransmission.</p>
UBR	<p>UBR circuits are usually provisioned for networks that require only a "best-effort" class of service.</p> <p>UBR circuits can be thought of more like Frame Relay Q-CIR circuits; they provide the service depending on network congestion. UBR circuits are suitable for WAN circuits between networks running applications that support delay and retransmission or Internet traffic.</p>
UBR+	<p>UBR+ circuits are not provisioned as UBR+ on ATM switches; UBR+ is specific to UBR configured as UBR+ on a Cisco router.</p> <p>UBR+ configuration enables you to configure a router with a minimum cell rate (MCR) to communicate to the ATM switch. The ATM network does not necessarily guarantee UBR levels; they still must be negotiated with an ATM service provider and agreed to in an SLA.</p>
ABR	<p>ABR circuits provide a negotiated level of quality in ATM networks providing an MCR, burst when the network is not congested. With ABR circuits, the ATM network provides a level of service, and communicates network status information to routers by setting information contained in resource management (RM) cells that allows the routers' ATM interfaces to share network resources during periods of low traffic.</p>

To gain the full benefit of the ATM classes of service, certain ATM QoS parameters must be configured on the router's ATM interface. Each ATM class of service has its own parameters; these parameters are configured in PVC configuration mode using the ATM class of service commands. The exact configuration values and availability will depend on the ATM interface type and ATM switch configuration. Before ordering an ATM circuit, make sure that you are prepared to have the proper ATM hardware to use the circuit; some platforms support only certain ATM circuit types. The remainder of this section focuses mainly on router configuration for the 4500 and 4700 series NP-1A-OC3 interfaces. Most of the commands that apply to the 4500 series also apply to the 4700 series.

newer routers.

Configuring VBR-nrt Circuits

As the name implies, VBR-nrt circuits are designed to support traffic that does not require real-time characteristics and can tolerate jitter and delay. Although ATM service level configuration is not required, the router must be configured to support the proper ATM traffic-shaping values in order to provide the service provisioned by the ATM service provider. VBR-nrt VCs require three parameters to properly provision the circuit. These include the following:

- Sustained cell rate (SCR)
- Peak cell rate (PCR)
- Maximum burst size (MBS)

Each of these parameters is configured under PVC configuration mode using the following command:

```
vbr-nrt pcr scr[mbs]
```

The PCR, described in kbps, is the absolute peak rate that the ATM network will accept. The interface uses this value to throttle traffic peaks and smooth traffic so that traffic bursts will not be discarded in the ATM network. The SCR is the sustained rate that the ATM network will allow traffic to be transited at. The MBS, measured in cells, is the maximum burst size that will be accepted.

NOTE

When calculating your bandwidth requirements, always order circuits with room to grow, and provision ATM VCs should always be provisioned at the sustained rate. Never design networks to use the peak rate; otherwise, you may end up with an unusable or unstable network.

[Examples 4-15](#) and [4-16](#) show how an ATM VBR-nrt circuit is created between the Wilma and Fred routers.

Example 4-15. Using VBR-nrt on the Wilma Router

```
interface ATM0
no ip address
no atm ilmi-keepalive
!
interface ATM0.4 multipoint
ip address 192.168.25.1 255.255.255.252
pvc 4/481
protocol ip 192.168.25.2 broadcast
vbr-nrt 44209 9000
encapsulation aal5snap
```

Example 4-16. Using VBR-nrt on the Fred Router

```
interface ATM0
no ip address
no atm ilmi-keepalive
!
interface ATM0.4 multipoint
ip address 192.168.25.2 255.255.255.252
pvc 4/482
protocol ip 192.168.25.1 broadcast
vbr-nrt 44209 9000
encapsulation aal5snap
```

NOTE

If the MBS is not specified during configuration, as in the preceding example, the router uses :

value.

You can test this configuration by using extended pings with the show atm pvc, show atm vc de show controller atm 0.4 | begin Packet switching commands, as shown on the Fred router in [17](#).

Example 4-17. Verifying the ATM Configuration Using atm show Command Fred Router

```
Fred#show atm pvc
```

		VCD /	Peak Avg/Min Burst							
Interface	Name	VPI	VCI	Type	Encaps	SC	Kbps	Kbps	Cells	Sts
0.4	1	4	482	PVC	SNAP	VBR	44209	9000	95	UP

```
Fred#show atm vc detail
```

```
ATM0.4: VCD: 1, VPI: 4, VCI: 482
```

```
VBR-NRT, PeakRate: 44209, Average Rate: 9000, Burst Cells: 95
```

```
AAL5 LLC/SNAP, etype:0x0, Flags: 0x20, VCmode: 0x401
```

```
OAM frequency: 0 second(s)
```

```
InARP frequency: 15 minutes(s)
```

```
InPkts: 329444, OutPkts: 329722, InBytes: 1169546091, OutBytes: 1169566161
```

```
InPRoc: 329444, OutPRoc: 328129, Broadcasts: 1593
```

```
InFast: 0, OutFast: 0, InAS: 0, OutAS: 0
```

```
OAM cells received: 0
```

```
OAM cells sent: 0
```

```
Status: UP
```

```
Fred#show controllers atm 0.4 | begin Packet switching
```

```
Packet switching
```

```
Fastswitched 0
```

```
To-process 329564
```

```
Bridged 0
```

Transmit errors

Restarts	0
Pktid misses	0
Bad pktid	0
Wrong queue	0
No pkt	0
Tx errors	0
Bad VC	0

Receive errors

Bad pktid	0
Wrong queue	0
No pkt	0
CRC	0
Length	0
Giant	0
Reas tout	0
AAL5 format	0

In the preceding example, the `show atm pvc` command shows the VC configuration for the ATM PVC between the Fred and Wilma routers, and the `show atm vc detail` and `show controller atm 0.4 | begin switching` commands verify that packets were successfully transmitted without errors.

Configuring UBR and UBR+ Circuits

UBR circuits do not guarantee that all traffic sent out on an interface will necessarily be transmitted over the ATM network. These circuits are generally used under two circumstances: The traffic sent across them is not tolerant of delay and jitter and only requires best-effort service, or there is a cost limitation preventing a higher level of service. Standard UBR circuits require only one configuration parameter, the *PCR*, and are configured in PVC configuration mode using the `ubr pcr` command (where *pcr* is measured in kbps).

UBR+ circuits also allow for an MCR value, measured in kbps that allows for the support of peak and average cell rates. UBR+ is configured under PVC configuration mode using the `ubr+ pcr mcr` command. [Example 1](#) shows how the ATM UBR+ service level is used after configuring an additional 100-Mbps PVC between the Fred and Wilma routers. This example shows the PVC configuration from the Fred router.

Example 4-18. Adding a UBR+ PVC to the Mix

```
interface ATM0.5 multipoint
    ip address 192.168.25.5 255.255.255.252
pvc 5/582
    protocol ip 192.168.25.6 broadcast
ubr+ 106000 100000
    encapsulation aal5snap
```

You can verify this configuration by using atm show commands. [Example 4-19](#) shows the output of pvc and show atm vc vcd commands from the Fred router.

Example 4-19. Verifying the Configuration on the Fred Router

```
Fred#show atm pvc
      VCD /
      Peak   Avg/Min Burst
Interface Name      VPI   VCI   Type   Encaps   SC     Kbps   Kbps   Cells   Sts
0.4       1          4     482   PVC     SNAP     VBR    44209   9000    95     UP
0.5       4          5     582   PVC     SNAP     UBR+  106000  100000   UP

Fred#show atm vc 4
ATM0.5: VCD: 4, VPI: 5, VCI: 582
UBR+, PeakRate: 106000, Minimum Guaranteed Rate: 100000
AAL5-LLC/SNAP, etype:0x0, Flags: 0x20, VCmode: 0x1
OAM frequency: 0 second(s)
InARP frequency: 15 minutes(s)
InPkts: 9877, OutPkts: 9969, InBytes: 25996105, OutBytes: 26002689
InPRoc: 9877, OutPRoc: 9878, Broadcasts: 91
InFast: 0, OutFast: 0, InAS: 0, OutAS: 0
```

OAM cells received: 0

OAM cells sent: 0

Switching Modes

Status: UP routers use two modes to determine the paths and forward traffic, routing, and switching. Each protocol uses a routing method to determine the destination location for data unit packets, frames, or cells. Layer 3 and Layer 2 addresses are mapped to each other, and then, if route caching is configured, this information is stored in a route cache. When route caching is enabled after the destination for a packet is known and has been stored in the route cache, any future packets belonging to the same flow, containing the same destination address information, are forwarded to their destination interface using the information from the route cache; otherwise, the destination mapping is done on a per-packet basis. The process of mapping Layer 2 to Layer 3 addresses and forwarding to a destination interface is referred to as *switching*. Each interface has a default switching method; even if you do not explicitly configure a particular type of switching, the router will switch packets using its default method. The effectiveness of the switching method depends on the features you have enabled and the switching mode that is in use. Before discussing how QoS can be configured to improve existing network performance, it is important to verify that the router interfaces are using the most efficient switching method.

NOTE

Some QoS and security techniques have certain switching method requirements. When selecting a QoS method, always remember to plan for the required switching method.

Process Switching

Depending on the type of hardware and software installed, different router models use different switching modes. The most basic switching mode is *process switching*. Process switching copies the first packet in a flow to the system buffer. The destination is looked up in the routing table. The cyclic redundancy check (CRC) is computed using the route processor. Then the Layer 2 information for the packet is rewritten and sent to the destination interface. Any subsequent packets belonging to the same flow are switched using the same switching Layer 3-to-Layer 2 path. Process switching has the highest latency of all the switching types because it uses the system buffers and processor to process and store each packet as it is received. Process switching is enabled by disabling the default of either fast or optimum switching using the command `no ip route-cache` to disable fast switching and adding the optimum argument to disable optimum switching. Process switching is sometimes required for certain processor-intensive packet-processing processes, such as debugging IP packets.

Fast Switching

Fast switching uses the route cache to store information about packet flows. When fast switching is enabled, the first packet in a flow is stored in packet memory, a separate area in the system buffer, the system processor is used to perform the Layer 3-to-Layer 2 mapping, and then the path information is stored in the route cache so that any subsequent packets from the same flow can be fast switched. The next packet and any further packets from the same flow are fast switched. Because the destination of the packet flow is already known, with fast switching, the

route cache is consulted to find the destination interface. After the destination has been found and stored in the cache, the packet is rewritten with the proper Layer 2 header, and the CRC is computed using the interface's processor. The packet never interrupts the system processor, and because the destination interface information is known, the system buffer is not used to store the packet information. Fast switching is the default switching mode for many Cisco routers, including the 1600, 1700, 2500, and 2600 on Ethernet, Fast Ethernet, and serial interfaces. If fast switching has been disabled, it can easily be re-enabled using the `ip route-cache` command on the interface. You can monitor fast switching information by using the `show ip cache` command.

Optimum and Distributed Switching

Two other switching methods—not available to the 1600, 1700, 2500, or 2600 platforms—are optimum switching and distributed switching. With optimum switching, the same process used in fast switching is followed; the difference is that after the first packet has been processed, the path information for each subsequent packet from the flow is stored in the optimum switching cache, which is faster. Distributed switching requires the use of a Versatile Interface Processor (VIP) card to process switching information. The optimum switching method also uses a more efficient search algorithm that decreases the amount of lookups that must be performed by the VIP card. The VIP card retains a copy of the route cache and performs all switching locally so that the interface does not need to wait for the use of the shared packet memory in the system buffers or the system processor. Multiple VIP cards can also be installed to further increase switching performance. This makes distributed switching even faster than fast or optimized switching. Optimum switching mode is available only on high-end Cisco routers, such as the 7200. To enable optimum switching, use the `ip route-cache optimum` command on each interface where it is required. To monitor or troubleshoot optimum switching, use the `show ip cache optimum` command.

NetFlow Switching

NetFlow switching enables you to collect and store accounting IP traffic data that you can use for billing of network utilization. NetFlow switching uses the default fast or optimum switching mode for forwarding IP traffic; and in addition to route caching, NetFlow switching tracks information about IP network traffic flows. Flows are tracked by user, protocol, port, and type of service; this information can then be exported to a network management station. NetFlow switching operates by first performing standard fast, optimum, or CEF switching, as mentioned earlier; however, after a flow has been established, all new packets belonging to the same flow bypass access lists for the NetFlow interface, and statistics for that flow are collected. Because NetFlow accounting data is stored in the routing cache, the NetFlow switching data collection processes are transparent to all other network devices. NetFlow switching does, however, increase the load on the process or memory for the router, so it is a good idea to be aware of how much memory is required before implementing this switching method. By default, the NetFlow cache uses 64 bytes of memory per flow. If the default 65,536 flows are used, 4 MB of DRAM are required to support the NetFlow process for one interface.

NOTE

If a route caching method has not been configured and NetFlow switching is enabled, the default switching method (CEF, fast, or optimum) is enabled by default.

NetFlow switching is enabled using the ip route-cache flow command in interface configuration mode and monitored using the show ip cache flow command. This command shows the percentage of packets received at different packet sizes, the size of the NetFlow cache in bytes, the number of active and inactive flows, flow allocation problems, and detailed flow information, including source and destination interfaces. To export NetFlow cache entries to a network management station, use the ip flow-export command to specify the address of the station and the UDP port that will be used to send the data.

Cisco Express Forwarding

Cisco Express Forwarding (CEF) is the most efficient way to switch Layer 3 traffic. The reason why CEF switching is more advanced than fast or optimum switching is that CEF switching is less CPU intensive with the use of the *Forwarding Information Base (FIB)* and adjacency table. The FIB lookup table is used to store all known routes from the routing table using a more advanced search algorithm and data structure, bypassing the need for process switching. Unlike the other route caching switching methods, CEF uses the FIB, which adjusts to network topology changes as they happen. The adjacency table is used to store information about CEF neighbors. CEF nodes are considered to be neighbors if they are only one hop away from each other. The adjacency table stores Layer 2 next-hop addressing information for each of the FIB entries. Routes might have more than one path per entry, making it possible to use CEF to switch packets while load balancing across multiple paths. Each time a packet is received on a CEF-enabled interface, the FIB is consulted to look up the route, encapsulate the Layer 2 data, and switch the packet.

CEF switching is enabled globally using the ip cef command. After the ip cef command has been entered in global configuration mode, CEF switching is enabled on all CEF-capable interfaces by default. If CEF has been disabled on an interface, it can be re-enabled by issuing the ip route-cache cef command in interface configuration mode, and disabled using the no version of the same command. There is also a distributed version of CEF available for high-end Cisco routers, which is enabled by default after the ip cef command has been issued. You can monitor CEF by using the show ip cef command, and you can learn detailed CEF information by using the show ip cef detail routing command, as shown in [Example 4-20](#).

Example 4-20. show ip cef detail Command Output

```
Router#show ip cef detail

IP CEF with switching (Table Version 10), flags=0x0
  10 routes, 0 reresolve, 0 unresolved (0 old, 0 new)
  13 leaves, 17 nodes, 19240 bytes, 13 inserts, 0 invalidations
  0 load sharing elements, 0 bytes, 0 references
  2 CEF resets, 0 revisions of existing leaves
  refcounts: 1061 leaf, 1058 node
```

```
Adjacency Table has 2 adjacencies

0.0.0.0/32, version 0, receive

1.1.1.1/32, version 6, connected, receive

35.132.253.0/24, version 7, attached, connected, cached adjacency to Serial0/2

0 packets, 0 bytes

via Serial0/2, 0 dependencies

valid cached adjacency

35.132.253.0/32, version 4, receive

35.132.253.1/32, version 3, receive

35.132.253.255/32, version 5, receive

167.56.24.0/24, version 8, attached, connected, cached adjacency to Serial0/1

0 packets, 0 bytes

via Serial0/1, 0 dependencies

valid cached adjacency

167.56.24.0/32, version 1, receive

167.56.24.31/32, version 0, receive

167.56.24.255/32, version 2, receive

224.0.0.0/4, version 9

0 packets, 0 bytes, Precedence routine (0)

via 0.0.0.0, 0 dependencies

next hop 0.0.0.0

valid drop adjacency

224.0.0.0/24, version 2, receive

255.255.255.255/32, version 1, receive
```

CEF Load Balancing

As mentioned earlier, you can use CEF to load balance packet switching over multiple paths. CEF can be configured to load balance either per destination or per packet, depending on network

requirements. Balancing traffic on a per-destination basis sends packets with the same source and destination over the same path, distributing the traffic load of same-source destination traffic over the same path. If you use per-destination load balancing, packets with the same source and destination take the same path in each direction, not always the same return path, depending on routers in the reverse path. Because per-destination load balancing guarantees that packets follow the same path, packets arrive at their destination in the order that they were sent. This type of load balancing is best for traffic that requires packets to arrive in a certain sequence and is enabled by default when using CEF switching. If you will be requiring load distribution of traffic equally over multiple paths, consider using per-packet load balancing; however, it is important to remember that per-packet load balancing does not guarantee that packets will take the same path, which may cause packets to arrive out of order. Per-packet load balancing works best in situations where traffic must be evenly distributed over multiple paths due to uneven traffic loads. To change from per-destination to per-packet load balancing, disable per-destination load balancing on each required interface using the ip load-sharing per-destination command, and per-packet balancing is enabled using the ip load-sharing per-packet command, as shown in [Example 4-21](#).

Example 4-21. Changing to Per-Packet Load Balancing

```
Router(config)#int serial 0/1
Router(config-if)#no ip load-sharing per-destination
Router(config-if)#ip load-sharing per-packet
Router(config)#int serial 0/2
Router(config-if)#no ip load-sharing per-destination
Router(config-if)#ip load-sharing per-packet
```

Verifying CEF Configuration

To determine the current configured switching mode for an interface, use the show ip interface command. [Example 4-22](#) shows how this command was used to display the current switching mode for interface serial 0/1. According to the show ip interface command output, serial 0/1 is currently using the default fast switching mode with fast switching on the same interface and multicast fast switching enabled. Flow switching and distributed fast switching are currently not enabled.

Example 4-22. Viewing the Current Route Switch Configuration

```
Router#show ip interface serial 0/1
Serial0/1 is up, line protocol is up
```

Internet address is 167.56.24.31/24
Broadcast address is 255.255.255.255
Address determined by setup command
MTU is 1500 bytes
Helper address is not set
Directed broadcast forwarding is disabled
Outgoing access list is not set
Inbound access list is not set
Proxy ARP is enabled
Security level is default
Split horizon is enabled
ICMP redirects are always sent
ICMP unreachables are always sent
ICMP mask replies are never sent
IP fast switching is enabled
IP fast switching on the same interface is enabled
IP Flow switching is disabled
IP Fast switching turbo vector
IP multicast fast switching is enabled
IP multicast distributed fast switching is disabled
Router Discovery is disabled
IP output packet accounting is disabled
IP access violation accounting is disabled
TCP/IP header compression is disabled
RTP/IP header compression is disabled
Probe proxy name replies are disabled
Policy routing is disabled
Network address translation is disabled

```
WCCP Redirect outbound is disabled
```

```
WCCP Redirect exclude is disabled
```

```
BGP Policy Mapping is disabled
```

To enable NetFlow switching and disable multicast route caching, use the ip route-cache flow commands on the interface, as shown in [Example 4-23](#).

Example 4-23. Changing the Route Switch Configuration

```
Router(config-if)#ip route-cache ?
  cef          Enable Cisco Express Forwarding
  flow         Enable Flow fast-switching cache
  policy       Enable fast-switching policy cache for outgoing packets
  same-interface  Enable fast-switching on the same interface
<cr>
Router(config-if)#ip route-cache flow
Router(config-if)#^Z
Router#show ip int s 0/1
Serial0/1 is up, line protocol is up
  Internet address is 167.56.24.31/24
  Broadcast address is 255.255.255.255
  Address determined by setup command
  MTU is 1500 bytes
  Helper address is not set
  Directed broadcast forwarding is disabled
  Outgoing access list is not set
  Inbound access list is not set
  Proxy ARP is enabled
  Security level is default
```

Split horizon is enabled
ICMP redirects are always sent
ICMP unreachables are always sent
ICMP mask replies are never sent
IP fast switching is enabled
IP fast switching on the same interface is enabled
IP Flow switching is enabled
IP Flow switching turbo vector
IP multicast fast switching is disabled
IP multicast distributed fast switching is disabled
Router Discovery is disabled
IP output packet accounting is disabled
IP access violation accounting is disabled
TCP/IP header compression is disabled
RTP/IP header compression is disabled
Probe proxy name replies are disabled
Policy routing is disabled
Network address translation is disabled
WCCP Redirect outbound is disabled
WCCP Redirect exclude is disabled
BGP Policy Mapping is disabled

Table 4-9 briefly describes each of the switching modes available in Cisco IOS Software and lists the commands used to activate them.

Table 4-9. Switching Modes

Switching Mode	Description	IP Switching Command
Process switching	Each packet is processed one at a time by the system processor and buffers; address information is processed for each packet as well.	no ip route-cache
Fast switching	The first packet in a flow is process switched; each subsequent packet in a flow is fast switched using the route cache.	ip route-cache
Optimum switching	The first packet in a flow is process switched; each subsequent packet in a flow is fast switched using the optimum switching route cache.	ip route-cache optimum
Distributed switching	Packet processing is performed locally using a VIP card, preventing packets from the need to use the system processor, route cache, or buffers.	ip route-cache distributed
NetFlow switching	Store accounting data that can be used for network utilization collection and billing.	ip route-cache flow
CEF switching	Stores Layer 3 routing information in an FIB table and Layer 2 neighbor information in an adjacency table. Topology information stored in the FIB changes dynamically with the routing table. This makes CEF the most efficient switching method because no process switching is involved in the switching process.	To enable CEF globally: ip cef Per interface: ip route-cache cef

Compression

Another way to increase the number of packets that can be transmitted is to reduce the size of frames by enabling compression. Because compressed frames are smaller in size, more compressed frames can be sent across the media, improving transmission times. Compression is implemented either in hardware or in software, depending on the Cisco IOS Software version installed, the type of interface and encapsulation used, and the hardware platform that it is installed onto. This chapter covers only software compression techniques, in particular the STAC and Predictor compression algorithms.

Before enabling compression on any router, it is very important to check the processor and memory utilization. If a router's memory utilization exceeds 40 percent, compression will not be a helpful solution. It is also important to note that STAC and Predictor both support different encapsulation protocols and have different memory and CPU requirements. [Table 4-10](#) outlines these issues.

Table 4-10. Compression Issues

Compression Method	Protocol	System Requirements
STAC	HDLC, PPP, LAPB, X.25	Higher CPU requirements
Predictor	PPP, LAPB	Higher memory Requirements

The amount of traffic being transmitted, the type of packets being sent, and the amount of available bandwidth also affect the impact that compression has on a router. If you are considering implementing compression on an interface that is mainly used to download data that has already been compressed, for example, enabling compression will not be beneficial because data cannot be compressed twice. If the interface has a large amount of bandwidth, and large amounts of data are being transmitted, the dictionaries in memory are likely to be very large. To check memory utilization, use the `show memory` summary command and compare the total memory to the free memory. If you do not have much memory, your router will probably not be able to handle compression. To verify CPU utilization, use the `show process cpu` command; note the average processor utilization over a period of time. If it consistently reaches 40 percent, compression is probably not a performance solution. [Example 4-2](#) shows the processor utilization for a router before and after STAC compression was enabled.

Example 4-24. How Compression Affects Utilization

Before STAC Compression

```
Lilo#show proc cpu
```

```
CPU utilization for five seconds: 2%/0%; one minute: 0%; five minutes: 4%
```

After STAC Compression

```
Lilo#show proc cpu
```

CPU utilization for five seconds: 44%/36%; one minute: 47%; five minutes: 25%

The Stacker Compression Algorithm

The *stacker algorithm*, referred to as STAC LZS, is a compression algorithm based on the Lemple-Ziv standard algorithm, which replaces characters in a data stream with codes. These codes are stored in a dictionary containing definitions matching the symbolic code used to compress the data to the actual characters. The dictionary is constantly changing based on the types of traffic being compressed.

Cisco IOS Software supports the STAC compression method for PPP, LAPB, HDLC, Frame Relay, and interface encapsulations. Because the dynamic STAC compression dictionary stored in memory is constantly changing, it is very important to monitor the memory utilization on routers running the algorithm. Due to the constant examination of packets, interfaces that use the STAC compression algorithm require large amounts of available processor time.

To configure STAC compression on either a PPP- or HDLC-encapsulated point-to-point interface, you use the command `compress stac` on both sides of the connection. [Example 4-25](#) shows how STAC works on an HDLC connection between the Lilo and Stitch routers.

Example 4-25. STAC Compression Example

```
hostname Lilo

!
interface Serial0/2
  ip address 175.25.25.1 255.255.255.0
  no ip directed-broadcast
  clockrate 1300000
  compress stac
```

```
hostname Stitch

!
interface Serial0
  ip address 175.25.25.2 255.255.255.0
  no ip mroute-cache
  compress stac
```

To verify the operation of STAC compression, use the show compress command, as shown in [Example 26](#). This command displays information about compression-enabled interfaces; the number of byte compressed on 1-, 5-, and 10-minute intervals; and the statistics for the number of uncompressed compressed bytes that were sent and received.

Example 4-26. Using the show compress Command

```
Router#show compress

Serial0/2

    Software compression enabled

    uncompressed bytes xmt/rcv 7313/6614

    1 min avg ratio xmt/rcv 0.000/0.992

    5 min avg ratio xmt/rcv 0.000/0.993

    10 min avg ratio xmt/rcv 0.000/0.926

    no bufs xmt 0 no bufs rcv 0

    resyncs 0

    Additional Stacker Stats:

    Transmit bytes: Uncompressed = 18653960 Compressed = 6053

    Received bytes: Compressed =      5604 Uncompressed = 0
```

The Predictor Compression Algorithm

The *Predictor compression algorithm* is also a dictionary-based compression algorithm. While processing data, however, Predictor tries to predict the next series of characters in a data stream, using an index into the compression dictionary, which stores these sequences. If the next stream of data matches the index, the data sequence stored in the dictionary replaces the data sequence in the data stream. This prediction makes Predictor more efficient with its CPU use, but it also uses more memory than STAC.

To enable the Predictor compression method on a PPP- or LAPB-encapsulated interface, use the `compression predictor` command. [Example 4-27](#) shows how the Predictor compression method was used between the Lilo and Stitch routers.

Example 4-27. Using the Predictor Compression Method

```
hostname Lilo

!
interface Serial0/2
  ip address 175.25.25.1 255.255.255.0
  no ip directed-broadcast
  encapsulation ppp
  no ip mroute-cache
  clockrate 1300000
  compress predictor
!
```

```
hostname Stitch

!
interface Serial0
  ip address 175.25.25.2 255.255.255.0
  encapsulation ppp
  no ip mroute-cache
  compress predictor
```

To check the status of Predictor compression in Cisco IOS Software, use the show compress command. [Example 4-28](#) shows how the show compress command was used with Predictor to display information about the Predictor-enabled interface. The show compress command displays information about the number of compressed/uncompressed bytes that were sent out; the 1-, 5-, and 10-minute compression ratios; and displays troubleshooting information about memory issues in the no bufs area. When two ends of a connection lose synchronization between their dictionaries, time must be spent resynchronizing which adds latency to the connection. Information about dictionary resyncs is displayed in the dictionary resyncs area.

Example 4-28. Using the show compress Command with Predictor

```
Lilo#show compress
```

```
Serial0/2
```

```
Software compression enabled

uncompressed bytes xmt/rcv 681/544

1 min avg ratio xmt/rcv 0.414/0.328

5 min avg ratio xmt/rcv 0.211/0.118

10 min avg ratio xmt/rcv 0.211/0.118

no bufs xmt 0 no bufs rcv 0

resyncs 0
```

When running either of the compression algorithms, it is a good idea to monitor the processor and utilization for each router. [Example 4-29](#) shows the processor and memory utilization differences b the Lilo and Stitch routers. Notice that both routers experienced an increase in memory utilization, much of a change in processor utilization.

Example 4-29. Memory and CPU Use with Predictor

Lilo Before Predictor

```
Lilo#show process cpu

CPU utilization for five seconds: 0%/0%; one minute: 0%; five minutes: 0%

Lilo#show mem sum
```

	Head	Total(b)	Used(b)	Free(b)	Lowest(b)	Largest(b)
Processor	8148D770	5712016	3997864	1714152	1504420	1637856
I/O	1A00000	6291456	1909112	4382344	4382344	4382300

Lilo After Predictor

```
Lilo#show proc cpu

CPU utilization for five seconds: 1%/0%; one minute: 2%; five minutes: 0%

Lilo#show memory sum
```

	Head	Total(b)	Used(b)	Free(b)	Lowest(b)	Largest(b)
Processor	8148D770	5712016	4132576	1579440	1504420	1506656

```
I/O      1A00000      6291456      1909112      4382344      4382344      4382300
```

Stitch Before Predictor

Stitch#**show process cpu**

```
CPU utilization for five seconds: 11%/11%; one minute: 2%; five minutes: 2%
```

Stitch#**show memory sum**

	Head	Total(b)	Used(b)	Free(b)	Lowest(b)	Largest(b)
Processor	81257BA0	5932128	3578052	2354076	2149660	2228244
I/O	1800000	8388616	1746452	6642164	6642164	6642108

Stitch After Predictor

Stitch#**show process cpu**

```
CPU utilization for five seconds: 1%/0%; one minute: 2%; five minutes: 1%
```

Stitch#**show memory sum**

	Head	Total(b)	Used(b)	Free(b)	Lowest(b)	Largest(b)
Processor	81257BA0	5932128	3711024	2221104	2149660	2097044
I/O	1800000	8388616	1746452	6642164	6642164	6642108

After you have verified that the router can run the intended software, there are no Layer 1 problems. The router is using the most efficient switching mode, and you possibly considered using compression, have addressed all the basic issues that could be affecting router performance. Another, more advanced way to improve router performance is to configure a QoS mechanism. The next two chapters explain how various QoS types differ, how they are configured and monitored, and where each QoS feature works.

Lab 10: ATM QoS

This chapter focused on a number of quality-troubleshooting and -refining practices that you can use in the field or in a laboratory environment to provide better levels of quality for network applications. The next chapter focuses on ATM QoS techniques and their applications.

Lab Objectives

The primary focus of this lab is ATM technologies and QoS techniques; however, this lab also provides practice with the following technologies:

- EIGRP routing over NBMA networks

- Policy routing
- Voice over IP

Equipment Needed

- One Cisco LightStream 1010 ATM switch with two ATM OC-3 interfaces
- Two Cisco routers with ATM OC-3 interfaces; one with one Token Ring interface, and one with serial interface
- One Cisco router with one Token Ring and one Ethernet interface
- One Cisco router with one Ethernet interface and one FXS voice module
- One Cisco router with one serial interface and one FXS voice module
- One multistation access unit (MSAU) and Ethernet switch or hub

Physical Layout and Prestaging

For this lab, you use the network layout shown in [Figure 4-4](#). The City VetNet router will reach the Barn (TomsBarn) router via the OC-3 connection running from the City router and the Country Sto (CntryStr) router. The CntryStr router connects to the Feed Store (FeedStore) router via a Token R network. VoIP is used between the FeedStore router and the TomsBarn router, and between the Tc router and the rest of the network over an Ethernet connection.

Step 1. Cable the routers as shown in [Figure 4-4](#). Verify that all Layer 1 connections are working properly before continuing with the rest of the lab.

Step 2. Configure the ATM switch using the interfaces and VPI/VCI pairs shown in [Table 4-1](#).

Figure 4-4. Emergency Veterinarian Network (VetNet)

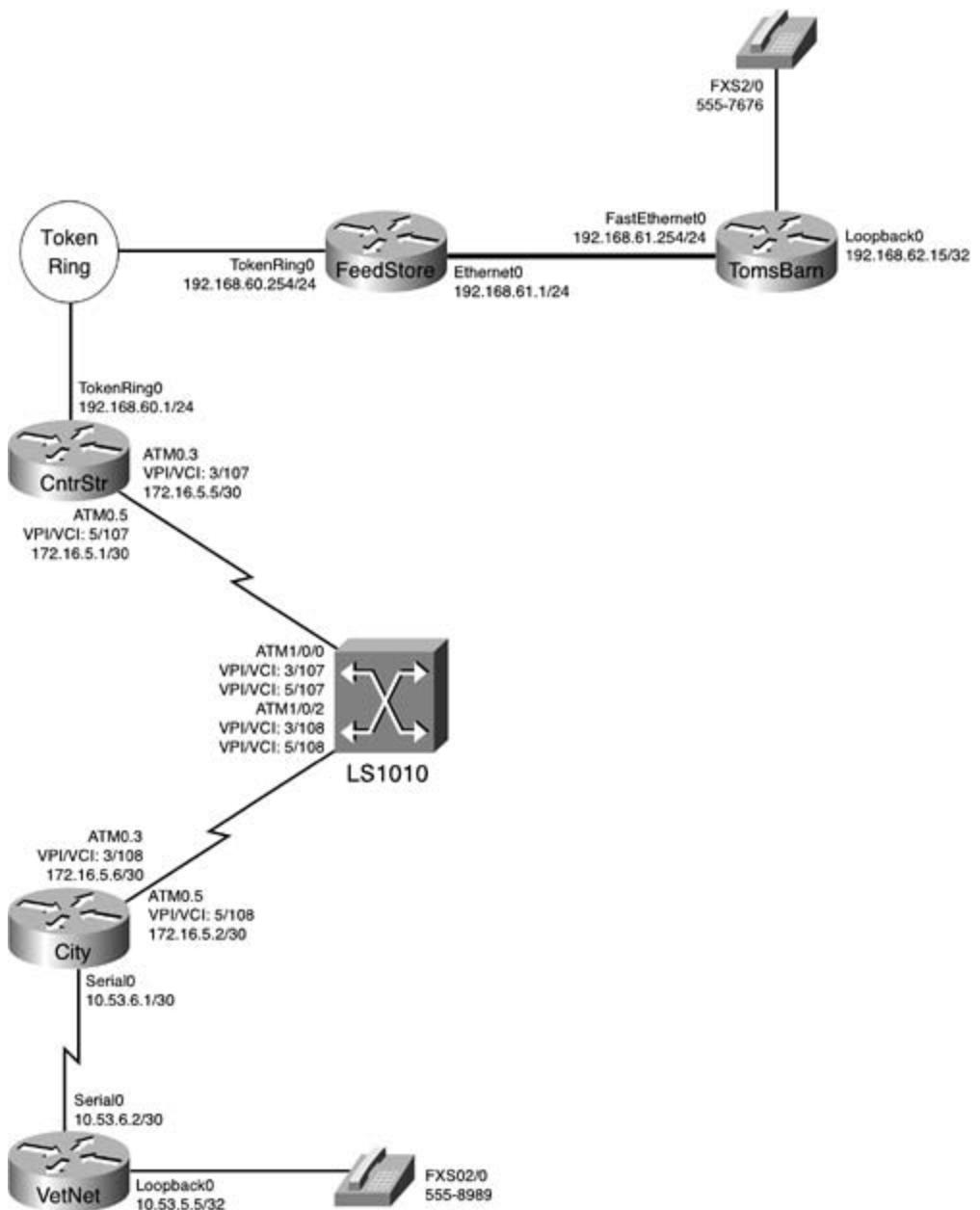


Table 4-11. ATM Switch Configuration

Switch ATM Interface	VPI	VCI	Router Name and Interface
ATM 1/0/0	3	107	CntryStr—ATM0.3
ATM 1/0/0	5	107	CntryStr—ATM0.5
ATM 1/0/2	3	108	City—ATM0.3
ATM 1/0/2	5	108	City—ATM0.5

[Example 4-30](#) shows the ATM configuration and the show atm vc command output from the ATM:

Example 4-30. ATM VC Configuration

```
ATM-Switch#show atm vc interface atm 1/0/0
```

```
hostname ATM-Switch
```

```
!
```

```
interface ATM1/0/0
```

```
no ip address
```

```
!
```

```
interface ATM1/0/1
```

```
no ip address
```

```
!
```

```
interface ATM1/0/2
```

```
no ip address
```

```
atm pvc 3 108 interface ATM1/0/0 3 107
```

```
atm pvc 5 108 interface ATM1/0/0 5 107
```

```
!
```

```
CRLF
```

```
ATM-Switch#show atm vc interface atm 1/0/0
```

Interface	VPI	VCI	Type	X-Interface	X-VPI	X-VCI	Encap	Status
ATM1/0/0	0	5	PVC	ATM2/0/0	0	39	QSAAL	UP
ATM1/0/0	0	16	PVC	ATM2/0/0	0	35	ILMI	UP
ATM1/0/0	3	107	PVC	ATM1/0/2	3	108		UP
ATM1/0/0	5	107	PVC	ATM1/0/2	5	108		UP

```
ATM-Switch#show atm vc interface atm 1/0/2
```

Interface	VPI	VCI	Type	X-Interface	X-VPI	X-VCI	Encap	Status
ATM1/0/2	0	5	PVC	ATM2/0/0	0	41	QSAAL	UP
ATM1/0/2	0	16	PVC	ATM2/0/0	0	37	ILMI	UP

ATM1/0/2	3	108	PVC	ATM1/0/0	3	107	UP
ATM1/0/2	5	108	PVC	ATM1/0/0	5	107	UP

Lab Exercise

Step 1. Configure all IP addresses as shown in [Table 4-12](#). Make sure that all routers are able to ping their directly connected neighbor's interface before you move to Step 2. Configure the ATM interfaces to use the ATM encapsulation type most suited to burst data traffic.

Table 4-12. IP Addressing for This Network Model

Router Name	Router Interface	IP Address
TomsBarn	FastEthernet0	192.168.61.254/24
	Loopback0	192.168.62.15/32
FeedStore	Ethernet0/0	192.168.61.1/24
	TokenRing0/0	192.168.60.254/24
CntryStr	ATM0.3	172.16.5.5/30
	ATM0.5	172.16.5.1/30
	TokenRing0	192.168.60.1/24
City	ATM0.3	172.16.5.6/30
	ATM0.5	172.16.5.2/30
	Serial2	10.53.6.1/30
VetNet	Serial1	10.53.6.2/30
	Loopback0	10.53.5.5/32

Step 2. Configure EIGRP routing for all routers, and put all router interfaces in EIGRP AS 62. Make sure that EIGRP routers only advertise the most specific routes; do not allow auto-summarization. Verify that all routers are able to ping the loopback interfaces on the TomsBarn and VetNet routers before proceeding to Step 3.

Step 3. Configure the ATM PVCs on the City and CntryStr routers so that the PVC on interface 0.3 will have an unspecified bit rate with a maximum burst rate of 149,344 Mbps, and a minimum cell rate of 44,209 Mbps, and interface 0.5 will have a non-real-time variable bit rate with a maximum burst rate of 6.176 Mbps, and a minimum guaranteed rate of 1.544 Mbps.

Step 4. Configure Voice over IP between the TomsBarn and VetNet routers. Use the loopback addresses for the session targets, and use FXS voice port 2/0 for the phones. Test the configuration by issuing test calls between the phones connected to the two routers.

Step 5. Configure policy routing on the CntryStr and City routers so that all voice, and only voice traffic (including call setup), will be sent through the 1.5-Mbps ATM interface. Verify that the traffic takes the path through the proper interface.

Step 6. The new OC-3 has caused a bottleneck to form on the serial line between the VetNet City routers. Enable compression on these routers using the compression method with the most efficient CPU utilization. This lab is complete when you have successfully placed test calls from TomsBarn and VetNet phones.

Lab Walkthrough

Step 1. Configure all IP addresses as shown in [Table 4-12](#). Make sure that all routers are able to ping their directly connected neighbor's interface before you move on to Step 2. Configure the ATM interfaces to use the ATM encapsulation type most suited to burst data traffic.

AAL5Snap is the ATM encapsulation type that was created specifically for today's burstier data needs. AAL5Snap encapsulation is configured using the encapsulation aal5snap command in PVC configuration mode, as shown on the CntryStr router in [Example 4-31](#).

Example 4-31. Using AAL5Snap Encapsulation

```
interface ATM0
    no ip address
    no atm ilmi-keepalive
!
interface ATM0.3 multipoint
    ip address 172.16.5.5 255.255.255.252
    pvc 3/107
        protocol ip 172.16.5.6 broadcast
        encapsulation aal5snap
    !
    !
interface ATM0.5 multipoint
    ip address 172.16.5.1 255.255.255.252
    pvc 5/107
        protocol ip 172.16.5.2 broadcast
```

```
encapsulation aal5snap
```

Step 2. Configure EIGRP routing for all routers, and put all router interfaces in EIGRP AS 62. Make sure that EIGRP routers only advertise the most specific routes; do not allow auto-summarization. You may not use EIGRP neighbor statements in this laboratory. Verify that all routers are able to ping the loopback interfaces on the TomsBarn and VetNet routers before you proceed to Step 3.

There are two ways to make EIGRP neighbors converge over an NMBA network. The first way is to use EIGRP neighbor statements to configure static neighbor relationships between the peers, which is not allowed in this lab. The second way is to use a Layer 2-to-Layer 3 protocol mapping with pseudo-broadcast support to allow the ATM interfaces to create pseudo-broadcasts, allowing them to converge over the NMBA network. This step requires an accurate ATM configuration to work properly. If you remember back to the ATM review section of this chapter, in newer versions of IOS Software, Layer 2-to-Layer 3 protocol mappings on ATM networks are created using the `protocol ip/p broadcast` statement in PVC configuration mode under the ATM subinterface. [Example 4-32](#) shows the ATM configuration for the City router.

Example 4-32. The City Router's ATM Configuration

```
interface ATM0
  no ip address
  no atm ilmi-keepalive
!
interface ATM0.3 multipoint
  ip address 172.16.5.6 255.255.255.252
  pvc 3/108
    protocol ip 172.16.5.5 broadcast
    encapsulation aal5snap
  !
  !
interface ATM0.5 multipoint
  ip address 172.16.5.2 255.255.255.252
  pvc 5/108
    protocol ip 172.16.5.1 broadcast
    encapsulation aal5snap
```

After verifying the ATM configuration, you can check the NMBA broadcast support by issuing a `show atm map` command and verifying that each PVC has an associated broadcast statement as shown, on the router, in [Example 4-33](#).

Example 4-33. show atm map on the City Router

```
City#show atm map

Map list ATM0.3pvc1 : PERMANENT
ip 172.16.5.5 maps to VC 1, VPI 3, VCI 108, ATM0.3
, broadcast

Map list ATM0.5pvc2 : PERMANENT
ip 172.16.5.1 maps to VC 2, VPI 5, VCI 108, ATM0.5
, broadcast
```

You can verify that the EIGRP configuration is working properly by pinging the loopback interfaces of the TomsBarn and VetNet routers. [Example 4-34](#) shows the EIGRP configuration from the CntryStr and the pings from the TomsBarn and VetNet routers.

Example 4-34. EIGRP Configuration from the CntryStr Router

```
router eigrp 62
network 172.16.5.0 0.0.0.3
network 172.16.5.4 0.0.0.3
network 192.168.60.0
no auto-summary
```

```
TomsBarn#ping 10.53.5.5
```

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 10.53.5.5, timeout is 2 seconds:

!!!!

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/6/8 ms
```

```
VetNet#ping 192.168.62.15
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 192.168.62.15, timeout is 2 seconds:
```

```
!!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/6/8 ms
```

NOTE

Earlier versions of Cisco IOS Software required PVC-independent map lists to map Layer 2-to-Layer 3 protocols. These commands still exist in newer versions of the software if you want to use them.

Step 3. Configure the ATM PVCs on the City and CntryStr routers so that the PVC on interface 0.3 will have an unspecified bit rate, with a maximum burst rate of 149,344 Mbps, and a minimum cell rate of 44,209 Mbps, and interface 0.5 will have a non-real-time variable bit rate, with a maximum burst rate of 6.176 Mbps, and a minimum guaranteed rate of 1.544 Mbps.

The ATM traffic-shaping exercise for this lab requires you to configure each PVC on the City and CntryStr routers with a separate level of ATM service. The first, bigger PVC is set to use a sustainable rate of 45 Mbps (DS3), and it is also able to burst to 150 Mbps; this is accomplished using the ATM service level on the ATM 3/107 and 3/108 PVCs. This configuration can be verified by using the `show atm vc` command. [Example 4-35](#) shows the UBR+ configuration for the City router.

Example 4-35. The City Router's UBR+ Configuration

```
interface ATM0.3 multipoint
  ip address 172.16.5.6 255.255.255.252
  pvc 3/108
    protocol ip 172.16.5.5 broadcast
    ubr+ 149344 44209
    encapsulation aal5snap
City# show atm vc
```

```
VCD /
```

Peak	Avg/Min	Burst
------	---------	-------

Interface	Name	VPI	VCI	Type	Encaps	SC	Kbps	Kbps	Cells	Sts
0.3	1	3	108	PVC	SNAP	UBR+	149344	44209		UP

The second, smaller, T1-sized PVC should be configured to use the VBR-nrt service level with a PCF 6,176 kbps, and an SCR of 1,544 kbps, as shown on the CntryStr router in [Example 4-36](#).

Example 4-36. The CntryStr's VBR-nrt Configuration

```
interface ATM0.5 multipoint
  ip address 172.16.5.1 255.255.255.252
  pvc 5/107
    protocol ip 172.16.5.2 broadcast
    vbr-nrt 6176 1544
    encapsulation aal5snap
```

NOTE

Even when you change the ATM service class for an ATM interface, the bandwidth parameter set when the show interface command is issued will not be changed. Remember, the bandwidth shown using the show interface command is only the EIGRP bandwidth metric for the interface.

Step 4. Configure Voice over IP between the TomsBarn and VetNet routers. Use the loopback addresses for the session targets, and use FXS voice port 2/0 for the phones. Test the configuration by issuing test calls between the phones connected to the two routers.

This step is very straightforward, assuming the rest of the configuration up to this point is working properly. All you have to do is set up two dial peers on each router, and set a session target to the local and remote dial peers. [Example 4-37](#) shows the voice configuration for the TomsBarn router.

Example 4-37. TomsBarn Voice over IP Configuration

```
dial-peer voice 5557676 pots
destination-pattern 5557676
```

```

port 2/0

!

dial-peer voice 5558989 voip

destination-pattern 5558989

session target ipv4:10.53.5.5

```

Step 5. Configure policy routing on the CntryStr and City routers so that all voice, and only voice traffic (including call setup), will be sent through the 1.5-Mbps ATM interface. Verify that the traffic takes the path through the proper interface.

This step requires a few tasks to work properly. First, on one of the routers, in this example the CntryStr router, create an access list that matches voice traffic coming from the TomsBar router. Next, create a route map that matches that traffic and sends it to interface ATM 0.5. Then, test and, if necessary, fine-tune that configuration using the debug ip policy command and calls initiated from the phone in TomsBarn. Then, after you have the configuration correct, repeat the same steps on the City router. [Example 4-38](#) shows the policy routing configuration from the CntryStr router.

Example 4-38. The Policy Routing Configuration for the CntryStr Router

```

interface TokenRing0

ip address 192.168.60.1 255.255.255.0

no ip route-cache

no ip mroute-cache

ip policy route-map voice-traffic

ring-speed 16

!

access-list 150 permit tcp host 192.168.61.254 host 10.53.6.2 eq 1720

access-list 150 permit tcp host 192.168.61.254 eq 1720 host 10.53.6.2

access-list 150 permit tcp host 192.168.61.254 host 10.53.5.5 eq 1720

access-list 150 permit udp host 192.168.61.254 host 10.53.6.2 range 16384 32767

route-map voice-traffic permit 10

match ip address 150

set interface ATM0.5

```

In the preceding example, the first three lines specify H.323 call setup traffic between the two routers. The last line specifies the RTP voice traffic. Route mapped voice traffic is used to configure the policy. This sends the access list 150 traffic to interface ATM 0.5. You can verify this by making test calls from the TomsBarn router to the VetNet router, and by using show route-map and debug ip policy to show the policy matches, as shown in [Example 4-39](#).

Example 4-39. show route-map and debug ip policy

```
CntryStr#show route-map voice-traffic

route-map voice-traffic, permit, sequence 10

Match clauses:

    ip address (access-lists): 150

Set clauses:

    interface ATM0.5

Policy routing matches: 3942 packets, 328996 bytes

02:24:57: IP: s=192.168.61.254 (TokenRing0), d=10.53.5.5, len 346, policy match
02:24:57: IP: route map voice-traffic, item 10, permit
02:24:57: IP: s=192.168.61.254 (TokenRing0), d=10.53.5.5 (ATM0.5), len 346, policy
02:24:57: IP: TokenRing0 to ATM0.5 172.16.5.2
02:24:58: IP: s=192.168.61.254 (TokenRing0), d=10.53.5.5, len 40, policy match
02:24:58: IP: route map voice-traffic, item 10, permit
02:24:58: IP: s=192.168.61.254 (TokenRing0), d=10.53.5.5 (ATM0.5), len 40, policy
02:24:58: IP: TokenRing0 to ATM0.5 172.16.5.2
02:24:58: IP: s=192.168.61.254 (TokenRing0), d=10.53.6.2, len 60, policy match
02:24:58: IP: route map voice-traffic, item 10, permit
02:24:58: IP: s=192.168.61.254 (TokenRing0), d=10.53.6.2 (ATM0.5), len 60, policy
```

Step 6. The new OC-3 has caused a bottleneck to form on the serial line between the VetNet and City routers. Enable compression on these routers using the compression method with the most efficient CPU utilization. This lab is complete when you have successfully placed test calls from TomsBarn and VetNet phones.

The Predictor compression algorithm makes the most efficient use of the router's CPU resources. Before you can use Predictor compression, however, you must use PPP encapsulation. After you have configured PPP and Predictor on the City and VetNet routers, you should be able to make successful test calls between the TomsBarn and VetNet routers. [Example 4-40](#) shows the compression configuration for the VetNet router.

Example 4-40. The VetNet Compression Configuration

```
interface Serial1
  ip address 10.53.6.2 255.255.255.252
  encapsulation ppp
  clockrate 1300000
  compress predictor
```

After you complete the test calls, this lab is finished. Compare your router configuration to those shown in [Example 4-41](#).

Example 4-41. Complete Router Configurations for This Lab

```
hostname TomsBarn
!
ip cef
!
interface Loopback0
  ip address 192.168.62.15 255.255.255.255
!
interface FastEthernet0
  ip address 192.168.61.254 255.255.255.0
!
router eigrp 62
```

```
network 192.168.61.0

network 192.168.62.15 0.0.0.0

no auto-summary

!

ip classless

!

dial-peer voice 5557676 pots

destination-pattern 5557676

port 2/0

!

dial-peer voice 5558989 voip

destination-pattern 5558989

session target ipv4:10.53.5.5
```

```
hostname FeedStore

!

ip cef

!

interface Ethernet0/0

ip address 192.168.61.1 255.255.255.0

!

interface TokenRing0/0

ip address 192.168.60.254 255.255.255.0

ring-speed 16

!

router eigrp 62

network 192.168.60.0

network 192.168.61.0
```

```
no auto-summary



---



```
hostname CntryStr
!
ip cef
!
interface TokenRing0
 ip address 192.168.60.1 255.255.255.0
ip route-cache policy
 no ip route-cache cef
 ip policy route-map voice-traffic
 ring-speed 16
!
interface ATM0
 no ip address
 no atm ilmi-keepalive
!
interface ATM0.3 multipoint
 ip address 172.16.5.5 255.255.255.252
pvc 3/107
 protocol ip 172.16.5.6 broadcast
 ubr+ 149344 44209
 encapsulation aal5snap
!
interface ATM0.5 multipoint
 ip address 172.16.5.1 255.255.255.252
pvc 5/107
 protocol ip 172.16.5.2 broadcast
```


```

```
vbr-nrt 6176 1544

encapsulation aal5snap

!

router eigrp 62

network 172.16.5.0 0.0.0.3

network 172.16.5.4 0.0.0.3

network 192.168.60.0

no auto-summary

!

ip classless

!

access-list 150 permit tcp host 192.168.61.254 host 10.53.6.2 eq 1720

access-list 150 permit tcp host 192.168.61.254 eq 1720 host 10.53.6.2

access-list 150 permit tcp host 192.168.61.254 host 10.53.5.5 eq 1720

access-list 150 permit udp host 192.168.61.254 host 10.53.6.2 range 16384 32767

route-map voice-traffic permit 10

match ip address 150

set interface ATM0.5


hostname City

!

ip cef

!

interface Serial0

ip address 10.53.6.1 255.255.255.252

encapsulation ppp

no ip route-cache cef

ip policy route-map voice-traffic
```

```
compress predictor

!

interface ATM0
    no ip address
    no atm ilmi-keepalive
!

interface ATM0.3 multipoint
    ip address 172.16.5.6 255.255.255.252
pvc 3/108
    protocol ip 172.16.5.5 broadcast
    ubr+ 149344 44209
    encapsulation aal5snap
!

interface ATM0.5 multipoint
    ip address 172.16.5.2 255.255.255.252
pvc 5/108
    protocol ip 172.16.5.1 broadcast
    vbr-nrt 6176 1544
    encapsulation aal5snap
!

router eigrp 62
    network 10.53.6.0 0.0.0.3
    network 172.16.5.0 0.0.0.3
    network 172.16.5.4 0.0.0.3
    no auto-summary
!

ip classless
!
```

```
access-list 1 deny    172.16.5.4 0.0.0.3
access-list 1 permit any
access-list 150 permit tcp host 10.53.6.2 host 192.168.61.254 eq 1720
access-list 150 permit tcp host 10.53.6.2 eq 1720 host 192.168.61.254
access-list 150 permit tcp host 10.53.6.2 host 192.168.62.15 eq 1720
access-list 150 permit udp host 10.53.6.2 host 192.168.61.254 range 16384 32767
route-map voice-traffic permit 10
  match ip address 150
  set interface ATM0.5
```

```
hostname VetNet
!
interface Loopback0
  ip address 10.53.5.5 255.255.255.255
!
interface Serial0
  ip address 10.53.6.2 255.255.255.252
  encapsulation ppp
  clockrate 1300000
  compress predictor
!
router eigrp 62
  network 10.53.5.5 0.0.0.0
  network 10.53.6.0 0.0.0.3
  no auto-summary
!
ip classless
!
```

```
dial-peer voice 5558989 pots
destination-pattern 5558989
port 2/0

!
dial-peer voice 5557676 voip
destination-pattern 5557676
session target ipv4:192.168.62.15
```

Further Reading

RFC 2330, *Framework for IP Performance Metrics*, by Paul L.Della Maggiora, Christopher E. Elliott, Robert L. Pavone, Jr., Kent J. Phelps, and James M. Thompson.

Network Consultants Handbook, by Matthew J. Castelli.

Internetworking Troubleshooting Handbook, Second Edition, by Cisco Systems.

Chapter 5. Integrated and Differentiated Services

The preceding chapter explored router performance and examined several route-switching mechanisms that you can use to provide certain levels of Quality of Service (QoS) by reducing latency and jitter caused by errors and device resource utilization. This chapter focuses on more granular QoS techniques provided by integrated and differentiated services. This chapter covers the following topics:

- How to provide a guaranteed level of service using Resource Reservation Protocol (RSVP)
- How to mark traffic with priority levels using the built-in Internet Protocol (IP) Type of Service (TOS) bits
- How to prioritize traffic using IP precedence bits
- How to use the new differentiated services codepoint bits for advanced traffic classification and marking

While analyzing these topics, this chapter also applies these technologies using practical examples and gives you the opportunity to gain real hands-on experience with the protocols with practical laboratory experiments.

Integrated Services

Integrated services, commonly referred to as IntServ, is an architecture for providing end-to-end QoS. IntServ solutions allow end stations to make quality requests upon the network; the network participates in this QoS scheme by either reserving or not reserving network resources for the requesting end stations. The integrated services architecture provides a way of guaranteeing network quality levels by specifically reserving services and controlling the load of the traffic on devices to provide the guaranteed service requirements. The most common implementation of the integrated services architecture is the RSVP signaling protocol.

Bandwidth Reservation Using RSVP

RSVP, also known as Resource Reservation Setup Protocol, is defined in RFC 2205 as a signaling protocol used for resource reservation, provides an end-to-end QoS reservation that is initiated by requesting host or application. RSVP supports multicast or unicast IP traffic in flows. A *flow* is basic defined as traffic from a particular IP address, protocol type, and port number that is destined to a specific IP address or multicast group on a specific port using a specific protocol type. Because flow is defined by source and destination protocol information, each flow provides a unidirectional description of a conversation between end stations. Using RSVP, real-time applications can specify the network quality parameters required for the application to function as designed. In RSVP, hosts usually request specific QoS features and routers along the path between the hosts providing the services. It is also important to note that RSVP requests are unidirectional flowing from the requesting host to the destination, without any device in between participating in the RSVP session. RSVP uses the information from the routing tables to find routes to the destination. With the information provided by the routing tables and the different message types, RSVP dynamically adjusts to changing network conditions.

RSVP also sends periodic refresh messages that are used to maintain the RSVP state. If the messages are not received within the specified period of time, defined in RSVP request messages, the RSVP session times out and the reservation is deleted.

RSVP requests use flow specifications referred to as flowspecs and filter specs to form a flow description. The *flow descriptor* is used to describe the characteristics of a flow. The *flowspec* defines the request from the host's quality requirements; the packet scheduler uses the information provided by the flowspec to determine the scheduling requirements for the flow, and the *filter spec* is used to define the requirements for the host's packet classifier. The *packet scheduler* determines when packets are to be forwarded, and the *packet classifier* determines the QoS characteristics for the packets in the flow.

Two types of flow reservations are classified in RSVP: distinct reservations and shared reservations. *Distinct reservations* are defined by a flow that has been initiated by one sender with one reservation created for each sender, whereas *shared reservations* flows may have originated from one or more senders. A separate reservation is created for each sender that requests a distinct reservation; only one reservation is created and shared for senders utilizing shared reservations. The shared reservation is typically used by applications. [Table 5-1](#) summarizes the RSVP reservation types and briefly describes their application.

Table 5-1. RSVP Reservation Types

Reservation Type	Description
Distinct reservation	One sender originates traffic flow.
Shared reservation	At least one sender originates flow(s). These flows are generally not operating at the same time; therefore, they can share the same reservation.

RSVP reservations use two types of lists to define groups of senders. *Explicit sender-selection lists* specify senders using a filter spec that defines single senders, and *wildcard lists* specify senders that share the same filter spec using the same QoS characteristics. Explicit senders use the fixed-filter (FF) style for distinct reservations or the shared-explicit (SE) style for shared reservations. Wildcard senders use wildcard-filter (WF) style for shared reservations and do not have a definition for distinct reservations. [Table 5-2](#) shows how filter types are matched to sender selections and the characteristics that belong to each of the styles.

Table 5-2. RSVP Reservation Styles

Filter Style	Description	Reservation Type	Sender Selection
Wildcard-filter style (WF)	Uses a single reservation that is shared by multiple flows	Shared	Wildcard
Fixed-filter style (FF)	Uses a single reservation for packets from one particular flow	Distinct	Explicit
Shared-explicit style (SE)	Used by multicast applications with flows from multiple sources	Shared	Explicit

As mentioned earlier, RSVP is an end-to-end QoS model, which means that each device in an RSVP path must request resources from another device. Each RSVP-enabled router in the path must make two decisions before granting a request: whether the router itself has adequate resource to provide the requested resources, and whether the requesting host has permission to make a reservation. These decisions are made by the Admission Control Module and the Policy Control Module. The *Admission Control Module* determines whether the router has the resources to grant, and the *Policy Control Module* determines whether the requesting host has the right to request the service. If both conditions are met, a resource reservation is made. If either condition fails, the router refuses the reservation request, and the traffic is still sent using regular service. RSVP uses several message types to pass reservation requests and reservation request parameters. These message types are covered shortly, after this chapter describes the steps required to set up an RSVP path. To set up an RSVP path, follow these steps:

Step 1. The RSVP sender, the host requesting services, sends an RSVP PATH message that describes the data it intends to send.

Step 2. Each RSVP router in the path to the destination reads the PATH message, saves the information about the previous-hop IP address, adds its IP address to the message as the previous hop, and then sends the message on to the next router.

Step 3. The receiving host receives the PATH information.

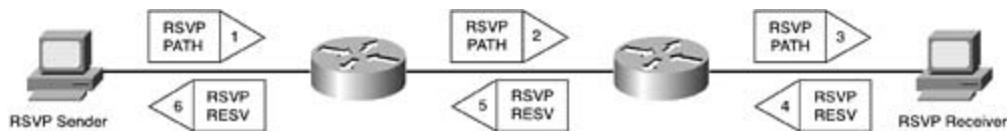
Step 4. After reading the PATH message, the RSVP receiver requests a resource reservation to the sending host, using the exact reverse path and using the RSVP RESV message.

Step 5. The RSVP-enabled routers either refuse the RSVP requests, if they do not have adeq resources, or they merge the request and request a reservation from the next router (in the reverse path).

Step 6. The original sending host receives the request from the closest next-hop router (the router that reserved the resources) and uses the reserved path.

[Figure 5-1](#) shows a diagram of how RSVP sessions are created using RSVP PATH and RESV messag

Figure 5-1. RSVP Session Setup Diagram



Remember a few key terms when using the RSVP protocol. An *RSVP sender* is the host who initiates RSVP reservation. The *RSVP receiver* is the host who the resources are reserved to. Any routers tha have been configured to run the RSVP protocol in between the sender and receiver are referred to . *RSVP-enabled routers*.

The *resource reservation path* (RSVP PATH) message, the message initially sent by the RSVP sende request a reservation, lists all the hops along the RSVP path that are used to reach the RSVP receiv The RSVP PATH message also makes it possible for each RSVP-enabled router to store an RSVP sta each reservation request. The *resource reservation request* (RSVP RESV) message is sent by the receiving host and processed by each RSVP-enabled router in the path until it arrives at the destin host, the RSVP sender. The sender receives and replies to RESV messages, sending them back to the receiving host using the exact reverse path that was originally used to send the request.

NOTE

The original RSVP RESV message sent by the RSVP receiver may not always be sent all the way back to the sending host in all situations. If multiple receivers send an RSVP RESV message, and there is a point where the flowspecs for these reservations merge, only the largest flowspec is forwarded all the way back to the sender. The RSVP RESV message may also include a request for a confirmation of the resource reservation. When that is the case, either the sender or the RSVP router (at the flowspec merge point) sends a confirmation to the receiver.

RSVP uses the IP protocol for all of its communication. Because IP is not a reliable protocol, someti RSVP messages will not be received by all required devices. To solve this problem, RSVP sends per refresh messages using the hello interval specified in the original PATH message. These messages .

sent using RSVP PATH and RESV messages. When a sending host application is finished using the resources, it should send an RSVP TEARDOWN message. The next hop router receives the TEARDO message, removes the reservation, and sends a TEARDOWN message to the next-hop router along path. The use of RSVP TEARDOWN messages is not limited to the RSVP sending host; the RSVP rec may also send a TEARDOWN message, at any time, if it decides to end the RSVP session. In the ev that a TEARDOWN message is lost, there is no need for concern, because RSVP sessions automatic time out when an interval called the *cleanup timeout interval* has been exceeded.

RSVP uses a number of message types to set up, maintain, and tear down RSVP sessions. In the e of a problem, these messages can be used to troubleshoot an RSVP session. [Table 5-3](#) describes th messages in detail.

Table 5-3. RSVP Message Types

Message Type	Message Details	Message Description
PATH	A required message used to set up an RSVP session	<p>PATH messages store information about the RSVP path s including the IP address of the previous hop; this inform is to be used by the receiving host as the reverse path to reach the sender.</p> <p>The PATH message includes the following fields:</p> <p>SESSION— Describes the receiver's destination IP addre (unicast or multicast), protocol type, and port number</p> <p>RSVP_HOP— The IP address and <i>logical outgoing interface (L/I)</i> of each RSVP-enabled device in the path, specifying each <i>previous hop (PHOP)</i> and <i>next hop (NHOP)</i> in the path</p> <p>TIME_VALUES— The refresh period for the RSVP session</p> <p>The PATH message also contains a <i>Sender Descriptor</i>, w is used to describe the sending host's characteristics, us the SENDER_TEMPLATE and SENDER_TSPEC. The SENDER_TEMPLATE contains the sending station's IP address, protocol type, and port number. The SENDER_TSPEC defines the required characteristics for t flow, such as the source and destination IP address, pro types, and port numbers.</p> <p>PATH messages are also used as periodic hello messages to keep RSVP sessions alive. The default hello interval is 30 seconds.</p>
PATH ERROR	An optional error message sent out when there is an error found in a PATH message	This message is sent to the sender as error notification when an error has been found in PATH messages.

PATH TEARDOWN	An optional error message sent out notifying the next hop router that the PATH is no longer valid and should be deleted	PATH TEARDOWN messages are sent out when a path is removed immediately. They can either be sent by an RSVP sender or RSVP-enabled router. The messages are to all RSVP-enabled routers along the reservation path and are forwarded to all RSVP receivers.
RESV	A required message sent out by RSVP receivers to share flow specifications	<p>RESV messages are used to transmit RSVP reservation requests and request data between RSVP-enabled devices. RESV messages contain the following data:</p> <p>The SESSION, RSVP_HOP, and TIME_VALUES fields as specified previously in the RSVP PATH message</p> <p>RESV_CONFIRM— Contains the IP address of a receiver requesting RSVP session confirmation</p> <p>SCOPE— Contains an explicit list of senders that this message applies to</p> <p>STYLE— The reservation style for the message</p> <p><i>Flow Descriptor List</i>— The list of flow descriptors</p> <p><i>Flow Descriptor</i>— The flow descriptor for this message, which includes the flowspec, the filter spec, and the reservation style (FF, WF, SE)</p>
RESV ERROR	An optional error message sent out when an RESV message error has been found	This message is sent to the receiver as error notification when an error has been found in an RESV message.
RESV CONFIRM	An optional message sent by the sender to the receiver as a notification that the message applies end to end	This message is sent out to the receiver to notify the receiver of an end-to-end RSVP session.
RESV TEARDOWN	An optional message sent by RSVP receivers and intermediate RSVP-enabled routers to indicate that an RSVP resource should be deleted	TEARDOWN messages are sent out when a path is to be removed immediately. These messages can be sent either by RSVP-enabled routers or by RSVP receivers and should be forwarded upstream to all RSVP-enabled routers and RSVP senders.

Two types of reservations can be requested using RSVP: controlled load services and guaranteed bit rate services. *Controlled load services* allow an RSVP session to flow through the network with the least possible interruption from other traffic flows, somewhat like an emulated circuit. *Guaranteed bit rate services* try to guarantee the worst-case delay that will be incurred by the flow when traveling across the network. Guaranteed bit rate services compute the delay taken from PATH messages along the RSVP path of a flow and provide this information to the receiver during resource reservation requests. Now that you have seen how RSVP uses the various message types to set up, maintain, and tear down RSVP reservations, it's time to look at how RSVP is configured on Cisco routers.

RSVP Configuration

The configuration of RSVP requires two steps. First, all router interfaces along the RSVP path must be configured to use Weighted Fair Queuing (WFQ). WFQ is required to provide flow support and queue to RSVP on a per-interface basis. RSVP bandwidth must be reserved on each interface. By default, you may reserve up to 75 percent of an interface's bandwidth.

NOTE

Low Latency Queuing (LLQ) can also be used to provide RSVP support. LLQ is covered in [Chapter 6](#), "QoS—Rate Limiting and Queueing Traffic."

Step 1. Enable WFQ along the RSVP path. For each router that is to have an interface participating in the RSVP reservation process, WFQ must be enabled. By default, WFQ is enabled on interfaces with less than E1 speeds. To enable WFQ, use the `fair-queue` command on each interface.

```
fair-queue [discard-threshold] [dynamic-queues] [reservable-queues]
```

With the exception of the *reservable-queues* value, the default WFQ settings will generally be sufficient for any low-bandwidth interface. The WFQ *discard-threshold* is a value ranging from 1 to 4096. This value specifies how many packets a congested interface should queue before discarding any new packets; the default value is 64. The *dynamic-queues* parameter enables you to specify the number of dynamic flows that should be allowed on a congested interface; the range for the *dynamic-queues* parameter is 16 to 4096 queues. By default, WFQ supports 256 dynamic queues. The *reservable-queues* parameter enables you to configure a limit on the number of RSVP reservable queues that WFQ will support; you can configure any number of queues ranging from 0 to 1000. By default, WFQ does not support reservable queues. WFQ is covered in detail in the next chapter.

Step 2. Configure RSVP bandwidth reservation limitations per interface using the `ip rsvp bandwidth` command. [Table 5-4](#) shows the optional RSVP bandwidth arguments and their descriptions:

```
ip rsvp bandwidth [reservable-bandwidth] [largest-flow]
```

Table 5-4. RSVP Bandwidth Arguments

Command	Description
<i>reservable-bandwidth</i>	(Optional) This command parameter enables you to configure the total amount of bandwidth that can be configured on an interface in kbps. The default setting is 7 percent of the available bandwidth in kilobits.
<i>largest-flow</i>	(Optional) This command parameter enables you to specify the size of the largest flow size in kbps. By default, the largest flow is limited to 75 percent of the available bandwidth in kilobits per second.

In addition to the RSVP bandwidth allocation configuration, you can use a number of other optional RSVP commands to customize the performance and security of RSVP. To configure RSVP with a static neighbor assignment, use the command `ip rsvp neighbor` and specify either a standard or extended numbered access-list (lists 1 through 199):

```
ip rsvp neighbor [access-list]
```

If you are using NetFlow switching with RSVP, the `ip rsvp flow-assist` command enables RSVP to NetFlow support for RSVP:

```
ip rsvp flow-assist
```

You can also configure RSVP to change the IP precedence or DSCP value of packets by using either `ip rsvp precedence` or `ip rsvp signalling` commands. Using the `ip rsvp precedence` command, you can change the IP precedence to a value between 0 and 7. With the `ip rsvp signalling dscp` command,

you can change the DSCP value to a value between 0 and 63. You can use the ip rsvp tos command to change the type of service (ToS) value to a value between 0 and 31. With each of these commands you can either change packets that conform to the flow size, packets that exceed the flow size, or both. Precedence, ToS, and DSCP packet marking are covered later in this chapter.

```
ip rsvp precedence [conform | exceed] precedence-value [conform | exceed]
```

precedence-value

```
ip rsvp signalling dscp dscp-value
```

```
ip rsvp tos [conform | exceed] tos-value [conform | exceed] tos-value
```

Simulating RSVP Messages

In a lab environment, it is possible to simulate static RSVP senders and receivers using the ip rsvp sender-host and ip rsvp reservation-host commands. The ip rsvp reservation-host command simulates an RSVP RESV message, and the ip rsvp sender-host command simulates an RSVP PA- message. [Table 5-5](#) shows the RSVP sender and reservation command parameters and their descriptions:

```
ip rsvp reservation-host destination-address source-address [IP-protocol-number  
| tcp | udp] destination-port source-port next-hop-address interface-name  
interface-number [ff | se | wf] [load | rate] average-bit-rate maximum-burst  
ip rsvp sender-host destination-address source-address [IP-protocol-number | tcp  
| udp] destination-port source-port next-hop-address interface-name interface
```

```
-number [ff | se | wf] [load | rate] average-bit-rate maximum-burst
```

NOTE

The `ip rsvp reservation-host` and `ip rsvp sender-host` commands may have different options available on different router platforms. You may need to issue a test run of the command to find which options are available on your router platform before deciding which options you will use.

Table 5-5. `rsvp simulation` Command Parameters

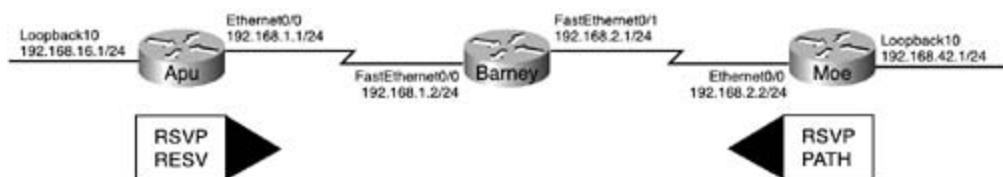
Command Parameter	Parameter Description
<code>destination-address</code>	The destination IP address of the RSVP session.
<code>source-address</code>	The source IP address of the RSVP session.
<code>[IP-protocol-number tcp udp]</code>	The port number associated with the RSVP flow. This port can be TCP, UDP, specific IP protocol number ranging from 0 to 255.
<code>destination-port</code>	The destination port number, ranging from 0 to 65,535. For unspecified ports, use 0 as both the source and destination port numbers.
<code>source-port</code>	The source port number, ranging from 0 to 65,535. For unspecified ports, use 0 as both the source and destination port numbers.
<code>[ff se wf]</code>	(<code>ip rsvp reservation-host</code> command only) Specifies the reservation style: FF (Fixed-Filter style)— Single reservation shared by multiple flows SE (Shared-Explicit style)— Single reservation for one flow WF (Wildcard-Filter style)— Multicast application support for multiple flows
<code>[load rate]</code>	The bandwidth reservation type, either load or rate. The load parameter is used to specify controlled load service, and the rate parameters specify a guaranteed bit rate.
<code>average-bit-rate</code>	The reserved average bit rate, in kbps. This value can range from 0 to 10,000,000.
<code>maximum-burst</code>	The maximum burst size in kilobytes. This value can range from 0 to 65,535.

[Example 5-1](#) shows how two hosts shown in [Figure 5-2](#), a sender and a receiver, are set up using the `rsvp sender-host` and `rsvp reservation-host` commands. To simulate RSVP senders or receivers, you enable RSVP on an interface, and the address for the source address of the RSVP sender/receiver must exist locally on the router.

Example 5-1. RSVP Simulation on the Apu Router

```
Apu#show run | begin Loopback
interface Loopback10
  ip address 192.168.16.1 255.255.255.0
  ip rsvp bandwidth 7000 7000
!
interface Ethernet0/0
  ip address 192.168.1.1 255.255.255.0
  ip rsvp bandwidth 7000 7000
!
router eigrp 170
  network 192.168.1.0
  network 192.168.16.0
  no auto-summary
  eigrp log-neighbor-changes
!
ip rsvp reservation-host 192.168.16.1 192.168.42.1 TCP 0 0 FF RATE 128 8
```

Figure 5-2. Simulating RSVP RESV and PATH Messages



In this example, the Apu router is simulating an RSVP session with the Moe router. The `ip rsvp reservation-host` command is used to simulate RSVP RESV messages from the Loopback10 interface on the Apu router to the Loopback10 interface on the Moe router. [Example 5-2](#) shows the detailed

reservation information from the Apu router.

Example 5-2. show ip rsvp reservation Information from the Apu Router

```
Apu#show ip rsvp reservation detail

RSVP Reservation. Destination is 192.168.16.1, Source is 192.168.42.1,
Protocol is TCP, Destination port is 0, Source port is 0
Reservation Style is Fixed-Filter, QoS Service is Guaranteed-Rate
Average Bitrate is 128K bits/sec, Maximum Burst is 8K bytes
Min Policed Unit: 0 bytes, Max Pkt Size: 65535 bytes
Resv ID handle: 00001301.

Policy: Forwarding. Policy source(s): Default
```

As you can see, the Apu router created a reservation from the Moe router's 192.168.42.1 IP address. This reservation will apply to any IP traffic. The Apu router reserves a guaranteed 128-kbps average bit rate, allowing a maximum burst of 8 kilobytes; therefore, the maximum amount of data that can be supported is 192 kbps during bursts. To continue verifying this RSVP session from end to end, you use the show ip rsvp senders command on the Barney router to verify that it received the RSVP message from the Moe router, as shown in [Example 5-3](#).

NOTE

The formula used to find the burst rate for RSVP is as follows:

$$BR = \frac{R}{T} + B$$

R = Bit-rate (in kbps)
T = Time interval (always 1 second)
B = Burst (converted from kilobytes to kilobits)
BR = Burst Rate

```
R(T) + B = BR
```

So, if you use the information from the previous example, this is how you find the burst rate.

```
128kbps(1s) + 64kbit = 192 kilobit
```

To convert from kilobytes to kilobits, use the following formula (where B is equal to the burst value in kilobytes):

```
B * 8 = burst value in kilobits
```

Example 5-3. Using the show ip rsvp sender Command to Verify End-to-E Reservations on the Barney Router

```
Barney#show ip rsvp sender
```

To	From	Pro	DPort	Sport	Prev	Hop	I/F	BPS	Bytes
192.168.16.1	192.168.42.1	TCP	0	0	192.168.2.2		Fa0/1	128K	8K

As you can see, the Barney router received the RSVP PATH message from the Moe router showing a previous hop of 192.168.2.2, the Moe router's Ethernet0/0 interface, and a destination host IP address of 192.168.16.1, the Apu router's Loopback10 interface. As a final end-to-end verification, [Example](#) shows the configuration and show ip rsvp sender detail information on the Moe router.

Example 5-4. RSVP Simulation on the Moe Router

```
Moe#show run | begin Loopback10
```

```

interface Loopback10
  ip address 192.168.42.1 255.255.255.0

ip rsvp bandwidth 7000 7000
!

interface Ethernet0/0
  ip address 192.168.2.2 255.255.255.0

ip rsvp bandwidth 7000 7000
!

router eigrp 170
  network 192.168.2.0
  network 192.168.42.0
  no auto-summary
  no eigrp log-neighbor-changes
  ip rsvp sender-host 192.168.16.1 192.168.42.1 tcp 0 0 128 8
Moe#show ip rsvp sender detail
PATH Session address: 192.168.16.1, port: 0. Protocol: TCP
  Sender address: 192.168.42.1, port: 0
  Traffic params - Rate: 128K bits/sec,Max. burst: 8K bytes
    Min Policed Unit: 0 bytes, Max Pkt Size 65535 bytes
  Path ID handle: 00000601.
  Incoming policy: Accepted. Policy source(s): Default
  Output on Ethernet0/0.Policy status: Forwarding. Handle: 00000601

```

In the preceding example, an RSVP sender, host 192.168.42.1, the IP address of loopback interface is set up to create an RSVP reservation to host 192.168.16.1 on TCP port 0. The `ip rsvp sender-h 192.168.16.1 192.168.42.1 tcp 0 0 128 64` command was used to create the RSVP PATH simulation message from the Moe router. This command does not appear in the running configuration.

Creating Static RSVP Reservations

RSVP reservations can also be statically configured using the ip rsvp reservation and ip rsvp sender commands. The ip rsvp reservation command, shown next, creates a static reservation for an RSVP receiver, and the ip rsvp sender command creates a static reservation for an RSVP sender. These commands enable you to configure both sides of an RSVP session reservation:

```
ip rsvp reservation destination-address source-address [IP-protocol-number | tcp | udp] destination-port source-port next-hop-address interface-name interface-number [ff | se | wf] [load | rate] average-bit-rate maximum-burst

ip rsvp sender destination-address source-address [IP-protocol-number | tcp | udp] destination-port source-port previous-hop-address interface-name interface-number average-bit-rate maximum-burst
```

Both the ip rsvp reservation and ip rsvp sender commands have several required parameters. [Table 5-6](#) lists these rsvp command arguments and their descriptions.

Table 5-6. static rsvp Commands and Descriptions

RSVP Command Argument	Description
<i>destination-address</i>	The IP address or host name of the RSVP receiver.
<i>source-address</i>	The IP address or host name of the RSVP sender.
[<i>IP-protocol-number</i> <i>tcp</i> <i>udp</i>]	<i>IP-protocol-number</i> is an IP protocol ranging from 0 to 255, or the TCP or UDP protocol.
<i>destination-port</i>	The destination port number, ranging from 0 to 65,535.
<i>source-port</i>	The source port number, ranging from 0 to 65,535.
<i>next-hop-address</i> or <i>previous-hop-address</i>	The ip rsvp reservation command requires the IP address or host name of the next hop. The ip rsvp sender command requires the IP address or name of the previous hop.

[ff se wf]	FF— Fixed-Filter reservations provide a single reservation for one flow. SE— Shared-Explicit reservations provide shared reservations for specified flows. WF— Wildcard-Filter reservations provide shared reservations for all senders.
[load rate]	Load— Represents controlled load service. Used to provide controlled load services by isolating flow with minimal interference from other flows by specifying an average bit rate and a maximum burst rate. Rate— Represents guaranteed bit rate. Used to provide a guaranteed bit rate by specifying an average bit rate and a maximum burst rate.
<i>average-bit-rate</i>	This value, ranging from 1 to 10,000,000, specifies the average bit rate to reserve in kbps.
<i>maximum-burst</i>	This value, ranging from 1 to 65,535, specifies the maximum amount that the reserved flow can burst in kilobits.

[Example 5-5](#) shows how the ip rsvp reservation command was used to set up a reservation from sender 152.148.89.91 to receiver 10.1.1.11 for TFTP traffic that is being sent to the next hop of 10 using an FF reservation with a 64-kbps average bit rate and a 4-kb maximum burst. The output of show ip rsvp host receivers is also shown.

Example 5-5. Using Static Reservations

```
RSVP-Example#show run | begin Serial0
interface FastEthernet0/0
  ip address 10.1.1.1 255.255.255.0
  ip rsvp bandwidth 75000 75000
!
interface Serial0/0
  ip address 10.2.2.1 255.255.255.0
  ip rsvp bandwidth 1158 1158
!
ip rsvp reservation 10.1.1.11 152.148.89.91 UDP 69 0 10.2.2.2 Serial0/0 FF
RATE 64 4
```

RSVP-Example#show ip rsvp host receivers

To	From	Pro	DPort	Sport	Next Hop	I/F	Fi	Serv	BPS	Bytes
10.1.1.11	152.148.89.91	UDP	69	0	10.2.2.2	Se0/0	FF	RATE	64K	4K

In the preceding example, a static RSVP session is configured between hosts 10.1.1.11 and 152.148.89.91. Host 152.148.89.91 will request the RSVP session using an RSVP PATH message, a host 10.1.1.11 will respond to the message using an RSVP RESV message. This RSVP session is reserved for any TFTP traffic sent by host 152.148.89.91.

Now that you have seen examples of how RSVP can be used for simulated RSVP sessions, dynamic sessions, or static RSVP reservations, it's time to look at other ways you can use RSVP for multiser vice applications.

Reserving the Proper Amount of Bandwidth for Voice

When configuring voice over IP for use with RSVP, it is very important to remember that there are different voice codecs that are available to choose from, and each of these codecs will have different requirements from the network. The codec used to sample and encode packets will affect the performance and quality of the calls. Complex codecs that sample data more often have a greater packetization delay; however, they also have lower required transmission rates because they compress the data and send fewer packets. To select a voice codec, use the `codeccodec-name` command under the remote voice over IP dial-peer to select a codec rate; the default codec is g729r8.

NOTE

Packetization delay is a measurement of the time it takes to sample raw voice data and encode that sampled data into a packet for transmission.

Table 5-7 shows the various voice codecs rates available on a Cisco 1750 series router, the codec rate in bits per second, the packetization delay, and the actual RSVP rate that the codec requests. Make sure you select a codec that will require a reasonable amount of bandwidth from the network. If you do not configure RSVP with enough bandwidth to create a reservation, and you configure dial-peers to request or accept RSVP settings, the calls will not be accepted.

Table 5-7. Voice Over IP Codecs

Codec Rate	Codec Name	Codec Rate in bps	Packetization Delay	Actual RSVP Rate Requested
g711alaw	G.711 A Law	64,000 bps	10 to 30 ms	80 k
g711ulaw	G.711 u Law	64,000 bps	10 to 30 ms	80 k
g723ar53	G.723.1 ANNEX-A	5300 bps	30 ms	18 k
g723ar63	G.723.1 ANNEX-A	6300 bps	30 ms	18 k
g723r53	G.723.1	5300 bps	30 ms	18 k
g723r63	G.723.1	6300 bps	30 ms	18 k
g726r16	G.726	16,000 bps	10 to 30 ms	32 k
g726r24	G.726	24,000 bps	10 to 30 ms	40 k
g726r32	G.726	32,000 bps	10 to 30 ms	48 k
g728	G.728	16,000 bps	10 to 30 ms	32 k
g729br8	G.729 ANNEX-B	8000 bps	10 to 30 ms	24 k
g729r8	G.729	8000 bps	10 to 30 ms	24 k

The `show dialer-peer voice | include codec` command displays the current codec configuration; can use this information to calculate the RSVP reservation information for voice traffic as shown in [Example 5-6](#). The full version of the `show dial-peer voice` command displays detailed information each of the dial-peers.

Example 5-6. Using Show Commands to Find the Codec

```
Show-me-the-codec#show dial-peer voice | include codec
codec = g729r8,    payload size = 20 bytes,
```

Using RSVP for Voice Traffic

To configure Voice over IP (VoIP) to request RSVP service, use the `req-qos` command under the `dial-peer` for the VoIP session. The `req-qos` command, which is short for `request qos`, is used to request certain QoS level from the network and can request three different types of service: best-effort, controlled-load, or guaranteed-delay. The `acc-qos` command defines the minimum amount of acceptable types of service that will be accepted from the network. The `controlled-load` command is used to request or accept traffic. The `best-effort` command is used to remove a preexisting RSVP reservation from a dial-peer connection. [Table 5-8](#) summarizes the dial-peer qos command parameters and gives a brief description of their usage.

Table 5-8. rsvp voice qos Command Summary

RSVPVoice Command	Command Description
best-effort	Best-effort service is, like its name implies, a best effort. Devices in the path between best-effort devices attempt to deliver packets to the best of their capability, but no special effort is made to prioritize best-effort traffic. This command is used to reissue a controlled-load or guaranteed-delay command from a dial peer.
controlled-load	Provides a reservation that provides a limited amount of delay and packet drop for real-time delay-sensitive applications. Similar to ATM VBR-rt PVCs, controlled-load reservations provide bandwidth reservations that limit the amount of delay and packet loss that real-time network applications will experience when traversing a loaded network.
guaranteed-delay	Provides a guaranteed rate, similar to ATM CBR PVCs, by gathering data from RSVP PATH messages.

The following four steps are required to enable VoIP reservation requests using the req-qos or acc-qos commands:

Step 1. Configure the local and remote VoIP dial peers using the dial-peer command.

Step 2. From dial-peer configuration mode, add the acc-qos or req-qos commands to the local dial peer.

Step 3. Each interface that will be forwarding voice traffic will have to have WFQ configured before the RSVP configuration can be applied. Prior to enabling RSVP, enable WFQ on the interface level using the fair-queue command.

Step 4. Configure RSVP for each interface. Before configuring RSVP, make sure you know how much bandwidth and delay that voice codec will require. After you know how much bandwidth to reserve, configure RSVP for each RSVP-enabled interface using the ip rsvp bandwidth *bandwidth* command.

NOTE

If you did not explicitly configure your voice codec and you need to find the codec type in use, you can do this using the show voice | include codec command mentioned earlier in this chapter.

The following example shows how the previously outlined steps are used to enable RSVP for VoIP calls on the Bender router. [Figure 5-3](#) shows the voice connection between the Bender router and its VoIP dial peer on the Frye router.

Step 1. Configure the local and remote VoIP dial peers using the dial-peer command. The following example shows the dial-peer configuration for the Bender router. In this example, the peer 5555678 specifies the local destination pattern, 5555678, and the local FXS port, port 2.

Dial-peer 5558765 specifies the remote peer that resides on the 129.44.85.1 router and is assigned the 5558765 destination pattern. The g726r16 voice codec is used for calls to this peer:

```
Bender(config)#dial-peer voice 5555678 pots
Bender (config-dial-peer)# destination-pattern 5555678
Bender (config-dial-peer)# port 2/1
Bender (config)# dial-peer voice 5558765 voip
Bender (config-dial-peer)# destination-pattern 5558765
Bender (config-dial-peer)# session target ipv4:129.44.85.1
Bender (config-dial-peer)# codec g726r16
```

Step 2. From dial-peer configuration mode, add the acc-qos or req-qos commands to the dial peer. In this example, the Bender router is configured to request and accept controlled load service from the network:

```
Bender(config-dial-peer)#dial-peer voice 5558765 voip
Bender(config-dial-peer)#req-qos controlled-load
Bender(config-dial-peer)#acc-qos controlled-load
```

Step 3. Each interface that will be forwarding voice traffic will have to have WFQ configured before the RSVP configuration can be applied. Therefore, prior to enabling RSVP, enable WFQ at the interface level using the fair-queue command.

One quick way to find the queuing strategy that is currently being used on an interface is to issue the show queueing interface *interface-name interface-number* command. You will see a queuing strategy of none if FIFO queuing is enabled; in this case, WFQ should be enabled before configuring RSVP:

```
Bender#show queueing interface fastEthernet 0 | include strategy  
  
Interface FastEthernet0 queueing strategy: none
```

In the following example, the Bender router connects to the Frye router using its FastEthernet0 interface, so WFO must be enabled here:

```
Bender(config)#interface FastEthernet0  
  
Bender(config-if)#ip address 129.44.85.5 255.255.255.0  
  
Bender(config-if)#fair-queue
```

Step 4. Configure RSVP for each interface. Before configuring RSVP, make sure you know how much bandwidth and delay that voice codec will require. Because the Bender router has already been configured to use the g726r16 codec, you know that RSVP requires at least a 32-kbps bandwidth reservation. To make sure that the RSVP configuration will allow reservations for this amount of bandwidth, use the ip rsvp bandwidth 32 command, as shown here:

```
Bender(config)#interface FastEthernet0  
  
Bender(config-if)#ip rsvp bandwidth 32
```

Figure 5-3. Bender and Frye Network



To verify the connection, place a test call from one of the routers and, while the test call is in progress, use the `show ip rsvp installed` and `show ip rsvp reservation detail` commands to display the current RSVP reservations. The `show ip rsvp installed` command displays a quick summary of the current RSVP sessions. The `show ip rsvp reservation detail` command displays all the characteristics that apply to each RSVP reservation, as shown in [Example 5-7](#).

Example 5-7. Using the `show ip rsvp reservation detail` Command to Verify VoIP

```
Bender#show ip rsvp installed
```

```
RSVP: FastEthernet0
```

BPS	To	From	Protoc	DPort	Sport	Weight	Conversation
32K	129.44.85.1	129.44.85.5	UDP	17176	18930	0	264

```
Bender#show ip rsvp reservation detail
```

```
RSVP Reservation. Destination is 129.44.85.1, Source is 129.44.85.5,
```

```
Protocol is UDP, Destination port is 17176, Source port is 18930
```

```
Next Hop is 129.44.85.1, Interface is FastEthernet0
```

```
Reservation Style is Fixed-Filter, QoS Service is Controlled-Load
```

```
Average Bitrate is 32K bits/sec, Maximum Burst is 160 bytes
```

```
Min Policed Unit: 80 bytes, Max Pkt Size: 80 bytes
```

```
Resv ID handle: 00000E01.
```

```
Policy: Forwarding. Policy source(s): Default
```

```
RSVP Reservation. Destination is 129.44.85.5, Source is 129.44.85.1,
```

```
Protocol is UDP, Destination port is 18930, Source port is 17176
```

```
Reservation Style is Fixed-Filter, QoS Service is Controlled-Load
```

```
Average Bitrate is 32K bits/sec, Maximum Burst is 160 bytes
```

```
Min Policed Unit: 80 bytes, Max Pkt Size: 80 bytes
```

```
Resv ID handle: 00000C01.  
Policy: Forwarding. Policy source(s): Default
```

In this example, each time a phone call is made between the 555-5678 and 555-8765 phones, two reservations are made, one from 129.44.85.1 to 129.44.85.5, and one from 129.44.85.5 to 129.44.85.1. Each reservation uses a controlled-load service to provide a 32-kbps average bit rate each call. As soon as the call has ended, the reservation is removed and the bandwidth is released for other purposes.

[Example 5-8](#) shows the full configurations for the RSVP controlled rate service for the VoIP session between the Bender and Frye routers used in the preceding example.

Example 5-8. Using VoIP and RSVP

```
Bender#show run | begin FastEthernet  
  
interface FastEthernet0  
    ip address 129.44.85.5 255.255.255.0  
    fair-queue 64 256 1  
    ip rsvp bandwidth 32 32  
!  
interface Serial1  
    dial-peer voice 5555678 pots  
    destination-pattern 5555678  
    port 2/1  
!  
dial-peer voice 5558765 voip  
    destination-pattern 5558765  
    session target ipv4:129.44.85.1  
    req-qos controlled-load  
    acc-qos controlled-load  
    codec g726r16
```

```
Frye#show run | begin FastEthernet

interface FastEthernet0
    ip address 129.44.85.1 255.255.255.0
    fair-queue 64 256 1
    ip rsvp bandwidth 32 32
!
dial-peer voice 5558765 pots
destination-pattern 5558765
port 2/0
!
dial-peer voice 5555678 voip
destination-pattern 5555678
session target ipv4:129.44.85.5
req-qos controlled-load
acc-qos controlled-load
codec g726r16
```

NOTE

If voice RSVP QoS parameters are only specified on one side of a connection, the call will never complete successfully. To successfully allow a voice call using RSVP, one side of the connection must request a level of service, and the other side must be willing to accept that level of service.

Troubleshooting RSVP

You can use a number of commands for RSVP troubleshooting. Before beginning the RSVP troubleshooting process, however, you should check a couple of items. First, verify that WFQ has been enabled for the RSVP interface. If it has not, enable WFQ using the fair-queue command. Second, using RSVP on fractional circuits, such as Frame Relay DS0s, remember to configure the interface bandwidth because serial interfaces default to 1158 kbps, or 75 percent of the interface's bandwidth.

The show ip rsvp neighbor command displays interfaces that have RSVP-attached neighbors and

IP address of the neighbor, as demonstrated in [Example 5-9](#).

Example 5-9. Showing RSVP Neighbors

```
Silly#show ip rsvp neighbor

Interfac Neighbor          Encapsulation
Sel.1    192.168.1.2      RSVP
Sel.2    192.168.2.2      RSVP
```

The `show ip rsvp sender` and `show ip rsvp request` commands provide a summarization of RSVP sender and other related information about the RSVP requests. To view detailed information about requests, use the detail version of the `show ip rsvp request` of the command. Examples of these commands are shown in [Example 5-10](#).

Example 5-10. RSVP show rsvp sender and request Commands

```
Smiley#show ip rsvp sender
```

To	From	Pro	DPort	Sport	Prev	Hop	I/F	BPS	Bytes
192.168.1.2	192.168.2.2	UDP	18182	18050	192.168.2.2		Sel.2	24K	1K
192.168.2.2	192.168.1.2	UDP	18050	18182	192.168.1.2		Sel.1	24K	1K

```
Smiley#show ip rsvp request
```

To	From	Pro	DPort	Sport	Next	Hop	I/F	Fi	Serv	BPS	Bytes
192.168.1.2	192.168.2.2	UDP	18182	18050	192.168.2.2		Sel.2	FF	RATE	24K	1K
192.168.2.2	192.168.1.2	UDP	18050	18182	192.168.1.2		Sel.1	FF	RATE	24K	1K

```
Grumpy#show ip rsvp request detail
```

RSVP Reservation. Destination is 192.168.2.2, Source is 192.168.1.2,
Protocol is UDP, Destination port is 18634, Source port is 18540
Next Hop is 192.168.2.1, Interface is Serial0
Reservation Style is Fixed-Filter, QoS Service is Guaranteed-Rate
Average Bitrate is 24K bits/sec, Maximum Burst is 1K bytes

The `show ip rsvp installed` command, shown in [Example 5-11](#), gives information about current RSVP reservations, such as the RSVP interface, the size of the reservation in bps, the source and destination IP addresses, the protocol, the source and destination ports, the weight of the RSVP flow, and the conversation number. The `show ip rsvp interfaces` command, also shown in [Example 5-11](#), displays information about each of the router's RSVP interfaces.

Example 5-11. `show ip rsvp installed` Command

```
Grumpy#show ip rsvp installed
```

RSVP: Serial1

BPS	To	From	Protocol	DPort	Sport	Weight	Conversation
-----	----	------	----------	-------	-------	--------	--------------

RSVP: Serial1.1

BPS	To	From	Protocol	DPort	Sport	Weight	Conversation
-----	----	------	----------	-------	-------	--------	--------------

24K 192.168.1.2 192.168.2.2 UDP 18182 18050 6 265

RSVP: Serial1.2

BPS	To	From	Protocol	DPort	Sport	Weight	Conversation
-----	----	------	----------	-------	-------	--------	--------------

24K 192.168.2.2 192.168.1.2 UDP 18050 18182 6 266

```
Grumpy#show ip rsvp interfaces
```

interface	allocated	i/f max	flow max	pct	UDP	IP	UDP_IP	UDP M/C
-----------	-----------	---------	----------	-----	-----	----	--------	---------

Se1 48K 1158K 1158K 4 0 0 0 0

Se1.1 24K 128K 128K 18 0 1 0 0

Se1.2 24K 128K 128K 18 0 1 0 0

To view information about all the current RSVP reservations, use the `show ip rsvp reservation` command. This command shows you the source and destination IP addresses for each reservation, protocol and source and destination port number, the next-hop IP address and interface used to reach each of the senders, the reservation filter type (FF, SE, or WF), the reservation type (RATE or LOA), the reservation size in bps, and the burst size in bytes, as shown in [Example 5-12](#).

Example 5-12. `show ip rsvp reservation` Command

```
Grumpy#show ip rsvp reservation
```

To	From	Proto	DPort	Sport	Next Hop	I/F	Fi	Serv	BPS	Bytes
192.168.1.2	192.168.2.2	UDP	18182	18050	192.168.1.2	Se1.1	FF	RATE	24K	1K
192.168.2.2	192.168.1.2	UDP	18050	18182	192.168.2.2	Se1.2	FF	RATE	24K	1K
192.168.2.3	192.168.1.2	UDP	18502	16808	192.168.2.2		FF	LOAD	24K	1K

Practical Example: RSVP and VoIP

VoIP requires a certain level of QoS to function properly. When using VoIP in a WAN environment with small, congested links, in most cases, some form of QoS will have to be implemented. Fortunately, Cisco routers have built-in support for RSVP, making it simple to configure. In the following lab, you practice your VoIP configuration and use RSVP to support the voice.

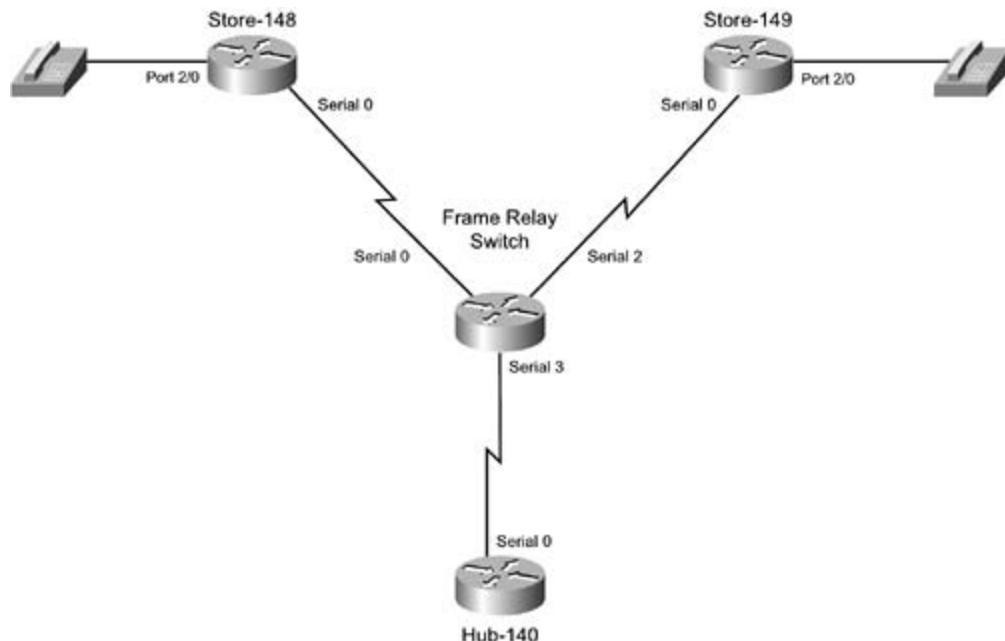
Lab Exercise

Dan's Pizza has more than 4000 locations nationwide. Each store has a Frame Relay connection to a hub site. The hub sites provide each district with access to the corporate network, support for all network applications, and one phone line for internal calls. In the past few months, several new applications have been deployed, making voice traffic somewhat jittery and causing conversations to be difficult to understand. RSVP will be implemented to reserve enough bandwidth to smooth out the voice calls. In this lab, you will configure part of the subnetwork, area 140, to provide quality service for voice traffic.

Lab Objective

The objective of this lab is to use RSVP to reserve bandwidth for voice traffic between two store locations. For this network model, you use the portion of the Dan's Pizza network shown in [Figure 5-4](#). This exercise demonstrates how RSVP is configured, using VoIP as the test application. The RSVP configuration is done using RSVP show and debug commands.

Figure 5-4. Dan's Pizza Subnetwork 140



Equipment Needed

To use RSVP and reserve bandwidth for voice traffic between the two store locations, the following equipment is needed:

- Two Cisco routers with at least one voice port and one serial port
- One Cisco router with one serial port
- One Cisco router with three serial ports to act as a Frame Relay switch
- Two telephones for testing purposes

Physical Layout and Prestaging

To complete the physical layout and prestaging, perform the following:

- Cable the routers as shown in [Figure 5-4](#).
- Attach one phone to a voice port on each of the voice routers.
- Configure the Frame Relay switch to use the PVC information in [Table 5-9](#).
- Verify that all interfaces are in an up/up state.

Table 5-9. Frame Switch Configurations for the Example

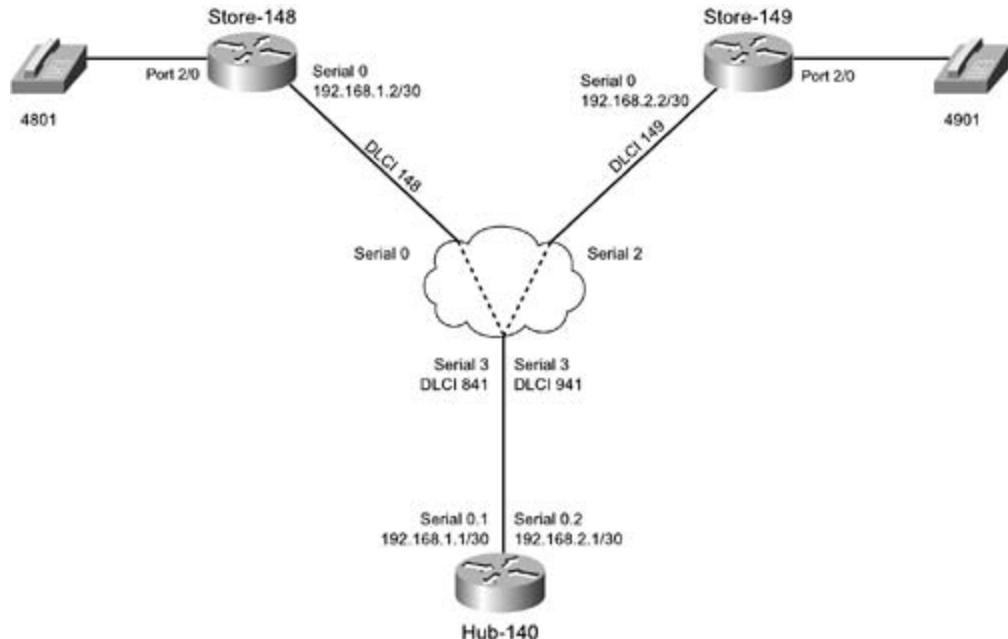
Local Interface	Local DLCI	Remote Interface	Remote DLCI
Serial 0	148	Serial 3	841
Serial 2	149	Serial 3	941
Serial 3	841	Serial 0	148
Serial 3	941	Serial 2	149

Lab Tasks

To complete this lab exercise, you need to complete the following tasks:

- Configure the IP network as shown in [Figure 5-5](#), applying IP addressing and Frame Relay configuration using subinterfaces on the Hub 140 router and physical interfaces on the Store 140 router.

Figure 5-5. Physical Layout for This Lab



- Configure OSPF on all routers; all serial interfaces should belong to OSPF area 0. Verify that [are reachable](#).
- Configure Store 148 and Store 149 to be able to call each other using the phone numbers from [5-5](#). Test phone connections.
- Configure the required RSVP support to allow Store 148 to call Store 149, and vice versa, with guaranteed bit rate service. Each flow should receive and average a bit rate of at least 24 kbps should be allowed to burst to a full 75 percent of the interface bandwidth. Test and verify that RSVP sessions work properly.

To do so, perform the steps in the following section.

Lab Walkthrough

Step 1. Attach each router to the Frame Relay switch; Hub 140, Store 148, and Store 149 should connect to the Frame Relay switch using serial data terminal equipment/data circuit-terminating equipment (DTE/DCE) connections. Note each serial connection and use this information to configure the Frame Relay switch. Store 148 should use DLCI 148 on its serial interface, Store 149 should be configured to use DLCI 149, and Hub 140 should be assigned DLCIs 841 and 941. Configure the routers to support their Frame Relay connections. Because Store 148 and Store 149 use two interfaces for their Frame Relay connections, they should be configured with a Frame Relay route pointing to Hub 140. Hub 140 uses multipoint subinterfaces, so it can also use Frame Relay route commands on each subinterface. [Example 5-13](#) shows the Frame Relay switch configuration for Frame Relay routes.

Example 5-13. Frame Relay Switch Configuration

```
frame-relay-switch#show run | begin frame
```

```

frame-relay switching

!

interface Serial0
    no ip address
    encapsulation frame-relay IETF
    clockrate 1300000
    frame-relay lmi-type ansi
    frame-relay intf-type dce
    frame-relay route 148 interface Serial3 841
    !

interface Serial2
    no ip address
    encapsulation frame-relay IETF
    frame-relay lmi-type ansi
    frame-relay intf-type dce
    frame-relay route 149 interface Serial3 941
    !

interface Serial3
    no ip address
    encapsulation frame-relay IETF
    clockrate 1300000
    frame-relay lmi-type ansi
    frame-relay intf-type dce
    frame-relay route 841 interface Serial0 148
    frame-relay route 941 interface Serial2 149
frame-relay-switch#show frame-relay route

Input Intf      Input Dlci      Output Intf      Output Dlci      Status
Serial0          148           Serial3          841           active

```

Serial2	149	Serial3	941	active
Serial3	841	Serial0	148	active
Serial3	941	Serial2	149	active

Step 2. After you have verified Frame Relay connectivity between routers, assign the IP address to Store 148 interface Serial 0 should use IP address 192.168.1.2/30. Store 149's serial interfaces should be assigned IP address 192.168.2.2/30, Hub 140 interface's Serial 0.1 should use 192.168.1.1 and 0.2 should use 192.168.2.1/30. Before moving on, you should verify that all Store router's serial interfaces can ping their directly connected hub subinterface.

Step 3. Configure OSPF on each router so that each router can ping its neighbor and each of the routers can ping each other. Use a nonbroadcast Open Shortest Path First (OSPF) configuration in this example.

To configure OSPF for the nonbroadcast connections between the hub router and the two store routers, you must configure OSPF for a nonbroadcast network. In this case, this requires the use of the ip ospf network non-broadcast command and static neighbor configurations. [Example 5-14](#) shows how the ip ospf network command is used on the Hub 140 router. Before moving on to Step 4, verify the OSPF configuration by pinging from one store router to the other using the IP addresses on the routers' serial interfaces.

Example 5-14. Hub 140 Router's OSPF Configuration

```
Hub-140#show run | begin Serial0/0.1

interface Serial0/0.1 multipoint
  ip address 192.168.1.1 255.255.255.252
  ip ospf network non-broadcast
  frame-relay map ip 192.168.1.2 841 broadcast
!
interface Serial0/0.2 multipoint
  ip address 192.168.2.1 255.255.255.252
  ip ospf network non-broadcast
  frame-relay map ip 192.168.2.2 941 broadcast
!
router ospf 1
  log-adjacency-changes
```

```

network 192.168.1.0 0.0.0.3 area 0

network 192.168.2.0 0.0.0.3 area 0

neighbor 192.168.2.2

neighbor 192.168.1.2

```

Step 4. After all routers can ping each other, configure VoIP on Store 148 as follows: Create peer. (In this example, I used peer number 4801 to keep things simple.) Assign dial-peer 48 destination dial pattern 4801. Dial peer 4801 must also be assigned to a port. (In this case, I port 2/0.) To dial the 4901 extension from the Store 149 router, you must create a VoIP dial specifies Store 149's serial IP address and assign it the destination pattern 4901. Store 149 is configured similarly to store 148. After each router's voice configuration is complete, you should be able to call the 4801 extension from Store 149's phone and the 4901 extension from Store 148's phone. [Example 5-15](#) shows the VoIP configuration for the Store 148 router.

Example 5-15. The Store-148 Router's Voice Over IP Configuration

```

Store-148#sho run | begin dial-peer

dial-peer voice 4801 pots

destination-pattern 4801

port 2/0

!

dial-peer voice 4901 voip

destination-pattern 4901

session target ipv4:192.168.2.2

```

Step 5. After you have tested the voice connectivity, it is time to configure RSVP. The first step in the RSVP configuration is to enable WFQ, if it is not already configured. WFQ is enabled using the queue command. Because this is a simple WFQ configuration, you can just type the fair-queue command and accept the defaults. After configuring WFQ, enable RSVP on the interface by using the ip rsvp bandwidth command. Make sure to reserve at least 24 kbps and allow bursting to 7 percent of the interface's bandwidth, in this case 1158 kbps. Next, enable voice over ip rsvp bandwidth requests using the req-qos command to request a guaranteed bit rate. [Example 5-16](#) shows the VoIP and RSVP configuration for the Store 149 router, and [Example 5-17](#) shows the output from the show ip rsvp reservation detail command from the Store 148 router.

Example 5-16. RSVP and Voice Configuration for Store 149

```
Store-149#show run | begin Serial

interface Serial0

ip address 192.168.2.2 255.255.255.252

ip ospf network non-broadcast

ip ospf priority 0

frame-relay map ip 192.168.2.1 149 broadcast

ip rsvp bandwidth 1158 24

!

dial-peer voice 4901 pots

destination-pattern 4901

port 2/0

!

dial-peer voice 4801 voip

destination-pattern 4801

session target ipv4:192.168.1.2

req-qos guaranteed-delay
```

Example 5-17. Reservation Information from the Store 148 Router

```
Store-148#show ip rsvp reservation detail

RSVP Reservation. Destination is 192.168.1.2, Source is 192.168.2.2,

Protocol is UDP, Destination port is 17188, Source port is 19346

Next Hop is 192.168.2.1, Interface is Serial0

Reservation Style is Fixed-Filter, QoS Service is Guaranteed-Rate

Average Bitrate is 24K bits/sec, Maximum Burst is 120 bytes

Min Policed Unit: 60 bytes, Max Pkt Size: 60 bytes

Resv ID handle: 00007601.
```

```
Policy: Forwarding. Policy source(s): Default

RSVP Reservation. Destination is 192.168.2.2, Source is 192.168.1.2,
Protocol is UDP, Destination port is 19346, Source port is 17188

Reservation Style is Fixed-Filter, QoS Service is Guaranteed-Rate

Average Bitrate is 24K bits/sec, Maximum Burst is 120 bytes

Min Policed Unit: 60 bytes, Max Pkt Size: 60 bytes

Resv ID handle: 00007201.

Policy: Forwarding. Policy source(s): Default
```

As you can see, in the preceding example, the Store 148 router reserved an average bit rate of 24 with a maximum burst rate of 120 bytes; this RSVP reservation is a guaranteed rate.

Another way to test the configuration is to enable detailed RSVP debugging using the debug ip rsvp command and then dial 4901 from the Store 148 router. When you pick up the 4901 phone, you should receive output similar to that shown in [Example 5-18](#).

Example 5-18. Sample debug ip rsvp detail Output

```
*Mar  1 05:28:57.294: RSVP 192.168.1.2_17598-192.168.2.2_18180: Static
reservation is new

Comment: New reservation requested

*Mar 1 05:28:57.294: RSVP-RESV: Locally created reservation. No admission/traffic
control needed

*Mar  1 05:28:57.298: RSVP session 192.168.1.2_17598: Sending PATH message for
192.168.1.2 on interface Serial0

Comment: RSVP PATH information from 192.168.1.2

Comment: Reservation information - IP addresses and port numbers

*Mar  1 05:28:57.298: RSVP:      version:1 flags:0000 type:PATH cksum:31D8 ttl:255
→ length:136

*Mar  1 05:28:57.298: SESSION           type 1 length 12:

*Mar  1 05:28:57.298: Destination 192.168.1.2, Protocol_Id 17, Don't Police ,
```

DstPort 17598

Comment: RSVP Destination Information

```
*Mar 1 05:28:57.298: HOP type 1 length 12: C0A80202
*Mar 1 05:28:57.298: : 00000000
*Mar 1 05:28:57.302: TIME_VALUES type 1 length 8 : 00007530
*Mar 1 05:28:57.302: SENDER_TEMPLATE type 1 length 12:
*Mar 1 05:28:57.302: Source 192.168.2.2, udp_source_port 18180
```

Comment: RSVP Sender information

```
*Mar 1 05:28:57.302: SENDER_TSPEC type 2 length 36:
*Mar 1 05:28:57.302: version=0, length in words=7
*Mar 1 05:28:57.302: Token bucket fragment (service_id=1, length=6 words
*Mar 1 05:28:57.302: parameter id=127, flags=0, parameter length=5
*Mar 1 05:28:57.302: average rate=3000 bytes/sec, burst depth=120 bytes
*Mar 1 05:28:57.302: peak rate =3000 bytes/sec
*Mar 1 05:28:57.306: min unit=60 bytes, max pkt size=60 bytes
```

Comment: Reservation parameters contained in TSPEC

```
*Mar 1 05:28:57.306: ADSPEC type 2 length 48:
*Mar 1 05:28:57.306: version=0 length in words=10
*Mar 1 05:28:57.306: General Parameters break bit=0 service length=8
*Mar 1 05:28:57.306: IS Hops:1
*Mar 1 05:28:57.306: Minimum Path Bandwidth (bytes/sec):193000
*Mar 1 05:28:57.306: Path Latency (microseconds):0
*Mar 1 05:28:57.306: Path MTU:1500
*Mar 1 05:28:57.306: Controlled Load Service break bit=0 service length=0
```

Comment: Minimum bandwidth, latency, and MTU requirements

```
*Mar 1 05:28:57.306:
*Mar 1 05:28:57.346: RSVP: version:1 flags:0000 type:PATH cksum:0000 ttl:254
→ length:136
```

*Mar 1 05:28:57.346: SESSION type 1 length 12:

*Mar 1 05:28:57.350: Destination 192.168.2.2, Protocol_Id 17, Don't Police ,
DstPort 18180

Comment: RSVP PATH information from 192.168.2.2

Comment: Reservation information - IP addresses and port numbers

*Mar 1 05:28:57.350: HOP type 1 length 12: C0A80201

*Mar 1 05:28:57.350: : 00000000

*Mar 1 05:28:57.350: TIME_VALUES type 1 length 8 : 00007530

*Mar 1 05:28:57.350: SENDER_TEMPLATE type 1 length 12:

*Mar 1 05:28:57.350: Source 192.168.1.2, udp_source_port 17598

*Mar 1 05:28:57.350: SENDER_TSPEC type 2 length 36:

*Mar 1 05:28:57.354: version=0, length in words=7

*Mar 1 05:28:57.354: Token bucket fragment (service_id=1, length=6 words

*Mar 1 05:28:57.354: parameter id=127, flags=0, parameter length=5

*Mar 1 05:28:57.354: average rate=3000 bytes/sec, burst depth=120 bytes

*Mar 1 05:28:57.354: peak rate =3000 bytes/sec

*Mar 1 05:28:57.354: min unit=60 bytes, max pkt size=60 bytes

*Mar 1 05:28:57.354: ADSPEC type 2 length 48:

*Mar 1 05:28:57.354: version=0 length in words=10

*Mar 1 05:28:57.354: General Parameters break bit=0 service length=8

*Mar 1 05:28:57.354: IS Hops:2

*Mar 1 05:28:57.354: Minimum Path Bandwidth (bytes/sec):193000

*Mar 1 05:28:57.358: Path Latency (microseconds):0

*Mar 1 05:28:57.358: Path MTU:1500

*Mar 1 05:28:57.358: Controlled Load Service break bit=0 service length=0

*Mar 1 05:28:57.358:

*Mar 1 05:28:57.358: RSVP 192.168.1.2_17598-192.168.2.2_18180: Received PATH
Message for 192.168.2.2(Serial0) from 192.168.2.1, rcv IP ttl=253

```
*Mar  1 05:28:57.358: RSVP 192.168.1.2_17598-192.168.2.2_18180: start requesting  
24 kbps FF reservation for 192.168.1.2(17598) UDP-> 192.168.2.2(18180) on  
Serial0 neighbor 192.168.2.1  
  
*Mar  1 05:28:57.366: RSVP 192.168.1.2_17598-192.168.2.2_18180: Sending RESV  
message 192.168.2.2(18180) <- 192.168.1.2(17:17598)  
  
*Mar  1 05:28:57.366: RSVP session 192.168.2.2_18180: send reservation to  
192.168.2.1 about 192.168.2.2  
  
<text omitted>  
  
Comment: Exchanging RSVP PATH and RSVP messages to create reservations  
  
*Mar  1 05:28:57.450: RSVP 192.168.1.2_17598-192.168.2.2_18180: RESV CONFIRM  
message for 192.168.2.2 (Serial0) from 192.168.2.1  
  
Comment: RSVP CONFIRM message  
  
*Mar  1 05:29:08.662: RSVP 192.168.2.2_18180-192.168.1.2_17598: remove sender  
host PATH 192.168.1.2(17598) <- 192.168.2.2(17:18180)  
  
*Mar  1 05:29:08.662: RSVP 192.168.2.2_18180-192.168.1.2_17598: remove Serial0  
RESV 192.168.1.2(17598) <- 192.168.2.2(17:18180)  
  
*Mar  1 05:29:08.662: RSVP 192.168.2.2_18180-192.168.1.2_17598: remove sender  
host PATH 192.168.1.2(17598) <- 192.168.2.2(17:18180)  
  
*Mar  1 05:29:08.666: RSVP session 192.168.1.2_17598: send path teardown  
multicast about 192.168.1.2 on Serial0  
  
Comment: Teardown session, remove sender 192.168.1.2  
  
<packet data omitted>  
  
*Mar  1 05:29:08.678: RSVP 192.168.1.2_17598-192.168.2.2_18180: remove receiver  
host RESV 192.168.2.2(18180) <- 192.168.1.2(17:17598)  
  
*Mar  1 05:29:08.678: RSVP 192.168.1.2_17598-192.168.2.2_18180: remove Serial0  
RESV request 192.168.2.2(18180) <- 192.168.1.2(17:17598)  
  
*Mar  1 05:29:08.678: RSVP session 192.168.2.2_18180: send reservation teardown  
to 192.168.2.1 about 192.168.2.2
```

```

Comment: Teardown session, remove receiver 192.168.2.2

*Mar  1 05:29:08.682: RSVP:      version:1 flags:0000 type:RTEAR cksum:572F ttl:255
  reserved:0 length:100

<packet data omitted>

*Mar  1 05:29:08.702: RSVP 192.168.1.2_17598-192.168.2.2_18180: PATH TEAR message
for 192.168.2.2 (Serial0) from 192.168.1.2

Comment: RSVP TEAR message from 192.168.1.2

*Mar  1 05:29:08.706: RSVP 192.168.1.2_17598-192.168.2.2_18180: remove Serial0
PATH 192.168.2.2(18180) <- 192.168.1.2(17:17598)

*Mar  1 05:29:08.714: RSVP:      version:1 flags:0000 type:RTEAR cksum:0000
ttl:255

<packet data omitted>

*Mar  1 05:29:08.726: RSVP 192.168.2.2_18180-192.168.1.2_17598: RESV TEAR message
for 192.168.1.2 (Serial0) from 192.168.2.1

Comment: RSVP TEAR message from 192.168.2.2

```

When the call is first initiated, you should see RSVP PATH and RESV messages creating the RSVP session. During the call, you should see further RSVP PATH and RESV messages as hello messages are sent to maintain the RSVP session through the call. The RSVP PATH messages should contain the RSVP reservation parameters for the call, including average rate, bytes per second, burst depth, peak rate, and packet size. After you hang up the call, you should see RSVP TEARDOWN messages. In addition to the RSVP debug output, you can display the RSVP configuration using the show commands listed earlier in the chapter.

[Example 5-19](#) shows the complete configuration for all the routers in this lab.

Example 5-19. Complete Router Configurations for This Lab

The Hub-140 Router

```

interface Serial0
  encapsulation frame-relay
  fair-queue 64 256 48
  frame-relay lmi-type ansi

```

```
ip rsvp bandwidth 1536 1536
!
interface Serial0.1 multipoint
ip address 192.168.1.1 255.255.255.252
ip ospf network non-broadcast
frame-relay map ip 192.168.1.2 841 broadcast
ip rsvp bandwidth 1158 24
!
interface Serial0/0.2 multipoint
ip address 192.168.2.1 255.255.255.252
ip ospf network non-broadcast
frame-relay map ip 192.168.2.2 941 broadcast
ip rsvp bandwidth 1158 24
!
router ospf 1
network 192.168.1.0 0.0.0.3 area 0
network 192.168.2.0 0.0.0.3 area 0
neighbor 192.168.2.2
neighbor 192.168.1.2 priority 1
```

The Store-148 Router

```
!
interface Serial0
ip address 192.168.1.2 255.255.255.252
encapsulation frame-relay
fair-queue 64 256 37
frame-relay lmi-type ansi
ip ospf network non-broadcast
```

```
ip ospf priority 0

frame-relay map ip 192.168.1.1 148 broadcast

ip rsvp bandwidth 1158 24

!

router ospf 1

log-adjacency-changes

network 192.168.1.0 0.0.0.3 area 0

neighbor 192.168.1.1 priority 1

!

voice-port 2/0

!

voice-port 2/1

!

dial-peer voice 4801 pots

destination-pattern 4801

port 2/0

!

dial-peer voice 4901 voip

destination-pattern 4901

session target ipv4:192.168.2.2

req-qos guaranteed-delay
```

The Store-149 Router

```
interface Serial0

ip address 192.168.2.2 255.255.255.252

encapsulation frame-relay IETF

fair-queue 64 256 37

frame-relay lmi-type ansi
```

```
ip ospf network non-broadcast
ip ospf priority 0
clockrate 1300000
frame-relay map ip 192.168.2.1 149 broadcast
ip rsvp bandwidth 1158 24
!
!
router ospf 1
network 192.168.2.0 0.0.0.3 area 0
neighbor 192.168.2.1 priority 1
!
voice-port 2/0
!
voice-port 2/1
!
dial-peer voice 4901 pots
destination-pattern 4901
port 2/0
!
dial-peer voice 4801 voip
destination-pattern 4801
session target ipv4:192.168.1.2
req-qos guaranteed-delay
```

Now that you have seen how IntServ can be applied to provide end-to-end QoS, it's time to explore differentiated services classify packets for specific levels of QoS.

Differentiated Services

Differentiated services, commonly referred to as DiffServ, provide a method of classifying packets into classes of service (COS). Classes of service are defined by the values defined in the Type of Service field of the IP header. The contents of this field were originally defined in RFCs 1122 and 1349, as Precedence and Type of Service fields. Several working groups made many valiant attempts at classification methods, but most of these efforts were not realized until recently, when newer multi applications began to require more quality control and fine-tuning from the network. RFC 1349 defines through 6 of the ToS byte as the Type of Service field with ToS definitions shown in [Table 5-10](#). This was originally intended as a mechanism to classify packets into different service types by marking an application's network requirements for delay, throughput, reliability, and cost.

NOTE

DiffServ classes of service are not to be confused with Layer 2 classes of service for Inter-Switch (ISL), or 802.1Q frame-marking services on local-area networks. This chapter only uses the term *class of service* to refer to Layer 3 packet marking.

Table 5-10. Type of Service Values

Hexadecimal Bits	Decimal Value	Type of Service	Cisco IOS Software ToS Value
0000	0	Normal	normal
1000	8	Minimize delay	min-delay
0100	4	Maximize throughput	max-throughput
0010	2	Maximize reliability	max-reliability
0001	1	Minimize cost	min-monetary-cost

Using the ToS values, it is possible to mark packets from certain applications and use that classification information later in the network when congestion is encountered to provide these applications with different levels of service. By default, all IP packets have a ToS value of 0000, specifying that they should be treated with a normal "best-effort" service level. With Cisco IOS Software, it is possible to change the ToS value to define application traffic using access lists, as shown in [Example 5-20](#). Using access lists, you can change the ToS value for packets using the ToS value name or a decimal value ranging from 0 to 15.

Example 5-20. Using the ToS Values with Access Lists

```
interface Serial1
```

```
ip address 192.168.1.2 255.255.255.252
ip ospf network non-broadcast
ip ospf priority 0
ip policy route-map throughput
frame-relay map ip 192.168.1.1 148 broadcast
!
ip local policy route-map throughput
!
access-list 150 permit udp host 192.168.1.2 range 16384 32767 host 192.168.2.2
range 16384 32767
access-list 150 permit udp host 192.168.2.2 range 16384 32767 host 192.168.1.2
range 16384 32767
access-list 150 permit tcp host 192.168.1.2 eq 1720 host 192.168.2.2
access-list 150 permit tcp host 192.168.1.2 host 192.168.2.2 eq 1720
!
route-map throughput permit 10
match ip address 150
set ip tos max-throughput
!
dial-peer voice 4801 pots
destination-pattern 4801
port 2/0
!
dial-peer voice 4901 voip
destination-pattern 4901
session target ipv4:192.168.2.2
```

In the preceding example, route-map throughput is used to mark all voice and signaling traffic s

access list 150 (UDP traffic ranging from ports 16,384 to 32,767 and TCP traffic on port 1720) with maximum throughput ToS. This information can be used later in the network to provide the voice better levels of service using DiffServ applications such as packet classifying, metering, marking, scheduling, and policing.

The remainder of this chapter focuses on DiffServ technologies, exploring packet marking using IP precedence, differentiated services codepoint (DSCP) values, and congestion control using Weighted Early Detection (WRED). The next chapter covers advanced traffic shaping and policing features, such as using generic traffic shaping and class-based shaping, traffic policing, and traffic classification using Committed Access Rate (CAR).

Setting IP Precedence

IP Precedence is a field in the ToS area of the IP header. Eight levels of precedence are possible, ranging from 0 to 7, as shown in [Table 5-11](#). Like the ToS values, IP precedence values can also be set to specific classifications for traffic.

Table 5-11. IP Precedence Values

Value	Description
Routine (0)	The default setting for IP packets.
Priority (1)	Sets priority precedence.
Immediate (2)	Sets immediate precedence.
Flash (3)	Sets Flash precedence.
Flash-Override (4)	Sets Flash-override precedence.
Critical (5)	Highest setting for nonrouter IP traffic.
Internet (6)	Sets Internet control precedence. Reserved for router traffic, such as routing.
Network Control (7)	Sets network control precedence. Reserved for router traffic and network control traffic.

When changing the precedence of IP packets, it is important to note two things. First, by default, all IP traffic except router-generated control and routing traffic uses the routine precedence value. If you do not change this setting, all IP packets use this setting. Second, although it is possible to use the Internet and Network Control values when changing IP precedence, these values are generally reserved for router and network control traffic; using them for other types of traffic may disrupt router operation, interrupting network service.

On Cisco routers, one of the simplest ways to set IP precedence is by using route maps. For more information on the configuration of route maps, refer to [Chapter 2](#), "Configuring Route Maps and Policy-Based Routing." Two basic steps are required for using route maps to set IP precedence: defining the packets to be affected and creating the route map to specify the change.

Step 1. Define the packets that are to be set using a standard or extended access list to specify traffic that is to have its precedence value changed. The following access list specifies all traffic from host 10.1.1.4:

```
Router(config)#access-list 15 permit host 10.1.1.4
```

Step 2. Create a route map to specify the packets to be modified and the change to be made

```
Router(config)#route-map precedence  
Router(config-route-map)#match ip address 15  
Router(config-route-map)#set ip precedence ?  
<0-7>          Precedence value  
critical        Set critical precedence (5)  
flash           Set flash precedence (3)  
flash-override Set flash override precedence (4)  
immediate       Set immediate precedence (2)  
internet        Set internetwork control precedence (6)  
network         Set network control precedence (7)  
priority        Set priority precedence (1)  
routine         Set routine precedence (0)  
<cr>  
Router(config-route-map)#set ip precedence 5  
Router(config-route-map)#exit
```

Step 3. Apply the route map to an interface using the ip policy route-map command:

```
Router(config)#interface ethernet 0/0  
Router(config-if)#ip policy route-map precedence
```

To monitor the status of the policy, you can use the show route-map command or debug ip poli show route-map command displays configuration and statistical information about the route map debug ip policy shows policy matches and misses. Be extremely cautious using the debug ip pol command on production routers; if the policy is working properly and you have too many matches, either overload the router or be unable to see your debugging information. [Example 5-21](#) shows o theshow route-map command.

NOTE

Theip policy route-map*route-map-name* command is used to apply policy routing on an interface-by-interface basis. This does not include locally router-generated packets. To apply p routing to router-generated traffic, use the ip local policy route-map*route-map-name* in glo configuration mode.

Example 5-21. show route-map Command

```
Router#show route-map precedence  
  
route-map precedence, permit, sequence 10  
  
Match clauses:  
    ip address (access-lists): 15  
  
Set clauses:  
    ip precedence critical  
  
Policy routing matches: 5 packets, 766 bytes  
  
Router#debug ip policy  
  
00:38:09: IP: s=10.1.1.1 (local), d=10.1.1.4, len 100, policy match
```

```
00:38:09: IP: route map precedence, item 15, permit
00:38:09: IP: s=10.1.1.1 (local), d=10.1.1.4, len 100, policy rejected -- normal f
00:38:09: IP: s=10.1.1.1 (local), d=10.1.1.4, len 100, policy match
00:38:09: IP: route map precedence, item 15, permit
```

As internetwork standards evolve, newer packet classification methods are constantly being added to IOS Software. At the time of this writing, there are several new ways to use the IP precedence value to classify and react to marked packets. These include the following:

- Marking packets with access lists
- Marking packets with route maps or policy routing
- Using packet classification with RSVP
- Classifying packets for queuing prioritization using WFQ, Priority Queuing (PQ), Custom Queue and Class-Based WFQ (CBWFQ)
- Advanced packet classification with CAR and traffic policing
- Shaping classified traffic using generic traffic shaping (GTS), class-based shaping, and Frame traffic shaping (FRTS)
- Prioritizing Real Time Protocol (RTP) traffic by setting IP RTP Priority
- Prioritizing real-time traffic using Low Latency Queuing (LLQ)
- Congestion control using WRED
- Marking voice traffic using DiffServ values

With the exception of FRTS, which was covered in the first edition of the *CCIE Practical Studies* series, these technologies are covered in [Chapter 6](#). Unfortunately, because this book must fit within a hard cover, we say that we must limit its size to a certain number of pages and eventually stop writing so that it can be published. Therefore, we cannot go into detail on each type of packet classification.

Marking Traffic with DSCP

In the past few years, the ToS field in the IP header has been redefined to support newer DiffServ technologies. The new Differentiated Service (DS) field contains two subfields that are broken down into what is known as codepoints. *Codepoints* are basically subclassification of the values within the DS field of an IP packet. The DS field contains two codepoints: the *Class Selector Codepoint*, formerly known as the IP Precedence field; and the *Assured Forwarding (AF) Codepoint*. While the DS field remains compatible with IP precedence, the class selector codepoints are bits 0, 1, and 2 (the first 3 bits of the DS field XXX000). The first 6 bits of the DS field belong to the DSCP field, which creates 64 possible classes to be used for packet marking. The AF codepoints are covered later in this section.

RFC 2474 and RFC 2475 describe the definition and architecture for DiffServ applications by using

field for packet marking. Packet marking is basically the process of reading, using, or changing the DSCP field to provide a *per-hop behavior (PHB)* for traffic conditioning, metering, shaping, or policing. A PHB is defined as a behavior or forwarding treatment that is applied to a *Behavior Aggregate (BA)*. BAs are packets with the same codepoint going in the same direction.

NOTE

The use of the DSCP field is defined in RFCs 2474, 2475, 2597, 2598, and 2697, and later updated in RFCs 3168 and 3260.

Within these 64 DSCP classes, the IETF has specified three class pools, as shown in [Table 5-12](#). The first pool, which uses the first 5 bits of the DSCP field ending with a 0, is reserved for standard class assignments and are administered by IANA. For example, the prefixes 000, 001, 010, 011, 100, 101, 110, and 111 are reserved aside to remain compatible with IP precedence. 000000 is reserved for best-effort traffic, and any value that does not match any other class is sent to the 00000 codepoint.

Table 5-12. DSCP Pools

Pool Number	Codepoint Value	Reservation
1	Bits 0,1,2,3,4 xxxxx0	Reserved for standards administered by IANA
2	Bits 0,1,2,3 xxxx11	Reserved for experimental or local use
3	Bits 0,1,2,3 xxxx01	Reserved for experimental or local use and future standards extensions

Using the DSCP field for packet marking allows for the creation of many classes for traffic prioritization, which is valuable when you are working with traffic that requires a guaranteed amount of bandwidth, low jitter, and low latency, such as voice or video. For this reason, RFC 2598 describes the use of *Expedited Forwarding (EF)* PHB. EF PHB provides the highest QoS defined for use with DiffServ. EF PHB provides four classes for high-priority traffic, with the class 101110 being the highest priority with the greatest quality of service provisions.

You can also use DSCP values with WRED to control the proactive drop of TCP packets by specifying four AF classes. RFC 2597 defines AF classes for specification of packet-drop priority. To illustrate the use of AF classes in a network environment, suppose you have defined three types of traffic as high priority; when network congestion reaches the point where packets must be dropped, with AF classes you can control the order in which packets are dropped. [Table 5-13](#) shows the AF classes and their drop priority. All four AF Class 1 begin with the standard IP Precedence value of 001, which is immediate precedence. Class 2 begins with the value 010, which is immediate precedence, Class 3 begins with the value 011, which is Flash override precedence, and Class 4 begins with the value 100, which is Flash-override precedence.

NOTE

The use of WRED is covered in detail later in this chapter.

Table 5-13. AF Classes and Drop Priority

Drop Precedence	Class 1	Class 2	Class 3	Class 4
Low drop	AF11	AF21	AF31	AF41
	DSCP 10	DSCP 18	DSCP 26	DSCP 34
	001010	010010	011010	100010
Medium drop	AF12	AF22	AF32	AF42
	DSCP 12	DSCP 20	DSCP 28	DSCP 36
	001100	010100	011100	100100
High drop	AF13	AF23	AF33	AF43
	DSCP 14	DSCP 22	DSCP 30	DSCP 38
	001110	010110	011110	100110

The DSCP value can be used with Cisco IOS Software in a number of ways. It can be used with access lists to specify DSCP values in IP packets. It can be used with class maps and policy maps to mark packets. The DSCP bit can also be used with CAR to specify actions to perform on packets based on their DSCP value. DSCP can be used with WRED to specify which traffic to drop first in a proactive packet-drop scenario. [Table 5-14](#) shows the DSCP values that can be set, either by name or by decimal number, and their descriptions.

Table 5-14. Cisco IOS Software's DSCP Values

DSCP Value Name	DSCP Value Decimal and Hexadecimal	Description
af11	10 001010	AF11— Assured forwarding, low drop probability, C DSCP, and priority precedence
af12	12 001100	AF12— Assured forwarding, medium drop probability, 1 DSCP, and priority precedence
af13	14 001110	AF13— Assured forwarding, high drop probability, 0 DSCP, and priority precedence

af21	18 010010	AF21— Assured forwarding, low drop probability, C DSCP, and immediate precedence
af22	20 010100	AF22— Assured forwarding, medium drop probability 2 DSCP, and immediate precedence
af23	22 010110	AF23— Assured forwarding, high drop probability, (C DSCP, and immediate precedence
af31	26 011010	AF31— Assured forwarding, low drop probability, C DSCP, and Flash precedence
af32	28 011100	AF32— Assured forwarding, medium drop probability 3 DSCP, and Flash precedence
af33	30 011110	AF33— Assured forwarding, high drop probability, (C DSCP, and Flash precedence
af41	34 100010	AF41— Assured forwarding, low drop probability, C DSCP, and Flash-override precedence
af42	36 100100	AF42— Assured forwarding, medium drop probability 4 DSCP, and Flash-override precedence
af43	38 100110	AF43— Assured forwarding, high drop probability, (C DSCP, and Flash-override precedence
cs1	1 001000	CS1 or Priority IP precedence 1
cs2	2 010000	CS2 or Immediate IP precedence 2
cs3	3 011000	CS3 or Flash IP precedence 3
cs4	4 100000	CS4 or Flash-override IP precedence 4
cs5	5 101000	CS5 or Critical IP precedence 5
cs6	6 110000	CS6 or Internet IP precedence 6
cs7	7 111000	CS7 or Network Control IP precedence 7

default	0 000000	The default "best-effort" value for all traffic
ef	46 101110	EF-PHB— Expedited forwarding, highest service level

The most standard application of DSCP classification is with access lists. [Example 5-22](#) shows two examples of how to use the AF DSCP value to mark all UDP voice traffic with the lowest drop probability and highest precedence. The recommended DSCP value for voice signaling traffic is DSCP 26 or AF31. This is essentially the same as marking the traffic with the Flash IP precedence value. By marking the packets with the AF31 DSCP value, you can ensure that queuing or congestion control mechanisms, such as WFQ or WRED, will give the packets high priority, recommended for voice signaling traffic, least drop probability, and you can also use other more advanced methods to control the quality levels provided to these applications.

Example 5-22. Using DSCP Classification to Prioritize Voice Traffic

```

interface Serial1
    ip address 192.168.1.2 255.255.255.252
    frame-relay map ip 192.168.1.1 148 broadcast
    ip rsvp bandwidth 1158 24
    ip rsvp signalling dscp 26
!
dial-peer voice 4801 pots
    destination-pattern 4801
    port 2/0
!
dial-peer voice 4901 voip
    destination-pattern 4901
    session target ipv4:192.168.2.2
    req-qos guaranteed-delay
    ip qos dscp af31 signalling

```

In the preceding example, the `ip rsvp signalling dscp 26` command is used to assign RSVP signaling traffic a DSCP value of 26, which corresponds to AF31.

the AF DSCP value of af31 (low drop/Flash). The second highlighted command, ip qos dscp af31 signalling, provides prioritized classification for voice signaling traffic, which can be used to prioritize traffic in other parts of the network. Each of these commands allows for the two separate protocols higher priorities for weighted queuing or congestion strategies during periods of congestion.

NOTE

The act of marking traffic with DSCP values by itself does not guarantee that the traffic will receive better treatment in a network. Packet marking just identifies the traffic so that you can apply queuing techniques to that traffic at other places in the network.

Now that you have learned ways to use the DSCP values to classify traffic for congestion control, it is time to examine how congestion control itself works and how it is configured.

Avoiding Congestion with WRED

When no congestion avoidance mechanism is in place, interfaces drop packets based on tail drop. This basically means that when the queue for an interface is full, any new packets arriving for transmission on that interface are dropped until the interface has enough queue space to service new packets. Another way to manage network congestion is by avoiding it altogether; Weighed Random Early Detection (WRED) was designed to do just that. Based on the Random Early Detection (RED) algorithm, developed by Sally Floyd and others, WRED proactively drops packets based on the estimated average queue size, minimum queue size, where no packets are dropped, and a maximum queue size, where all packets are dropped. WRED drops packets when congestion is encountered on a queue to prevent a scenario called *global synchronization*.

NOTE

For more information on RED, check out RFC 2309 and the RED research papers at <http://ftp.ee.lbl.gov/floyd/red.html> or Sally Floyd's website at <http://www.icir.org/floyd/>.

Global synchronization occurs when a network is congested and packets are dropped, causing all TCP stations to simultaneously back off and then retransmit the dropped packets, which wastes network resources. During incidents of global synchronization, network traffic will continuously frequently peak and then drop off because the end stations running TCP applications have synchronized. WRED is designed to prevent global synchronization by proactively dropping packets from larger traffic flows, causing smaller dominant network end stations to decrease their TCP window size and send fewer packets between acknowledgments, reducing their network utilization, making more room for smaller traffic flows and preventing further packet loss.

NOTE

The major difference between WRED and RED is that WRED weighs traffic flows based on the value of the IP Precedence field in the IP header and RED does not. With WRED, higher-priority traffic receives a higher weight and is less likely to be dropped during periods of network congestion.

It is important to note that WRED works only with TCP traffic, because TCP is connection oriented, using flow control using windowing and acknowledgments. Because UDP, IPX, and other non-IP protocols (such as AppleTalk and Internetwork Packet Exchange) are connectionless and do not provide a window mechanism like TCP, they may be adversely affected by WRED. If interface congestion consists mostly of connectionless, or non-IP traffic, the WRED congestion avoidance method will not provide a benefit.

In Cisco IOS Software, you can configure an interface using WRED in two ways. The simplest way to configure WRED is by enabling it on an interface using the `random-detect` command. After enabling WRED, you may also configure the weight for the mean queue depth calculation by using the `random-detect exponential-weighting-constant` command. This command specifies a weight to be used by WRED when calculating the average queue length; the default weight factor is 9:

```
random-detect exponential-weighting-constant
```

Acceptable exponent values range from 1 to 16 and are in the format 2^n . To configure the IP precedence values used to weigh the packets use the `random-detect precedence` command, which specifies the minimum and maximum WRED packet thresholds and the mark probability denominator. By default, the minimum threshold for an IP precedence of 0 is set to half maximum threshold for the interface. [Table 5-15](#) explains the minimum and maximum thresholds and the mark probability denominator in more detail.

```
random-detect precedenceprecedence-value minimum-threshold maximum threshold  
[mark-probability-denominator]
```

Table 5-15. WRED and IP Precedence Values

Command Argument	Description
<i>precedence-value</i>	The specific IP precedence-value to be matched, ranging from 0 to 7.
<i>minimum-threshold</i>	The minimum number of packets that will be queued before packets with the specified precedence value will be randomly dropped.
<i>maximum-threshold</i>	The maximum number of packets that will be queued before all packets of the specified precedence value will be tail dropped.
[<i>mark-probability-denominator</i>]	(Optional) This value represents the fraction for the amount of packets that will be dropped during periods of congestion when the average queue size is at maximum capacity. In other words, before the maximum threshold has been met, one out of every 10 mark probability denominator packets will be dropped.

You can customize WRED configurations for network applications by setting individual precedence values. The minimum and maximum packet queue sizes can be defined for each of the eight IP precedence levels. You can use the mark-probability-denominator argument to change the rate at which packets are dropped. For example, the default mark-probability-denominator for a WRED interface is 10, so if a packet level is between the minimum and maximum threshold values, one out of every 10 packets is dropped. After the maximum threshold is met, packets of this precedence value will be tail dropped. [Example 5-23](#) shows how WRED has been configured to limit the size of the lower-priority queues, queues 0 through 4, and increase the minimum average queue size for critical (precedence 5) traffic to 35 packets.

Example 5-23. Using WRED and IP Precedence

```
Sally-1#show run | begin Serial0

interface Serial0
    ip address 289.22.78.1 255.255.255.0
    ip ospf network point-to-point
    no ip mroute-cache
    random-detect
        random-detect precedence 0 17 40
        random-detect precedence 1 19 40
        random-detect precedence 2 21 40
        random-detect precedence 3 23 40
        random-detect precedence 4 25 40
        random-detect precedence 5 35 40 20
```

[Example 5-24](#) shows a before and after snapshot of the WRED parameters as seen using the show random-detect command on a serial interface.

Example 5-24. Before and After the WRED Configuration Change

```
Sally-1#show queueing random-detect
```

Current random-detect configuration:

Serial0

Queueing strategy: random early detection (WRED)

Exp-weight-constant: 9 (1/512)

Mean queue depth: 0

Class	Random drop	Tail drop	Minimum threshold	Maximum threshold	Mark probability
0	0	0	20	40	1/10
1	0	0	22	40	1/10
2	0	0	24	40	1/10
3	0	0	26	40	1/10
4	0	0	28	40	1/10
5	0	0	31	40	1/10
6	0	0	33	40	1/10
7	0	0	35	40	1/10
rsvp	0	0	37	40	1/10

```
Sally-1#show queueing random-detect
```

Current random-detect configuration:

Serial0

Queueing strategy: random early detection (WRED)

Exp-weight-constant: 9 (1/512)

Mean queue depth: 0

Class	Random	Tail		Minimum	Maximum	Mark
		drop	drop	threshold	threshold	probability
0	0	0	0	17	40	1/10
1	0	0	0	19	40	1/10
2	0	0	0	21	40	1/10
3	0	0	0	23	40	1/10
4	0	0	0	25	40	1/10
5	0	0	0	35	40	1/20
6	0	0	0	33	40	1/10
7	0	0	0	35	40	1/10
rsvp	0	0	0	37	40	1/10

As seen in the preceding example, the `show queueing random-detect` command displays the WRED configuration for each WRED-enabled interface, including the exponent weight constant, the number of packets dropped for each precedence value, and the minimum and maximum values for each of the precedence values and RSVP.

As previously mentioned, by default WRED works with the IP precedence values to prevent high-priority packets from being dropped during periods of congestion. If the volume of traffic is high enough that the interface still becomes congested, and the packet levels are between the minimum and maximum thresholds, then packets of a certain precedence value will be dropped according to the configured thresholds. WRED can also be leveraged to work with DSCP values using the `random-detect dscp-based` command, as shown in [Example 5-25](#).

NOTE

In the event that an interface receives a high volume of non-TCP traffic, high-priority traffic, or traffic marked with IP precedence or DSCP values, may exceed the maximum thresholds, causing prioritized packets to be tail dropped.

Example 5-25. Using DSCP Values with WRED

```
Store-148#sho run | begin Serial1
interface Serial1
```

```

no ip address

encapsulation frame-relay

random-detect dscp-based

frame-relay lmi-type ansi

```

In the preceding example, WRED was configured so that the weight will be calculated using DSCP rather than IP precedence. WRED's capabilities are greatly enhanced when it is used in combination with DSCP classification. Instead of supporting the eight IP precedence queues supported by precedence-based WRED, DSCP-based WRED supports all the AF- and CS-based DSCP values, and each of these queues is altered using the random-detect dscp-based *dscp-value minimum-threshold, maximum-threshold, probability-denominator* command. [Example 5-26](#) shows the output from the show queueing command after configuring DSCP-based WRED.

Example 5-26. show queueing and DSCP-Based WRED

```
Sally-1#show queueing
```

Current fair queue configuration:

Interface	Discard threshold	Dynamic queues	Reserved queues	Link queues	Priority queues
Serial0	64	256	37	8	1

Current DLCI priority queue configuration:

Current priority queue configuration:

Current custom queue configuration:

Current random-detect configuration:

Serial1

Queueing strategy: random early detection (WRED)

Exp-weight-constant: 9 (1/512)

Mean queue depth: 0

dscp	Random drop pkts/bytes	Tail drop pkts/bytes	Minimum thresh	Maximum thresh	Mark prob
af11	0/0	0/0	33	40	1/10

af12	0/0	0/0	28	40	1/10
af13	0/0	0/0	24	40	1/10
af21	0/0	0/0	33	40	1/10
af22	0/0	0/0	28	40	1/10
af23	0/0	0/0	24	40	1/10
af31	0/0	0/0	33	40	1/10
af32	0/0	0/0	28	40	1/10
af33	0/0	0/0	24	40	1/10
af41	0/0	0/0	33	40	1/10
af42	0/0	0/0	28	40	1/10
af43	0/0	0/0	24	40	1/10
cs1	0/0	0/0	22	40	1/10
cs2	0/0	0/0	24	40	1/10
cs3	0/0	0/0	26	40	1/10
cs4	0/0	0/0	28	40	1/10
cs5	0/0	0/0	31	40	1/10
cs6	0/0	0/0	33	40	1/10
cs7	0/0	0/0	35	40	1/10
ef	0/0	0/0	37	40	1/10
rsvp	0/0	0/0	37	40	1/10
default	0/0	0/0	20	40	1/10

Current per-SID queue configuration:

WRED information is also summarized with the show interface command, which displays the number of dropped packets, as shown in [Example 5-27](#).

Example 5-27. show interface Command and WRED

```
Sally-1#show interface serial 0
```

```
Serial0 is up, line protocol is up

Hardware is PQUICC with 56k 4-wire CSU/DSU

Internet address is 2.2.2.1/24

MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input 00:00:17, output 00:00:02, output hang never

Last clearing of "show interface" counters never

Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0

Queueing strategy: random early detection(RED)

5 minute input rate 0 bits/sec, 0 packets/sec

5 minute output rate 0 bits/sec, 0 packets/sec

2826 packets input, 201606 bytes, 0 no buffer

Received 2821 broadcasts, 0 runts, 0 giants, 0 throttles

1427 input errors, 99 CRC, 479 frame, 0 overrun, 0 ignored, 841 abort

3934 packets output, 274630 bytes, 0 underruns

0 output errors, 0 collisions, 243 interface resets

0 output buffer failures, 0 output buffers swapped out

175 carrier transitions

DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

WRED also includes support for RSVP. By default WRED has a 37-packet minimum average queue : RSVP traffic, the largest of all average queue sizes. You can customize the RSVP WRED configuration using the random-detect precedence rsvp or random-detect dscp rsvp commands to configuir minimum and maximum average queue sizes.

NOTE

If you are planning to use FIFO queuing on an interface running WRED and you are considerir

another queuing method, such as WFQ, CQ, or PQ, in the future, you should be aware that WF and WFQ, CQ, and PQ are all mutually exclusive technologies. After WRED has been configured, it must be removed before any other queuing method can be enabled.

WRED can also be configured to support individual traffic flows. Flow-Based RED is commonly referred to as FRED. Each flow consists of a source and destination IP address and port number. FRED monitors traffic information for each flow and prevents any resource-intensive flows from monopolizing the resources by allocating buffers to each flow.

To enable FRED, you must first enable WRED using the random-detect command, and then enable FRED using the random-detect flow command, and then, if necessary, configure the average queue depth factor. The number of dynamic queues allowed. By default, FRED is limited to 256 flows with an average queue depth factor of 4. The average depth factor is used to scale the number of buffers available to each flow, which determines how many packets permitted per queue, and is configurable using the random-detect flow average-depth-factor command. The depth factor can be 1, 2, 4, 8, or 16; the default average depth factor is 4.

```
random-detect flow average-depth-factor depth-factor
```

The maximum number of active flows is set using the random-detect flow count command. The value can range from 16 to 32,768, with the default value of 256 flows.

```
random-detect flow count flow-count
```

These FRED flow configuration tools enable you to create more granular congestion control configurations that you can apply different congestion control actions to traffic based on DSCP values, limit the number of flows, and define the size of the queues, as shown in [Example 5-28](#).

Example 5-28. Creating Custom WRED Configurations

```

Store-148#sho run | begin Serial1

interface Serial1
  no ip address
  encapsulation frame-relay
  random-detect dscp-based
  random-detect flow
  random-detect flow average-depth-factor 2
  frame-relay lmi-type ansi

```

The preceding example created three new fields in the output of the show queueing random-detect command. The *mean queue depth*, which is also shown when WRED is enabled, displays the average depth by taking an average of the minimum and maximum queue depth sizes for each queue. The *count* field displays the maximum number of flows that will be permitted with the current configuration. *Average depth factor* field displays the current average depth factor configuration, and the *flows* field displays the number of active flows, the maximum number of active flows, and the maximum number of possible active flows given the current configuration. [Example 5-29](#) shows the output of the show queueing random-detect command after the application of the configuration shown earlier in [Example 5-28](#).

Example 5-29. show queueing Command Output After Flow Configuration

```

Sally-1# show queueing random-detect interface Serial 1

Current random-detect configuration:

Serial1

  Queueing strategy: random early detection (WRED)

  Exp-weight-constant: 9 (1/512)

  Mean queue depth: 0

  Max flow count: 256          Average depth factor: 2

  Flows (active/max active/max): 0/0/256

  dscp      Random drop      Tail drop      Minimum  Maximum  Mark
                pkts/bytes       pkts/bytes     thresh   thresh   prob
  af11      0/0              0/0            33       40        1/10

```

af12	0 / 0	0 / 0	28	40	1 / 10
af13	0 / 0	0 / 0	24	40	1 / 10
af21	0 / 0	0 / 0	33	40	1 / 10
af22	0 / 0	0 / 0	28	40	1 / 10
af23	0 / 0	0 / 0	24	40	1 / 10
af31	0 / 0	0 / 0	33	40	1 / 10
af32	0 / 0	0 / 0	28	40	1 / 10
af33	0 / 0	0 / 0	24	40	1 / 10
af41	0 / 0	0 / 0	33	40	1 / 10
af42	0 / 0	0 / 0	28	40	1 / 10
af43	0 / 0	0 / 0	24	40	1 / 10
cs1	0 / 0	0 / 0	22	40	1 / 10
cs2	0 / 0	0 / 0	24	40	1 / 10
cs3	0 / 0	0 / 0	26	40	1 / 10
cs4	0 / 0	0 / 0	28	40	1 / 10
cs5	0 / 0	0 / 0	31	40	1 / 10
cs6	0 / 0	0 / 0	33	40	1 / 10
cs7	0 / 0	0 / 0	35	40	1 / 10
ef	0 / 0	0 / 0	37	40	1 / 10
rsvp	0 / 0	0 / 0	37	40	1 / 10
default	0 / 0	0 / 0	20	40	1 / 10

This chapter covered several ways to provide QoS to applications using integrated and differentiated services. Many of the technologies are difficult to understand without the application of a queuing, or policing mechanism to apply an actual action upon receiving a marked packet. The full benefits of DiffServ design will not be seen until advanced queuing, shaping, and policing techniques are applied. The next chapter explores how DiffServ technologies can be extended and added to by applying more advanced queuing, shaping, policing, and classification techniques.

Practice Scenario

The following practical scenario is provided to help reinforce some of the concepts that have been discussed in this chapter.

Lab 11: The Jetsons Meet IntServ and DiffServ

Integrated and differentiated services provide several enhancements to today's congested networks. In this practical scenario, you explore the various ways that these technologies can be used together to provide more efficient networks.

Lab Exercise

In this lab scenario, you configure integrated and differentiated service to provide better VoIP quality for the users in the Jetsons network. The network used in this scenario will make use of many of the technologies in this chapter, including RSVP with DSCP classification and WRED for congestion control through the ATM WAN.

Lab Objectives

In this lab, you complete the following objectives:

- Use RSVP to reserve resources for VoIP traffic.
- Apply DSCP marking for certain types of RSVP and voice signaling traffic.
- Use WRED to control congestion across the wide-area network.
- Apply voice codecs to provide the best compression, quality, and reliability.
- Refresh ATM skills by applying WRED and RSVP to ATM WAN interfaces.
- Configure a LightStream 1010 ATM switch for PVC connections between ATM router interfaces.

Equipment Needed

The following equipment is needed:

- One LightStream ATM switch with two OC-3 modules
- Two Cisco routers with ATM OC-3 interfaces; one router with at least one serial interface, and the other router with one Token Ring interface
- One router with one Ethernet and one Token Ring interface
- One router with one serial and one FXS voice interface and a phone for testing

- One router with one Fast Ethernet and one FXS voice interface and a phone for testing
- One hub or switch for Ethernet connectivity, and one multistation access unit (MSAU) for Token Ring connections

NOTE

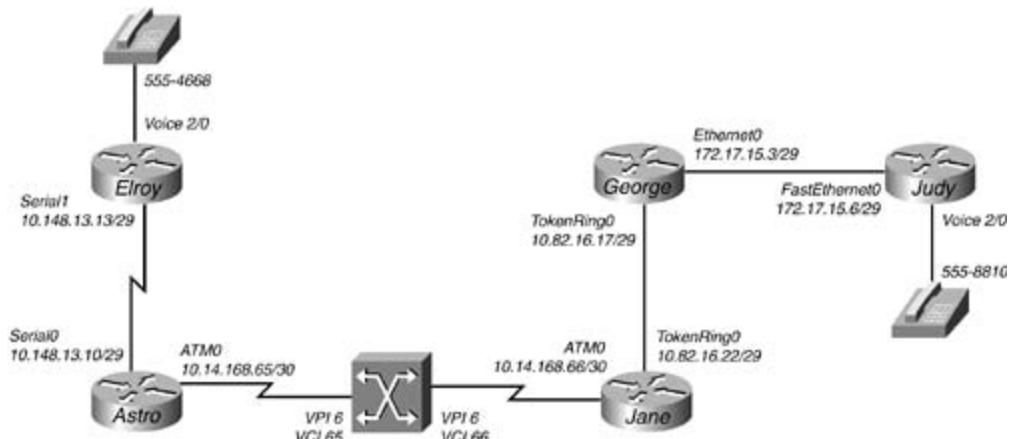
This lab makes use of ATM equipment as the wide-area core network. If you do not have ATM equipment, simulate these connections with Frame Relay. This lab also uses Token Ring interfaces; because Token Ring is not one of the key components for this experiment, however, you can use Ethernet in its place.

Physical Layout and Prestaging

The following physical layout and prestaging needs to be completed:

- Cable the routers as shown in [Figure 5-6](#), and connect the ATM OC-3 interfaces to the ATM switch.

Figure 5-6. The Jetsons Network



- Connect the Elroy and Astro serial interfaces using back-to-back cables.
- Connect the Jane and George routers to an MSAU.
- Connect the Judy and George routers using an Ethernet switch or hub.
- Connect telephones to the FXS ports on the Elroy and Judy routers.
- Configure the ATM switch using the information from [Table 5-16](#).

Table 5-16. ATM PVC Configuration

Router Interface	VPI	VCI	Switch Interface	VPI	VCI
Astro ATMO	6	65	ATM1/0/2	6	65
Jane ATMO	6	66	ATM1/0/0	6	66

Configuring ATM switching for two PVCs is a very simple process. Just create one ATM PVC statement on one of the interfaces specifying that ATM traffic on that PVC should go to the other ATM interface connected to the remote network. [Example 5-30](#) shows the configuration for the ATM switch.

Example 5-30. ATM Switch Configuration

```
interface ATM1/0/2
no ip address
atm pvc 6 65  interface ATM1/0/0 6 66
```

- Configure all IP addresses on the serial, ATM, Token Ring, and Ethernet interfaces as shown in the preceding figure. Verify that all routers are able to reach their directly connected neighbor using pings.

Lab Tasks

Follow these steps to complete this lab:

Step 1. Enable Enhanced Interior Gateway Routing Protocol (EIGRP) process 32074 on all routers, and make sure that they do not classfully summarize networks. Verify IP connectivity before proceeding to Step 2.

Step 2. Configure VoIP for the phones connected to the FXS interfaces on the Elroy and Judy routers using the phone numbers shown in [Figure 5-5](#). The phones should automatically dial each other when taken off the hook. Use one of the voice codecs that consumes the least amount of bandwidth. Verify this configuration by test calls in both directions.

Step 3. Configure RSVP request and acceptance for guaranteed delay service on all VoIP traffic. Make sure all RSVP and voice signaling traffic is classified as the highest priority using DSCP marking. Do not allow an interface to use more bandwidth than 50 percent of the smallest Jetsons network interface. The largest flow should not be any larger than the flow size required for the voice codec in use. Test the configuration on both phones before continuing to Step 4. This step requires quite a few tasks to work properly.

Step 4. Enable WRED to control congestion on the serial interfaces of the Astro and Elroy routers. Each router should weigh the priority of packets based on their DSCP values; packets marked with the 000000 DSCP value should be discarded after 20 bytes, and there should be no more than default DSCP packets before WRED begins to discard them as well.

After all routers have been cabled, verify connectivity using the show cdp neighbors and show ip interface brief commands. This will save a lot of time troubleshooting cabling and clock rate problems. After verifying Layer 2 connectivity, assign IP addresses to each of the routers using the information from [Figure 5-6](#). After you have assigned all IP addresses, verify Layer 3 connectivity between directly connected networks using the ping command. Then, after you have verified that all directly connected router interfaces are reachable, you are ready to proceed with the rest of this lab.

Lab Walkthrough

The following walkthrough shows the steps that were followed to successfully complete this practical scenario:

Step 1. Enable EIGRP process 32074 on all routers, and make sure that they do not classfully summarize networks. Verify IP connectivity before proceeding to Step 2.

This step sounds a little easier than it is. In the beginning as you are enabling EIGRP routing, you may begin to notice that the Astro and Jane routers do not automatically become neighbors. This is because they are connecting over a nonbroadcast multiaccess (NBMA) ATM network. Two tasks must be completed before these two peers will become EIGRP neighbors.

- Create an ATM map list to map the Layer 2 to Layer 3 addresses and enable broadcasts, just like a Frame Relay map statement, and apply the map list to the ATM subinterface using the map-group *map-list-name* command as shown in [Example 5-31](#).

Example 5-31. ATM Configuration for the Astro Router

```
Astro#show run | begin ATM

interface ATM0
    no ip address
    no atm ilmi-keepalive
!
interface ATM0.20 multipoint
    ip address 10.14.168.65 255.255.255.252
```

```

map-group atm

atm pvc 20 6 65 aal5snap

!

map-list atm

ip 10.14.168.66 atm-vc 20 broadcast

```

The atm map-group maps the IP address to the ATM address of the interface. After you have applied the map group to the ATM subinterface, you should be able to verify the ATM configuration using the show atm map and show atm vc commands, as shown in [Example 5-32](#).

Example 5-32. Verifying the ATM Configuration on the Astro Router

```

Astro#show atm map

Map list atm : PERMANENT

ip 10.14.168.66 maps to VC 20

    , broadcast

Astro#show atm vc

      VCD /
      Peak   Avg/Min Burst
      Interface Name      VPI   VCI   Type     Encaps   SC     Kbps   Kbps   Cells   Sts
      0.20       20          6     65   PVC      SNAP     UBR   155000
                                         UP

```

- Optionally, create a static EIGRP neighbor assignment using the `EIGRP neighbor /P-address interface-name interface-number` command. [Example 5-33](#) shows the EIGRP configuration from the Astro router and the resulting `show ip eigrp neighbors` command output.

Example 5-33. The EIGRP Configuration for the Astro Router

```

Astro#show run | begin eigrp

router eigrp 32074

```

```

network 10.14.168.64 0.0.0.3

network 10.148.13.8 0.0.0.7

neighbor 10.14.168.66 ATM0.20

no auto-summary

```

Astro#show ip eigrp neighbors

IP-EIGRP neighbors for process 32074

H	Address	Interface	Hold	Uptime	SRTT	RTO	Q	Seq	Type
			(sec)		(ms)		Cnt	Num	
1	10.14.168.66	AT0.20	13	00:18:05	1264	5000	0	7	S
0	10.148.13.13	Se0	13	00:19:28		1	200	0	8

Step 2. Configure VoIP for the phones connected to the FXS interfaces on the Elroy and Judy routers using the phone numbers shown in [Figure 5-6](#). The phones should automatically dial each other when taken off the hook. Use one of the voice codecs that consumes the least amount of bandwidth. Verify this configuration by test calls in both directions.

This step requires most of the same principles applied in all the other VoIP examples so far: configuring two dial peers; and setting destination patterns, session targets, ports, and codecs. The least resource-intensive voice codec is one of the g.723 codecs. The only difference in this configuration is the automatic dial configuration. This is easily accomplished using the connection *plar dial-string* command under the voice port. [Example 5-34](#) shows the VoIP configuration for the Judy router. This example also shows that two calls were successfully placed. You can display active call summary information by using the show call active voice command on both routers.

Example 5-34. VoIP Configuration and Test Data for the Judy Router

```

Judy#show run | begin voice-port

voice-port 2/0

connection plar 5554668

!

voice-port 2/1

!

```

```

dial-peer voice 5558810 pots
destination-pattern 5558810
port 2/0

!
dial-peer voice 5554668 voip
destination-pattern 5554668
session target ipv4:10.148.13.13
codec g723ar63

Astro#show call active voice

Telephony call-legs: 1
SIP call-legs: 0
H323 call-legs: 1

Judy#show call active voice

Telephony call-legs: 1
SIP call-legs: 0
H323 call-legs: 1

```

Step 3. Configure RSVP request and acceptance for guaranteed delay service on all VoIP traffic. Make sure all RSVP and voice signaling traffic is classified as the highest priority using DSCP marking. Do not allow any interface to use more bandwidth than 50 percent of the smallest Jetsons network interface. The largest flow should be no larger than the flow size required for the voice codec in use. Test the configuration on both phones before continuing to Step 4. This step requires quite a few tasks to work properly.

- First enable RSVP on all interfaces using the reserved bandwidth of 772 bps, which is 50 percent of the smallest interface bandwidth of a serial interface. The largest reservable flow should not be greater than 18 bps, the rate of the voice codec. And all RSVP signaling traffic should be marked with the EF DSCP value. This can all be accomplished using two commands: ip rsvp bandwidth 772 18, and ip rsvp signalling dscp 46.
- Next, you need to configure all voice traffic to request and accept guaranteed delay service from the network. This requires only two configuration tasks: entering the req-qos guaranteed-delay, acc-qos guaranteed-delay, and ip qos dscp ef signalling commands in the dial-peer configuration for the remote peer on both the Elroy and Judy routers. [Example 5-35](#) shows the RSVP configuration for the Elroy router.

Example 5-35. Elroy VoIP RSVP Configuration

```
Elroy#show run | begin Serial1

interface Serial1
    ip address 10.148.13.13 255.255.255.248
    fair-queue 64 256 26
    ip rsvp bandwidth 772 18
    ip rsvp signalling dscp 46
!
voice-port 2/0
    connection plan 5558810
!
voice-port 2/1
!
dial-peer voice 5554668 pots
    destination-pattern 5554668
    port 2/0
!
dial-peer voice 5558810 voip
    destination-pattern 5558810
    session target ipv4:172.17.15.6
    req-qos guaranteed-delay
    acc-qos controlled-load
    codec g723ar63
    ip qos dscp ef signalling
```

You can verify this step by using the show ip rsvp reservation detail command on the Elroy router. This command should display data similar to that shown in [Example 5-36](#).

Example 5-36. show ip rsvp reservation detail Command Output from the Elroy Router

```
Elroy#show ip rsvp reservation detail

RSVP Reservation. Destination is 10.148.13.13, Source is 172.17.15.6,
Protocol is UDP, Destination port is 16394, Source port is 19344
Reservation Style is Fixed-Filter, QoS Service is Guaranteed-Rate
Average Bitrate is 18K bits/sec, Maximum Burst is 80 bytes
Min Policed Unit: 40 bytes, Max Pkt Size: 40 bytes
Resv ID handle: 0000B801.

Policy: Forwarding. Policy source(s): Default

RSVP Reservation. Destination is 172.17.15.6, Source is 10.148.13.13,
Protocol is UDP, Destination port is 19344, Source port is 16394
Next Hop is 10.148.13.10, Interface is Serial1
Reservation Style is Fixed-Filter, QoS Service is Guaranteed-Rate
Average Bitrate is 18K bits/sec, Maximum Burst is 80 bytes
Min Policed Unit: 40 bytes, Max Pkt Size: 40 bytes
Resv ID handle: 0000BA01.

Policy: Forwarding. Policy source(s): Default
```

Step 4. Next, enable WRED to control congestion on the serial interfaces of the Astro and Elroy routers. Each router should weigh the priority of packets based on their DSCP values; packets marked with the 000000 DSCP value should be discarded after 20 bytes, and there should be no more than default DSCP packets before WRED begins to discard them as well.

This command only requires two tasks: enabling DSCP-based WRED and creating a limit for packets with the default DSCP value. The WRED configuration for the Elroy router is shown in [Example 5-37](#).

Example 5-37. WRED Configuration for the Elroy Router

```
Elroy#show run | begin Serial1
```

```
interface Serial1
  ip address 10.148.13.13 255.255.255.248
  random-detect dscp-based
  random-detect dscp 0 20 30
  ip rsvp bandwidth 772 18
  ip rsvp signalling dscp 46
```

As a final WRED configuration step, you can verify the WRED default DSCP values using the `show queueing random-detect | begin default` command, as shown in [Example 5-38](#).

Example 5-38. Verifying the WRED Configuration on the Elroy Router

```
Elroy#show queueing random-detect | begin default
default      0/0          0/0          20          30    1/10
```

[Example 5-39](#) shows the complete configurations for this lab.

Example 5-39. The Complete Configurations for Lab 5

Elroy Router Configuration

```
interface Serial1
  ip address 10.148.13.13 255.255.255.248
  random-detect dscp-based
  random-detect dscp 0 20 30
  ip rsvp bandwidth 772 18
  ip rsvp signalling dscp 46
!
router eigrp 32074
  network 10.148.13.8 0.0.0.7
```

```
no auto-summary

no eigrp log-neighbor-changes

!

voice-port 2/0

connection plan 5558810

!

voice-port 2/1

!

dial-peer voice 5554668 pots

destination-pattern 5554668

port 2/0

!

dial-peer voice 5558810 voip

destination-pattern 5558810

session target ipv4:172.17.15.6

req-qos guaranteed-delay

acc-qos controlled-load

codec g723ar63

ip qos dscp ef signalling
```

Astro Router Configuration

```
interface Serial0

ip address 10.148.13.10 255.255.255.248

random-detect dscp-based

random-detect dscp 0 20 30

clockrate 1300000

ip rsvp bandwidth 772 18

!
```

```
interface ATM0
no ip address
no atm ilmi-keepalive
ip rsvp bandwidth 772 18
!
interface ATM0.20 multipoint
ip address 10.14.168.65 255.255.255.252
map-group atm
atm pvc 20 6 65 aal5snap
ip rsvp bandwidth 772 18
!
router eigrp 32074
network 10.14.168.64 0.0.0.3
network 10.148.13.8 0.0.0.7
neighbor 10.14.168.66 ATM0.20
no auto-summary
!
map-list atm
ip 10.14.168.66 atm-vc 20 broadcast
```

Jane Router Configuration

```
interface TokenRing0
ip address 10.82.16.22 255.255.255.248
ring-speed 16
ip rsvp bandwidth 772 18
!
interface ATM0
no ip address
```

```
no atm ilmi-keepalive

ip rsvp bandwidth 772 18

!

interface ATM0.20 multipoint

ip address 10.14.168.66 255.255.255.252

map-group atm

atm pvc 20 6 66 aal5snap

ip rsvp bandwidth 772 18

!

router eigrp 32074

network 10.14.168.64 0.0.0.3

network 10.82.16.16 0.0.0.7

neighbor 10.14.168.65 ATM0.20

no auto-summary

!

map-list atm

ip 10.14.168.65 atm-vc 20 broadcast
```

George Router Configuration

```
interface Ethernet0/0

ip address 172.17.15.3 255.255.255.248

ip rsvp bandwidth 772 18

!

interface TokenRing0/0

ip address 10.82.16.17 255.255.255.248

ring-speed 16

ip rsvp bandwidth 772 18

!
```

```
router eigrp 32074

network 10.82.16.16 0.0.0.7

network 172.17.15.0 0.0.0.7

no auto-summary
```

Judy Router Configuration

```
interface FastEthernet0

ip address 172.17.15.6 255.255.255.248

ip rsvp bandwidth 772 18

ip rsvp signalling dscp 46

!

router eigrp 32074

network 172.17.15.0 0.0.0.7

no auto-summary

!

voice-port 2/0

connection plar 5554668

!

voice-port 2/1

!

dial-peer voice 5558810 pots

destination-pattern 5558810

port 2/0

!

dial-peer voice 5554668 voip

destination-pattern 5554668

session target ipv4:10.148.13.13

req-qos guaranteed-delay
```

```
acc-qos controlled-load  
codec g723ar63  
ip qos dscp ef signalling
```

Further Reading

RFC 1122, *Requirements for Internet Hosts—Communication Layers*, by Robert Braden.

RFC 1349, *Type of Service in the Internet Protocol Suite*, by Philip Almquist.

RFC 2205, *Resource ReSerVation Protocol (RSVP)—Version 1 Functional Specification*, by Bob Braden, Lixia Zhang, Steve Berson, Shai Herzog, and Sugih Jamin.

RFC 2309, *Recommendations on Queue Management and Congestion Avoidance in the Internet*, by Craig Partridge, Larry Peterson, K. K. Ramakrishna, Scott Shaker, John Wroclawski, and Lixia Zhang.

RFC 2474, *Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers*, by Kathleen Nichols, Steven Blake, Fred Baker, and David L. Black.

RFC 2475, *An Architecture for Differentiated Services*, by Steven Blake, David L. Black, Mark A. Carlson, Elwyn Davies, Zheng Wang, and Walter Weiss.

RFC 2597, *Assured Forwarding PHB Group*, by Juha Heinanen, Fred Baker, Walter Weiss, and John Wroclawski.

RFC 2598, *An Expedited Forwarding PHB*, by Van Jacobson, Kathleen Nichols, and Kedarnath Poduri.

RFC 2697, *A Single Rate Three Color Marker*, by Juha Heinanen and Roch Guerin.

Doukalis, Bill. *Putting VoIP to Work, Softswitch Network Design and Testing*.

Doukalis, Bill. *IP Telephony*.

Huston, Geoff. *Internet Performance Survival Guide*.

Ibe, Oliver C. *Converged Network Architectures*.

Chapter 6. QoS — Rate Limiting and Queuing Traffic

The preceding two chapters discussed router performance management, equipment-quality management, ATM quality of service (QoS), Layer 3 switching methods, compression, applying end-to-end QoS with integrated services, and marking traffic priority with differentiated services. After you have applied these QoS methods, you then need to consider the most effective queuing mechanism for each specific traffic type. Each interface uses some type of queuing; the type you decide to use will depend on the amount of control over traffic your service policies require, the link bandwidth, and the traffic-quality requirements. This chapter discusses various queuing methods and their application, including the following:

- First-In, First-Out Queuing
- Weighted Fair Queuing
- Priority Queuing
- Custom Queuing

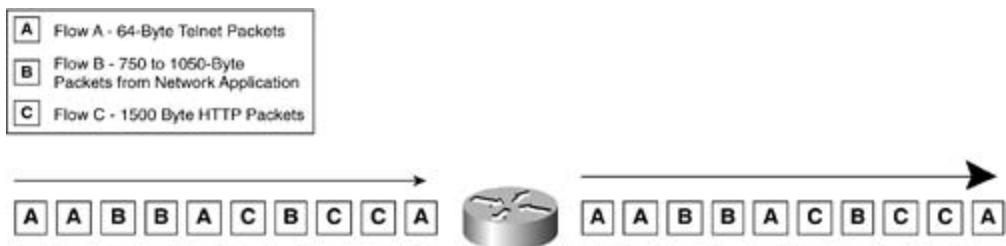
After covering "the basic four" queuing types, this chapter explores more advanced traffic shaping, queuing, policing, and marking technologies, such as the following:

- Generic traffic shaping
- Class-Based Weighted Fair Queuing
- Class-based shaping
- Traffic policing
- Low Latency Queuing
- Setting IP RTP Priority
- Using committed access rate to enforce traffic policy

The Basics: FIFO Queuing

First-in, first-out (FIFO) queuing is the default queuing strategy that applies to all interfaces with more than 2 Mbps, or, in other words, E1 size or greater interfaces. With the FIFO Queuing strategy, packets are forwarded through the interface in the order that they are received. For example, [Figure 6-1](#) shows three traffic conversations, or flows. Conversation A consists of Telnet packets that are approximately 64 bytes; packets in conversation B are from a network application, and range from 750 and 1020 bytes; and packets from conversation C are HTTP web traffic packets, which are approximately 1500 bytes. When these three host stations send packets during periods of low network traffic utilization, all three conversations should be successful; if these same three conversations take place during a period of high network utilization, however, packets from conversation C will be interspersed between the much smaller packets from the A and B conversations, which could potentially cause jittery behavior from the Telnet session.

Figure 6-1. Example of FIFO Queuing



In most situations, when network application traffic is within the line interface limits, there are usually no problems running FIFO Queuing; when an interface begins to encounter periods of high congestion, or has a high concentration of larger-sized packets, however, FIFO Queuing might pose problems to protocols that use smaller packet sizes or applications that are not tolerant of network delay. Real-time applications, such as voice and video applications, are also highly sensitive to *serialization delay*, the time it takes an interface to serialize packets; these applications typically do not run well when interspersed with other data traffic on low-speed serial interfaces.

Therefore, when an interface is consistently meeting or exceeding its bandwidth limitations, or in environments where networks experience frequent traffic bursts, a more advanced queuing mechanism might be required.

Weighed Fair Queuing

Based on the min-max fair-share algorithm, *Weighed Fair Queuing (WFQ)* is the default queuing method for interfaces with bandwidth less than E1 speed (2048 kbps).

The min-max fair-share algorithm allocates resources based on demand in a round-robin queuing system. With the min-max fair-share algorithm, smaller packets are transmitted before larger packets. Packets waiting to be transmitted are queued, based on an equation that takes the capacity of available resource bandwidth and divides it by the number of packets waiting to be queued:

$$\text{Fair allocation} = \frac{(\text{resource capability} - \text{resource already allocated})}{\text{Number of packets}}$$

One thing that sets the Cisco WFQ algorithm apart from the min-max fair-share algorithm is that WFQ bases its weight measurement on the value of the IP Precedence field from the IP header. The WFQ algorithm attempts to use this to fairly balance the load between large and small packets by weighing the packet size and considering the precedence of the packet. For a packet with an IP precedence value of 0, the default routine precedence, the weight is found using the following formula:

$$\text{Weight} = \frac{32768}{(\text{IP Precedence} + 1)}$$

[Table 6-1](#) shows the values used to generate weight values based on IP precedence values.

Table 6-1. Weight Table

IP Precedence Value	Weight
0	32,768
1	16,384
2	10,923
3	8192
4	6554
5	5461
6	4681
7	4096

NOTE

In earlier versions of Cisco IOS Software, prior to IOS Release 12.0(5)T, weight was calculated using a different base value. To find the weight value for older Cisco IOS versions, replace the 32768 value with 4096, as shown here:

```
Weight = 4096 ( IP Precedence + 1)
```

When stations communicate using source and destination IP addresses, IP protocols, and TCP or UDP port numbers, this is considered a *flow*. WFQ uses two flow types: active flows, which are active conversations with packets waiting to be transmitted; and inactive flows, which are new conversations that have not been seen before, or idle flows from completed conversations.

During the WFQ process, packet size is noted when new packets arrive. If the IP flow that they belong to is new, a rounded packet size is also used. Together, the packet size, the rounded packet size, and the value of the IP Precedence field are used to generate a sequence number. Lower sequence numbers are transmitted first. After the weight has been found, a sequence number is generated for each packet waiting to be queued. Note that the IP precedence value for a flow is considered only for the first packet in a flow; subsequent packets use the weight of the first packet:

Sequence number for inactive flow	$SN = (P * W) + R$
Sequence number for active flow	$SN = W + RN$

SN = Sequence Number
P = Packet size (bytes)
W = Weight
R = Rounded packet size
RN = Sequence number of last packet in an active flow

[Figure 6-2](#) shows how the packets from different flows are queued and forwarded using WFQ. In this example, there are flows from four conversations: conversation A, with two 1024-byte packets with an IP precedence value of one, labeled A1 and A2; conversation B, with three 64-byte packets with the default IP precedence value of 0; conversation C, with four 64-byte packets with an IP precedence of 5; and conversation D, with one 768-byte packet with an IP precedence value of 0. The packets arrive at the WFQ router in the order shown on the right side of the figure: C-1, A-1, B-1, B-2, C-2, C-3, C-4, A-2, B-3, and D-1. Because packet C-1 arrives

at the WFQ router first, it is the first packet for which the sequence number needs to be calculated. Packet C-1 is assigned a sequence number of 35,010, by applying the inactive flow formula shown in [Example 6-1](#).

Example 6-1. Math Behind WFQ and the C Packets

Packets C-1 is 64 bytes with IP Precedence = 5

$$\text{Weight} = 32768/5+1$$

$$\text{Weight} = 5461$$

$$\text{SN} = (64 \times 5461) + 60$$

$$\text{SN} = 349504 + 60$$

$$\text{SN} = 349564$$

Packet C-2 is 64 bytes

$$\text{SN} = 5461 + 349564$$

$$\text{SN} = 355025$$

Packet C-3 is 64 bytes:

$$\text{SN} = 5461 + 355025$$

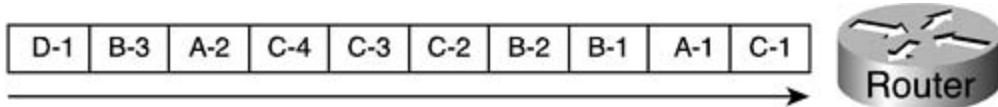
$$\text{SN} = 360486$$

Packet C-4 is 64 bytes:

$$\text{SN} = 5461 + 360486$$

$$\text{SN} = 365947$$

Figure 6-2. Weighted Fair Queuing Diagram



In this example, packet C-1, a 64-byte packet with an IP precedence value of 5, is assigned a weight of 5461. The weight for this example is found by applying the $\text{Weight} = 32,768 / (\text{Precedence} + 1)$ formula, and the sequence number is found by using the $\text{SN} = (\text{P} * \text{W}) + \text{R}$ formula for inactive flows mentioned earlier in this chapter. Any new packets that arrive for the C conversation will use the $\text{SN} = \text{W} + \text{RN}$ formula to calculate the sequence number for an active flow. The sequence numbers for packets C-2, C-3, and C-4 are found using the active flow formula just mentioned. The next packet, packet C-2, uses the weight and sequence number from packet C-1, $\text{W} = 5461$ and $\text{RN} = 349,564$ to yield a new sequence number of 355,025 for packet C-2. [Example 6-2](#) shows how the sequence number is found for packet A-1 and A-2.

Example 6-2. Calculating the Sequence Number for Packets A-1 and A-2

Packet A-1 is 1024 bytes with IP Precedence = 0

Weight = $32768 / 0 + 1$

Weight = 32768

$\text{SN} = (1024 \times 32768) + 1000$

$\text{SN} = 33554432 + 1000$

$\text{SN} = 33555432$

Packet A-2 is 1024:

$\text{SN} = 32768 + 33555432$

$\text{SN} = 33588200$

Because the A conversation is a new flow, the WFQ router calculates the sequence number for packet A-1 using the inactive flow formula, which yields a weight of 32,768, and a sequence number of 33,555,432. The weight and sequence number from packet A-1 is used to help find the sequence number for packet A-2, using the active flow formula, $\text{SN} = \text{W} + \text{RN}$, or $32,768 + 33,555,432 = 33,588,200$. Packet B-1, a new flow, uses the inactive flow formula, and packets B-2 and B-3 use the active flow formula shown in [Example 6-3](#).

Example 6-3. Finding the Sequence Number for Packets B-1, B-2, and B-3

Packet B-1 is 64 bytes with IP Precedence = 0

Weight = 32768

SN = (64 x 32768) + 60

SN = 2097152 + 60

SN = 2097212

Packet B-2 is 64 bytes

SN = 32768 + 2097212

SN = 2129980

Packet B-3 is 64 bytes:

SN = 32768 + 2129980

SN = 2162748

The sequence number for packet D is shown next, in [Example 6-4](#).

Example 6-4. Sequence Number for Packet D-1

Packet D-1 is 768 bytes with IP Precedence = 0

Weight = 32768

SN = (768 x 32768) + 700

SN = 25165824 + 700

SN = 25166524

When all the information from the last few packets is put together, you end up with the outcome shown in [Table 6-2](#).

Table 6-2. Order in Which Packets Are Transmitted

Packet Name	Sequence Number
C-1	349,564
C-2	355,025
C-3	360,486
C-4	365,947
B-1	2,097,212
B-2	2,129,980
B-3	2,162,748
D-1	25,166,524
A-1	33,555,432
A-2	33,588,200

The sequence numbers in the preceding table are applied to each packet as it is scheduled for transmission on the WFQ interface, and packets are transmitted in order of smallest to greatest sequence number, as shown in [Figure 6-3](#). The smaller packets with higher priority and smaller sequence number are transmitted first, whereas larger packets with routine priority and larger sequence number must wait for smaller packets to be transmitted. WFQ excels in environments where there are conversations consisting of smaller packets or packets of high IP precedence requiring real-time transmission speeds (Telnet packets, for instance).

Figure 6-3. Transmit Order for WFQ Packets



As mentioned earlier, WFQ is the default queuing method on interfaces E1 size or smaller. If WFQ has been disabled, you can easily re-enable it by using the fair-queue command. [Table 6-3](#) shows the fair-queue command arguments and their descriptions.

```
fair-queue [congestive-discard-threshold] [dynamic-queues] [reservable-queues]
```

Table 6-3. fair-queue Command Arguments

Argument	Description
<i>congestive-discard-threshold</i>	(Optional) The number of packets allowed in each queue. Range from 1 to 4096. Default congestive discard threshold is 64.
<i>dynamic-queues</i>	(Optional) The number of dynamic queues that can be created. Values range from 0 to 4096 in powers of 2 beginning with 16 (16, 32, 64, 128, 256, 512, 1024, 2048, and 4096). The default number of dynamic queues is 256.
<i>reservable-queues</i>	(Optional) When RSVP has been enabled, the number of reservable queues can be configured. Range from 0 to 1000. By default, there are no reservable queues.

To enable WFQ with the default queue sizes, you can just type the fair-queue command with no arguments, and WFQ will be enabled with the default queue size of packets and 256 dynamic queues. To remove WFQ, which changes the queuing method to FIFO, type no fair-queue. To view the current queuing method in use on an interface, use the show interface command. The individual queuing values were shown earlier in [Table 6-3](#) and are highlighted in [Example 6-5](#).

Example 6-5. Display Queuing Configuration

```
Vacation#show interface serial 0/1
```

```
Serial0/1 is up, line protocol is up
```

```
Hardware is PowerQUICC Serial
```

```
MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input 00:00:09, output 00:00:03, output hang never

Last clearing of "show interface" counters never

Input queue: 0/75/0 (size/max/drops); Total output drops: 0

Queueing strategy: weighted fair

Output queue: 0/1000/64/0 (size/max total/threshold/drops)

  Conversations 0/1/256 (active/max active/max total)

  Reserved Conversations 0/0 (allocated/max allocated)
```

To limit the display of queuing information, you can also use the `show queueing interface` command, which shows queuing information for a particular interface. As shown in [Example 6-6](#), this command displays the same queuing information as is available using the `show interface` command.

Example 6-6. `show queueing interface` Command

```
Vacation#show queueing interface serial 0/1

  Input queue: 0/75/0 (size/max/drops); Total output drops: 0

  Queueing strategy: weighted fair

  Output queue: 0/1000/64/0 (size/max total/threshold/drops)

    Conversations 0/1/256 (active/max active/max total)

    Reserved Conversations 0/0 (allocated/max allocated)
```

When the `show queueing` command is used without any arguments, it displays all the queuing methods in use on each interface in a router and the queuing configurations. When the `fair` argument is used with this command, the output displays only information about WFO, as show in [Example 6-7](#).

NOTE

The `show queueing` command does not display all queuing information for FIFO Queuing; this information is shown using the `show interface` command.

Example 6-7. `show queueing` Command

```
Vacation#show queueing
```

Current fair queue configuration:

Interface	Discard	Dynamic	Reserved
	threshold	queue count	queue count
Serial0/0	64	256	0
Serial0/1	64	256	0
Serial0/2	64	256	0

Current priority queue configuration:

Current custom queue configuration:

Current random-detect configuration:

```
Router#show queueing fair
```

Current fair queue configuration:

Interface	Discard	Dynamic	Reserved
	threshold	queue count	queue count
Serial0/0	64	256	0
Serial0/1	64	256	0
Serial0/2	64	256	0

Sometimes, certain applications require real-time transmission speeds or are intolerant of the delays incurred by queuing traffic. If this is the case, you might need to remove WFQ or tune the queue sizes. [Example 6-8](#) shows how the queue size on the Boston router is changed so that there are only 32 possible dynamic queues, and each queue will only hold 48 packets.

Example 6-8. Boston Router Queuing Configuration

```
Boston(config)#interface serial 0/1
Boston(config-if)# fair-queue 48 32
Boston(config-if)#^Z
Boston#show interface serial 0/1
Serial0/1 is up, line protocol is up
Hardware is PowerQUICC Serial
MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation HDLC, loopback not set
Keepalive set (10 sec)
Last input 00:00:05, output 00:00:07, output hang never
Last clearing of "show interface" counters never
Input queue: 0/75/0 (size/max/drops); Total output drops: 0
Queueing strategy: weighted fair
Output queue: 0/1000/48/0 (size/max total/threshold/drops)
  Conversations 0/0/32 (active/max active/max total)
  Reserved Conversations 0/0 (allocated/max allocated)
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
  455 packets input, 26845 bytes, 0 no buffer
  Received 455 broadcasts, 0 runts, 0 giants, 0 throttles
  3 input errors, 0 CRC, 3 frame, 0 overrun, 0 ignored, 0 abort
  457 packets output, 31892 bytes, 0 underruns
  0 output errors, 0 collisions, 7 interface resets
  0 output buffer failures, 0 output buffers swapped out
  2 carrier transitions
```

DCD=up DSR=up DTR=up RTS=up CTS=up

NOTE

Before changing queue sizes, always perform a detailed traffic analysis and test the configuration to avoid causing production-network problems.

As you learned in the preceding chapter, WFQ is required to run other QoS features, such as WRED and Resource Reservation Protocol (RSVP). WFQ is also the foundation of Low Latency Queuing (LLQ) and Class-Based Weighted Fair queuing (CBWFQ), so it is important to understand how WFQ and traffic-classification and marking technologies work.

Priority Queuing

When situations call for a queuing scheme that allows certain applications to have priority over all others, Priority Queuing (PQ) should be considered. PQ has four queues, each with a different priority; packets from each queue are forwarded after the queue with the highest priority has emptied. With PQ, you have four queue priorities: High, Medium, Normal, and Low. Within each queue, packets are forwarded on a first-in, first-out basis. Keep in mind a few things when using PQ:

- The queue size does not necessarily affect the amount of forwarding time that packets in that queue receive. The limit of the queue size for PQ is configured in packets. Each queue is served in order of priority. The High priority queue is always served first; then, if the High priority queue is empty, the Medium queue is emptied. Anytime a packet is received in the High queue, that queue is emptied before processing any other queues. After the Medium priority queue is emptied, if there are not any packets in the High priority queue, the Normal queue is emptied. Finally, if the High, Medium, and Normal queues are empty, the Low priority queue is emptied. So, there is a possibility that when PQ is in use, packets in lower-priority queues will not be forwarded in a timely manner, adding delay for applications with packets that use the lower-priority protocols, causing network applications to time out.
- If a packet does not match any of the configured queues, that packet goes to the default queue, which is the Normal queue. You can change the default queue, as shown later in this chapter.
- PQ is not dynamic; it does not adjust to network patterns. When PQ is in use, it is a good idea to periodically perform network baselines and analyze traffic to make sure that the queue sizes and protocol distributions are configured correctly to handle traffic at peak times.

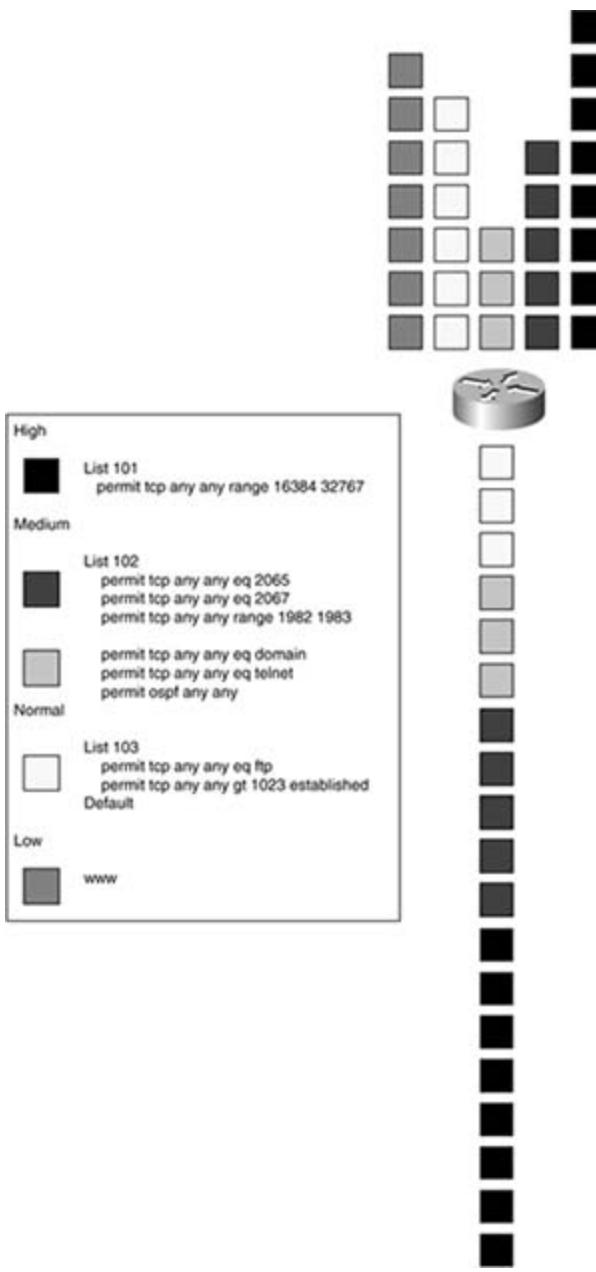
[Table 6-4](#) shows how each of the four priority queues is serviced.

Table 6-4. Priority Queues

Queue	Description
High	<p>Packets arriving in the High priority queue are serviced immediately. After the High priority queue has been emptied, the Medium, Normal, and Low priority queues are serviced. If at any time packets arrive for the High priority queue, they are forwarded before any other queue receives service, until the High priority queue has been emptied.</p> <p>The default size of the High priority queue is 20 packets.</p>
Medium	<p>After the High priority queue has been emptied, the Medium queue is serviced. If any packets arrive for the High priority queue while the Medium priority queue is forwarding, the packets in the High priority queue are forwarded first, until the queue is empty, and then the Medium queue receives attention again.</p> <p>The default size of the Medium priority queue is 40 packets.</p>
Normal	<p>If there are no packets in the High or Medium queues, the Normal queue is serviced. If packets arrive in the High or Medium queues, they are forwarded in order of High to Medium, and after those queues have emptied, packets in the Normal queue are forwarded.</p> <p>The default size of the Normal priority queue is 60 packets.</p> <p>By default, all unspecified traffic is assigned to the Normal priority queue; however, you can change this behavior by using the default argument.</p>
Low	<p>Packets in the Low priority queue are forwarded if all the other queues are empty. If a packet arrives in any of the other queues, those queues are cleared first in order of priority, until they are empty, and then the Low priority queue is serviced again.</p> <p>The default size of the Low priority queue is 80 packets.</p>

[Figure 6-4](#) shows how packets are queued when PQ is in effect.

Figure 6-4. Priority Queuing Diagram



To configure PQ, you use the `priority-list` command to create a priority list. You can configure up to 16 different priority lists. Each list contains the four queues: High, Medium, Normal, and Low. Packets are assigned to one of the four queues based on their characteristics: protocol, ingress interface, packet size, and so on. Traffic that has not been defined in one of the four queues is sent to the default queue, which, unless explicitly configured otherwise, is the Normal queue. [Table 6-5](#) shows the `priority-list` command, its arguments, keywords, and their descriptions.

Table 6-5. `priority-list` Command and Descriptions

Command	Argument	Description
priority-list list-number default {high medium normal low}	None	Defines the default queue for the specified priority queue list number. The default queue is where packets that do not match any other statement are sent. If unspecified, the default queue is the Normal queue.
priority-list list-number interface interface-number{high medium normal low}	None	Specifies that any traffic from the particular ingress interface is the traffic to be prioritized and the queue that those packets should be assigned to.
priority-list list-number protocol argument	arp{high medium normal low} [gt frame-size ltframe-size]	Specifies the ARP protocol. Specifies High, Medium, Normal, or Low queue. (Optional)gt specifies a frame size greater than the specified ARP frame size, ranging from 0 to 65,535. (Optional)lt specifies a frame size less than the specified ARP frame size, ranging from 0 to 65,535.
	bridge{high medium normal low} [gt frame-size listaccess-list-number ltframe-size]	Specifies transparent bridging protocols. Specifies High, Medium, Normal, or Low queue. (Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535. (Optional)list specifies an associated access list (200-299) should be used for traffic designations. (Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.

<pre>bstun{high medium normal low} [address BSTUN-group-number hex- address gtframe-size ltframe-size]</pre>	<p>Specifies the Block Serial Tunnel (BSTUN) protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)address specifies a particular BSTUN group number, ranging from 1 to 255, and an address in hexadecimal.</p> <p>(Optional)gt specifies a frame size greater than the specified BSTUN frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified BSTUN frame size, ranging from 0 to 65,535.</p>
<pre>cdp{high medium normal low} [gt frame- size ltframe-size]</pre>	<p>Specifies the Cisco Discovery Protocol (CDP).</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified CDP frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified CDP frame size, ranging from 0 to 65,535.</p>
<pre>compressedtcphigh medium normal low [gtframe-size lt frame-size]</pre>	<p>Specifies compressed TCP traffic as the protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>
<pre>dlsw{high medium normal low} [gt frame- size] [lt frame-size]</pre>	<p>Specifies DLSw as the protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>

<code>ip{high medium normal low} [fragments gtframe-size list access-list-number lt frame-size tcport-number udpport-number]</code>	<p>Specifies a protocol from the TCP/IP suite as the protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)fragment specifies the prioritization of IP packet fragments, that is, IP packets with the Fragment Offset field set to 1.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)list specifies an associated access list (1–199) that should be used for traffic designations.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)tcp specifies that traffic from or to a particular TCP port as the designated traffic.</p> <p>Ranges are port numbers 0 to 65,535 or a keyword from the following list:</p> <p>bgp, chargen, cmd, daytime, discard, domain, echo, exec, finger, ftp, ftp-data, gopher, hostname, ident, irc, klogin, kshell, login, lpd, nntp, pim-auto-rp, pop2, pop3, smtp, sunrpc, syslog, tacacs, talk, telnet, time, uucp, whois, and www</p> <p>(Optional)udp specifies that traffic from or to a particular UDP port is the designated traffic.</p> <p>Ranges are port numbers 0 to 65,535 or a keyword from the following list:</p> <p>biff, bootpc, bootps, discard, dnsix, domain, echo, isakmp, mobile-ip, nameserver, netbios-dgm, netbios-ns, netbios-ss, ntp, pim-auto-rp, rip, snmp, snmptrap, sunrpc, syslog, tacacs, talk, tftp, time, who, or xdmcp</p>
--	---

<pre>ipx{high medium normal low} [gt <i>frame-size</i>] [<i>list list-number</i>] [lt <i>frame-size</i>]</pre>	<p>Specifies the IPX protocol.</p> <p>(Optional)gt specifies a frame size greater than the specified IPX frame size, ranging from 0 to 65,535.</p> <p>(Optional)list specifies an IPX standard or extended access list (800–999).</p> <p>(Optional)lt specifies a frame size less than the specified IPX frame size, ranging from 0 to 65,535.</p>
<pre>llc2{high medium normal low} [gt <i>frame-size</i>] [lt <i>frame-size</i>]</pre>	<p>Specifies the Logical Link Control, Type-2 (LLC2) protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>
<pre>pad{high medium normal low}[gt<i>frame-size</i>] [lt <i>frame-size</i>]</pre>	<p>Specifies the X.25 Packet Assembler/Disassembler (PAD) protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>
<pre>qllc{high medium normal low}[gt<i>frame-size</i>] [lt <i>frame-size</i>]</pre>	<p>Specifies the Qualified Logical Link Control (QLLC) protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>

	<pre>rsrb{high medium normal low}[gtframe-size] [lt frame-size]</pre>	<p>Specifies the Remote Source Route Bridging (RSRB) protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>
	<pre>snapshot{high medium normal low}[gtframe-size] [lt frame-size]</pre>	<p>Specifies Snapshot routing traffic.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>
	<pre>stun{high medium normal low}[address STUN-group STUN-address gtframe-size lt frame-size]</pre>	<p>Specifies the Serial Tunneling (STUN) protocol.</p> <p>Specifies High, Medium, Normal, or Low queue.</p> <p>(Optional)address specifies the STUN group number, ranging from 0 to 255, and a hexadecimal STUN address, which must be written in hexadecimal form (for example, 0x01).</p> <p>(Optional)gt specifies a frame size greater than the specified frame size, ranging from 0 to 65,535.</p> <p>(Optional)lt specifies a frame size less than the specified frame size, ranging from 0 to 65,535.</p>
priority-list list-number queue-limit	<i>high-queue-limit</i> <i>medium-queue-limit</i> <i>normal-queue-limit</i> <i>low-queue-limit</i>	Changes the individual queue size limits for each of the priorities (High, Medium, Normal, and Low) for the PQ list number.

As just shown, PQ enables you to classify traffic in different ways:

- Protocol type— This includes the major protocol type, such as IP or IPX, and any

subprotocol information, such as TCP or UDP port numbers.

- Interface— The interface from which the traffic is coming.
- Packet size— The size of the packet, either greater or less than a specified value, including the MAC encapsulation, in bytes.
- Fragments— Fragmented packets.
- Multiple criteria— Using an access list to define more than one traffic attribute.

PQ configuration requires three steps: define the queue assignments, customize the queuing configuration, and apply the configuration to an interface:

Step 1. Define the queues. Using the priority-list command, specify the protocol attribute or interface for each of the four priority queues. In this example, access-list 188 defines GRE and NTP packets; these packets are assigned to the High priority queue, Telnet packets are assigned to the Medium priority queue, SMTP packets are assigned to the Normal priority queue, and HTTP web packets are considered low priority and sent to the Low priority queue using the priority-list command:

```
access-list 188 permit gre any any
access-list 188 permit udp any any eq ntp
priority-list 1 protocol ip high list 188
priority-list 1 protocol ip medium tcp telnet
priority-list 1 protocol ip normal tcp smtp
priority-list 1 protocol ip low tcp www
```

Step 2. Customize queuing configuration. Configure the default queue for unassigned packets. If a default queue is not explicitly defined, all undefined packets are sent to the Normal queue:

```
Bart(config)#priority-list 7 default medium
```

Optionally, you can change sizes for the four queues. The queue-limit command enables you to define the sizes, in packets, for each of the queues using the priority-list/*list-number* queue-limit*high-limit medium-limit normal-limit low-limit* command:

```
Bart(config)#priority-list 7 queue-limit 40 20 30 20
```

Step 3. Assign the priority list to an interface. Tunnels and subinterfaces might not be configured for PQ:

```
interface Serial0/1
  ip address 10.2.1.1 255.255.255.0
  priority-group 7
```

To view the configuration of PQ on an interface, use the show interface command:

```
Queueing strategy: priority-list 7
Output queue (queue priority: size/max/drops):
  high: 34/40/54, medium: 0/20/0, normal: 0/30/0, low: 0/20/0
```

[Example 6-9](#) shows how PQ was used to give voice traffic the greatest priority. Data-link switching (DLSw), Domain Name System (DNS), Telnet, and Open Shortest Path First (OSPF) traffic receive medium priority, and FTP and any other unspecified traffic wait in the Normal priority queue. In this example, World Wide Web traffic is of the lowest priority. [Example 6-10](#) shows how this configuration looks using the show queueing priority command.

Example 6-9. Priority Queuing in Action

```
interface Serial0/1
    ip address 158.42.18.12 255.255.255.0
    priority-group 1
!
access-list 101 remark High Priority Queue - voice traffic
access-list 101 permit udp any any range 16384 32767
access-list 101 permit tcp any any eq 1720
access-list 102 remark Medium Priority Queue - DLSw, DNS, Telnet, OSPF
access-list 102 permit tcp any any eq 2065
access-list 102 permit tcp any any eq 2067
access-list 102 permit tcp any any range 1981 1983
access-list 102 permit tcp any any eq domain
access-list 102 permit tcp any any eq telnet
access-list 102 permit ospf any any
access-list 103 remark Normal Priority Queue - FTP and established
access-list 103 permit tcp any any eq ftp
access-list 103 permit tcp any any gt 1023 established
priority-list 1 protocol ip high list 101
priority-list 1 protocol ip medium list 102
priority-list 1 protocol ip normal list 103
priority-list 1 protocol ip low tcp www
```

Example 6-10. Displaying Priority Queuing Configuration Data

```
Bart#show queueing priority

Current DLCI priority queue configuration:

Current priority queue configuration:

List Queue Args

1      high   protocol ip          list 101
1      medium protocol ip        list 102
1      normal  protocol ip       list 103
1      low    protocol ip         tcp port www
```

After applying this configuration and waiting for data transmissions, [Example 6-11](#) shows that the High priority queue currently has 34 packets in the queue; the maximum size of the queue in packets is 20, and the High priority queue has dropped 54 packets. However, the Medium, Normal, and Low priority queues are empty and have not dropped any packets. In this case, you might want to obtain further packet analysis to re-adjust the queue sizes for a more even distribution of packets.

Example 6-11. Showing Priority Queuing with Test Traffic

```
Bart#show interfaces serial 0/1

Serial0/1 is up, line protocol is up

Hardware is PowerQUICC Serial

Internet address is 158.42.18.12/24

MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
      reliability 255/255, txload 1/255, rxload 1/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input never, output never, output hang never

Last clearing of "show interface" counters never
```

```
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: priority-list 1
Output queue (queue priority: size/max/drops):
    high: 34/20/54, medium: 0/40/0, normal: 0/60/0, low: 0/80/0
5 minute input rate 139000 bits/sec, 7 packets/sec
5 minute output rate 308000 bits/sec, 33 packets/sec
    4 packets input, 240 bytes, 0 no buffer
Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
    0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
    228 packets output, 341544 bytes, 0 underruns
    0 output errors, 0 collisions, 0 interface resets
    0 output buffer failures, 0 output buffers swapped out
    0 carrier transitions
DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

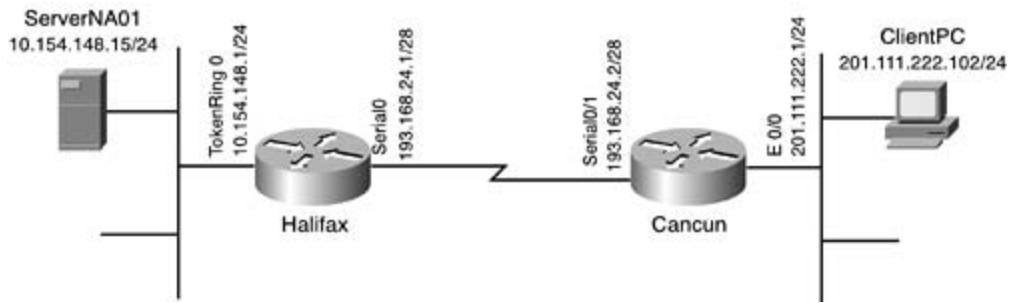
Practical Example: Applying Priority Queuing

This lab tests PQ in a real network model using traffic generated by a Windows PC and another Windows server. To test the PQ configuration, you configure the PC and server to send and receive typical TCP/IP network messages by setting up Dynamic Host Configuration Protocol (DHCP), Microsoft Windows Internet Naming Service (WINS), and DNS services on the workstation, and queuing this traffic on the routers between the client workstation and the server.

Lab Exercise

This lab requires two routers, each with one Ethernet or Token Ring interface and one serial interface. The two routers should be configured and cabled, as shown in [Figure 6-5](#). This lab also contains two end stations: one Microsoft Windows server running FTP server, WINS, and DNS services, and one Windows client PC configured to use the Windows server for DNS and WINS services. To validate the queuing configuration, the Windows PC and server are required. If you do not have a PC or server, you can still complete the router configuration portion of the lab. Without traffic-generating software, however, queue sizes are unlikely to increase.

Figure 6-5. North American Network



Lab Objectives

In this lab, you learn the following:

- How to configure PQ
- How to test PQ configuration

Equipment Needed

- For this lab, you need two Cisco routers, each with one Ethernet or Token Ring interface and one serial interface.
- One PC running Windows software with a network card running TCP/IP.
- One PC running Windows Server software with a network card running TCP/IP with a DNS, FTP, and WINS server configured.

Physical Layout and Prestaging

- Cable the routers, as shown in [Figure 6-5](#).
- Attach each PC to the network (the router's interface), as shown in [Figure 6-5](#).

Lab Tasks

Step 1. Configure routers, as shown in [Figure 6-5](#). The Halifax router should have an Ethernet or Token Ring interface connected to the server and should connect to the Cancun router over its serial interface. The IP addresses should also be assigned, as shown earlier in [Figure 6-5](#).

Step 2. Configure a Windows server computer to provide DNS, WINS, and FTP services. The server should be configured to use the static IP address of 10.154.148.15/24. FTP clients will connect to the FTP server using passive FTP sessions. Later, a Windows client PC will be configured to use the services of WINS and DNS settings from the server. You can validate TCP/IP services on the client and server computers by using the ipconfig /all

command at the MS-DOS prompt.

Step 3. Instead of configuring a static IP address, DNS server, and WINS server on the Windows client PC, configure the Cancun router to provide the information using DHCP. Use the following values to configure DHCP:

DHCP scope:	201.111.222.0/24
Default gateway:	201.111.222.1
DHS server:	10.154.148.15
Domain name:	cciepsv2.net
WINS Server:	10.154.148.15

Step 4. Configure PQ and any access lists that might be required to support the protocols shown in [Table 6-6](#).

Table 6-6. Priority Queuing Configuration

Queue	Protocol
High	DNS WINS
Medium	Windows NetBIOS support NetBIOS session, datagram and name services, and DNS and WINS management SNMP
Normal	Passive-mode FTP
Low	World Wide Web HTTP traffic All unspecified traffic

Step 5. Assign the PQ process to the interface that will queue all client traffic across the WAN connection between the Cancun and Halifax routers. (Remember the rules for efficient traffic queuing on different interface types.)

Step 6. Validate that the client and server computer can ping each other. Using a passive FTP session, copy a file from the client PC to ServerNA01. Try to use FTP to get another file from the server. While copying these files, look at the queuing information from the show interface output.

Lab Walkthrough

Step 1. Configure routers, as shown in [Figure 6-5](#). The Halifax router should have an Ethernet interface connected to the server and a serial interface connected to the Cancun router. The IP addresses should also be assigned, as shown earlier in [Figure 6-5](#).

Step 2. Configure a Windows server computer to provide DNS, WINS, and FTP services. The server should be configured to use the static IP address of 10.154.148.15/24. FTP clients will connect to the FTP server using passive FTP sessions. Later, a Windows client PC will be configured to use the services of WINS and DNS settings from the server. You can validate TCP/IP services on the client and server computers by using the ipconfig /all command at the MS-DOS prompt.

[Example 6-12](#) shows the output of the ipconfig /all command on the server and PC client computers. If there are any connectivity problems with the server or client computers, remember to verify that each of the computers is configured to use the default gateway of the Ethernet interface on the router. Also, verify that each of the computers can ping its default gateway, each hop on the way to the other computer, and lastly, the other computer.

Example 6-12. TCP/IP Configuration for Windows Server and Client Computers

The Server

```
C:\>ipconfig /all

Windows 2000 IP Configuration

  Host Name . . . . . : ServerNA01
  Primary DNS Suffix . . . . . : cciepsv2.net
  Node Type . . . . . : Hybrid
  IP Routing Enabled. . . . . : No
  WINS Proxy Enabled. . . . . : No

Ethernet adapter Local Area Connection:

  Connection-specific DNS Suffix . :
  Description . . . . . : FEM6556C-3Com Global 8-100+56K CardB
  us PC Card-(Fast Ethernet) #2
  Physical Address. . . . . . . . . : 00-50-DA-AC-5D-4C
  DHCP Enabled. . . . . . . . . : No
  IP Address. . . . . . . . . : 10.154.148.15
  Subnet Mask . . . . . . . . . : 255.255.255.0
```

```
Default Gateway . . . . . : 10.154.148.1
DNS Servers . . . . . : 10.154.148.15
Primary WINS Server . . . . . : 10.154.148.15
```

The Client

```
C:\>ipconfig /all
```

```
Windows 98 IP Configuration
```

```
Host Name . . . . . : clientpc.cciepsv2.net
DNS Servers . . . . . : 10.154.148.15
Node Type . . . . . : Hybrid
NetBIOS Scope ID. . . . . :
IP Routing Enabled. . . . . : No
WINS Proxy Enabled. . . . . : No
NetBIOS Resolution Uses DNS : Yes
```

0 Ethernet adapter :

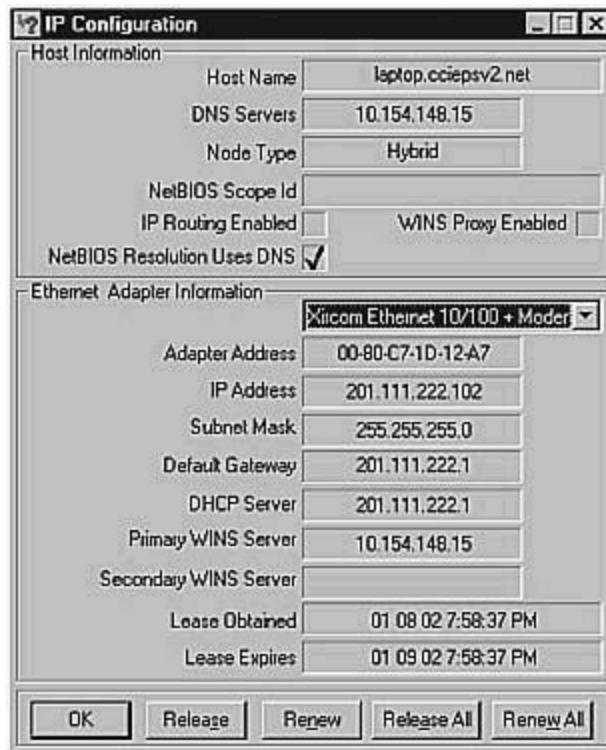
```
Description . . . . . : Xircom Ethernet 10/100 + Modem 56 PC Card
Physical Address. . . . . : 00-80-C7-1D-12-A7
DHCP Enabled. . . . . : Yes
IP Address. . . . . : 201.111.222.102
Subnet Mask . . . . . : 255.255.255.0
Default Gateway . . . . . : 201.111.222.1
DHCP Server . . . . . : 201.111.222.1
Primary WINS Server . . . . . : 10.154.148.15
Secondary WINS Server . . . . . :
Lease Obtained. . . . . : 01 07 02 7:23:30 PM
Lease Expires . . . . . : 01 08 02 7:23:30 PM
```

NOTE

In Windows 95, the ipconfig command does not exist. To verify the TCP/IP configuration in Windows 95, use the winipcfg.exe command from Run on the Start menu. As shown in [Figure](#)

6-6, winipcfg.exe is a graphical program that displays the same information as ipconfig does at the command prompt.

Figure 6-6. winipcfg.exe Program



Step 3. Instead of configuring a static IP address, DNS server, and WINS server on the Windows client PC, configure the Cancun router to provide the information using DHCP. Use the following values to configure DHCP:

DHCP scope:	201.111.222.0/24
Default gateway:	201.111.222.1
DHS server:	10.154.148.15
Domain name:	cciepsv2.net
WINS server:	10.154.148.15

To configure DHCP for the client PC, on the Cancun router, the following steps were taken:

- a.Create a DHCP pool. In this example, the client-pcs pool was created:

```
ip dhcp pool client-pcs
```

b. Assign a network, default router, DNS server, WINS server, and domain name to the DHCP pool:

```
network 201.111.222.0 255.255.255.0
default-router 201.111.222.1
dns-server 10.154.148.15
domain-name cciepsv2.net
netbios-name-server 10.154.148.15
```

c. Set aside any addresses that you do not want to use for DHCP by using the exclude-address command. In this example, the range of addresses from 201.111.222.1 to 100 were excluded from the DHCP range:

```
ip dhcp excluded-address 201.111.222.1 201.111.222.100
```

[Example 6-13](#) shows the DHCP configurations for the Cancun router.

Example 6-13. Cancun Router's DHCP Configuration

```
ip dhcp excluded-address 201.111.222.1 201.111.222.100
!
```

```
ip dhcp pool laptops

network 201.111.222.0 255.255.255.0

default-router 201.111.222.1

dns-server 10.154.148.15

domain-name cciepsv2.net

netbios-name-server 10.154.148.15
```

Step 4. Configure PQ and any access lists that might be required to support the protocols shown in [Table 6-6](#).

To configure the PQ, as shown earlier in [Table 6-6](#), three access lists were used. Access list 101 was used to specify DNS and WINS traffic. Access list 102 was used to specify the Windows NetBIOS and Simple Network Management Protocol (SNMP) traffic. Windows uses TCP port 135 for DNS and WINS management traffic, TCP port 139, and UDP ports 137 and 138, or keywords netbios-ns and netbios-ss, for NetBIOS traffic between Windows computers. And finally, access list 103 was used to specify passive FTP traffic and the use of the random TCP ports greater than 1023 that FTP uses during file copies. Without this specification, the return FTP traffic would have been sent to the Low priority queue rather than the Normal priority queue:

```
access-list 101 permit tcp any host 10.54.148.15 eq domain

access-list 101 permit udp any host 10.54.148.15 netbios-ns

access-list 101 permit udp any any eq snmp

access-list 102 permit tcp any host 10.54.148.15 eq 135

access-list 102 permit udp any host 10.54.148.15 eq netbios-ns

access-list 102 permit udp any host 10.54.148.15 eq netbios-ss

access-list 102 permit tcp any host 10.54.148.15 eq 139

access-list 103 permit tcp any host 10.54.148.15 eq ftp

access-list 103 permit tcp any host 10.54.148.15 gt 1023 established
```

The access list numbers were used with the priority-list command to create the four priority queues, and the default keyword was used to assign all unspecified traffic to the Low priority queue:

```
priority-list 10 protocol ip high list 101  
priority-list 10 protocol ip medium list 102  
priority-list 10 protocol ip normal list 103  
priority-list 10 protocol ip low  
priority-list 10 default low
```

Step 5. Assign the PQ process to the interface that will queue all client traffic across the WAN connection between the Cancun and Halifax routers. (Remember the rules for efficient traffic queuing on different interface types.)

The PQ process was assigned to the serial interface of the Cancun router using the priority-group command:

```
interface Serial0/1  
priority-group 10
```

Step 6. Validate that the client and server computer can ping each other. Using a passive FTP session, copy a file from the client PC to ServerNA01. Try to use FTP to get another file from the server. While copying these files, look at the queuing information from the show interface output.

Experimenting with the traffic in this lab, a number of different traffic types, TFTP file copies, extended pings, packet generation, file copies in Windows Explorer, and web surfing were tried, which is how the results shown in the [Example 6-14](#) were generated.

Example 6-14. Viewing the Queuing Information During FTP Sessions

```
Cancun#show interfaces serial 0/1

Serial0/1 is up, line protocol is up

Hardware is PowerQUICC Serial

Internet address is 193.168.24.2/29

MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 28/255, rxload 1/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input 00:00:01, output 00:00:05, output hang never

Last clearing of "show interface" counters 00:03:56

Input queue: 0/75/0 (size/max/drops); Total output drops: 0

Queueing strategy: priority-list 10

Output queue (queue priority: size/max/drops):

    high: 0/20/0, medium: 0/40/0, normal: 3/60/0, low: 0/80/0

5 minute input rate 7000 bits/sec, 10 packets/sec

5 minute output rate 174000 bits/sec, 18 packets/sec

    2726 packets input, 156448 bytes, 0 no buffer

    Received 28 broadcasts, 0 runts, 0 giants, 0 throttles

    0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort

    4983 packets output, 6970545 bytes, 0 underruns

    0 output errors, 0 collisions, 0 interface resets

    0 output buffer failures, 0 output buffers swapped out

    0 carrier transitions

    DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

You have completed this practical example when you have sent some test traffic and verified the

PQ configuration. [Example 6-15](#) shows the completed configurations for the Halifax and Cancun routers.

Example 6-15. Complete Configurations for the Practical Example

```
hostname Cancun
!
ip dhcp excluded-address 201.111.222.1 201.111.222.100
!
ip dhcp pool laptops
  network 201.111.222.0 255.255.255.0
  default-router 201.111.222.1
  dns-server 10.154.148.15
  domain-name cciepsv2.net
  netbios-name-server 10.154.148.15
!
interface Ethernet0/0
  ip address 201.111.222.1 255.255.255.0
!
interface Serial0/1
  ip address 193.168.24.2 255.255.255.248
  priority-group 10
  clockrate 1300000
!
router rip
  version 2
  network 193.168.24.0
  network 201.111.222.0
!
```

```
access-list 101 permit tcp any any host 10.54.148.15 eq domain
access-list 101 permit udp any any host 10.54.148.15 eq netbios-ns
access-list 101 permit udp any any eq snmp
access-list 102 permit tcp any host 10.54.148.15 any eq 135
access-list 102 permit udp any host 10.54.148.15 any eq netbios-ns
access-list 102 permit udp any host 10.54.148.15 any eq netbios-ss
access-list 102 permit tcp any host 10.54.148.15 any eq 139
access-list 103 permit tcp any host 10.54.148.15 any eq ftp
access-list 103 permit tcp any host 10.54.148.15 any gt 1023 established
priority-list 10 protocol ip high list 101
priority-list 10 protocol ip medium list 102
priority-list 10 protocol ip normal list 103
priority-list 10 protocol ip low
priority-list 10 default low
```

```
hostname Halifax
!
interface Ethernet0
  ip address 10.154.148.1 255.255.255.0
!
interface Serial0
  ip address 193.168.24.1 255.255.255.248
!
router rip
  version 2
  network 10.0.0.0
  network 193.168.24.0
```

Now that you have seen how PQ works, you might have noted one of the reasons why you might not want to enable PQ in your network: Low priority queue starvation. When you must queue traffic, but you do not have a strict-priority requirement, there are several other queuing mechanisms that you can consider as an alternative to strict PQ.

Custom Queuing

Each of the queuing methods discussed so far make a best effort to forward traffic of a certain priority. These queuing methods also have rather static configuration capabilities. WFQ enables you to control only the size and number of the queues and does not allow for much customization, which might be quite a problem if you must sort multiple traffic. PQ enables you to configure only four queues and the number of packets allowed in those queues. PQ also has one major drawback: Lower-priority queues might not receive enough attention; and, in some cases, depending on the amount of high-priority traffic, they might not receive any attention at all. Custom Queuing (CQ) works around many of these issues with its highly customizable configuration properties.

Custom Queuing earns its name by having a total of 17 queues, 16 of which are configurable for user-defined traffic types. The first queue, queue 0, is the system queue and is used by the Cisco IOS Software for system traffic; this queue is not user configurable. Each of the 16 other queues has a queue size limitation in either bytes, or a limit on the number of packets that they are capable of containing. Each queue is serviced until the byte count or packet limit is met. If either of these events occur, the forwarding of the current packet is finished, and then the next queue is emptied (or reaches the byte or packet limit), and so on, in a round-robin approach, ensuring that each queue receives equal attention and that no one queue can prevent other queues from receiving attention. If a queue is full, any new packets destined for that queue are dropped. If a queue is empty, it is skipped and the next queue is serviced. CQ queue content is determined by the following:

- Ingress interface (the interface that they were received by).
- An access list, CQ supports all major protocols including IP, IPX, AppleTalk, and SNA protocols and their access lists.
- Packet size, either greater or less than a specified size.
- Or specific protocol characteristic defined either by an address, port number, or Cisco IOS Software parameter.

In [Figure 6-7](#), for example, you can see that there are six queues. Queue 1 has been allocated to use 50 percent of the available interface bandwidth. Queue 2 is allocated 20 percent of the bandwidth. Queue 3 is allocated 12 percent; Queue 4, 5 percent; Queue 5, 3 percent; and Queue 6 is allotted the remaining 10 percent of the bandwidth. The line with the arrow indicates the order in which the queues are serviced. Each queue is emptied, to its byte or packet limit, and then the next queue is serviced. With this queuing scheme, after Queue 1 has transmitted all of its packets, Queues 2, 3, 4, 5, and 6 are serviced in that order. While the other queues were being serviced, new packets arrived in most of the queues, as shown in [Figure 6-8](#). Again, each of the queues is serviced until their allocated limits are reached, and then the next queue is emptied to its limit. If one of the queues does not contain any packets, as is the case with Queue 4, it is skipped. After a queue's packet or byte size limitation is met, any new packets destined for that queue are dropped.

Figure 6-7. Custom Queuing Diagram

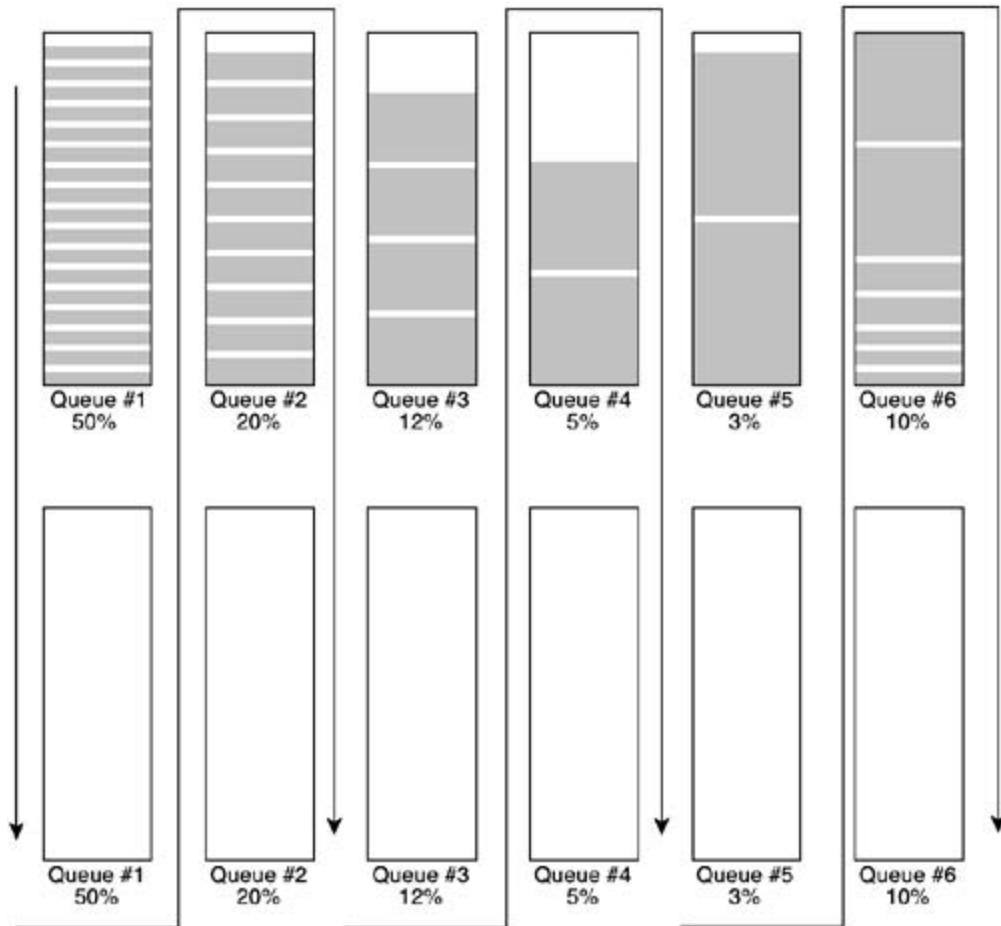
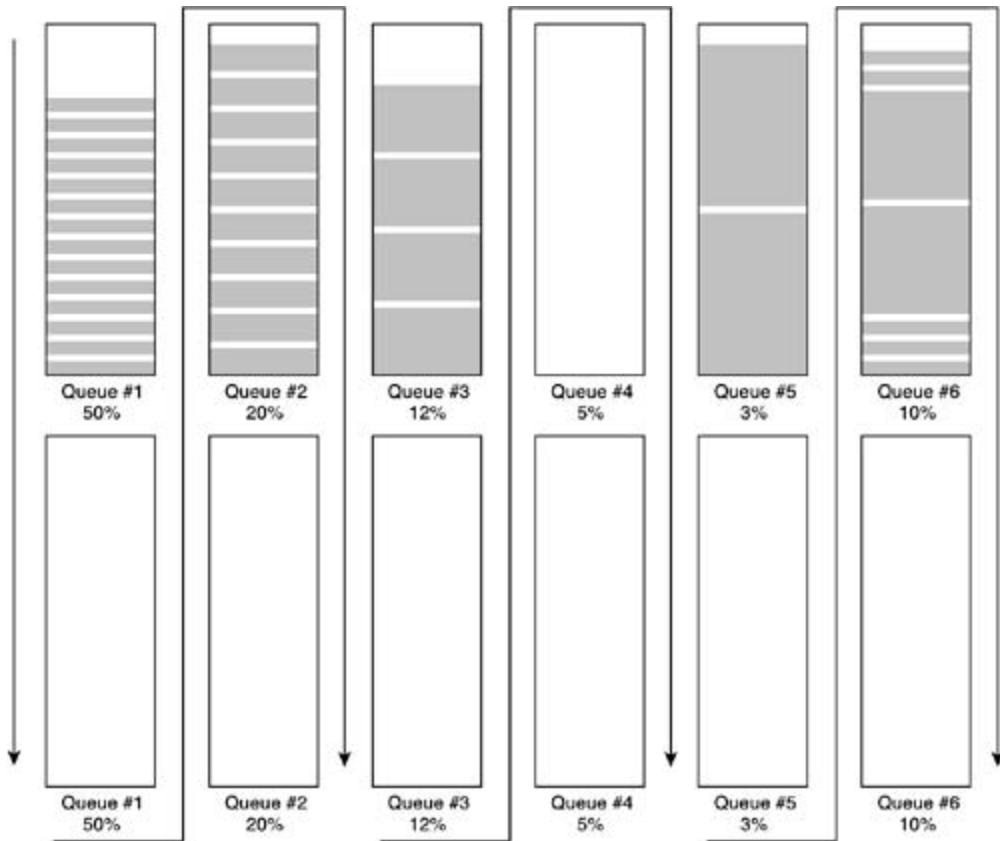


Figure 6-8. Custom Queuing Diagram Revisited



In [Figure 6-8](#), Queue 2 is 100 percent full. A queue is full when the numbers of items in the queue reach the queue limit, or the size of the queue, in bytes, has been reached. With CQ, when a queue is full, the last packet in the queue is transmitted before the next queue is serviced. If a queue fills up while waiting for service, any new packets for the queue are dropped.

NOTE

Although there are 17 queues in CQ, only 16 are user configurable. Queue 0 is used by the operating system to forward network control traffic. When you are using the queue-list command, the 0 queue will appear to be available for configuration; however, it should not be used for traffic unless the router generates it.

The `queue-list` command defines a set of 16 custom queues and up to 16 of these custom queue access lists can be defined per router. [Table 6-7](#) shows the `queue-list` command, its arguments, parameters, and their descriptions.

Table 6-7. Custom Queuing Syntax

Command	Argument	Description
queue-listlist-numberdefault queue-number	None	<p>The default command defines the default queue for traffic that has not been specifically assigned to one of queues.</p> <p>The <i>list-number</i> specifies to which queue list the configuration is to be applied. This number ranges from 1 to 16.</p> <p>The <i>queue-number</i> specifies to which of the 17 queues the command is being applied. This number ranges from 0 to 16.</p>
queue-listlist-numberinterface interface-name interface-number queue-number	None	<p>The interface command is used to specify that all traffic from a certain ingress interface, defined by the following interface name and number, is to be assigned to the queue specified by the <i>queue-number</i> argument.</p>
queue-listlist-numberlowest-customqueue-number	None	<p>The lowest-custom command is used to specify the lowest queue number used by the queue list if all 16 queues are not used for CQ.</p>
queue-listlist-numberprotocol protocol queue-number	Arguments for protocol: arp [gt frame-size lt frame-size]	<p>The protocol command is used to specify that all traffic from the following protocol is to be sent to the queue number specified.</p> <p>The arp keyword is used to specify the ARP protocol.</p> <p>(Optional) gt specifies traffic from the ARP protocol with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) lt specifies traffic from the ARP protocol with a packet size less than that specified, ranging from 0 to 65,535.</p>
	bridge [gt frame-size listlist-number lt frame-size]	<p>The bridge keyword is used to specify the transparently bridged traffic.</p> <p>(Optional) gt specifies traffic from a bridged protocol with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) list specifies traffic belonging to the access list (200–299) specified by the list number.</p> <p>(Optional) lt specifies traffic from a bridged protocol with a packet size less than that specified, ranging from 0 to 65,535.</p>

<pre>bstun [<i>address group-number hex-number /gt frame-size ltframe-size</i>]</pre>	<p>The bstun keyword is used to specify the BSTUN protocol.</p> <p>(Optional) address specifies traffic from a particular BSTUN group and address in hexadecimal format. The BSTUN groups range from 1 to 255.</p> <p>(Optional) gt specifies BSTUN traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) lt specifies BSTUN traffic with a packet size less than that specified, ranging from 0 to 65,535.</p>
<pre>cdp [<i>gt frame-size lt frame-size</i>]</pre>	<p>The cdp keyword is used to specify the CDP protocol.</p> <p>(Optional) gt specifies CDP traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) lt specifies CDP traffic with a packet size less than that specified, ranging from 0 to 65,535.</p>
<pre>compressedtcp [<i>gt frame-size lt frame-size</i>]</pre>	<p>The compressedtcp keyword is used to specify the compressed TCP traffic.</p> <p>(Optional) gt specifies compressed TCP traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) lt specifies compressed TCP traffic with a packet size less than that specified, ranging from 0 to 65,535.</p>
<pre>dlsw [<i>gt frame-size lt frame-size</i>]</pre>	<p>The dlsw keyword is used to specify the DLSw+ protocol.</p> <p>(Optional) gt specifies DLSw+ traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) lt specifies DLSw+ traffic with a packet size less than that specified, ranging from 0 to 65,535.</p>

<pre>ip [fragments gt frame-size listlist- number ltframe-size tcptcp-protocol udp udp-protocol]</pre>	<p>The ip keyword is used to specify the TCP/IP suite of protocols.</p> <p>(Optional) The fragments keyword specifies only fragmented IP packets of the fragmented packet are matched, not the first fragment.</p> <p>(Optional) gt specifies IP traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) list specifies traffic belonging to the access list (1–199 or 1300–1399) specified by the list number.</p> <p>(Optional) lt specifies IP traffic with a packet size less than that specified, ranging from 0 to 65,535.</p> <p>(Optional) tcp specifies that traffic from or to a particular TCP port number. Ranges are TCP port numbers 0 to 65,335 or a keyword from the following list:</p> <p>bgp, chargen, cmd, daytime, discard, domain, echo, exec, finger, ftp, ftp-data, gopher, hostname, ident, irc, klogin, kshell, login, lpd, nntp, pim-auto-rp, pop2, pop3, smtp, sunrpc, syslog, tacacs, talk, telnet, time, uucp, whois, and www</p> <p>(Optional) udp specifies that traffic from or to a particular UDP port number. Ranges are UDP port numbers 0 to 65,335 or a keyword from the following list:</p> <p>biff, bootpc, bootps, discard, dnsix, domain, echo, isakmp, mobile-ip, nameserver, netbios-dgm, netbios-ns, netbios-ss, ntp, pim-auto-rp, rip, snmp, snmptrap, sunrpc, syslog, tacacs, talk, tftp, time, who, and xdmcp</p>
<pre>llc2 [gt frame-size ltframe-size]</pre>	<p>The llc2 keyword is used to specify the LLC-2 protocol.</p> <p>(Optional) gt specifies LLC-2 traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) lt specifies LLC-2 traffic with a packet size less than that specified, ranging from 0 to 65,535.</p>

<code>pad [gt <i>frame-size</i> lt <i>frame-size</i>]</code>	The <code>pad</code> keyword is used to specify the PAD protocol. (Optional) <code>gt</code> specifies PAD traffic with a packet size greater than that specified, ranging from 0 to 65,535. (Optional) <code>lt</code> specifies PAD traffic with a packet size less than that specified, ranging from 0 to 65,535.
<code>qllc [gt <i>frame-size</i> lt <i>frame-size</i>]</code>	The <code>qllc</code> keyword is used to specify the QLLC protocol. (Optional) <code>gt</code> specifies QLLC traffic with a packet size greater than that specified, ranging from 0 to 65,535. (Optional) <code>lt</code> specifies QLLC traffic with a packet size less than that specified, ranging from 0 to 65,535.
<code>rsrb [gt <i>frame-size</i> lt <i>frame-size</i>]</code>	The <code>rsrb</code> keyword is used to specify the RSRB protocol. (Optional) <code>gt</code> specifies RSRB traffic with a packet size greater than that specified, ranging from 0 to 65,535. (Optional) <code>lt</code> specifies RSRB traffic with a packet size less than that specified, ranging from 0 to 65,535.
<code>snapshot [gt <i>frame-size</i> lt <i>frame-size</i>]</code>	The <code>snapshot</code> keyword is used to specify Snapshot routing traffic. (Optional) <code>gt</code> specifies Snapshot routing traffic with a packet size greater than that specified, ranging from 0 to 65,535. (Optional) <code>lt</code> specifies Snapshot routing traffic with a packet size less than that specified, ranging from 0 to 65,535.

	<pre>stun [address group-number hex-number gt frame-size ltframe-size]</pre>	<p>The <code>stun</code> keyword is used to specify the STUN protocol.</p> <p>(Optional) <code>address</code> specifies traffic from a particular STUN group and address in hexadecimal format. The STUN groups range from 1 to 255.</p> <p>(Optional) <code>gt</code> specifies STUN traffic with a packet size greater than that specified, ranging from 0 to 65,535.</p> <p>(Optional) <code>lt</code> specifies STUN traffic with a packet size less than that specified, ranging from 0 to 65,535.</p>
<pre>queue-list list-number queue queue-number [byte-count byte-size] [limit queue-entries]</pre>	None	<p>The <code>byte-count</code> argument specifies a size limit in bytes for the specified queue. Byte counts range from 1 to 16,777,215.</p> <p>The <code>limit</code> argument specifies a limit to the number of entries that may exit in the specified queue. This limit ranges from 0 to 32,767.</p> <p>The use of these arguments is covered later in this section.</p>
<pre>queue-list list-number stun queue-number address group-number hex-number</pre>	None	<p>The <code>stun</code> argument specifies STUN traffic belonging to the STUN group particular with the specific hexadecimal address.</p> <p>The STUN group numbers range from 1 to 255, and the hexadecimal address must be written with the <code>0x</code> prefix.</p>

CQ configuration requires four steps: define the traffic that is to be queued using access lists, create the queue list by creating queues and assigning traffic types to the queues, customize the queues, and apply the queues to an interface. In the next example, these steps are used to configure a sample network.

Step 1. Create the queue list by assigning traffic types to a queue.

In this example, distribute traffic, as shown in [Table 6-8](#).

Table 6-8. Protocol Distribution for Custom Queuing Exercise

Queue Number	Traffic Type
1	OSPF, SNMP
2	GRE
3	DLSw+
4	DNS, SMTP and DHCP
5	Windows NetBIOS support
6	NFS
7	Passive-mode FTP to 192.16.12.8, TFTP
8	WWW
9	Other

To configure these nine queues, use seven IP access lists, as shown in [Example 6-16](#).

Example 6-16. Access Lists for Custom Queuing

```

access-list 101 permit ospf any any
access-list 101 permit udp any any eq snmp
access-list 102 permit gre any any
access-list 103 remark DLSw 2065, 2067, 1981, 1982, and 1983
access-list 103 permit tcp any any eq 2065
access-list 103 permit tcp any any eq 2067
access-list 103 permit tcp any any eq 1981
access-list 103 permit tcp any any eq 1982
access-list 103 permit tcp any any eq 1983
access-list 104 permit tcp any any eq domain
access-list 104 permit tcp any any eq smtp
access-list 104 permit udp any any eq bootpc
access-list 105 permit tcp any any eq 139
access-list 105 permit udp any any eq netbios-dgm
access-list 105 permit udp any any eq netbios-ns
access-list 105 permit udp any any eq netbios-ss

```

```
access-list 106 permit tcp any any eq 2049  
access-list 106 permit udp any any eq 2049  
access-list 107 permit tcp any 192.16.12.8eq ftp  
access-list 107 permit tcp any 192.16.12.8gt 1023 established  
access-list 107 permit udp any any eq tftp
```

Step 2. After the access lists have been configured, it is time to configure the queuing assignments. This is accomplished using the queue-list command and referencing the access lists with the queue-list command, as shown in [Example 6-17](#).

Example 6-17. Queue List Configuration

```
queue-list 3 protocol ip 1 list 101  
queue-list 3 protocol ip 2 list 102  
queue-list 3 protocol ip 3 list 103  
queue-list 3 protocol ip 4 list 104  
queue-list 3 protocol ip 5 list 105  
queue-list 3 protocol ip 6 list 106  
queue-list 3 protocol ip 7 list 107  
queue-list 3 protocol ip 8 tcp www
```

Step 3. Next, customize the queuing configuration. In this example, default IP traffic should be sent out Queue 9:

```
queue-list 3 default 9
```

Step 4. Assign the queuing scheme to an interface. This is accomplished using the

custom-queue-list command in interface configuration mode:

```
interface Serial0/2
  ip address 165.11.2.1 255.255.255.0
custom-queue-list 3
```

After CQ has been enabled for an interface, you can verify its configuration in two ways: the show queueing command and the show interface command. The show queueing command displays the current queuing configuration for the router. If more than one queuing type is in use, you can add the custom keyword onto the show queueing command to specify only the CQ configuration, as shown in [Example 6-18](#).

Example 6-18. Verifying CQ Configuration

```
FS_HQ#show queueing custom

Current custom queue configuration:

List Queue Args
 3     9      default
 3     1      protocol ip      list 101
 3     2      protocol ip      list 102
 3     3      protocol ip      list 103
 3     4      protocol ip      list 104
 3     5      protocol ip      list 105
 3     6      protocol ip      list 106
 3     7      protocol ip      list 107
 3     8      protocol ip      tcp port www
 3     9      protocol ip
```

To see the queue packet size limits, use the show interface command. [Example 6-19](#) shows that CQ 3 is in use with each of the 16 queues limited to 20 packets, the default.

Example 6-19. Using the show interface Command for Custom Queuing

```
FS_HQ#sh int s0/2

Serial0/2 is up, line protocol is up

Hardware is PowerQUICC Serial

Internet address is 165.11.2.1/24

MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 6/255, rxload 6/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input 00:00:00, output 00:00:02, output hang never

Last clearing of "show interface" counters never

Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0

Queueing strategy: custom-list 3

Output queues: (queue #: size/max/drops)

 0: 0/20/0 1: 0/20/0 2: 0/20/0 3: 0/20/0 4: 0/20/0
 5: 0/20/0 6: 0/20/0 7: 0/20/0 8: 0/20/0 9: 0/20/0
10: 0/20/0 11: 0/20/0 12: 0/20/0 13: 0/20/0 14: 0/20/0
15: 0/20/0 16: 0/20/0

5 minute input rate 41000 bits/sec, 4 packets/sec

5 minute output rate 41000 bits/sec, 4 packets/sec

1087 packets input, 1437808 bytes, 0 no buffer

Received 53 broadcasts, 0 runts, 0 giants, 0 throttles

0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort

1079 packets output, 1435130 bytes, 0 underruns
```

```

0 output errors, 0 collisions, 6 interface resets

0 output buffer failures, 0 output buffers swapped out

18 carrier transitions

DCD=up  DSR=up  DTR=up  RTS=up  CTS=up

```

Notice that each queue is displayed with the current size of the queue, the maximum number of packets per queue, and the number of packets that have been dropped in each queue. In the preceding example, each of the queues is currently empty; this is because CQ is used only when there is congestion on an interface, and in this case, this interface is transmitting less than one packet per second.

You have control over the size of each of the queues with CQ. Before changing the bandwidth allocation for each of the queues, consider a few things. First, consider the average packet size when adjusting queue size by limiting the size of the queue in bytes. If you set the byte count size of your queue to 2000 bytes, and your average packet size is 1024 bytes, for example, only two packets will be sent from this queue each time it is serviced. Second, if you set a packet size that is too large, the bandwidth might not be properly allocated, resulting in wasted queue space. Therefore, it is better to analyze average packet sizes before allocating bandwidth to the queues, because setting queue sizes that are too small will cause irregular packet transmission, and setting queue sizes too large will underutilize the queue size or cause one protocol to monopolize the interface bandwidth.

Nine basic steps are required to determine the size of bandwidth that should be allocated to each queue. The byte-count command enables you to control the size of the individual queues. The byte-count command is basically used to allocate bandwidth to particular traffic types based on a percentage of traffic. Before allocating traffic, it is important to determine the average packet sizes per protocol and queue, and the total amount of interface bandwidth. Then determine the percentage of interface bandwidth that each of these queues requires.

For example, the following steps outline how a simple queuing scheme is created, consisting of generic routing encapsulation (GRE), WWW, and passive-mode FTP traffic, using the same protocols defined in the preceding example.

Step 1. Find the average packet size for each protocol. [Table 6-9](#) shows the average packets sizes for the protocols for this example. This table also provides the bandwidth allocation that should be used for this example:

Average packet size (A)

Total amount of traffic in bytes (B)

Total number of packets (P)

$$A = B/P$$

Table 6-9. Packet Sizes for Protocols

Protocol	Bandwidth Allocation	Average Packet Size
GRE	55	794
WWW	20	746
FTP	25	678

Step 2. Find the ratio of packets that must be sent to accumulate the percentage of bandwidth allocated to the queue in bytes. The percentage of bandwidth should have been found before beginning the bandwidth allocation process. This ratio is found by dividing the percentage of bandwidth by the packet size (in bytes). [Table 6-10](#) displays the results of this equation:

Traffic ratio (R)

Percentage of bandwidth (B)

Packet size (P)

$$R = B/P$$

$$55/794 = 0.06926$$

$$20/746 = 0.02680$$

$$25/678 = 0.03687$$

Table 6-10. CQ Traffic Ratios

Protocol	Bandwidth Allocation	Average Packet Size	Ratio
GRE	55	794	0.06926
WWW	20	746	0.02680
FTP	25	678	0.03687

Step 3. Normalize the ratio found in Step 2; this is accomplished by dividing each of the ratios by the lowest ratio found in Step 2. [Table 6-11](#) shows the normalized ratios for this example:

Lowest ratio (L)

Ratio (R)

Normalized number (N)

$$N = R/L$$

0.02680 is the lowest ratio

0.06926/0.02680 = 2.58 rounded to 2.6

0.02680/0.02680 = 1

0.03687/0.02680 = 1.38 rounded to 1.4

Table 6-11. CQ Normalized Ratios

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio
GRE	55	794	0.06926	2.6
WWW	20	746	0.02680	1
FTP	25	678	0.03687	1.4

Step 4. Round each ratio with a decimal up to the next highest whole number. The packet ratio should be rounded to a whole number because CQ transmits the last full packet in the queue before moving on to the next queue. [Table 6-12](#) shows the ratios for this example in whole numbers.

Table 6-12. CQ Whole Ratios

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio	Whole Ratio
GRE	55	794	0.06926	2.6	3
WWW	20	746	0.02680	1	1
FTP	25	678	0.03687	1.4	2

Step 5. To convert the packet ratio to a byte count, the ratio must be multiplied by the average packet size. [Table 6-13](#) displays the byte counts:

Packet ratio (R)

Average packet size (P)

Byte count (B)

$$B = R * P$$

$$3 \times 794 = 2382$$

$$1 \times 746 = 746$$

$$2 \times 678 = 1356$$

Table 6-13. CQ Byte Counts

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio	Whole Ratio	Byte Count
GRE	55	794	0.06926	2.6	3	2382
WWW	20	746	0.02680	1	1	746
FTP	25	678	0.03687	1.4	2	1356

Step 6. To find the bandwidth distribution that this ratio represents, combine the total bandwidth used by all queues:

Bandwidth distribution (D)

Byte count (B)

$$D = B + B + B \text{ (each } B\text{)}$$

$$2382 + 746 + 1356 = 4484$$

Step 7. To find the total percentage of bandwidths, in bytes, used by each queue, divide each byte count by the total bandwidth distribution. [Table 6-14](#) shows the percentages of bandwidth for this example:

Percentage of bandwidth (P)

Bandwidth distribution (D)

Byte count (B)

$$P = B/D$$

4484

$$2382/4484 = 53$$

$$746/4484 = 17$$

$$1356/4484 = 30$$

Table 6-14. CQ Bandwidth Percentages

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio	Whole Ratio	Byte Count	Percentage of Bandwidth
GRE	55	794	0.06926	2.6	3	2382	53
WWW	20	746	0.02680	1	1	746	17
FTP	25	678	0.03687	1.4	2	1356	30

Step 8. If this ratio is not close enough to the original bandwidth allocation percentage, go back to Step 3 and multiply the ratio by another value. In this example, I tried using the numbers 2 and 3. Notice that 2 comes the closest to the required byte count, and 3 goes over the byte count. In this case, I decided to try 2.5, which is the closest to the original

required percentage of bandwidth allocation. [Table 6-15](#) shows the final bandwidth percentage allocations and byte count sizes for this example:

2.6 x 2 = 5.2 rounded to 6

1 x 2 = 2

1.4 x 2 = 2.8 rounded to 3

6 x 794 = 4764/8288 = 58

2 x 746 = 1492/8288 = 18

3 x 678 = 2032/8288 = 25

8288

2.6 x 3 = 7.8 rounded to 8

1 x 3 = 3

1.4 x 3 = 4.2 rounded to 5

8 x 794 = 6352/11980 = 53

3 x 746 = 2238/11980 = 19

5 x 678 = 3390/11980 = 28

11980

2.6 x 2.5 = 6.5 rounded to 7

1 x 2.5 = 2.5 rounded to 3

1.4 x 2.5 = 3.5 rounded to 4

7 x 794 = 5558/10508 = 53%

3 x 746 = 2238/10508 = 21%

4 x 678 = 2712/10508 = 26%

Table 6-15. Final Bandwidth Allocations per Queue

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio	Whole Ratio	Byte Count	Percentage of Bandwidth
GRE	55	794	0.06926	2.6	7	5558	53
WWW	20	746	0.02680	1	3	2238	21
FTP	25	678	0.03687	1.4	4	2712	26

Step 9. After the byte counts have been found, apply them to the queues using the queue-list byte-count command, as shown in [Example 6-20](#).

Example 6-20. Complete CQ Custom Byte-Count Configuration

```

interface Serial0/2
  ip address 165.11.2.1 255.255.255.0
  custom-queue-list 5
!
access-list 110 permit gre any any
access-list 120 permit tcp any any eq ftp
access-list 120 permit tcp any any gt 1023 established
queue-list 5 protocol ip 1 list 110
queue-list 5 protocol ip 2 list 120
queue-list 5 protocol ip 3 tcp www
queue-list 5 queue 1 byte-count 5558
queue-list 5 queue 2 byte-count 2238
queue-list 5 queue 3 byte-count 2712
FS_HQ#show queueing custom

```

Current custom queue configuration:

List	Queue	Args
5	1	protocol ip list 110
5	2	protocol ip list 120
5	3	protocol ip tcp port www
5	1	byte-count 5558
5	2	byte-count 2238
5	3	byte-count 2712

This chapter began by discussing the four basic queuing types available in Cisco IOS Software. The remainder of this chapter goes beyond basic queuing techniques and applies technologies from the preceding two chapters, combining and contrasting them with queuing techniques from this chapter, to create customized QoS solutions. The next sections focus on more advanced queuing, shaping, policing, prioritization, and classification techniques, beginning with the next section, which discusses more advanced traffic policy enforcement techniques.

Enforcing Traffic Policy with QoS

Networks generally have basic traffic policy requirements that must be enforced. For instance, service providers provide customers with WAN circuits such as ATM or Frame Relay. These circuits are provisioned with certain service level agreements that the service providers enforce on customers to provide all customers certain service levels. Customers are responsible for making sure that their network's traffic complies with those agreements by shaping, rate limiting, and prioritizing their own traffic with QoS tools supplied in Cisco IOS Software. This section explores these technologies and shows how they can be used to provide QoS to network applications.

Traffic Shaping

Traffic shaping forces traffic to comply with certain bandwidth-allocation limitations by reducing the outbound traffic rate. Unlike traffic policing, which discards traffic that exceeds burst sizes, during traffic, bursts traffic-shaping buffers the additional packets and sends them out when bandwidth is available, or when the number of buffered packets falls below the configured limit, thus smoothing flow of traffic.

NOTE

Traffic shaping does not replace proper circuit provisioning; it is designed to smooth traffic bursts. Traffic shaping does not supply additional bandwidth to an interface. Interfaces that are continuously congested still discard packets.

Traffic shaping uses a token-bucket system to determine whether to transmit, delay, or drop new packets. With the token-bucket system, each interface has *committed information rate (CIR)*, which is the rate at which the interface can transmit packets for an interval of time, or in token-bucket theory the rate at which the tokens are added to the bucket. The *sustained burst rate (Bc)* defines the maximum number of tokens that the bucket can contain at a given interval. When a packet arrives at an interface, it takes a token from the bucket. When a packet is transmitted, the token is released; and after the *time interval (Tc)*, the token is returned to the bucket. If the bucket is empty, any new packets arriving at that interface are queued until the time interval has elapsed and the tokens have been replenished. If the CIR is consistently exceeded, tokens are removed from the bucket faster than they are being replenished, filling the queue and causing packets to be dropped. The key to good traffic shaping design is to create a bucket that will constantly have enough tokens to either queue and forward each packet, and replace tokens after packets have been removed from the buffer and transmitted.

Generic Traffic Shaping

Traffic shaping can be applied to a number of different Layer 2 technologies, such as Ethernet, ATM (variable bit rate [VBR] and available bit rate [ABR]), High-Level Data Link Control (HDLC), PPP (ISDN and dialup interfaces are not supported), and Frame Relay. With the exception of Frame Relay, all technologies support generic traffic shaping (GTS), introduced in Cisco IOS Software Release 11.2; it has the capability to shape outgoing traffic on a per-interface basis. GTS can also shape certain types of traffic defined in an access list by specifying group traffic shaping.

NOTE

For more information on Frame Relay traffic shaping (FRTS), see *CCIE Practical Studies*, Volume I, [Chapter 5](#), "WAN Protocols and Technologies: Frame Relay."

Before enabling GTS, you must know a few things. First, like Frame Relay traffic shaping, to config

GTS, you must know the target bit rate for the interface, commonly referred to as the *committed information rate (CIR)*. This is the rate at which traffic is sent during normal circumstances. It is also helpful, but not necessary, to know the sustained and excess burst rates available for traffic burst. *sustained burst rate (Bc)* is the rate in bits that traffic is allowed to burst beyond the normal traffic per interval. The *excess burst rate (Be)* is the rate at which traffic is allowed to burst beyond the sustained burst rate during the first interval. Tokens are replenished in the traffic-shaping token bucket each time interval (*Tc*). To properly configure traffic shaping, you must first know the time interval traffic shaping uses to replenish the token bucket, which is found using the following formula:

$$Tc = Bc/CIR$$

NOTE

The time interval for traffic shaping cannot be less than 10 ms or greater than 125 ms. The router finds the best time interval based on the $Tc = Bc/CIR$ formula. The default time interval is 125 ms. The time interval is a result of the CIR and Bc configuration and is not user configurable. Cisco recommends that the Bc should be 1/8 the CIR, which will create eight 125-ms time intervals per second.

To configure GTS for all interface traffic, use the traffic-shaping rate command on each interface where traffic shaping is required. To define specific traffic that is to be shaped, use the traffic-shape group command and an access list. [Table 6-16](#) shows the GTS command available in Cisco IOS Software Release 12.12(T), the command's arguments, and the argument descriptions:

```
traffic-shape {group | rateaccess-list}target-bit-rate[sustained] [excess] [buffer limit]
```

Table 6-16. Generic Traffic Shaping Command Arguments

Command Argument	Description
group access-list	Specifies that all traffic matching the access list (1–2699) is to be shaped.
rate	Specifies that all traffic on this interface is to be shaped.
target-bit-rate	The normal rate that traffic will be transmitted (CIR) at, ranging from 8000 to the interface's full bit rate in bits per second. For example, a 100-Mbps interface's full CIR will range from 8000 to 100,000,000. Some Cisco IOS Software versions have different range values for this command. You must use a value that exists in the range provided by the software version that the router is running.
sustained	(Optional) The sustained bit rate (Bc) that traffic is allowed to burst to, ranging from 0 to 100,000,000 in bits per interval. The sustained burst rate that the traffic can burst per interval can be found using the following formula: $Bc = Tc * CIR$
excess	(Optional) The excess bit rate (Be) that traffic is allowed to burst to beyond the sustained bit rate during the first interval, ranging from 0 to 100,000,000 in bits per interval. The Be is an optional parameter that assumes that the token bucket will be completely full: $Be = Bc * 2$
buffer	(Optional) Used to specify a buffer limit, ranging from 1 to 4096.

GTS configuration requires two steps: find the traffic-shaping values, and configure an interface for traffic shaping.

Step 1. Find the correct traffic-shaping values. To find the traffic-shaping values for your particular traffic-shaping configuration, you need the following information:

- CIR
- Bc
- Be

If you will be configuring only traffic shaping to the interface's CIR limitations, you need to know only the CIR for the particular interface. For a more granular configuration, you can also provide the Bc. The Bc specifies the number of bits that the interface can transmit within a given interval. If you do not know your Bc, you can find it using the following formula:

$$Bc = CIR * Tc$$

And the final, optional, item that you must have before configuring GTS is the Be. The Be specifies the amount of traffic that can burst when the interface has replenished enough tokens to support a burst; this will generally be considered the first interval. The Be is found using the following formula:

$$Be = Bc * 2$$

If the interface will not be supporting burst, you use the following formula:

$$Be = Bc$$

Step 2. From interface configuration mode, enable traffic shaping using the traffic-shaping command. In the following example, traffic shaping is being used to limit the rate on all traffic interface serial0/0 to 256 kbps. This limit is imposed by delaying any traffic over 32 kb/interval. The interval of time used to shape traffic is 125 ms. So, in this case, during each 125-ms interval, the interface serial0/0 can transmit up to 32 kb. Any amount of traffic that exceeds the 32 kb limit during that interval will be queued until the next interval:

```
interface Serial0/0
  ip address 10.1.1.5 255.255.255.0
  traffic-shape rate 256000 32000 32000 1000
```

```
Router#show traffic-shape
```

```
Interface      Se0/0
```

	Access	Target	Byte	Sustain	Excess	Interval	Increment	Adapt
VC	List	Rate	Limit	bits/int	bits/int	(ms)	(bytes)	Active
-		256000	8000	32000	32000	125	4000	-

In [Example 6-21](#), packets from the 136.78.65.0/28 network are transmitted over the WAN interface shown in [Figure 6-9](#). Traffic shaping is used to constrain the amount of traffic leaving Ethernet 0, with the source address beginning with 136.78.65.0/28, to 512 kbps, with a 64-kb/interval sustained bit rate. In this case, there is no excess burst rate. This means that traffic from the 136.78.65.0/28 network will be shaped to 64 kb for each of the eight 125-ms intervals, which will amount to 512 kb. If the interface receives more than 64 kb in any one interval, the excess traffic will be queued until the next interval, preventing the interface from sending more than 512 kbps or 64 kb per 125 ms.

Example 6-21. Using GTS to Shape Traffic

```

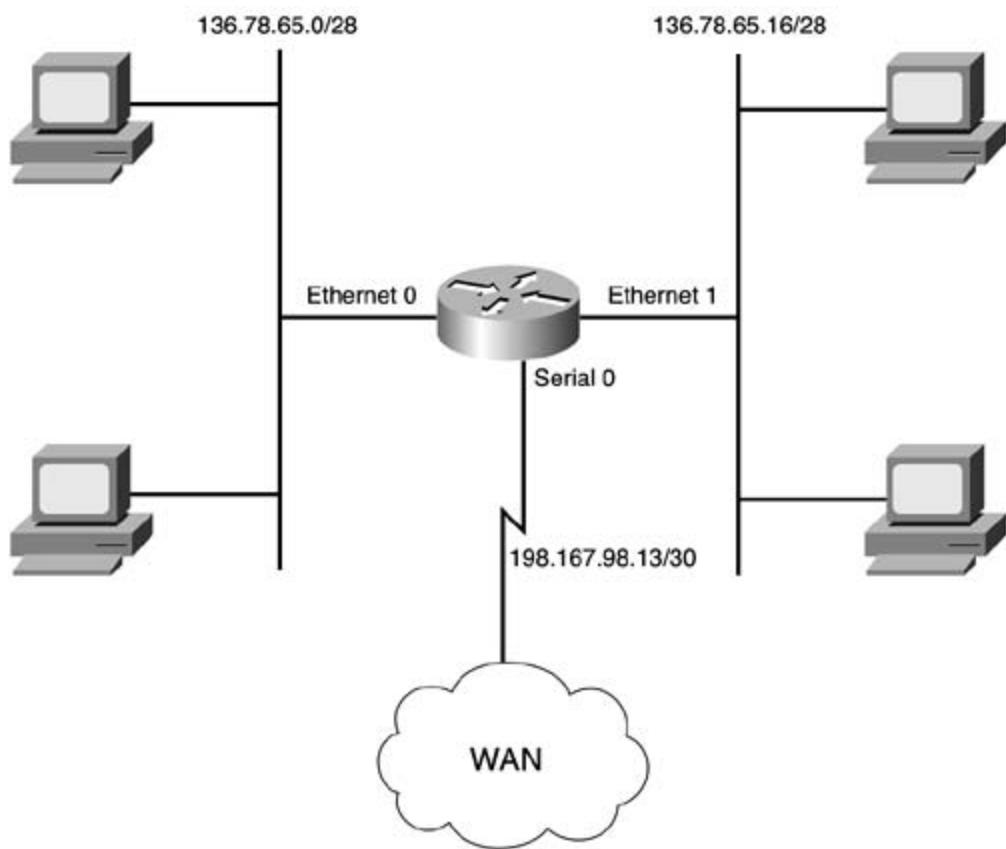
interface Ethernet0
    ip address 136.78.65.1 255.255.255.240
    traffic-shape rate 512000 64000 64000
!
interface Ethernet1
    ip address 136.78.65.17 255.255.255.240
!
interface Serial0
    ip address 198.167.98.14 255.255.255.252
!
access-list 136 permit ip 136.78.65.0 0.0.0.15 any
!
LAN-Router#show traffic-shape

Interface      Et0
          Access Target      Byte   Sustain     Excess      Interval  Increment Adapt
          VC       List     Rate      Limit   bits/int   bits/int   (ms)      (bytes)   Active
          -        136     512000   8000    64000      0          125        8000      -
          LAN-Router#show traffic-shape statistics

          Access Queue      Packets      Bytes      Packets      Bytes      Shaping
          I/F       List     Depth
          Et0        136      0          39         2886      0          0          no

```

Figure 6-9. Using GTS to Limit LAN to WAN Traffic



To view the GTS configuration, use the `show traffic-shaping` command. The `show traffic-shaping statistics` command enables you to monitor GTS activity. The command displays information about current queue depth on each of the GTS-enabled interfaces, the number of packets sent with and without traffic-shaping queuing delays, and whether traffic shaping is currently active. As long as the traffic rate is below the traffic-shaping rate, the traffic will not be shaped. When the traffic rate exceeds the configured traffic-shaping parameters—or, in other words, if packets are arriving at the interface faster than tokens are being replenished—the excess traffic will be shaped. Traffic shaping will be applied only when an interface is exceeding its CIR, Bc, and Be.

Classifying and Marking Traffic with CAR

Committed access rate (CAR) is a traffic policy classification and marking method used to police IP on IP precedence, DSCP value, MAC addresses, or access lists.

Traffic policy classification involves defining a traffic policy and using CAR to enforce rate limits. Traffic that conforms to the configured rate limit can be forwarded as is, or it can be marked to provide QoS at various points all the way through the network.

Marking changes the value of the IP precedence or DSCP in the ToS byte from the IP header. The marking action is defined either when a packet conforms to a value or when a packet exceeds a value. When marking traffic, CAR affects how traffic is treated at points later in the network because WFQ and VPI take into account the CAR-assigned ToS values, giving higher-priority traffic a better weight.

CAR uses the token-bucket scheme, similar to that used by traffic shaping to determine whether an interface has resources available to transmit a packet by checking to see whether there are enough tokens in the token bucket. If the interface has the resources to forward the packet (tokens are available), the tokens are removed from the token bucket, the packet is transmitted, and, after the interval has elapsed, the tokens are added back into the token bucket. If the interface does not have resources available, no tokens are available; CAR defines the action taken on the packet. The actions that CAR matches are conform actions, where the packet conforms to the specified traffic trait, or exceed actions, where traffic exceeds a certain traffic trait value. CAR uses definitions to define traffic rates:

- Normal rate— Like the CIR in traffic shaping, the normal rate in CAR can be described as the average rate of traffic, or the average rate that tokens are added to the bucket.
- Normal burst— Like the sustained bit rate (B_c) in traffic shaping, the normal burst is the amount of traffic allowed to exceed the normal traffic rate during an interval of time.
- Excess burst— Traffic that exceeds the normal burst. When excess burst is configured, tokens are borrowed and added to the bucket to allow for a certain amount of traffic bursts. After the borrowing of tokens have been used, any further traffic received on that interface is dropped. Traffic bursts occur only for short periods of time, before causing the token bucket to run out of tokens:
 - Cisco recommends that the normal traffic rate be equal to the average traffic rate over time. The normal burst rate should equal the normal rate in bytes (times 8 for bits) * 1.544 Mbps. If you are planning to use an extended rate, the extended rate must be greater than the normal burst rate. If the extended burst rate is not greater than the normal burst rate ($B_c = Be$), the interface will not allow for extended bursts. So the extended rate should be the normal burst rate times 1.544 Mbps. For example, if the normal burst is 2.316 Mbps, and the excess burst is 4.64 Mbps, the extended rate would be 6.96 Mbps.

NOTE

When determining which shaping or policing method you should deploy on your network, always follow one rule of thumb: Traffic shapers shape traffic using buffers, so shaping should always be applied to an egress interface where excess traffic can be buffered. Traffic policing or CAR is more effective when applied to inbound traffic because policing and rate limiting do not buffer traffic.

To configure CAR, use the rate-limit command in interface configuration mode as shown here. [Table 6-17](#) shows the rate-limit command arguments and their descriptions in Cisco IOS Software Release 12.

```
rate-limit {input | output} {rate | access-group {access-list-number | rate-limit list-number} | dscp dscp-value | qos-group qos-group-index } normal-burst maximum-conform-action {continue | drop | set-dscp-continue dscp-value | set-dscp-transmit value | set-mpls-exp-continue mpls-exp-value | set-mpls-exp-transmit mpls-exp-value | set-prec-continue precedence-value | set-prec-transmit precedence-value | set-qos-continue qos-group-index | set-qos-transmit qos-group-index | transmit} exceed-action {continue | drop | set-dscp-continue dscp-value | set-dscp-transmit dscp-value | set-mpls-exp-continue mpls-exp-value | set-mpls-exp-transmit mpls-exp-value | set-prec-continue precedence-value | set-prec-transmit precedence-value | set-qos-continue qos-group-index | set-qos-transmit qos-group-index | transmit}
```

Table 6-17. CAR Command Arguments and Their Descriptions

Command Argument	Description
<code>input output</code>	Specifies the traffic direction.
<code>normal-rate</code>	The average traffic rate, under normal circumstances, for a period bits/second ranging from 8000 to 2,000,000,000.
<code>access-group {access-list-number rate-limit rate-list-number}</code>	Specifies either a standard or extended access list, ranging from 1 to 99. Rate lists 0–99 are used to specify IP precedence values, and rate lists 100–199 are used to specify MAC addresses.
<code>dscp dscp-value</code>	Specifies a DSCP value ranging from 0 to 63.
<code>qos-group qos-group-index</code>	Specifies a QoS group ranging from 0 to 99.

<i>normal-burst</i>	<p>Specifies the normal burst size in bytes, ranging from 1000 to 512</p> <p>The normal burst is found using the following formula:</p> $\text{Normal burst (Bc)} = \text{normal rate (CIR in bytes)} * 1.5 \text{ seconds}$
<i>maximum-burst</i>	<p>Specifies the excess burst size in bytes, ranging from 2000 to 1,024</p> <p>If used, you can find the excess burst by using the following formula:</p> $\text{Excess Burst (Be)} = \text{Normal burst (Bc)} * 2$ <p>Otherwise, excess burst equals normal burst, as shown here:</p> $\text{Excess burst (Be)} = \text{normal burst (Bc)}$
<i>conform-action</i>	Any packets conforming to the normal rate will do the activity specified next value.
<i>continue</i>	Continues processing through the rest of the list.
<i>drop</i>	Immediately drops the packet and exits the list.
<i>set-dscp-continuedscp-value</i>	Sets the DSCP value to the specified value, ranging from 0 to 63, and continues processing the rest of the list.
<i>set-dscp-transmitdscp-value</i>	Sets the DSCP value, ranging from 0 and 63, transmits the packet, and exits the list without further processing.
<i>set-mpls-exp-continuempls-exp-value</i>	Sets the MPLS experimental value, ranging from 0 to 7, and continues processing the rest of the list.
<i>set-mpls-exp-transmitmpls-exp-value</i>	Sets the MPLS experimental value, ranging from 0 to 7, immediately transmits the packet, and exits the list without any further processing.
<i>set-prec-continueprecedence-value</i>	Sets the IP precedence value, ranging from 0 to 7, and continues processing the rest of the list.
<i>set-prec-transmitprecedence-value</i>	Sets the IP precedence value, ranging from 0 to 7, transmits the packet, and exits the list without further processing.

<code>set-qos-continueqos-group-index</code>	Sets the QoS group number, ranging from 0 to 99, for the packet and continues processing the rest of the list.
<code>set-qos-transmitqos-group-index</code>	Sets the QoS group number for the packet, ranging from 0 to 99, transmits the packet, and exits the list without further processing.
<code>transmit</code>	Transmits the packet and stops evaluating the list.
<code>exceed-action</code>	Specifies the action to take if the normal rate has been exceeded.
	The action to take upon an exceeded action.
<code>continue</code>	Continues processing through the rest of the list.
<code>drop</code>	Immediately drops the packet and exits the list.
<code>set-dscp-continuedscp-value</code>	Sets the DSCP value to the specified value, ranging from 0 to 63, and continues processing the rest of the list.
<code>set-dscp-transmitdscp-value</code>	Sets the DSCP value, ranging from 0 and 63, transmits the packet, and exits the list without further processing.
<code>set-mpls-exp-continuempls-exp-value</code>	Sets the MPLS experimental value, ranging from 0 to 7, and continues processing the rest of the list.
<code>set-mpls-exp-transmitmpls-exp-value</code>	Sets the MPLS experimental value, ranging from 0 to 7, immediately transmits the packet, and exits the list without any further processing.
<code>set-prec-continueprecedence-value</code>	Sets the IP precedence value, ranging from 0 to 7, and continues processing the rest of the list.
<code>set-pres-transmitprecedence-value</code>	Sets the IP precedence value, ranging from 0 to 7, transmits the packet, and exits the list without further processing.
<code>set-qos-continueqos-group-index</code>	Sets the QoS group number for the packet, ranging from 0 to 99, and continues processing the rest of the list.
<code>set-qos-transmitqos-group-index</code>	Sets the QoS group number for the packet, ranging from 0 to 99, transmits the packet, and exits the list without further processing.
<code>transmit</code>	Transmits the packet and stops evaluating the list.

In [Example 6-22](#), the `rate-limit` command is used with access list 101 to limit incoming traffic for host 195.42.48.155 to 2 Mbps with a 375,000-byte normal burst and 750,000-byte excess burst. Any traffic conforming to the normal traffic rate will have its IP precedence value set to Flash-override (4) and transmitted immediately. Traffic exceeding the normal burst rate will be continued to be processed.

Next, CAR is used to police and mark traffic. First, this `rate-limit` command is used with access list 101 to limit all passive FTP traffic to host 195.42.48.7 to 4 Mbps. Then, it is also used to set the normal burst rate to 1,000 bytes and the extended burst rate to 1,500,000 bytes. Any traffic that conforms to the rate limits is transmitted, and the router should continue on with CAR list processing. Any FTP traffic that exceeds the rate limit will be dropped.

NOTE

The following formulas were used to find the CAR parameters for the FTP example:

1. Normal rate in bytes = normal rate in bps * (1 byte / 8 bits = 125)

4,000,000 bits * 125 = 500,000,000 bits = 500,000 bytes

2. Normal burst = normal rate in bytes * 1.5 seconds

500,000 bytes * 1.5 = 750,000 bytes

3. Excess burst = normal burst * 2

750,000 * 2 = 1,500,000 bytes

Example 6-22. Using CAR to Police and Mark Traffic

```
interface Ethernet0
    ip address 195.42.48.1 255.255.255.0
    rate-limit input access-group 101 2000000 375000 750000 conform-action set-prec-
    continue 4 exceed-action continue
    rate-limit input 2000000 3000 6000 conform-action
        transmit exceed-action drop
    rate-limit input access-group 102 4000000 750000 1500000 conform-action continue
    exceed-action drop
    rate-limit output 2000000 3000 6000 conform-action
    transmit exceed-action drop
!
access-list 101 permit ip any host 195.42.48.155
access-list 102 permit tcp any host 195.42.48.7 eq ftp
access-list 102 permit tcp any host 195.42.48.7 gt 1023 established
```

Another way to specify traffic with CAR is to use the access-list rate-limit command, in conjunction with the rate limit command, to police traffic based on either IP precedence values or MAC addresses. The access-list command is similar to the access-list command. Lists 0 through 99 are IP precedence lists used to

specify an exact IP precedence value (0 through 7) or specify certain precedence values using a mask. Values from 1 through 199 are used to specify MAC addresses:

```
access-list rate-limitlist-number{precedence-value | precedence-mask)
```

```
access-list rate-limitlist-number MAC-address
```

Precedence masks are created by converting the IP precedence values to 8-bit numbers. The router converted the 8-bit number 00000001, for instance, and the priority bit, 1, is converted to 00000001 in [Table 6-18](#).

Table 6-18. IP Precedence Mask Values

Precedence Value	8-Bit Number Value
Routine (0)	00000001
Priority (1)	00000010
Immediate (2)	00000100
Flash (3)	00001000
Flash-override (4)	00010000
Critical (5)	00100000
Internet (6)	01000000
Network (7)	10000000

To find the bitmask value for the IP precedence mask, add the 8-bit number values for each of the values to be matched. This number is then converted to hexadecimal, the format required for the configuration command. In the example, to match all high-priority traffic—Network, Internet, and Critical—a binary bitmask of 11100000 is added. This is converted to hexadecimal. This equals E0.

Network (7)	10000000
Internet (6)	01000000
Critical (5)	00100000
Bitmask =	11100000

So, to create an access list that matches the IP precedence values 1, 3, 5, and 7, you would create 10101010, and the mask would convert to AA in hexadecimal.

Network (7)	10000000
Critical (5)	00100000
Flash (3)	00001000
Priority (1)	00000010
Bitmask =	10101010

[Example 6-23](#) shows how the rate-limit access list is used to specify the odd IP precedence traffic at 256 kbps, with 48,000-byte normal burst and 96,000-byte excess burst.

Example 6-23. Using a Rate-Limit Access List

```
interface Serial0/0
    ip address 36.128.42.11 255.255.255.0
    rate-limit output access-group 1 256000 48000 96000 conform-action continue
    exceed-action drop
!
access-list rate-limit 1 mask AA
```

To verify and monitor CAR behavior, use the show interface rate-limit command. This command provides information about each of the rate limits that have been configured on a per-interface basis. [Exam](#) ple 6-23 shows the show interface rate-limit command for the CAR configuration from the Serial 0/0 interface.

Example 6-24. show interface rate-limit Command

```
Simpson#show int e 0 rate-limit
Simpson#show interfaces serial 0/0 rate-limit
Serial0/0
    Output
        matches: access-group 1
        params: 256000 bps, 48000 limit, 96000 extended limit
```

```
conformed 2050 packets, 1534364 bytes; action: continue  
exceeded 629 packets, 514122 bytes; action: drop  
last packet: 160ms ago, current burst: 122 bytes  
last cleared 00:21:28 ago, conformed 9000 bps, exceeded 3000 bps
```

Now that you have seen basic ways to control traffic policies by using traffic shaping, and rate limit to examine how you can prioritize real-time voice traffic by using IP RTP Priority.

Prioritizing Real-Time Voice Traffic

IP RTP priority allows all outbound Real Time Protocol (RTP) traffic to be strictly prioritized over all other traffic on an interface level; all other traffic is fairly queued using WFQ. IP RTP Priority is useful on links with speeds less than 1.544 Mbps (T1), where voice traffic is more at risk of delay due to fragmentation, congestion, queuing, or serialization. Because voice traffic is real-time traffic, it is extremely sensitive to delay. You enable IP RTP Priority by using the `ip rtp priority` command in interface configuration mode. The priority queue created by the `ip rtp priority` command is a strict-priority queue; after the bandwidth configured with the `ip rtp priority` command has been exceeded, all further packets in that queue are discarded until queue space is available to store packets. Before configuring RTP Priority on any interface, you have some important information to gather: the number of voice calls that will be placed, the voice codec in use, and the call frequency. You must also consider whether you will be prioritizing only voice traffic or whether you will also need to prioritize control traffic. For this reason, it is crucial that the IP RTP Priority bandwidth be correctly allocated. As with LLQ, it is always better to err on the safe side and allow slightly more bandwidth than required than to have packets dropped because of packet headers, network jitter, or control traffic. As with CBWFQ and LLQ, the sum of the bandwidth configured for IP RTP Priority cannot exceed 75 percent of the interface's available bandwidth; the remaining 25 percent is reserved for network control and routing traffic.

To enable IP RTP Priority from interface configuration mode, use the `ip rtp priority` command. [Table 6-19](#) lists the `ip rtp priority` command arguments and their descriptions:

```
ip rtp priority starting-port-number port-range bandwidth
```

Table 6-19. `ip rtp priority` Command Arguments

Command Argument	Description
<i>starting-port-number</i>	The first RTP port number to assign to the priority queue. RTP port numbers are UDP ports ranging from 2000 to 65,535.
<i>port-range</i>	The RTP port range that when added to the starting port number equals the full range of RTP ports for prioritization, ranging from 0 to 16,383.
<i>bandwidth</i>	Specifies the maximum bandwidth to be used for the RTP Priority queue, ranging from 0 to 2000 in kbps.

[Example 6-25](#) shows how RTP Priority is used to strictly prioritize all RTP traffic ranging from UDP ports 16,384 to 32,767 (the full range of RTP ports) and limit the priority queue to 64 kbps. All other traffic on this interface is queued fairly using WFQ.

Example 6-25. Using ip rtp priority to Prioritize Voice Traffic

```
interface Serial0
bandwidth 256
ip address 85.114.95.1 255.255.255.0
encapsulation frame-relay
fair-queue 64 256 0
frame-relay interface-dlci 110
ip rtp priority 16384 16383 64
```

To verify RTP configuration, you can either use the show interface or show queue command. Each command shows the same type of RTP Priority data, the bandwidth reservation. [Example 6-26](#) shows the show interface command output for an interface before RTP Priority was applied, and [Example 6-27](#) shows the output from the show interface and show queueing commands after RTP Priority has been applied.

Example 6-26. Before Configuring RTP Priority

```
Simpson#show interfaces serial 0 | begin Queue
Queueing strategy: weighted fair
Output queue: 0/1000/64/0 (size/max total/threshold/drops)
  Conversations 0/2/256 (active/max active/max total)
  Reserved Conversations 0/0 (allocated/max allocated)
  Available Bandwidth 1158 kilobits/sec
```

Example 6-27. Display RTP Priority Bandwidth

```
Simpson#show queueing interface serial 0

Interface Serial0 queueing strategy: fair

Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0

Queueing strategy: weighted fair

Output queue: 0/1000/64/0 (size/max total/threshold/drops)

  Conversations 0/2/256 (active/max active/max total)

  Reserved Conversations 0/0 (allocated/max allocated)

  Available Bandwidth 1094 kilobits/sec
```

```
Simpson#show interfaces serial 0 | begin Queue

Queueing strategy: weighted fair

Output queue: 0/1000/64/0 (size/max total/threshold/drops)

  Conversations 0/2/256 (active/max active/max total)

  Reserved Conversations 0/0 (allocated/max allocated)

  Available Bandwidth 1094 kilobits/sec
```

The first example shows the interface before applying RTP Priority. In this example, the interface has 1158 kbps available for all interface traffic. (1158 kbps is exactly 75 percent of the serial interface's bandwidth; the other 25 percent of the bandwidth is reserved for router control and signaling traffic.) The second example shows the same router interface after RTP Priority has been applied. In this example, RTP Priority was configured to reserve 64 kbps for the IP RTP strict-priority queue, so only 1094 kbps is left available for other all other unspecified traffic. The debug priority command displays WFO output drops for the strict-priority RTP queue.

As you can see, setting RTP Priority for interfaces with smaller amounts of bandwidth can help save resources for time-critical, delay-sensitive RTP traffic. This section has shown how you can apply traffic shaping, rate limiting, and voice traffic prioritization on an interface basis to provide policy enforcement using QoS techniques. The next section explores more powerful and granular QoS techniques that can be applied within Cisco IOS Software's class-based queuing solutions.

Class-Based Queuing Solutions

Class-Based Weighed Fair Queueing (CBWFQ) combines advantages of CQ and WFQ to create an advanced method that provides fair queuing to up to 64 user-defined classes. CBWFQ classes can be defined per access list, or input interface; each class has its own queue. Classes are customized using characteristics such as bandwidth, weight, and queue size. After a queue exceeds its maximum size, packets are dropped according to the default behavior, or WRED if configured to do so. Traffic that does not match any class characteristic is sent to the default queue where each flow (traffic sharing the same source and destination number) is fairly queued using WFQ.

Before configuring CBWFQ, you need to be aware of a number of rules, including the following:

- Before CBWFQ can be installed, interfaces must be running their default queuing method. CBWFQ uses the default method of queuing.
- Unless specified, CBWFQ uses tail drop rather than WRED when dropping packets.
- If you are planning to use CBWFQ with WRED, make sure that the interface is not already running WRED.
- CBWFQ does not support subinterfaces; it must be installed on a physical interface.
- CBWFQ supports only ATM variable bit rate (VBR) and available bit rate (ABR) circuits.
- Policy maps can be used for more than one interface, saving configuration space.
- The CBWFQ-configured bandwidth must not exceed 75 percent of the interface bandwidth. This is used for overhead control and routing traffic. If the bandwidth used by a policy map exceeds the configured bandwidth for an interface, the policy map is denied and removed from all other interfaces.
- CBWFQ, CQ, PQ, WFQ, and WRED are all mutually exclusive, service policies must be removed before a new queuing method can be installed.
- CBWFQ supports queue size limits and WRED, but not both in the same class policy.

As discussed in the following section, CBWFQ is a powerful QoS tool. Using CBWFQ, you can configure granular QoS policies managing different types of traffic in different ways on the same interface.

CBWFQ can also use Network-Based Application Recognition (NBAR) protocol heuristics specified with a protocol name. Although NBAR is not covered in great detail in this book, NBAR CBWFQ configuration is described later in this chapter.

NOTE

NBAR protocol heuristics help identify protocols and applications that previously required long and complicated access lists. NBAR uses packet description language modules (PDLMs) to define protocol characteristics. PDLMs can be found on the Cisco website in the Software Download area under Cisco IOS Software, Other Cisco IOS Extensions, Packet Description Language Modules. PDLMs are loaded like any other software code or configurations. After you have loaded a PDLM, you can specify it using the `ip nbar path: filename` command in global configuration mode.

NOTE

CBWFQ NBAR support requires the use of Cisco Express Forwarding (CEF) switching on the interface where the service policy is applied.

CBWFQ classes are defined using class maps. Class maps contain the match criterion, which is used to identify the protocol that belongs to each class. Class maps make use of the new Cisco IOS Software modular interface (CLI) and are created using the `class-map` command. The `class-map` command differs between Cisco IOS version 12.1 and 12.2. In 12.2, the optional `match-any` or `match-all` statement is added.

In Cisco IOS Software Release 12.2 and higher, you can also specify the type of class map by using the `match-all` or `match-any` statements. The `match-all` class map matches all of the criteria (logical AND), and the `match-any` class map matches any of the criteria specified by the class map (logical OR).

Cisco IOS Software Release 12.1:

```
class-map class-name
```

Cisco IOS Software Release 12.2:

```
class-map [match-any | match-all] class-name
```

NOTE

A number of QoS changes were made in Cisco IOS Software Release 12.2. In this chapter, Cisco IOS Software Release 12.2 is used in all examples. To remain compatible with Cisco IOS Software Release 12.1, use commands that are available in versions 12.1 and 12.2.

After you have created the class map, you enter the class map configuration mode, where you can criteria. Using the match command within the class map configuration mode, you can define class lists, input interfaces, protocol types, and many other items as definitions. [Table 6-20](#) shows the configuration commands and their definitions as of Cisco IOS Software Release 12.2(7).

Table 6-20. Class Map match Command Values

Match Command	IOS Version	Description
access-group { access-list-number nameaccess-list-name }	12.1	Matches an access list, ranging from 1 to 2699, or a named access list.
any	12.2	Matches any packets.
class-mapclass-map-name	12.2	Matches another nested class map.
cscos-value	12.2	Class of service (CoS) matches one of the IEEE 802.1Q/ISL class of service/user priority values, ranging from 0 to 7. Up to 4 CoS value entries may be made using spaces as separators.
destination-address machex-address	12.2	Matches an destination MAC address in hexadecimal xxxx.xxxx.xxxx format.
input-interfaceinterface-name interface-number	12.1	Matches an input interface.

<pre>ip {dscp{dscp-value} precedence{precedence-value} rtp{lower-port-range range}}</pre>	12.2	<p>ip dscp matches up to 8 DSCP values from 0 to 63, one of the 12 AF classes mentioned in Table 7-14, one of the 7 Class Selector (CS) codepoints corresponding to an IP precedence value, the default DSCP value, or the Expedited Forwarding (EF) PHB value.</p> <p>ip precedence matches (up to 4) IP precedence values using either an integer value (0–7), or the IP precedence names from Table 6-14.</p> <p>ip rtp matches a RTP UDP port number from 2000 to 65,535, and a RTP UDP port range from 0 to 16,383.</p>
<pre>mpls experimental{value}</pre>	12.2	<p>Multiprotocol label switching (MPLS).</p> <p>Matches up to 8 MPLS values, ranging from 0 to 7.</p>
<pre>not {access-group{access-list-number} any class-map{class-map-name} destination-address {mac hex address} input-interface{interface-name interface-number} ip {dscp{dscp-value} precedence{precedence-value} rtp{lower-port-range range}} mpls{value} qos-group{qos-group-index} sources-address {mac hex address}}</pre>	12.2	Does not match an access-group, any, class-map, destination-address, input-interface, ip, mpls, qos-group, or sources-address specified.
<pre>protocol{protocol-name}</pre>	12.1 [*]	<p>Matches the specified protocol using NBAR heuristics:</p> <ul style="list-style-type: none"> arp— IP ARP bgp— BGP protocol bridge— Bridging bstun— Block Serial Tunnel

cdp— Cisco Discovery Protocol
citrix— Citrix traffic
clns— ISO CLNS
clns_es— ISO CLNS end system
clns_is— ISO CLNS intermediate system
cmns— ISO CMNS
compressedtcp— Compressed TCP
cuseeme— CU-SeeMe desktop videoconference
custom-01— Custom protocol
custom-01
custom-02— Custom protocol
custom-02
custom-03— Custom protocol
custom-03
custom-04— Custom protocol
custom-04
custom-05— Custom protocol
custom-05
custom-06— Custom protocol
custom-06
custom-07— Custom protocol
custom-07
custom-08— Custom protocol
custom-08
custom-09— Custom protocol
custom-09
custom-10— Custom protocol
custom-10
dhcp— DHCP protocol
dlsw— Data-link switching
dns— DNS lookup
egp— EGP routing protocol
eigrp— EIGRP routing Protocol

exchange— MS-RPC for Exchange
fasttrack— FastTrack traffic
(KaZaA, Morpheus, Grokster, and
so on)
finger— Finger
ftp— FTP protocol
gnutella— Gnutella traffic
(BearShare,LimeWire,Gnutella, and
so on)
gopher— Gopher
gre— GRE tunneling protocol
http— HTTP web traffic
icmp— ICMP protocol
imap— IMAP Protocol
ip— IPv4 protocol
ipinip— IP in IP tunnel
encapsulation
ipsec— IP Security Protocol
(ESP/AH)
ipv6— IPv6
ipx— Novell IPX
irc— Internet Relay Chat
kerberos— Kerberos
authentication
l2tp— L2F/L2TP tunnel
ldap— LDAP directory protocol
llc2— LLC-2
napster— Napster traffic
netbios— NetBIOS
netshow— Microsoft NetShow
nfs— UNIX Network File System
nntp— Network News Transfer
Protocol
notes— Lotus Notes

novadigm— Novadigm EDM
ntp— Network Time Protocol
pad— X.25 PAD
pcanywhere— Symantec
pcANYWHERE
pop3— Post Office Protocol
pptp— Microsoft PPTP tunneling
printer— LPD print spooler
qllc— QLLC protocol
rcmd— BSD r commands (rsh,
rlogin, rexec)
realaudio— Real Audio streaming
protocol
rip— RIP routing protocol
rsrb— RSRB bridging
rsvp— RSVP protocol
rtp— Real Time Protocol
secure-ftp— FTP over TLS/SSL
secure-http— Secured HTTP
secure-imap— IMAP over TLS/SSL
secure-irc— IRC over TLS/SSL
secure-ldap— LDAP over TLS/SSL
secure-nntp— NNTP over TLS/SSL
secure-pop3— POP3 over
TLS/SSL
secure-telnet— Telnet over
TLS/SSL
smtp— SMTP protocol
snapshot— Snapshot routing
protocol
snmp— SNMP protocol
socks— SOCKS
sqlnet— SQL*NET for Oracle

		sqlserver— MS SQL Server
		ssh— Secured Shell
		streamwork— Xing Technology StreamWorks player
		stun— Serial Tunnel protocol
		sunrpc— Sun RPC
		syslog— System logging utility
		telnet— Telnet
		tftp— TFTP protocol
		vdolive— VDOLive streaming video
		vofr— Voice over Frame Relay
		xwindows— X Windows remote access
		xns— Xerox Network Services
qos-group qos-group-index	12.2	Matches a specified QoS group, ranging from 0 to 99.
source-address machex-address	12.2	Matches a source MAC address in hexadecimal format (xxxx.xxxx.xxxx).

[*] Not all protocols are available in all versions of Cisco IOS Software.

After you have entered class map configuration mode, you can do a number of things besides enter command. To configure a description for your class map, use the *description* command. To rename without removing it, use the *rename* command.

After defining the class map, you must then define a policy map to make the policy that will be applied. Policy maps are defined using the *policy-map policy-name* command, which enters you into configuration mode, specified by the (config-pmap)# prompt. The policy map is applied to interfaces or policies. To enter policy map configuration mode, use the *policy-map* command. In this mode, you can add a description to the policy map, alter the configuration, or rename the policy map.

NOTE

Using the Cisco Modular QoS command-line interface, you can also embed policies and classes within policies and classes, by which you can create very granular QoS configurations without the need to define each class or policy definition.

After you are in policy map configuration mode, you must define the class that the policy will apply with the *class-name* command, which enters you into policy map class configuration mode specified by the prompt.

After you are in policy map class configuration mode, the mode used to configure the policy for the specified, you can define the parameters for the service policy. [Table 6-21](#) shows the service policy

Table 6-21. Service Policy Parameters

Policy Command	IOS Version	Description
<pre>bandwidth {bandwidth-limit percent percentage remaining percent remaining-percentage)</pre>	12.1	<p>Assigns a bandwidth limit for the class. This limit can be either an amount specified in kbps or a percentage (not to exceed 75% of the interfaces bandwidth).</p> <p>To use a specific amount of bandwidth, enter the amount, ranging from 8 to 2,000,000 in kbps.</p> <p>To specify a percentage of interface bandwidth, use the percent or remaining percent keywords, followed by a value ranging from 1-100 percent.</p>
<pre>police {rate-bps{[normal-burst- [excess-burst] [bcnormal-burst] [bcexcess-burst] cirrate-bps [normal-burst] [excess-burst] [bc normal-burst] [beexcess-burst pir [peak-rate]excess-burst]} [conform-actionaction] [exceed- actionaction] [violate-action action] }</pre>	12.2	<p>Enables traffic policing for the traffic defined in this class.</p> <p>Class-Based policing is covered later in this chapter.</p>

<pre>priority {bandwidth <i>burst</i> percent <i>percentage burst</i>}</pre>	12.1	<p>Creates a strict-priority queue within the service policy, referred to as Low Latency Queuing (LLQ), which is covered later in this chapter.</p> <p>bandwidth defines a limit for the strict-priority queue, ranging from 8 to 2,000,000 in kbps.</p> <p>burst 32 to 2,000,000 in bytes.</p> <p>percent defines a percentage of bandwidth, from 1-100 percent.</p> <p>burst ranges from 32 to 200000 in bytes.</p>
<pre>queue-limit<i>number-of-packets</i></pre>	12.1	<p>Defines a maximum queue size. After the queue size has been exceeded, all packets are dropped using tail drop.</p> <p>The range is from 1 to 512 packets. The default value is 64 on all non-VIP-based platforms.</p>
<pre>random-detect [<i>dscp</i>] <i>dscp-value</i> <i>minimum-threshold</i> <i>max-threshold</i> <i>mark-probability-denominator</i> <i>dscp-based</i> <i>ecn</i> <i>exponential-weighing-constant</i> <i>weighted-average</i> <i>precedence</i> [<i>precedence-value</i>] <i>minimum-threshold</i> <i>max-threshold</i> <i>mark-probability-denominator</i> <i>rsvp</i> <i>minimum-threshold</i> <i>max-threshold</i> <i>mark-probability-denominator</i>]</pre>	12.1 [*]	<p>Enables WRED for packets that exceed the maximum queue size.</p> <p><i>dscp value</i> matches (up to 4 values) a DSCP value from 0 to 63, one of the 12 AF classes, one of the 7 Class Selector (CS) code-points corresponding to an IP precedence value (1–7), the default DSCP value, the Expedited Forwarding (EF) PHB value, or RSVP traffic specifying a minimum and maximum threshold in packets and optionally the RSVP mark probability denominator. You can find the AF, CS, and EF value descriptions in Table 7-14.</p> <p><i>dscp-based</i> enables DSCP-based WRED rather than precedence-based WRED.</p> <p><i>ecn</i>—Explicit congestion notification.</p> <p><i>exponential-weighting-constant</i> specifies the weight to be used by WRED when calculating average queue length; the default weight factor is 9.</p>

		<p>Ranges from 1 to 16 in the format $2^{\wedge} [number]$.</p> <p>prec-based enables precedence-based WRED, the default WRED behavior.</p> <p>precedence configures the parameters for the IP precedence values—for each IP precedence value from 0 to 7, the minimum and maximum threshold of a packet that must be reached for packet drop, and the mark probability denominator that defines the fraction of packets that are dropped when the thresholds have been exceeded.</p>
service-policy	12.2	Specifies another nested policy map name.
shape	12.2	<p>Configures class-based shaping, covered later in this chapter.</p> <p>average $CIR[Bc] / Be$.</p> <p>max-buffers configures a maximum buffer limit.</p> <p>peak $CIR[Bc] / Be$.</p>

[*] DSCP commands do not appear until 12.2

By default, all traffic that has not been defined as belonging to a class is provided with best-effort service. A default class can also be defined. Default classes allow for the configuration of any unclassified traffic. Unclassified traffic in the default class can either be given the same level of service that would achieve fairness on a shared enabled interface, with each unclassified traffic flow receiving a fair share of the remaining bandwidth, or it can be queued on a FIFO basis with a bandwidth restriction.

The default class is defined by creating a class-default class, using the command `class class-default` in policy map configuration mode, which enters you into policy map class configuration mode for the class.

```
Router(config-pmap)#class class-default
```

When you are defining the class-default class, the `fair-queue` command becomes available, allowing you to enable fair queuing for the traffic in the class.

unclassified traffic to be queued using WFQ. This command is available only for the default class:

fair-queue dynamic-queue-limit

Using the fair-queue command, you can define a dynamic queue limit for all WFQ traffic in the default class. The *dynamic-queue-limit* ranges from 16 to 4096 and can be entered in powers of 2 ($2^{[number]}$).

Alternatively, instead of configuring WFQ for the remaining unclassified traffic, you can set a bandwidth limit for FIFO best-effort queuing with the bandwidth command.

NOTE

When configuring the default class, it is important to note that either WFQ or a bandwidth limit can be configured, but both commands cannot be configured together.

The default class can also have class parameters, such as traffic policing, IP RTP Priority, tail drop limits, WRED, and class-based shaping, as mentioned previously in [Table 6-21](#).

After the class map has been characterized and the policy map has been defined, you now have a service policy. To apply the service policy to an interface, use the service-policy command in interface configuration mode. Enter the service policy command on either inbound or outbound interface traffic by using the input or output arguments:

```
Interface serial0  
service-policy {input | output} policy-name
```

Using CBWFQ, you can classify traffic types into service groups and apply the appropriate policies to each group. You can also define traffic limitations or prioritization. In the following example, two classes are defined. ClassIP provides a guaranteed interface bandwidth to IP traffic and also uses WRED as a congestion-avoidance mechanism. ClassNonIP provides a guaranteed interface bandwidth to NonIP traffic and also uses WRED as a congestion-avoidance mechanism.

25 percent of the interface bandwidth to IPX traffic; because IPX is not supported by WRED, however, congestion, tail drop is used to discard packets. Any other remaining unclassified traffic is to be queued:

Step 1. The first step required for CBWFQ configuration is to define the class. In this example, to match all IP traffic:

```
Simpson(config)#class-map ClassIP
```

Step 2. After the class has been defined, from within the class map configuration mode, define characteristics. The ClassIP class must match all IP packets, so the match protocol ip state the match criteria has been defined, you can exit class map configuration mode:

```
Simpson(config-cmap)#match protocol ip  
Simpson(config-cmap)#exit
```

Step 3. (Optional) Create any other required classes, up to 64. This step is required for each will be used for the service policy. In this example, ClassIPX is defined to match all IPX traffic:

```
Simpson(config)#class-map ClassIPX  
Simpson(config-cmap)#match protocol ipx  
Simpson(config-cmap)#exit
```

Step 4. Create a policy map. The policy map is used to define class policies. One policy map classes and their policies. In this example, the myPolicy policy is used for the class policy def and ClassIPX:

```
Simpson(config)#policy myPolicy
```

Step 5. Specify the class map to be used with the service policy under the policy map. To cre for the IP traffic, ClassIP is specified under myPolicy:

```
Simpson(config-pmap)#class ClassIP
```

Step 6. Within the policy map class configuration mode, specify the policy parameters. As m ClassIP is assigned 50 percent of the interface bandwidth. This is accomplished using the bai 50 command. To configure the policy to use WRED for IP congestion avoidance, the random used without any parameters:

```
Simpson(config-pmap-c)#bandwidth percent 50
```

```
Simpson(config-pmap-c)#random-detect
```

```
Simpson(config-pmap-c)#exit
```

Step 7. (Optional) If necessary, repeat Steps 5 and 6 for each class definition. Next, ClassIP percent of the interface bandwidth:

```
Simpson(config-pmap)#class ClassIPX  
Simpson(config-pmap-c)#bandwidth percent 25  
Simpson(config-pmap-c)#exit
```

Step 8. (Optional) Create a default class for all unclassified traffic. In this example, a default queue any unclassified traffic using up to 16 dynamic WFQ queues:

```
Simpson(config-pmap)#class class-default  
Simpson(config-pmap-c)#fair-queue 16  
Simpson(config-pmap-c)#exit  
Simpson(config-pmap)#exit
```

Step 9. After you finish creating the class map and policy, apply the policy to an interface using the **service-policy** command. To activate the service policy, it is applied to an interface. In this example, outbound traffic on interface serial 0/1:

```
Simpson(config)#int s 0/1  
Simpson(config-if)#service-policy output myPolicy
```

Step 10. [Example 6-28](#) shows the complete configuration for the example from the preceding steps.

Example 6-28. Final Configuration for the CBWFQ Example

```
class-map match-all ClassIPX
  match protocol ipx

class-map match-all ClassIP
  match protocol ip

!
policy-map myPolicy
  class ClassIP
    bandwidth percent 50
    random-detect
  class ClassIPX
    bandwidth percent 25
  class class-default
    fair-queue 16
!
interface Serial0/1
  ip address 192.168.3.1 255.255.255.252
  ipx network 10AB
  service-policy output myPolicy
```

Step 11. Monitor and verify the configuration for the policy using the show policy-map or map interface commands. The show policy-map myPolicy command shows how myPolicy in this example, ClassIP is configured with 50 percent of the interface bandwidth to IP traffic using the default WRED IP precedence settings. ClassIPX limits all IPX traffic to 25 percent of bandwidth using tail drop in the event of congestion. And all unclassified traffic is assigned to class-default is queued using WFQ:

```
Simpson#show policy-map myPolicy
```

```
Policy Map myPolicy
```

```
Class ClassIP
```

```
Bandwidth 50 (%)
```

```
    exponential weight 9
```

class	min-threshold	max-threshold	mark-probability
-------	---------------	---------------	------------------

-	-	-	-
---	---	---	---

0	-	-	1/10
---	---	---	------

1	-	-	1/10
---	---	---	------

2	-	-	1/10
---	---	---	------

3	-	-	1/10
---	---	---	------

4	-	-	1/10
---	---	---	------

5	-	-	1/10
---	---	---	------

6	-	-	1/10
---	---	---	------

7	-	-	1/10
---	---	---	------

rsvp	-	-	1/10
------	---	---	------

```
Class ClassIPX
```

```
Bandwidth 25 (%) Max Threshold 64 (packets)
```

```
Class class-default
```

```
    Flow based Fair Queueing
```

```
Bandwidth 0 (kbps) Max Threshold 64 (packets)
```

The show policy-map interface serial 0/1 command displays detailed information on the service 0/1, including the number of packets sent, packet transmission rate, number of dropped packets, r packets, and detailed queuing information.

```
Simpson#sh policy-map interface serial 0/1
```

```
Serial0/1
```

```
Service-policy output: myPolicy
```

```
Class-map: ClassIP (match-all)
```

```
5 packets, 520 bytes
```

```
5 minute offered rate 0 bps, drop rate 0 bps
```

```
Match: protocol ip
```

```
Queueing
```

```
Output Queue: Conversation 25
```

```
Bandwidth 50 (%)
```

```
Bandwidth 772 (kbps)
```

```
(pkts matched/bytes matched) 5/520
```

```
(depth/total drops/no-buffer drops) 0/0/0
```

```
exponential weight: 9
```

```
mean queue depth: 0
```

class	Transmitted	Random drop	Tail drop	Minimum	Maximum	Mark
	pkts/bytes	pkts/bytes	pkts/bytes	thresh	thresh	prob
0	5/520	0/0	0/0	20	40	1/10
1	0/0	0/0	0/0	22	40	1/10
2	0/0	0/0	0/0	24	40	1/10
3	0/0	0/0	0/0	26	40	1/10
4	0/0	0/0	0/0	28	40	1/10
5	0/0	0/0	0/0	30	40	1/10

	0 / 0	0 / 0	0 / 0	32	40	1 / 10
6	0 / 0	0 / 0	0 / 0	34	40	1 / 10
7	0 / 0	0 / 0	0 / 0	36	40	1 / 10
rsvp	0 / 0	0 / 0	0 / 0			

Class-map: ClassIPX (match-all)

0 packets, 0 bytes

5 minute offered rate 0 bps, drop rate 0 bps

Match: protocol ipx

Queueing

Output Queue: Conversation 26

Bandwidth 25 (%)

Bandwidth 386 (kbps) Max Threshold 64 (packets)

(pkts matched/bytes matched) 0/0

(depth/total drops/no-buffer drops) 0/0/0

Class-map: class-default (match-any)

140 packets, 9840 bytes

5 minute offered rate 0 bps, drop rate 0 bps

Match: any

Queueing

Flow Based Fair Queueing

Maximum Number of Hashed Queues 16

(total queued/total drops/no-buffer drops) 0/0/0

When monitoring a CBWFQ-enabled interface, you can use the show interface output to display the configuration, including the queuing strategy, queuing counters, and whether WFO is enabled, as well as the WFO queues and RSVP conversations. Before you apply any CBWFQ commands, the band

show interfaces command will be equal to the 75 percent of the interface bandwidth. That is the amount available to be used by CBWFQ; the other 25 percent is reserved for router control traffic and in this example, the available bandwidth prior to the CBWFQ configuration was 1158 kb, 75 percent or 868 kb available on the serial interface. After applying the CBWFQ configuration, the interface's available bandwidth is 0 kb. If the bandwidth configured using the bandwidth command within a service policy exceeds the amount available, the policy will be removed from the interface and any other interfaces that it is applied to. The amount of bandwidth available for CBWFQ by using the max-reserved-bandwidth *percent* configuration mode, although using this command may seriously affect router performance. [Example](#) shows how CBWFQ affects the output from the show interfaces command before and after applying CBWFQ.

Example 6-29. CBWFQ and the show interfaces Command

```
Simpson#show interfaces serial 0/1

Serial0/1 is up, line protocol is up

Hardware is PowerQUICC Serial

Internet address is 192.168.3.1/24

MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 252/255, txload 1/255, rxload 1/255

Encapsulation HDLC, loopback not set

Keepalive set (10 sec)

Last input 00:00:09, output 00:00:00, output hang never

Last clearing of "show interface" counters never

Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0

Queueing strategy: weighted fair

Output queue: 0/1000/64/0 (size/max total/threshold/drops)

  Conversations 0/1/16 (active/max active/max total)

  Reserved Conversations 0/0 (allocated/max allocated)

  Available Bandwidth 1158 kilobits/sec

5 minute input rate 0 bits/sec, 0 packets/sec

5 minute output rate 0 bits/sec, 0 packets/sec

  74999 packets input, 4663284 bytes, 0 no buffer

  Received 60312 broadcasts, 0 runts, 0 giants, 0 throttles

  7 input errors, 0 CRC, 7 frame, 0 overrun, 0 ignored, 0 abort
```

```
60335 packets output, 4175959 bytes, 0 underruns  
0 output errors, 0 collisions, 15 interface resets  
0 output buffer failures, 0 output buffers swapped out  
13 carrier transitions  
DCD=up DSR=up DTR=up RTS=up CTS=up
```

```
Simpson#show interfaces serial 0/1
```

```
Serial0/1 is up, line protocol is up  
  
Hardware is PowerQUICC Serial  
  
Internet address is 192.168.3.1/24  
  
MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,  
reliability 255/255, txload 1/255, rxload 1/255  
  
Encapsulation HDLC, loopback not set  
  
Keepalive set (10 sec)  
  
Last input 00:00:06, output 00:00:06, output hang never  
  
Last clearing of "show interface" counters never  
  
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0  
  
Queueing strategy: weighted fair  
  
Output queue: 0/1000/64/0 (size/max total/threshold/drops)  
  
Conversations 0/1/16 (active/max active/max total)  
  
Reserved Conversations 2/2 (allocated/max allocated)  
  
Available Bandwidth 0 kilobits/sec  
  
5 minute input rate 0 bits/sec, 0 packets/sec  
  
5 minute output rate 0 bits/sec, 0 packets/sec  
  
74950 packets input, 4660302 bytes, 0 no buffer  
  
Received 60263 broadcasts, 0 runts, 0 giants, 0 throttles  
  
6 input errors, 0 CRC, 6 frame, 0 overrun, 0 ignored, 0 abort  
  
60284 packets output, 4172143 bytes, 0 underruns
```

```

0 output errors, 0 collisions, 14 interface resets

0 output buffer failures, 0 output buffers swapped out

13 carrier transitions

DCD=up  DSR=up  DTR=up  RTS=up  CTS=up

```

This section introduced CBWFQ and described some ways that you can apply this technology to manage traffic based on classes. The next section discusses CBWFQ's own traffic-shaping mechanism: class

Class-Based Shaping

As mentioned in the preceding section, as of Cisco IOS Software Release 12.2, it is possible to enable CBWFQ for service policies using class-based shaping. Class-based shaping enables you to configure class-by-class basis within service policies rather than a per-interface basis using GTS. Class-based shaping from within CBWFQ by using the `shape` command in policy map class configuration mode. [Table 6](#) lists the class-based shaping command and its arguments:

```

shape {average target-bit-rate [sustained-bit-rate] [excess-per-interval] | peak
      target-bit-rate [sustained-bit-rate] [excess-per-interval] | max-buffers buffers

```

Table 6-22. Class-Based Shaping Command Arguments and Their Descriptions

Command	Description
---------	-------------

<p><code>averagetarget-bit-rate</code> <code>[sustained-bit-rate]</code> <code>[excess-per-interval]</code></p>	<p>The CBS average command configures the router to shape traffic to an average rate; with average-rate shaping, the shaper shapes all traffic to the normal burst rate for each interval. Like the GTS CIR, the target bit rate is the normal rate at which traffic will be transmitted (CIR), ranging from 8000 to the interface's full bit rate in bits per second. For example, a 1.544-Mbps interface's full CIR will range from 8000 to 154,400,000.</p> <p>(Optional) Like the GTS sustained bit rate (Bc), the CBS sustained bit rate is that traffic is allowed to burst to a multiple of 128 ranging from 256 to 1,544,000 (on a serial interface) in bits per interval. Cisco recommends that instead of manually calculating the value, you let the algorithm configure the sustained bit rate.</p> <p>You can find the sustained burst rate that the traffic can burst per interval by using the following formula:</p> $Bc = Tc * CIR$ <p>(Optional) The excess bit/interval (Be) that traffic is allowed to burst to beyond the sustained bit rate, a multiple of 128 ranging from 0 to 1,544,000 (on a serial interface) in bits per interval. Cisco recommends that instead of manually calculating the value, you let the algorithm configure the sustained bit rate. If the Be is not entered, the software assumes that Be = Bc.</p> <p>Excess burst will always be greater than normal bursts, so the recommended formula for finding Be is this:</p> $Be = Bc * 2$
<p><code>peaktarget-bit-rate</code> <code>[sustained-bit-rate]</code> <code>[excess-per-interval]</code></p>	<p>The CBS peak command configures the router to shape traffic to the peak rate (Be + Bc) per interval. With peak-rate shaping, if tokens are available, traffic is shaped to the normal burst rate, but the excess burst per interval. Like the GTS CIR, the target bit rate is the normal rate that traffic will be transmitted at (CIR), ranging from 8000 to the interface's full bit rate in bits per second. For example, a 1.544-Mbps interface's full CIR will range from 8000 to 1,544,000.</p> <p>(Optional) Like the GTS sustained bit rate (Bc), the CBS sustained bit rate is that traffic is allowed to burst to a multiple of 128 ranging from 256 to 1,544,000 (on a serial interface) in bits per interval. Cisco recommends that instead of manually calculating the value, you let the algorithm configure the sustained bit rate.</p>

peaktarget-bit-rate	You can find the sustained burst rate that the traffic can burst per interval by using the following formula:
[sustained-bit-rate]	$B_c = T_c * CIR$
[excess-per-interval]	(Optional) The excess bit/interval (Be) that traffic is allowed to burst to beyond the sustained bit rate, a multiple of 128 ranging from 0 to 1,544,000 (on a serial interface) in bits per interval. Cisco recommends that instead of manually calculating the value you let the algorithm configure the sustained bit rate. If the Be is not entered, the software assumes that Be = Bc. Excess burst will always be greater than normal bursts, so the recommended formula for finding Be is this: $Be = B_c * 2$
max-buffersbuffers	(Optional) Used to specify a buffer limit ranging from 1 to 4096.

The `shape` command is similar to the `traffic-shape` command used by GTS, having two choices for *average* and *peak*. If you use *average*, the shaping type traffic is shaped to the amount specified in (CIR), with the option to configure a sustained bit rate (Bc) and an excess bit rate (Be). The peak traffic to burst past the CIR to a peak rate when bandwidth is available using the CIR, Be, and Bc as [Example 6-30](#); however, Cisco does not recommend manual configuration of the normal and excess when using CBS.

Example 6-30. Using Class-Based Shaping with WFQ

```

class-map match-all Internet-traffic

match protocol ip

match access-group 101

!

!

policy-map Internet

class Internet-traffic

bandwidth percent 20

shape peak 768000 19200 38400

!

interface Serial0/1

```

```
ip address 36.128.42.11 255.255.255.0
service-policy output Internet
!
access-list 101 permit tcp any any eq www
access-list 101 permit tcp any host 192.168.1.1 eq ftp
access-list 101 permit tcp any host 192.168.1.1 gt 1023 established
```

In this example, all web and passive FTP traffic exiting interface serial 0/1 is to be shaped to a 768 limited to 20 percent of the interface's bandwidth. Under circumstances where there is available bandwidth, burst up to the 38,400 bits per interval if tokens are available, which is specified with the `pe` parameter. [Example 6-31](#) verifies the configuration with the `show policy-map` command.

Example 6-31. Verifying the Class-Based Shaping Configuration

```
Internet-Router#show policy-map Internet
Policy Map Internet
Class Internet-traffic
  Bandwidth 20 (%) Max Threshold 64 (packets)
  Traffic Shaping
    Peak Rate Traffic Shaping
      CIR 768000 (bps) Max. Buffers Limit 1000 (Packets)
      Bc 19200          Be 38400
```

```
Internet-Router# show policy-map interface serial 0/1
```

```
Serial0/1
```

```
Service-policy output: Internet
```

```
Class-map: Internet-traffic (match-all)
  0 packets, 0 bytes
```

```
5 minute offered rate 0 bps, drop rate 0 bps
```

```
Match: protocol ip
```

```
Match: access-group 101
```

```
Queueing
```

```
Output Queue: Conversation 265
```

```
Bandwidth 20 (%)
```

```
Bandwidth 308 (kbps) Max Threshold 64 (packets)
```

```
(pkts matched/bytes matched) 0/0
```

```
(depth/total drops/no-buffer drops) 0/0/0
```

```
Traffic Shaping
```

Target/Average	Byte	Sustain	Excess	Interval	Increment
Rate	Limit	bits/int	bits/int	(ms)	(bytes)
2304000/768000	7200	19200	38400	25	7200

Adapt	Queue	Packets	Bytes	Packets	Bytes	Shaping
Active	Depth			Delayed	Delayed	Active
-	0	0	0	0	0	no

```
Class-map: class-default (match-any)
```

```
3 packets, 404 bytes
```

```
5 minute offered rate 0 bps, drop rate 0 bps
```

```
Match: any
```

Now that you can see how easy it is to add traffic shaping policy to traffic classes using CBWFQ, co policing applies within CBWFQ.

Class-Based Policing

When traffic policy must be enforced, and actions are to be performed when traffic complies, exceeds certain rates, you might consider using traffic policing. *Traffic policing* enables you to configure and

policies that can limit either inbound or outbound traffic with user-defined criteria. You define the traffic policies using class maps and policy maps, and applying the resulting traffic service policies to interfaces. You can use traffic policing to enforce a maximum traffic rate by transmitting, dropping, or marking packets.

Earlier in the chapter, you learned about traffic shaping and rate limiting with CAR. This section explains how traffic policing is used to enforce traffic rates, the same type of principles that apply to traffic shaping. Traffic shaping, for instance, when outbound traffic is being shaped, it is being buffered at the egress interface. Traffic shaping and traffic policing both use a token-bucket algorithm; tokens are replenished at the traffic rate. When a packet arrives, there must be enough tokens in the token bucket. Traffic policing applies to incoming and outgoing traffic. Traffic shaping does not use buffering to enforce policies. With traffic shaping, tokens are added only to the bucket when a packet arrives. With traffic policing, tokens are always being added back into the bucket. If there are not enough tokens in the bucket when a packet arrives, the packet is dropped or classified; traffic policing does not queue packets. Traffic policing does not remove tokens from the bucket when either an exceed or violate action takes place.

During traffic bursts, traffic is either dropped or marked. Because traffic policing does not support I shaping, traffic policing drops packets that exceed the interface's bandwidth limits. That is why traffic classification is used to mark packets for later action based on QoS values, such as the ATM CLP bit, Frame Relay DE bit, IP precedence, or DSCP values. When traffic is usually at an edge device, other QoS methods, such as WFQ, WRED, or traffic shaping, can be applied. So, if the interface has the bandwidth to forward a burst packet, and the traffic policy permits it, the packet will be forwarded with the appropriate traffic policy. The traffic policy for the transmitted burst packet shows the type of action; this action should mark the packet as a burst packet by setting a discard bit or marking it. If normal and excess burst parameters are correctly configured, traffic policing should encourage end hosts to increase their TCP window size when they realize packets have been dropped, preventing global synchronization issues.

Another behavior that differs among traffic shaping, CAR, and traffic policing is the use of the two-traffic shaping, when you define a violate action, you are actually defining a second bucket that will already exceed the normal and excess burst rate.

Traffic policing is configured using the police statement in policy map class configuration mode with the `police` command. There are several ways to configure traffic policing in Cisco IOS Software using the `police` command. One way, shown here, is to enter all the traffic-policing parameters, simultaneously, which can be quite cumbersome.

```
police {rate-bps {[normal-burst] [excess-burst] | [bc normal-burst] [bc excess-bu  
cir rate-bps [normal-burst] [excess-burst] [bc normal-burst] [be excess-burst |  
[peak-rate]excess-burst]} [conform-action {action | exceed-action} [exceed-actio  
action [violate-action action]
```

The other way to configure traffic policing is by entering the policy map police configuration mode command, as shown here:

```
police {rate-bps {[normal-burst] [excess-burst] | [bc normal-burst] [bc excess-bu  
cir rate-bps [normal-burst] [excess-burst] [bc normal-burst] [be excess-burst |  
[peak-rate]excess-burst]}
```

After the police command has been issued, you will be transferred into policy map police configuration mode by the Router(config-pmap-c-police)# prompt. In this mode, you can issue or remove any conform, exceed, and violate actions, one at a time, without having to type long commands. The conform, exceed, and violate actions follow:

```
conform-action {drop | set-clp-transmit | set-dscp-transmit dscp-value | set frde-t  
| set-mpls-exp-transmit mpls-experimental-value | set-prec-transmit precedence-v  
set-qos-group gos-group-index | transmit}  
  
exceed-action {drop | set-clp-transmit | set-dscp-transmit dscp-value | set frde-t  
| set-mpls-exp-transmit mpls-experimental-value | set-prec-transmit precedence-v  
set-qos-group gos-group-index | transmit}  
  
violate-action {drop | set-clp-transmit | set-dscp-transmit dscp-value | set frde-t  
| set-mpls-exp-transmit mpls-experimental-value | set-prec-transmit precedence-v  
set-qos-group gos-group-index | transmit}
```

[Table 6-23](#) shows the police command and policy map police configuration mode command arguments and descriptions.

Table 6-23. Traffic Policing Commands and Descriptions

Command Argument	Description
traffic-rate	The average traffic rate, under normal conditions, over a period of time in bits/second, ranging from 0 to 2,000,000,000: $CIR = Tc/Bc \text{ in bps}$
normal-burst	(Optional) Specifies the normal burst size, ranging from 1000 to 512,000,000: $Bc(\text{in bytes}) = CIR(\text{in bps}) * (1.5 \text{ seconds})$ Note: 1.5 seconds is an average round-trip time. If the average round-trip time is not 1.5 seconds, change this value to accurately represent the time.
excess-burst	(Optional) Specifies the excess burst size, ranging from 1000 to 512,000,000: $Be(\text{in bytes}) = Bc * 2$
conform-action	(Optional) Any packets conforming to the traffic profile will do the activity specified by the no-drop command.
drop	Specifies the conform action to be performed.
exceed-action	Skips redundant action configuration and goes straight to exceed action. This is useful when conform and exceed actions are the same.
set-clp-transmit	Sets the ATM cell loss priority (CLP) for the cell.

<code>set-frde-transmit</code>	Sets the Frame Relay discard eligible and transmits the packet.
<code>set-dscp-transmitdscp-value</code>	Sets the DSCP value (ranging from 0 to 7) and transmits the packet.
<code>set-mpls-exp-transmitmpls-experimental-value</code>	Sets the MPLS experimental value (ranging from 0 to 255) and transmits the packet.
<code>set-prec-transmitprecedence-value</code>	Sets the IP precedence value (ranging from 0 to 7) and transmits the packet.
<code>set-qos-groupqos-group-index</code>	Sets the QoS group number (ranging from 0 to 7) and transmits the packet.
<code>transmit</code>	Transmits the packet.
<code>[exceed-action {drop set-clp-transmit set-frde-transmit set-dscp-transmitdscp-value set-mpls-exp-transmitmpls-experimental-value set-prec-transmitprecedence-value set-qos-groupqos-group-index transmit}]</code>	(Optional) The exceed-action command to take when traffic is in the next burst range (Bc to Be). The exceed-action is accompanied by an action to perform.
<code>[violate-action {drop set-clp-transmit set-frde-transmit set-dscp-transmitdscp-value set-mpls-exp-transmitmpls-experimental-value set-prec-transmitprecedence-value set-qos-groupqos-group-index transmit}]</code>	(Optional) The violate-action command to take when traffic has surpassed the burst range (Be). The violate-action is accompanied by an action to perform.

There are four or five steps (depending on whether you decide to use the long form of the command policy map police mode form of the command) required in traffic policy configuration: defining the specify traffic characteristics, defining the policies that contain the police actions to take upon traffic the resulting service policy to an interface, and verifying and monitoring the configuration.

Step 1. Define the traffic class using the class-map command. The traffic class is used to define matched by the policy. In this example, class IP-traffic is used to match all IP traffic, and Class matches all IPX traffic:

```
Simpson(config)#class-map IP-traffic  
Simpson(config-cmap)#match protocol ip  
Simpson(config-cmap)#exit  
Simpson(config)#class-map IPX-traffic  
Simpson(config-cmap)# match protocol ipx  
Simpson(config-cmap)#exit
```

Step 2. Define a policy to use for service policy configuration, and assign traffic policies to class. For example, policy WAN-traffic is used to limit all IP traffic to 512 kbps with a 96,000-byte burst size. The formula is CIR * (1byte) / (8 bits) * 1.5 seconds. This formula is recommended by Cisco. Packets conforming to the policy are transmitted, and traffic exceeding the policy is dropped. The same type of policy is also configured using class IPX-traffic:

```
Simpson(config)#policy-map WAN-traffic  
Simpson(config-pmap)#class IP-traffic  
Simpson(config-pmap-c)#police 512000 96000 conform-action transmit exceed-action drop  
Simpson(config-pmap-c)#exit
```

```
Simpson(config)#policy-map WAN-traffic  
Simpson(config-pmap)#class IPX  
Simpson(config-pmap-c)#police 512000 96000 conform-action transmit exceed-action drop  
Simpson(config-pmap-c)#exit  
Simpson(config-pmap)#exit
```

Step 3. Or if you used the modular policy map police configuration mode method, you would use the 512000 96000 command to enter policy map police configuration mode. You would then enter the exceed actions in that mode, as shown here:

```
Simpson(config-pmap-c)#police 512000 96000  
Simpson(config-pmap-c-police)#  
Simpson(config-pmap-c-police)#conform-action transmit  
Simpson(config-pmap-c-police)#exceed-action drop  
Simpson(config-pmap-c-police)#exit  
Simpson(config-pmap-c)#class IPX-traffic  
Simpson(config-pmap-c)#police 512000 96000  
Simpson(config-pmap-c-police)#  
Simpson(config-pmap-c-police)#conform-action transmit  
Simpson(config-pmap-c-police)#exceed-action drop  
Simpson(config-pmap-c-police)#exit  
Simpson(config-pmap-c)#exit
```

Step 4. Assign the policy map to an interface as a service policy:

```
Simpson(config)#interface serial 0/1  
Simpson(config-if)#service-policy output WAN-traffic
```

Step 5. Verify the configuration. To verify and monitor the traffic-policing configuration, use map or show policy-map interface command. The show policy-map command displays the current traffic policy configuration, and the show policy-map interface command displays information about the state of the current traffic policies:

```
Simpson#show policy-map WAN-traffic  
  
Policy Map WAN-traffic  
  
  Class IP-traffic  
  
    police cir 512000 bc 96000  
  
      conform-action transmit  
  
      exceed-action drop  
  
  Class IPX-traffic  
  
    police cir 512000 bc 96000  
  
      conform-action transmit  
  
      exceed-action drop  
  
Simpson#show policy-map interface serial 0/1  
  
Serial0/1  
  
  Service-policy output: WAN-traffic  
  
    Class-map: IP-traffic (match-all)  
  
      6887 packets, 5241646 bytes
```

```
5 minute offered rate 121000 bps, drop rate 75000 bps
```

```
Match: protocol ip
```

```
police:
```

```
  cir 512000 bps, bc 96000 bytes
```

```
conformed 4351 packets, 1857386 bytes; actions:
```

```
    transmit
```

```
exceeded 2536 packets, 3384260 bytes; actions:
```

```
    drop
```

```
conformed 46000 bps, exceed 75000 bps
```

```
Class-map: IPX-traffic (match-all)
```

```
0 packets, 0 bytes
```

```
5 minute offered rate 0 bps, drop rate 0 bps
```

```
Match: protocol ipx
```

```
police:
```

```
  cir 512000 bps, bc 96000 bytes
```

```
conformed 0 packets, 0 bytes; actions:
```

```
    transmit
```

```
exceeded 0 packets, 0 bytes; actions:
```

```
    drop
```

```
conformed 0 bps, exceed 0 bps
```

```
Class-map: class-default (match-any)
```

```
19 packets, 1428 bytes
```

```
5 minute offered rate 0 bps, drop rate 0 bps
```

```
Match: any
```

[Example 6-32](#) shows how traffic policing is used to assign traffic policies to different types of traffic

uses access list 101 to specify SNMP, DNS, DHCP, syslog, and TFTP traffic. Class user-traffic uses a specify NetBIOS and Telnet traffic as user traffic. And class internet uses access list 103 to define I-passive FTP traffic to host 10.1.1.141 as Internet traffic. These classes are each assigned traffic police command for each class under policy traffic-policy. Class management is assigned a 2-Mbps 375,000-byte normal burst and a 750,000-byte extended burst. Packets that conform to the norma to an IP precedence value of Flash-override (4) and transmitted. When traffic from class managem excess burst rate, it is still transmitted, but the IP precedence value for the packet is no longer cha the user-traffic class conforming to the normal traffic rate of 3 Mbps with a normal burst of 562,50 extended burst of 1,125,000 bytes has its IP precedence value set to Flash (3) and is still transmitl burst rate has been exceeded. Traffic from the internet class that conforms to the rate limit of 5 Mbps burst of 937,500 bytes and an extended burst of 1,875,000 is transmitted; traffic exceeding that re

Example 6-32. Using Traffic Policing to Regulate Traffic

```
class-map match-all management
  match access-group 101

class-map match-all internet
  match access-group 103

class-map match-all user-traffic
  match access-group 102
!

policy-map traffic-policy
  class management
    police cir 2000000 bc 375000 be 750000
      conform-action set-prec-transmit 4
      exceed-action transmit

  class user-traffic
    police cir 3000000 bc 562500 be 1125000
      conform-action set-prec-transmit 3
      exceed-action transmit

  class internet
    police cir 5000000 bc 937500 be 1875000
      conform-action transmit
      exceed-action drop
```

```

!
interface Ethernet0/0
  ip address 10.1.1.101 255.255.255.0
  service-policy output traffic-policy
!
access-list 101 permit udp any any eq snmp
access-list 101 permit udp any any eq domain
access-list 101 permit tcp any any eq domain
access-list 101 permit udp any any eq bootps
access-list 101 permit udp any any eq bootpc
access-list 101 permit udp any any eq syslog
access-list 101 permit udp any any eq tftp
access-list 102 permit udp any any eq netbios-dgm
access-list 102 permit udp any any eq netbios-ns
access-list 102 permit udp any any eq netbios-ss
access-list 102 permit tcp any any eq telnet
access-list 103 permit tcp any any eq www
access-list 103 permit tcp any host 10.1.1.141 eq ftp
access-list 103 permit tcp any host 10.1.1.141 gt 1023 established

```

Example 6-33 shows how the show policy-map command and the show policy-map interface command provide information about the traffic-policy policy.

Example 6-33. Using the show policy-map Command

```
Simpson#show policy-map traffic-policy
```

```
Policy Map traffic-policy
```

```
  Class management
```

```
police cir 2000000 bc 375000 be 750000
    conform-action set-prec-transmit 4
    exceed-action transmit

Class user-traffic

police cir 3000000 bc 562500 be 1125000
    conform-action set-prec-transmit 3
    exceed-action transmit

Class internet

police cir 5000000 bc 937500 be 1875000
    conform-action transmit
    exceed-action drop
```

```
Simpson#show policy-map interface ethernet 0/0
```

```
Ethernet0/0
```

```
Service-policy output: traffic-policy
```

```
Class-map: management (match-all)
  0 packets, 0 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: access-group 101

police:
  cir 2000000 bps, bc 375000 bytes
  conformed 0 packets, 0 bytes; actions:
    set-prec-transmit 4
  exceeded 0 packets, 0 bytes; actions:
    transmit
  conformed 0 bps, exceed 0 bps
```

```
Class-map: user-traffic (match-all)

 0 packets, 0 bytes

 5 minute offered rate 0 bps, drop rate 0 bps

Match: access-group 102

police:

  cir 3000000 bps, bc 562500 bytes

conformed 0 packets, 0 bytes; actions:

  set-prec-transmit 3

exceeded 0 packets, 0 bytes; actions:

  transmit

conformed 0 bps, exceed 0 bps
```

```
Class-map: internet (match-all)

 0 packets, 0 bytes

 5 minute offered rate 0 bps, drop rate 0 bps

Match: access-group 103

police:

  cir 5000000 bps, bc 937500 bytes

conformed 0 packets, 0 bytes; actions:

  transmit

exceeded 0 packets, 0 bytes; actions:

  drop

conformed 0 bps, exceed 0 bps
```

```
Class-map: class-default (match-any)

 794 packets, 54247 bytes

 5 minute offered rate 0 bps, drop rate 0 bps

Match: any
```

Simpson#

The next example, [Example 6-34](#), shows how a two-bucket traffic policy sets the ToS bits for different traffic type and burst size. [Example 6-34](#) shows how class Servers sets the traffic policy for all traffic network 209.145.63.0/27. Class apps specifies all traffic using the Telnet, SMTP protocols, or passing through 209.145.63.8, and class web specifies HTTP web traffic. In the example traffic belonging to the Servers class conforms to the average bit rate of 4 Mbps with a 750,000-byte normal burst and 1,500,000-byte, have its DSCP value changed to cs2. Traffic exceeding the normal burst will have its DSCP value changed to cs3. Any Servers traffic that violates the excess burst rate will be transmitted without a DSCP value change. Class apps specifies that traffic going to the servers on the 209.145.63.0/27 network will have a 3-Mbps average, 562,500-byte normal burst, and a 1,125,000-byte extended burst. Traffic conforming to the apps class has a DSCP value set to cs3, traffic exceeding the normal burst will have its DSCP changed to cs4, and traffic exceeding the extended burst will have its DSCP changed to cs5. The policy will be transmitted without a DSCP change. And finally, web traffic belonging to class web will have the same traffic-policing configuration parameters as class apps; but the conform, exceed, and violate action cases are different. Traffic conforming to the web policy will be transmitted with the DSCP value unchanged, and the excess and normal burst will be dropped. With this type of configuration, devices at the edge of the network will specify ToS settings to alter the QoS treatment for downstream devices running WFQ or WRED. By changing the DSCP value, the drop precedence of the packets is changed to a higher value, lowering the chances of the packets being dropped.

Example 6-34. Using a Two-Bucket Traffic Policy

```
class-map match-all apps
    match access-group 102
class-map match-all Servers
    match access-group 101
class-map match-all web
    match access-group 103
!
policy-map policy1
    class Servers
        police cir 4000000 bc 750000 be 1500000
        conform-action set-dscp-transmit cs2
        exceed-action set-dscp-transmit cs4
        violate-action transmit
    class apps
```

```

police cir 3000000 bc 562500 be 1125000
    conform-action set-dscp-transmit cs3
    exceed-action set-dscp-transmit cs4
    violate-action transmit
class web
police cir 3000000 bc 562500 be 1125000
    conform-action transmit
    exceed-action drop
!
interface Ethernet0/0
ip address 10.1.1.111 255.255.255.0
service-policy output policy1
!
access-list 101 permit ip any 209.145.63.0 0.0.0.31
access-list 102 permit tcp any any eq telnet
access-list 102 permit tcp any any eq smtp
access-list 102 permit tcp any host 209.145.63.8 eq ftp
access-list 102 permit tcp any host 209.145.63.8 gt 1023 established
access-list 103 permit tcp any any eq www

```

Example 6-35 shows the show policy-map policy1 and show policy-map interface command o

Example 6-35. Two-Bucket show Commands

```

Simpson#show policy-map policy1
Policy Map policy1
Class Servers
police cir 4000000 bc 750000 be 1500000

```

```
conform-action set-dscp-transmit cs2
exceed-action set-dscp-transmit cs4
violate-action transmit

Class apps
police cir 3000000 bc 562500 be 1125000
conform-action set-dscp-transmit cs3
exceed-action set-dscp-transmit cs4
violate-action transmit

Class web
police cir 3000000 bc 562500 be 1125000
conform-action transmit
exceed-action drop

Simpson#show policy-map interface ethernet 0/0
Ethernet0/0

Service-policy output: policy1

Class-map: Servers (match-all)
0 packets, 0 bytes
5 minute offered rate 0 bps, drop rate 0 bps
Match: access-group 101
police:
cir 4000000 bps, bc 750000 bytes, be 1500000 bytes
conformed 0 packets, 0 bytes; actions:
set-dscp-transmit cs2
exceeded 0 packets, 0 bytes; actions:
set-dscp-transmit cs4
violated 0 packets, 0 bytes; actions:
```

```
        transmit

        conformed 0 bps, exceed 0 bps, violate 0 bps


Class-map: apps (match-all)
0 packets, 0 bytes

5 minute offered rate 0 bps, drop rate 0 bps

Match: access-group 102

police:
    cir 3000000 bps, bc 562500 bytes, be 1125000 bytes
    conformed 0 packets, 0 bytes; actions:
        set-dscp-transmit cs3
    exceeded 0 packets, 0 bytes; actions:
        set-dscp-transmit cs4
    violated 0 packets, 0 bytes; actions:
        transmit
    conformed 0 bps, exceed 0 bps, violate 0 bps


Class-map: web (match-all)
0 packets, 0 bytes

5 minute offered rate 0 bps, drop rate 0 bps

Match: access-group 103

police:
    cir 3000000 bps, bc 562500 bytes
    conformed 0 packets, 0 bytes; actions:
        transmit
    exceeded 0 packets, 0 bytes; actions:
        drop
    conformed 0 bps, exceed 0 bps
```

```
Class-map: class-default (match-any)
  714 packets, 48821 bytes
  5 minute offered rate 0 bps, drop rate 0 bps
  Match: any
```

Sometimes, shaping and policing will not be the best solution to the problem. In some cases, certain traffic classes require strict-priority queueing. The next section shows how you can use Low Latency Queuing to provide strict-priority queuing for traffic classes, like those created with PQ, within a class-based queuing design.

Low Latency Queuing (LLQ)

Low Latency Queuing (LLQ), also known as Priority-Based Weighted Fair Queuing, makes it possible to define strict-priority traffic classes from within a class-based policy using CBWFQ and the modular QoS CLI.

LLQ allows traffic from at least one class policy to be sent to one strict-priority queue called a *prioritized queue*. There are two major advantages to using LLQ over PQ or CBWFQ alone. With PQ, as long as the highest priority queue has bandwidth available, it might be allowed to monopolize the bandwidth, starving out other lower-priority queues. With LLQ, the bandwidth of the highest priority queue is limited to a certain user-defined bandwidth. After this limit has been exceeded, any traffic arriving for transmission on the priority queue is dropped until sufficient resources have been made available. CBWFQ fairly allocates bandwidth among all the priority queues. This occasionally causes problems for applications that require guaranteed resources with little tolerance for jitter. LLQ solves this problem by creating the one high-priority queue that, when configured properly, guarantees bandwidth to the traffic arriving for transmission on the priority queue with minimal jitter.

To enable LLQ, use the **priority** command from within the policy class configuration mode. The **priority** command takes two arguments: **bandwidth**, and **burst**. The **bandwidth** argument is used to specify the bandwidth limit for the traffic arriving for transmission on the priority queue. The optional **burst** argument specifies the amount of traffic, in bytes, that is allowed to exceed the bandwidth limit:

```
Simpson(config-pmap-c)#priority bandwidth [burst]
```

Under normal conditions, when there is no congestion, the strict-priority traffic is not limited by the bandwidth limit. When the bandwidth limit has been reached, any traffic arriving for transmission on the priority queue is dropped. Because LLQ has been designed with the intent of providing strict-priority queuing, the priority class does not support the use of the **random-detect** command because WRED does not support the use of the **random-detect** command. When used with the **priority** command, the bandwidth parameter is not supported because the **priority** command has its own bandwidth parameter and because the priority queue is not subject to congestion avoidance with UDP traffic.

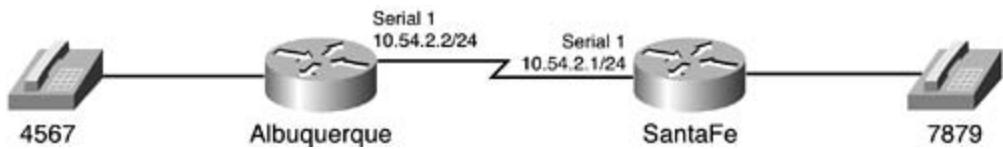
use queue limits for traffic policing. The queue-limit command is also not supported in the priority class. If unsupported commands are issued from within the priority class, an error appears warning that the command has been removed before the command can be issued.

Before you configure LLQ, it is important to know how much bandwidth will be required to support the traffic that is specified for the priority class. LLQ has a traffic-metering algorithm that considers the Layer 2 frame size when allocating bandwidth; however, it does not compensate for network jitter from upstream routers, ATM cells, or router-generated control or routing traffic. If bandwidth allocations are not large enough to allow the traffic to be transmitted during periods of unusually high traffic or bursts, the following list displays the reasons why using LLQ with CBWFQ:

- Because LLQ uses its own bandwidth parameter when policing traffic, the bandwidth command is not supported in priority classes.
- To properly support connectionless voice traffic, WRED is not supported in priority classes.
- Because LLQ uses bandwidth as its policing limitation, queue limits are not allowed in the priority class.
- LLQ is not supported with VoIP on Frame Relay.

To demonstrate the use of LLQ with CBWFQ for Voice over IP (VoIP) using routers with FXS ports, Figure 6-10 shows how Router Albuquerque and Router Santa Fe are connected over a serial HDLC point-to-point link connected to Router Albuquerque uses extension 4567, and the phone connected to Router Santa Fe is extension 7879. Lately, during periods of network congestion, the voice calls from Albuquerque have been dropping. To solve this problem, LLQ is being implemented on the Albuquerque router. Because Router Albuquerque is running Cisco IOS version 12.4(7)T8, it has been determined that the priority queue on this interface will require only a maximum bandwidth of 128 Kbps.

Figure 6-10. Using LLQ with Voice Traffic



[Example 6-36](#) shows how a service policy is created to prioritize all voice traffic while still providing sufficient bandwidth for other traffic.

Example 6-36. Using LLQ with Voice over IP

```
hostname Albuquerque
```

```
!
```

```
class-map data
```

```
match protocol ip
```

```

class-map voice
  match access-group 101
!
policy-map voice-data
  class voice
    priority 30
  class data
    bandwidth 1125
    random-detect
!
dial-peer voice 4567 pots
  destination-pattern 4567
  port 2/0
!
dial-peer voice 7879 voip
  destination-pattern 7879
  session target ipv4:10.54.2.1
!
interface Serial1
  ip address 10.54.2.2 255.255.255.0
  service-policy output voice-data
!
access-list 101 permit udp any any range 16384 32767
access-list 101 permit tcp any any eq 1720

```

The voice class matches all VoIP ports, defined in access list 101, and the data class matches the II policy map voice-data assigns the voice class to a strict-priority class using 30 kb of bandwidth, inc router jitter and control traffic, and the data class is limited to 1125 kb of bandwidth and will use V discard packets during periods of congestion. [Example 6-37](#) shows the show policy-map commar displays a summary of the policy configuration and how it works with the traffic sent across this ne

Example 6-37. show policy-map Command Output

```
Albuquerque#show policy-map voice-data
```

```
Policy Map voice-data
```

```
Weighted Fair Queueing
```

```
Class voice
```

```
  Strict Priority
```

```
    Bandwidth 30 (kbps)
```

```
Class data
```

```
    Bandwidth 1125 (kbps)
```

```
    exponential weight 9
```

class	min-threshold	max-threshold	mark-probability
<hr/>			
0	-	-	1/10
1	-	-	1/10
2	-	-	1/10
3	-	-	1/10
4	-	-	1/10
5	-	-	1/10
6	-	-	1/10
7	-	-	1/10
rsvp	-	-	1/10

```
Albuquerque#show policy-map interface serial 1
```

```
Serial1 output : voice-data
```

```
Weighted Fair Queueing
```

```
Class voice
```

```
  Strict Priority
```

```

Output Queue: Conversation 264

Bandwidth 30 (kbps) Packets Matched 152

(total drops/bytes drops) 0/0

Class data

Output Queue: Conversation 265

Bandwidth 1125 (kbps) Packets Matched 48

(depth/total drops/no-buffer drops) 0/0/0

exponential weight: 9

mean queue depth: 0

drops: class random tail min-th max-th mark-prob

      0     0     0    20    40   1/10
      1     0     0    22    40   1/10
      2     0     0    24    40   1/10
      3     0     0    26    40   1/10
      4     0     0    28    40   1/10
      5     0     0    30    40   1/10
      6     0     0    32    40   1/10
      7     0     0    34    40   1/10
  rsvp    0     0    36    40   1/10

```

As you can see, CBWFQ can perform a number of QoS techniques. After you have seen some of the can be applied, you will probably imagine all kinds of ways that you can apply this technology in ne following:

- Marking traffic for policy enforcement
- Classifying traffic into policy groups
- Queuing certain traffic with WFQ or PQ technologies
- Performing tail drop or WRED, depending on traffic type
- Prioritizing traffic to reserve bandwidth
- Shaping traffic

- Enforcing traffic policy by policing traffic

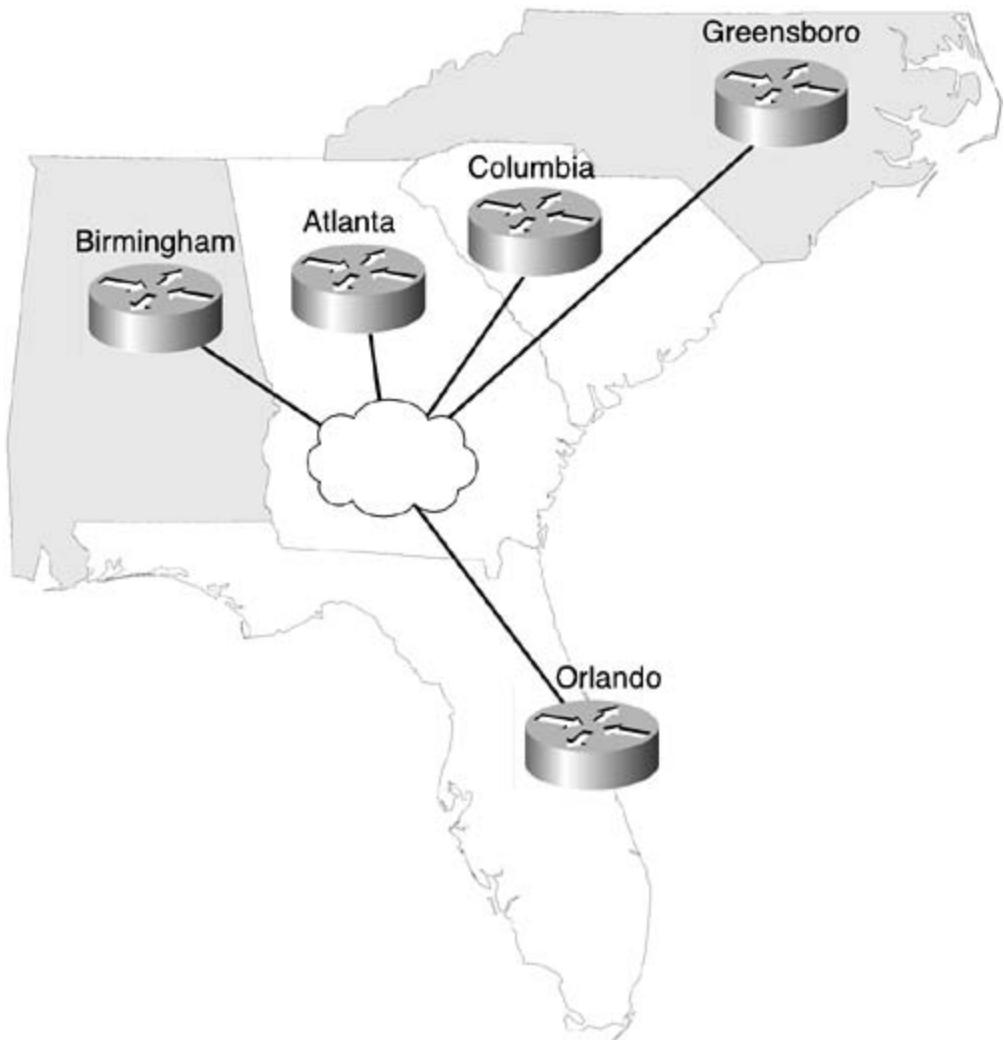
As you might imagine, these three chapters easily could have been expanded into an entire book or series. The best way to test and apply these QoS technologies is in a laboratory environment with test traffic and then move the QoS solution into production after completing several tests. With some creativity and knowledge of the concepts presented in these QoS chapters, you can create some extremely versatile QoS solutions.

Practice Scenarios

Lab 12: Custom Queuing

The law firm Blackerby, Smith, and Heitz, commonly referred to as BSH, has a network consisting of one headquarters site in Orlando containing all the servers and a PBX. They currently have two branch sites: Columbia and Atlanta. In the next two months, however, they plan to add two other new sites: one in Birmingham, and one in Greensboro, as shown in [Figure 6-11](#).

Figure 6-11. Blackerby, Smith, and Heitz Network Diagram



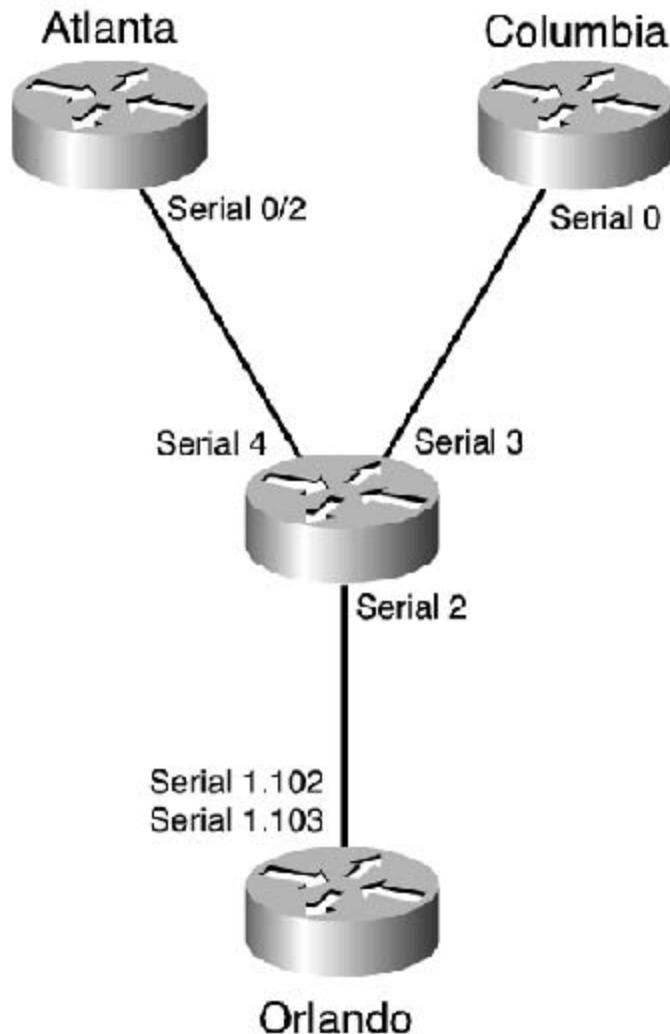
Equipment Needed

This lab requires the following:

- Three routers with one serial interface, one Ethernet interface, and two FXS voice ports
- One router with four serial interfaces to act as a Frame Relay switch
- (Optionally) Two computers with Ethernet interfaces
- (Optionally) One extra router with one Ethernet interface

The core of this lab requires four routers. Three of the routers require one serial interface, and one the routers, which will act as a Frame Relay switch, requires four serial interfaces. The routers should be attached by their serial interfaces as shown in [Figure 6-12](#).

Figure 6-12. Physical Lab Configuration



Physical Layout and Prestaging

- Configure the Frame Relay as shown in [Figure 6-13](#) using the IP addressing and DLCI assignments shown in [Table 6-24](#).

Figure 6-13. Frame Relay DLCI Configuration

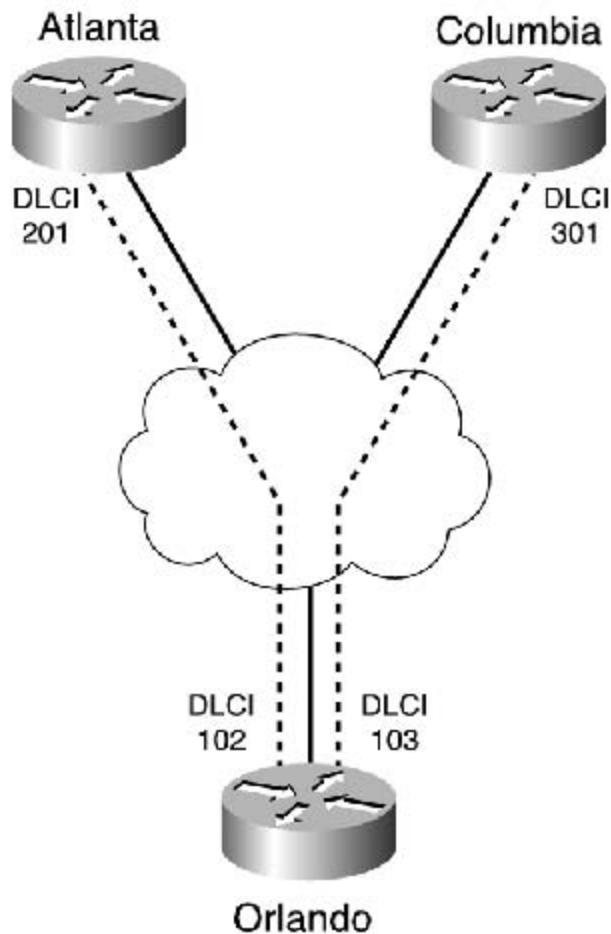


Table 6-24. IP Address and Frame Relay DLCI Assignments

Router Interface	DLCI	IPAddress
Atlanta Serial 0/2	201	192.168.2.2/30
Columbia Serial 0	301	192.168.3.2/30
Orlando Serial 1.102	102	192.168.2.1/30
Orlando Serial 1.103	103	192.168.3.1/30

- Configure the Frame Relay switch as shown in [Figure 6-13](#) using the DLCI assignments in [Tab 6-25](#).

Table 6-25. Frame Relay Switch DLCI Assignments

Local Interface	Local DLCI	Remote Interface	Remote DLCI
Serial 4	201	Serial 2	102
Serial 3	301	Serial 2	103
Serial 2	102	Serial 4	201
Serial 2	103	Serial 3	301

Lab Objectives

Each site has several computers that the local office staff uses to access files and applications at the headquarters site in Orlando. Each site also has two telephones that are used to dial the headquarters site. Calls to the Orlando site from the branch offices happen infrequently at various times during the day; both phone lines are rarely used at the same time. All the voice and data traffic between the Orlando and Atlanta sites is carried over Frame Relay circuits with 256-kbps CIR. The headquarters site currently has Frame Relay T1, with a 768-kbps CIR. The current traffic patterns have recently been analyzed, and it has been found that during peak hours, 9:00 to 10:30 a.m., 12:00 to 1:00 p.m., and 3:30 to 5:00 p.m., traffic is very bursty, and some of the applications are intolerant of the delays caused by the bursty periods. While planning the upgrade of the network for the two new sites, it has been decided that the Frame Relay circuit in Orlando will have its CIR increased to 1.544 Mb. This should ease some of the issues with the bursty traffic. To prevent any new problems, it has been decided that Custom Queuing will be implemented before the upgrade, only at the Orlando site. The objectives for this lab include the following:

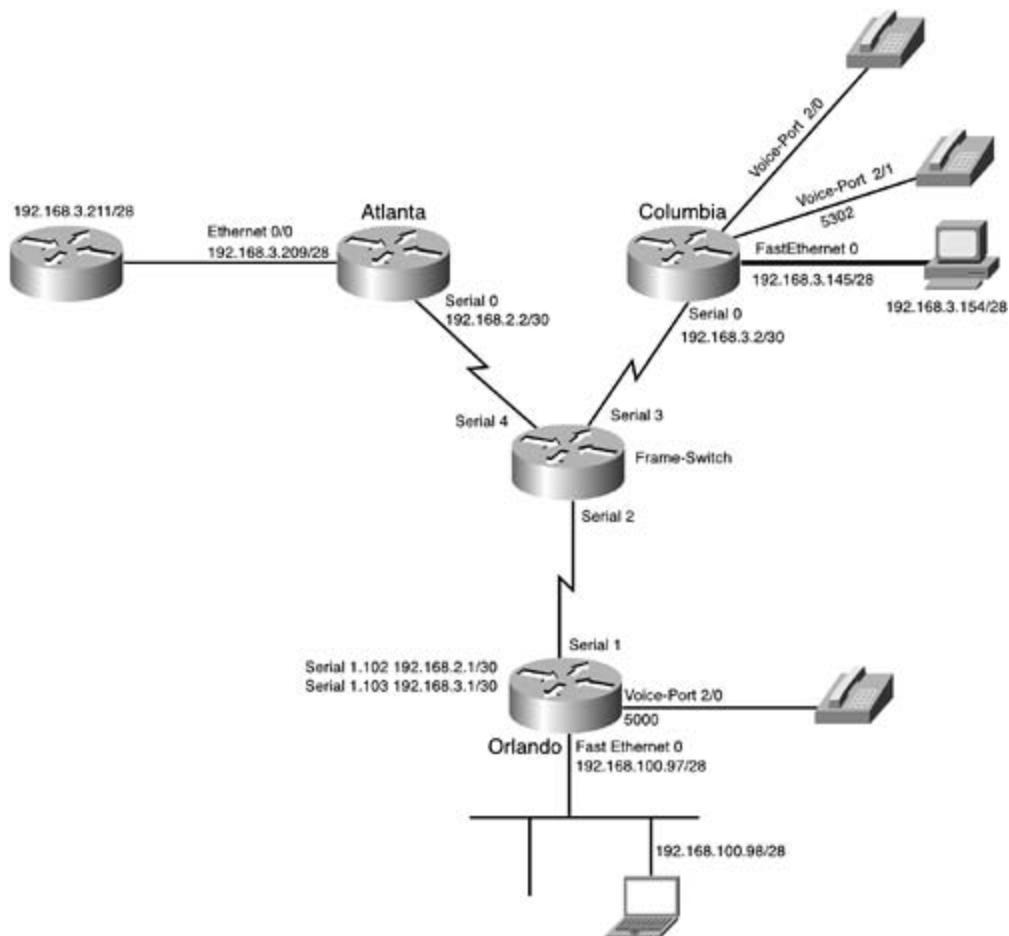
- Configure VoIP between the FXS cards on the Orlando and Columbia routers.
- Configure Custom Queuing to support traffic limitations based on byte count.

Lab Tasks

Step 1. Configure the Orlando router to connect to the Atlanta and Columbus routers, without the use of frame-relay map statements. Also, configure the Atlanta and Columbia routers to reach the Orlando router. At this point, all routers should have both line and protocol in an up state.

Step 2. Configure the IP addresses for each router, as shown in [Figure 6-14](#). Configure all networks to belong to OSPF area 0 and verify IP connectivity.

Figure 6-14. Complete Network Diagram



Step 3. If possible, configure VoIP between Columbia and Orlando, as shown in [Figure 6-14](#). Configure one of the phones in Columbia to use extension 5301 and the other to use 5302, and configure the Orlando site to have only one phone using extension 5000. Verify that all phones can dial each other.

Step 4. Configure two computers, one on the 192.168.3.144 network and one on the 192.168.100.96 network.

Step 5. Place another router on the 192.168.3.208 network. Configure this router with a default route to the 192.168.3.209 interface on the Atlanta router. Configure this router to allow Telnet access.

Step 6. Verify that hosts on networks 192.168.3.144 and 192.168.100.96 can Telnet to the router at 192.168.3.211.

Step 7. Using the information from [Table 6-26](#) and the formulas from the "Custom Queuing" section earlier in the chapter, enter the byte-count data in [Table 6-27](#). The information from Byte Count fields will be used to configure the byte-count queue limits.

Table 6-26. Bandwidth Percentages for This Lab

Queue Number	Protocol(s)	Percentage Bandwidth	Average Packet Size
1	Voice	25	64
2	DHCP, DNS, SNMP	5	79
3	Telnet	10	64
4	SMTP	10	625
5	Passive FTP to 192.168.3.211	10	315
6	WWW	5	1024
7	Other	25	1042

Table 6-27. Byte-Count Limitation Data

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio	Whole Ratio	Byte Count
Voice	25%	64				
DHCP, DNS, SNMP	5%	79				
Telnet	10%	64				
SMTP	10%	625				
Passive FTP to 192.168.3.211	10%	315				
WWW	5%	1024				
Other	25%	1042				

Step 8. Configure CQ for the serial interface on the Orlando router, using the byte-count limitations that you found in [Table 6-27](#), for each of the queues. Configure any access lists necessary to sort the traffic into the queues.

Step 9. Make Queue 7 is the default queue for all unspecified traffic.

Lab Walkthrough

Configure the Frame Relay switch so that the switch has DLCI 201. It should match up with DLCI 1 and DLCI 301, and it should also match up with 103. [Example 6-38](#) shows the complete Frame Rel switch configuration.

Example 6-38. Frame Relay Switch Configuration

```
hostname Frame-Relay
!
frame-relay switching
!
interface Serial2
    description Connection to Orlando
    no ip address
    encapsulation frame-relay
    frame-relay lmi-type ansi
    frame-relay intf-type dce
    frame-relay route 102 interface Serial4 201
    frame-relay route 103 interface Serial3 301
!
interface Serial3
    description Connection to Columbia
    no ip address
    encapsulation frame-relay
    frame-relay lmi-type ansi
    frame-relay intf-type dce
    frame-relay route 301 interface Serial2 103
!
interface Serial4
    description Connection to Atlanta
    no ip address
    encapsulation frame-relay
    frame-relay lmi-type ansi
    frame-relay intf-type dce
```

```

frame-relay route 201 interface Serial2 102
!
end

```

In the example, notice that the frame-relay route statements for interface serial 2 both have local DLCI numbers for DLCI 102 and 103. These numbers are matched to the DLCI numbers assigned to the Orlando router. The other two DLCI numbers, 201 and 203, are assigned to interfaces 3 and 4, which connect to the Atlanta and Columbus routers. [Example 6-39](#) shows the Frame Relay routing table from the Frame Relay switch.

Example 6-39. Frame Relay Routing Table of the Frame Relay Switch

```

Frame-Switch#show frame route

Input Intf Input Dlci Output Intf Output Dlci Status

Serial2      102 Serial4      201 active
Serial2      103 Serial3      301 active
Serial3      301 Serial2      103 active
Serial4      201 Serial2      102 active

```

Step 1. Configure the Orlando router to connect to the Atlanta and Columbus routers without the use of frame-relay map statements. Also, configure the Atlanta and Columbus routers to reach the Orlando router. At this point, all routers should have both line and protocol in an up state.

To configure the Layer 2 connections from the Orlando router to the Atlanta and Columbus routers without the use of frame-relay map statements, use subinterfaces on the Orlando router's serial interface:

```

Orlando(config)#interface Serial1
Orlando(config-if)#encapsulation frame-relay

```

```
Orlando(config-if)#clockrate 1300000
Orlando(config-if)#interface Serial0.102 point-to-point
Orlando(config-if)#frame-relay interface-dlci 102
Orlando(config-if)#interface Serial0.103 point-to-point
Orlando(config-if)#frame-relay interface-dlci 103
```

The other two routers should just need the encapsulation frame-relay command and a clock rate as they are on the data circuit-terminating equipment (DCE) side of the connection:

```
Atlanta(config-if)#int s 0/2
Atlanta(config-if)#encapsulation frame-relay
Atlanta(config-if)#clockrate 1300000
Columbia(config-if)#int s 0
Columbia(config-if)#encapsulation frame-relay
Columbia(config-if)#clockrate 1300000
```

Step 2. Configure the IP addresses for each router, as shown in [Figure 6-14](#). Configure all networks to belong to OSPF area 0 and verify IP connectivity.

To establish IP connectivity from the Atlanta and Columbus routers to the Orlando router, the following addresses are assigned. Make sure to use the ip ospf network point-to-point command for the OSPF connections. The following example shows the Frame Relay interface configuration for the Orlando subinterfaces:

```
Orlando(config)#interface Serial1.102 point-to-point
Orlando(config-if)#ip address 192.168.2.1 255.255.255.252
```

```
Orlando(config-if)#ip ospf network point-to-point

Orlando(config)#interface Serial1.103 point-to-point

Orlando(config-if)# ip address 192.168.3.1 255.255.255.252

Orlando(config-if)#ip ospf network point-to-point
```

The Atlanta and Columbia routers are allowed to use frame-relay map statements. After all IP addresses have been assigned, each router will require OSPF configuration. The following example shows the Frame Relay interface configuration for the Atlanta and Columbia routers:

```
Atlanta(config)# int s 0/2

Atlanta(config-if)#ip address 192.168.2.2 255.255.255.252

Atlanta(config-if)#frame-relay map ip 192.168.2.1 201 broadcast

Atlanta(config-if)#ip ospf network point-to-point

Columbia(config)#int s 0

Columbia(config-if)#ip address 192.168.3.2 255.255.255.252

Columbia(config-if)#frame-relay map ip 192.168.3.1 301 broadcast

Columbia(config-if)#ip ospf network point-to-point
```

Step 3. If possible, configure VoIP between Columbia and Orlando, as shown in [Figure 6-14](#). Configure one of the phones in Columbia to use extension 5301 and the other to use 5302, and configure the Orlando site to have only one phone using extension 5000. Verify that all phones can dial each other.

If you have the two voice-capable routers with FXS cards required to complete this step, you need to create two dial peers on each router. One dial-peer statement will be for pots. This statement should specify the destination pattern, which is the number dialed from the telephone, and the port which is the locally connected voice port. The other dial-peer statement is the voip statement, which specifies the destination pattern for the remote telephone and the IP address that VoIP will use when that number is dialed:

```
Orlando(config)#dial-peer voice 5000 pots
Orlando (config-dial-peer)#destination-pattern 5000
Orlando (config-dial-peer)# port 2/0
Orlando (config-dial-peer)#dial-peer voice 5301 voip
Orlando (config-dial-peer)# destination-pattern 5301
Orlando (config-dial-peer)# session target ipv4:192.168.3.2
Orlando (config-dial-peer)#dial-peer voice 5302 voip
Orlando (config-dial-peer)# destination-pattern 5302
Orlando (config-dial-peer)# session target ipv4:192.168.3.2
Columbia(config)#dial-peer voice 5301 pots
Columbia (config-dial-peer)# destination-pattern 5301
Columbia (config-dial-peer)# port 2/0
Columbia (config-dial-peer)#dial-peer voice 5302 pots
Columbia (config-dial-peer)# destination-pattern 5302
Columbia (config-dial-peer)# port 2/1
Columbia (config-dial-peer)#dial-peer voice 5000 voip
Columbia (config-dial-peer)# destination-pattern 5000
Columbia (config-dial-peer)# session target ipv4:192.168.3.1
```

Step 4. Configure two computers, one on the 192.168.3.144 network and one on the 192.168.100.96 network.

If you have two extra computers, place one on the 192.168.3.144 network and one on the 192.168.100.96 network.

Step 5. Place another router on the 192.168.3.208 network. Configure this router with a def route to the 192.168.3.209 interface on the Atlanta router. Configure this router to allow Telnet access.

The fourth router should need only an IP address on its Ethernet interface and a default route to 192.168.3.209:

```
Router(config)#interface Ethernet0
Router(config-if)#ip address 192.168.3.211 255.255.255.240
Router(config)#exit
Router(config)#ip route 0.0.0.0 0.0.0.0 192.168.3.209
Router(config)#line vty 0 4
Router(config-line)#login
Router(config-line)#pass cisco
```

Step 6. Verify that hosts on networks 192.168.3.144 and 192.168.100.96 can Telnet to the router at 192.168.3.211.

If you were able to complete Step 4, you should be able to verify that hosts on the networks 192.168.3.144 and 192.168.100.96 can ping each other. If you completed Step 5 successfully both of those hosts should also be able to Telnet to the router on the 192.168.3.208 network.

Step 7. Using the information from [Table 6-26](#) and the formulas from earlier in the chapter, enter the byte-count data in [Table 6-27](#). The information from the Byte Count fields will be used to configure the byte-count queue limits. [Table 6-28](#) shows the byte-count sizes for this lab.

Table 6-28. Byte-Count Sizes for Custom Queuing

Protocol	Bandwidth Allocation	Average Packet Size	Ratio	Normalized Ratio	Whole Ratio	Byte Count	Actual Bandwidth
Voice	25%	64	0.3906	79.7	80	5120	26.8%
DHCP, DNS, SNMP	5%	79	0.0633	12.9	13	1027	5.3%
Telnet	10%	64	0.1563	31.9	32	2048	10.7%
SMTP	10%	625	0.016	3.3	4	2500	13%
Passive FTP to 192.168.3.211	10%	315	0.0317	6.5	7	2205	11.5%
WWW	5%	1024	0.0049	1	1	1024	5.3%
Other	25%	1042	0.0240	4.9	5	5210	27.2%
						19,134	

Step 8. Configure CQ for the serial interface on the Orlando router, using the byte-count limitations that you found in [Table 6-27](#) for each of the queues. Configure any access lists necessary to sort the traffic into the queues.

For this lab, access list 101 was used to specify voice traffic; access list 102 was used to specify DHCP, DNS, and SNMP traffic; and access list 103 was used to specify FTP traffic. These access lists were used with queue list 1 to specify the traffic and byte counts for each queue. The queue list was applied to interface serial 1 using the custom-queue-list command:

```

Orlando(config)#access-list 101 permit tcp any any eq 1720
Orlando(config)#access-list 101 permit udp any any range 16384 32767
Orlando(config)#access-list 101 remark Voice traffic
Orlando(config)#access-list 102 remark DHCP, DNS and SNMP traffic
Orlando(config)#access-list 102 permit udp any any eq bootpc
Orlando(config)#access-list 102 permit udp any any eq domain
Orlando(config)#access-list 102 permit tcp any any eq domain
Orlando(config)#access-list 102 permit udp any any eq snmp
Orlando(config)#access-list 103 remark FTP and random port for data
Orlando(config)#access-list 103 permit tcp any host 192.168.3.211 eq ftp

```

```

Orlando(config)#access-list 103 permit tcp any host 192.168.3.211 gt 1023 establis
Orlando(config)#queue-list 1 protocol ip 1 list 101
Orlando(config)#queue-list 1 protocol ip 2 list 102
Orlando(config)#queue-list 1 protocol ip 3 tcp telnet
Orlando(config)#queue-list 1 protocol ip 4 tcp smtp
Orlando(config)#queue-list 1 protocol ip 5 list 103
Orlando(config)#queue-list 1 protocol ip 6 tcp www
Orlando(config)#queue-list 1 protocol ip 7
Orlando(config)#queue-list 1 queue 1 byte-count 5120
Orlando(config)#queue-list 1 queue 2 byte-count 1027
Orlando(config)#queue-list 1 queue 3 byte-count 2048
Orlando(config)#queue-list 1 queue 4 byte-count 2500
Orlando(config)#queue-list 1 queue 5 byte-count 2205
Orlando(config)#queue-list 1 queue 6 byte-count 1024
Orlando(config)#queue-list 1 queue 7 byte-count 5210
Orlando(config)#interface Serial1
Orlando(config-if)#custom-queue-list 1

```

Step 9. Make Queue 1 the default queue for all unspecified traffic.

To make Queue 7 the default queue, you need to use only the default version of the queue-l command to specify Queue 7:

```
queue-list 1 default 7
```

[Example 6-40](#) shows the complete configuration for the Orlando router.

Example 6-40. Orlando Router Configuration

```
hostname Orlando
!
voice-port 2/0
!
voice-port 2/1
!
dial-peer voice 5000 pots
destination-pattern 5000
port 2/0
!
dial-peer voice 5301 voip
destination-pattern 5301
session target ipv4:192.168.3.2
!
dial-peer voice 5302 voip
destination-pattern 5302
session target ipv4:192.168.3.2
!
interface Serial1
no ip address
encapsulation frame-relay
custom-queue-list 1
clockrate 1300000
!
interface Serial1.102 point-to-point
ip address 192.168.2.1 255.255.255.252
```

```
ip ospf network point-to-point
frame-relay interface-dlci 102
!
interface Serial1.103 point-to-point
ip address 192.168.3.1 255.255.255.252
ip ospf network point-to-point
frame-relay interface-dlci 103
!
interface FastEthernet0
ip address 192.168.100.97 255.255.255.240
!
router ospf 101
network 192.168.2.0 0.0.0.3 area 0
network 192.168.3.0 0.0.0.3 area 0
network 192.168.100.96 0.0.0.15 area 0
!
access-list 101 permit tcp any any eq 1720
access-list 101 permit udp any any range 16384 32767
access-list 101 remark Voice traffic
access-list 102 remark DHCP, DNS and SNMP traffic
access-list 102 permit udp any any eq bootpc
access-list 102 permit udp any any eq domain
access-list 102 permit tcp any any eq domain
access-list 102 permit udp any any eq snmp
access-list 103 remark FTP and random port for data
access-list 103 permit tcp any host 192.168.3.211 eq ftp
access-list 103 permit tcp any host 192.168.3.211 gt 1023 established
queue-list 1 protocol ip 1 list 101
```

```
queue-list 1 protocol ip 2 list 102
queue-list 1 protocol ip 3 tcp telnet
queue-list 1 protocol ip 4 tcp smtp
queue-list 1 protocol ip 5 list 103
queue-list 1 protocol ip 6 tcp www
queue-list 1 protocol ip 7
queue-list 1 default 7
queue-list 1 queue 1 byte-count 5120
queue-list 1 queue 2 byte-count 1027
queue-list 1 queue 3 byte-count 2048
queue-list 1 queue 4 byte-count 2500
queue-list 1 queue 5 byte-count 2205
queue-list 1 queue 6 byte-count 1024
queue-list 1 queue 7 byte-count 5210
```

!

Example 6-41 shows output from the show interface and show queueing commands. Notice that the show interface command shows that CQ is enabled and that there are currently no packets in the queues. The show queueing command output was used to display information about the custom queues used in this lab.

Example 6-41. Output from show interface and show queueing on the Orlando Router

```
Orlando#show interface serial 1
Serial0 is up, line protocol is up
  Hardware is PowerQUICC Serial
    MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
      reliability 255/255, txload 42/255, rxload 1/255
    Encapsulation FRAME-RELAY, loopback not set
```

```
Keepalive set (10 sec)

LMI enq sent 604, LMI stat recv 597, LMI upd recv 0, DTE LMI up

LMI enq recv 0, LMI stat sent 0, LMI upd sent 0

LMI DLCI 0 LMI type is ANSI Annex D frame relay DTE

FR SVC disabled, LAPF state down

Broadcast queue 0/64, broadcasts sent/dropped 1431/3, interface broadcasts 1224

Last input 00:00:05, output 00:00:05, output hang never

Last clearing of "show interface" counters 01:47:08

Input queue: 0/75/2/0 (size/max/drops/flushes); Total output drops: 33540

Queueing strategy: custom-list 1

Output queues: (queue #: size/max/drops)

 0: 0/20/0 1: 0/20/0 2: 0/20/0 3: 0/20/0 4: 0/20/0

 5: 0/20/0 6: 0/20/0 7: 0/20/33540 8: 0/20/0 9: 0/20/0

10: 0/20/0 11: 0/20/0 12: 0/20/0 13: 0/20/0 14: 0/20/0

15: 0/20/0 16: 0/20/0

5 minute input rate 4000 bits/sec, 25 packets/sec

5 minute output rate 259000 bits/sec, 27 packets/sec

 14023 packets input, 884229 bytes, 0 no buffer

Received 0 broadcasts, 0 runts, 0 giants, 0 throttles

 1 input errors, 0 CRC, 1 frame, 0 overrun, 0 ignored, 0 abort

14672 packets output, 16220918 bytes, 0 underruns

 0 output errors, 0 collisions, 4 interface resets

 0 output buffer failures, 0 output buffers swapped out

 15 carrier transitions

  DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

Orlando#**show queueing**

Current fair queue configuration:

Current priority queue configuration:

Current custom queue configuration:

List	Queue	Args
1	7	default
1	1	protocol ip list 101
1	2	protocol ip list 102
1	3	protocol ip tcp port telnet
1	4	protocol ip tcp port smtp
1	5	protocol ip list 103
1	6	protocol ip tcp port www
1	7	protocol ip
1	1	byte-count 5120
1	2	byte-count 1027
1	3	byte-count 2048
1	4	byte-count 2500
1	5	byte-count 2205
1	6	byte-count 1024
1	7	byte-count 5210

Current random-detect configuration:

[Example 6-42](#) shows the complete configuration for the Atlanta router, and [Example 6-43](#) shows the complete configuration for the Columbia router.

Example 6-42. Atlanta Router Configuration

```
hostname Atlanta
!
interface Ethernet0/0
  ip address 192.168.2.209 255.255.255.240
!
```

```
interface Serial0/2
  ip address 192.168.2.2 255.255.255.252
  encapsulation frame-relay
  ip ospf network point-to-point
  clockrate 1300000
  frame-relay map ip 192.168.2.1 201 broadcast
!
router ospf 101
  network 192.168.2.0 0.0.0.3 area 0
  network 192.168.2.208 0.0.0.15 area 0
!
```

Example 6-43. Columbia Router Configuration

```
hostname Columbia
!
voice-port 2/0
!
voice-port 2/1
!
dial-peer voice 5301 pots
  destination-pattern 5301
  port 2/0
!
dial-peer voice 5302 pots
  destination-pattern 5302
```

```
port 2/1

!
dial-peer voice 5000 voip
destination-pattern 5000
session target ipv4:192.168.3.1

!
interface Serial0
ip address 192.168.3.2 255.255.255.252
encapsulation frame-relay
ip ospf network point-to-point
clockrate 1300000
frame-relay map ip 192.168.3.1 301 broadcast

!
interface FastEthernet0
ip address 192.168.3.145 255.255.255.240

!
router ospf 101
network 192.168.3.0 0.0.0.3 area 0
network 192.168.3.144 0.0.0.15 area 0
```

Lab 13: Managing Internet Traffic with CBWFQ and NBAR

In this lab, you take the lessons learned up to this point and apply them to a real-world QoS simulation. This simulation applies CBWFQ to solve a common Internet problem: users using enterprise networks for personal entertainment.

Lab Exercise

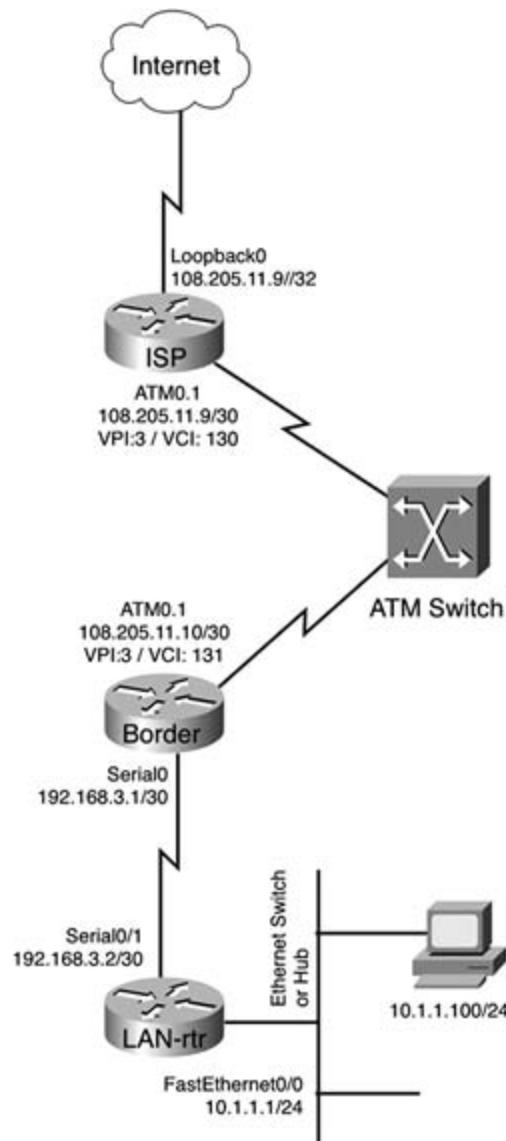
In this lab, NBAR heuristics specify certain classes of data and apply a service policy to the class enforcing proper Internet usage. This scenario includes the following technologies:

- Classifying traffic with NBAR
- Marking traffic with DSCP bits
- Configuring ATM QoS
- Prioritizing traffic with bandwidth reservations
- Selectively applying tail drop, WRED, and WFQ for certain traffic types
- Selecting the appropriate queuing and switching types

Lab Objective

The objective of this lab is to apply the QoS technologies used up to this point to put together an Internet service policy for the network model shown in [Figure 6-15](#).

Figure 6-15. Model of an Internet Border



Equipment Needed

- One Cisco router with one OC-3 ATM interface
- One Cisco router with one OC-3 ATM interface and one serial interface
- One LightStream ATM switch with two OC-3 ATM interfaces
- One Cisco router with one serial port and one Ethernet port
- One PC with an Ethernet NIC running TCP/IP
- One Ethernet switch or hub

Physical Layout and Prestaging

- Cable the routers as shown in [Figure 6-15](#).
- Attach the PC to the Ethernet switch or hub and configure it to be on the 10.1.1.0/24 network.
- Configure the ATM switch to use the PVC information from [Figure 6-15](#).
- Apply IP addresses to each router interface, except for the ATM interfaces on the Border and ISP routers, and verify that the routers can ping their directly connected neighbor.
- Verify that all interfaces are in an up/up state.

Lab Tasks

Step 1. Configure the ATM PVCs on the ISP and Border routers. Assign the ISP router's ATM 0.1 interface VPI: 3 and VCI 130, and the Border router's ATM 0.1 interface should be assigned VPI: 3 VCI: 131. Configure these routers to use VBR-nrt for a 45-Mbps sustained cell rate and a 50-Mbps peak cell rate. Verify that each of the routers can ping each other.

Step 2. Configure all routers except the ISP router to belong to EIGRP AS 148. Summarize all routes on their true network boundary; do not use classful summarization. Have the Border router redistribute the default route pointing to the ISP router. Verify that all routers can ping all other routers in the network before moving to Step 3.

Step 3. From the Border router, configure network address translation (NAT) so that all inside networks, 10.1.1.0/24 and 192.168.0.0/16, can get the Internet, beyond the ISP router, without any additional routing. Verify that the host PC can reach the ISP router on its 108.205.11.9/32 interface.

Step 4. Configure a policy for the outbound interface on the LAN-rtr. This policy should match the variables shown in [Table 6-29](#).

Step 5 . Enable DSCP WRED on the outbound ATM interface for the Border router. This is where the policies created in Step 4 finish their execution.

Table 6-29. Policy Configuration

Class Name	Traffic Type	Policy
High-Pri_Internet	HTTP traffic to cisco.com	Reserve 15% bandwidth. Mark each packet with the EF DSCP value.
Med-Pri-Internet	All other HTTP and SSH traffic	Reserve 55% bandwidth. Mark these packets with the CS3 DSCP value.
Low-Pri-Internet	FTP, Telnet, SFTP, HTTPS, and secure POP3	Reserve 5% bandwidth Apply WRED instead of tail-drop. Mark these packets with the CS1 DSCP value.
No-Pri_Internet	Gnutella, MS NetShow, Napster, NNTP, Real Audio, Streamwork streaming protocol	Limit to 8 bps any packets conforming to this policy. Have their DSCP bits set to the default DSCP value. All packets exceeding this value are to be dropped.
Default	Unclassified	Use WFQ and WRED to queue and drop packets.

Lab Walkthrough

Step 1. Configure the ATM PVCs on the ISP and Border routers. Assign the ISP router's ATM 0.1 interface VPI: 3 and VCI 130, and the Border router's ATM 0.1 interface should be assigned VPI: 3 VCI: 131. Configure these routers to use VBR-nrt for a 45-Mbps sustained cell rate and a 50-Mbps peak cell rate. Verify that each of the routers can ping each other.

This step is relatively straightforward and requires only a few items. Configure an ATM PVC on the ISP and Border routers using VBR-nrt shaping and verify that the routers can reach each other:

ISP Router

```
interface ATM0.1 multipoint
ip address 108.205.11.9 255.255.255.252
pvc 3/130
protocol ip 108.205.11.10 broadcast
```

```
vbr-nrt 50000 45000  
encapsulation aal5snap
```

Border Router

```
interface ATM0.1 multipoint  
ip address 108.205.11.10 255.255.255.252  
pvc 3/131  
protocol ip 108.205.11.9 broadcast  
vbr-nrt 50000 45000  
encapsulation aal5snap
```

Step 2. Configure all routers except the ISP router to belong to EIGRP AS 148. Summarize all routes on their true network boundary; do not use classful summarization. Have the Border router redistribute the default route pointing to the ISP router. Verify that all routers can ping all other routers in the network before moving on to Step 3.

This step requires only a few items to work properly. First, you must create the correct network statements so that the entire 108.205.0.0/16 network is not advertised to the internal network beyond the Border router. Next, you must turn off auto-summarization to prevent classful summarization, and last you need to use the redistribute static command to redistribute the default route as shown here on the Border router:

```
router eigrp 148  
redistribute static  
network 108.205.11.8 0.0.0.3  
network 192.168.3.0  
no auto-summaryip route 0.0.0.0 0.0.0.0 108.205.11.9
```

Step 3. From the Border router, configure NAT so that all inside networks, 10.1.1.0/24 and 192.168.0.0/16, can get the Internet, beyond the ISP router, without any additional routing. Verify that the host PC can reach the ISP router on its 108.205.11.9/32 interface.

Only three task are required to configure Step 3: create an access list that specifies the two internal networks, create a NAT statement to NAT the addresses specified by the access list to the ATM 0.1 interface's IP address, and apply the NAT configuration to the ATM0.1 and Serial0 interfaces on the Border router, as shown here:

```
interface Serial0
    ip address 192.168.3.1 255.255.255.252
    ip nat inside
!
interface ATM0.1 multipoint
    ip address 108.205.11.10 255.255.255.252
    ip nat outside
    pvc 3/131
        protocol ip 108.205.11.9 broadcast
        vbr-nrt 50000 45000
        encapsulation aal5snap
    !
    ip nat inside source list 1 interface ATM0.1 overload
!
access-list 1 permit 192.168.0.0 0.0.255.255
access-list 1 permit 10.1.1.0 0.0.0.255
```

Step 4. Configure a policy for the outbound interface on the LAN-rtr. This policy should match the variables shown in [Table 6-28](#).

This step requires multiple items to work properly. First, you must define a class map for

each of the traffic types defined in the table, assigning each of the protocol types to the class to which it belongs. Next, create a policy map that references each class definition and apply the required policy to each of the classes. Then, create a class-default class to match all undefined traffic and apply the default policy. This policy is then applied to the Serial0/1 interface using the outbound service-policy command, as shown here, from the LAN-rtr router:

```
class-map match-all No-Pri_Internet
    match protocol gnutella
    match protocol netshow
    match protocol napster
    match protocol nntp
    match protocol realaudio
    match protocol streamwork

class-map match-all Low-Pri-Internet
    match protocol ftp
    match protocol telnet
    match protocol secure-ftp
    match protocol secure-http
    match protocol secure-pop3

class-map match-all High-Pri_Internet
    match protocol http host "cisco.com"

class-map match-all Med-Pri-Internet
    match protocol http
    match protocol ssh

!
policy-map Internet-Policy
    class High-Pri_Internet
```

```

bandwidth percent 15

set ip dscp ef

class Med-Pri-Internet

bandwidth percent 55

set ip dscp cs3

class Low-Pri-Internet

bandwidth percent 5

random-detect

set ip dscp cs1

class No-Pri_Internet

police cir 8000

conform-action set-dscp-transmit default

exceed-action drop

class class-default

fair-queue

random-detect

!

interface Serial0/1

ip address 192.168.3.2 255.255.255.252

service-policy output Internet-Policy

clockrate 1300000

```

Step 5. Enable DSCP WRED on the outbound ATM interface for the Border router. This is where the policies created in Step 4 finish their execution.

The final step requires only one line of configuration, shown here. After you have completed this part of the configuration, any traffic marked with a DSCP value on the LAN-rtr router will have DSCP-based WRED applied on the outbound ATM interfaces upon exit from the Border router. Remember, the random-detect statement is supported only on physical interfaces:

```
interface ATM0
no ip address
no atm ilmi-keepalive
random-detect dscp-based
```

[Example 6-44](#) shows the complete router configurations for this lab.

Example 6-44. Complete Router Configurations

```
hostname ISP
!
interface ATM0
no ip address
no atm ilmi-keepalive
!
interface ATM0.1 multipoint
ip address 108.205.11.9 255.255.255.252
pvc 3/130
protocol ip 108.205.11.10 broadcast
vbr-nrt 50000 45000
encapsulation aal5snap
```

```
hostname Border
!
ip cef
!
```

```
interface Serial0
    ip address 192.168.3.1 255.255.255.252
    ip nat inside
!
interface ATM0
    no ip address
    no atm ilmi-keepalive
    random-detect dscp-based
!
interface ATM0.1 multipoint
    ip address 108.205.11.10 255.255.255.252
    ip nat outside
    pvc 3/131
    protocol ip 108.205.11.9 broadcast
    vbr-nrt 50000 45000
    encapsulation aal5snap
!
router eigrp 148
    redistribute static
    network 108.205.11.8 0.0.0.3
    network 192.168.3.0
    no auto-summary
!
ip nat inside source list 1 interface ATM0.1 overload
ip classless
ip route 0.0.0.0 0.0.0.0 108.205.11.9
!
access-list 1 permit 192.168.0.0 0.0.255.255
```

```
access-list 1 permit 10.1.1.0 0.0.0.255
```

```
hostname LAN-rtr
```

```
!
```

```
ip cef
```

```
!
```

```
class-map match-all No-Pri-Internet
```

```
    match protocol gnutella
```

```
    match protocol netshow
```

```
    match protocol napster
```

```
    match protocol nntp
```

```
    match protocol realaudio
```

```
    match protocol streamwork
```

```
class-map match-all Low-Pri-Internet
```

```
    match protocol ftp
```

```
    match protocol telnet
```

```
    match protocol secure-ftp
```

```
    match protocol secure-http
```

```
    match protocol secure-pop3
```

```
class-map match-all High-Pri-Internet
```

```
    match protocol http host "cisco.com"
```

```
class-map match-all Med-Pri-Internet
```

```
    match protocol http
```

```
    match protocol ssh
```

```
!
```

```
policy-map Internet-Policy
```

```
    class High-Pri-Internet
```

```
        bandwidth percent 15
```

```
set ip dscp ef

class Med-Pri-Internet

bandwidth percent 55

set ip dscp cs3

class Low-Pri-Internet

bandwidth percent 5

random-detect

set ip dscp cs1

class No-Pri-Internet

police cir 8000

conform-action set-dscp-transmit default

exceed-action drop

class class-default

fair-queue

random-detect

!

!

interface Ethernet0/0

ip address 10.1.1.1 255.255.255.0

!

interface Serial0/2

ip address 192.168.3.2 255.255.255.252

service-policy output Internet-Policy

clockrate 1300000

!

router eigrp 148

network 10.1.1.0 0.0.0.255

network 192.168.3.0 0.0.0.3
```

no auto-summary

Further Reading

IP Quality of Service, by Srinivas Vigesna.

Cisco IOS 12.0 Quality of Service, by Cisco Systems.

Cisco Voice over Frame Relay, ATM, and IP, by Scott McQuerry, Kelly McGrew, and Stephen Foy.

Integrating Voice and Data Networks, by Scott Keagy.

Deploying Cisco Voice over IP Solutions, by Phil Bailey.

RFC 1122, *Requirements for Internet Hosts—Communication Layers*, by Robert Braden.

RFC 1349, *Type of Service in the Internet Protocol Suite*, by Philip Almquist.

RFC 2205, *Resource ReSerVation Protocol (RSVP)—Version 1 Functional Specification*, by Bob Braden, Lixia Zhang, Steve Berson, Shai Herzog, and Sugih Jamin.

RFC 2474, *Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers*, by Kathleen Nichols, Steven Blake, Fred Baker, and David L. Black.

RFC 2475, *An Architecture for Differentiated Services*, by Steven Blake, David L. Black, Mark A. Carlson, Elwyn Davies, Zheng Wang, and Walter Weiss.

RFC 2597, *Assured Forwarding PHB Group*, by Juha Heinanen, Fred Baker, Walter Weiss, and John Wroclawski.

RFC 2598, *An Expedited Forwarding PHB*, by Van Jacobson, Kathleen Nichols, and Kedarnath Poduri.

RFC 2697, *A Single Rate Three Color Marker*, by Juha Heinanen and Roch Guerin.

Part V: BGP Theory and Configuration

[Chapter 7](#) BGP-4 Theory

[Chapter 8](#) Introduction to BGP-4 Configuration

[Chapter 9](#) Advanced BGP Configuration

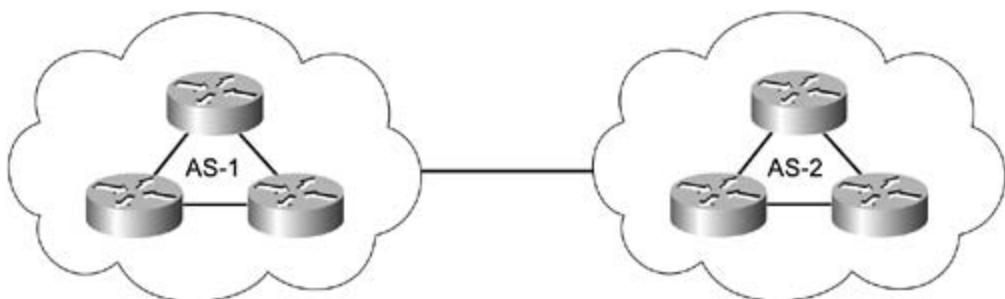
Chapter 7. BGP-4 Theory

Border Gateway Protocol version 4 (BGP-4), the latest version of BGP, is an extension to BGP versions 3 and 2. BGP-4 is currently the routing protocol used to manage routing for the IPv4 Internet. BGP, originally drafted in RFCs 1105, 1163, and 1267, replaced Exterior Gateway Protocol (EGP) as the Internet routing protocol in the early 1990s. This chapter introduces the BGP protocol, explains BGP terminology, and covers BGP protocol operation. The next chapter focuses on BGP configuration.

BGP Overview

BGP-4, referred to in the rest of this book as BGP, is an interdomain routing protocol used to route IPv4 traffic between autonomous systems. *Autonomous systems* are defined as routing domains that are under the same administrative control and follow the same policies. [Figure 7-1](#) shows the connection of two autonomous systems, AS 1 and AS 2. Each of these autonomous systems contains routers that follow the same policies, and are generally under the same administrative control.

Figure 7-1. BGP Autonomous Systems



Like IP addresses, public autonomous system numbers (AS numbers) must be unique to each network and are assigned by a Regional Internet Registry (RIR), such as American Registry for Internet Numbers (ARIN) in the United States. Interior Gateway Protocols (IGPs) are used to manage the routing inside of the routing domain (autonomous system), and Exterior Gateway Protocols (EGP), such as BGP, are used to route between the various routing domains (autonomous systems).

There are two BGP session types: internal BGP (I-BGP) and external BGP (E-BGP). I-BGP is used to route traffic within an autonomous system. All traffic in this autonomous system must comply with the same routing policies and present the same view of the autonomous system to E-BGP networks. E-BGP routes traffic between bordering autonomous systems. Each autonomous system maintains its own routing policies, and border routers are used to enforce routing policy control. Each autonomous system that participates in routing with the public Internet requires a unique AS number. AS numbers range from 1 to 65,535, with the range of 64,512 to 65,535 reserved for private autonomous system use. Routers participating in BGP sessions are referred to as *BGP speakers*. BGP speakers form BGP peering sessions over reliable TCP connections using TCP port 179. BGP relies on the TCP protocol to provide session TCP establishment, flow control, retransmission, and session teardown.

NOTE

For two BGP peers to form a BGP session, they must first have an active TCP session. When troubleshooting BGP connectivity problems, it is important to verify that each of the BGP peers are able to reach each other using TCP port number 179.

BGP sessions are initiated, maintained, and closed using different message types. These message types help BGP peers to progress through various connection states. After each of the peers has entered the *Established* state, they will then exchange routing updates. After the initial routing tables have been exchanged, BGP routing updates contain only route changes (additions, modifications, and route removals). If, for any reason, the TCP session between the BGP peers is broken, the BGP process is immediately terminated, and all routes learned through that BGP session are removed from the routing table.

NOTE

BGP messages types are covered in detail in the "[BGP Messages](#)" section of this chapter.

When exchanging routing information, each BGP speaker might receive multiple BGP paths but will only use and forward the best path to each destination network. If a BGP speaker cannot verify the reachability of a path using the information from the main IP routing table, BGP will not use the path. It will, however, store all the routes, including those that are not currently chosen as best paths, in one of the other internal BGP tables.

NOTE

The BGP route selection process is covered in detail later in this chapter in the "[Route Selection Process](#)" section.

Unlike distance-vector or link-state protocols, BGP makes route determinations based on the AS path that is used to reach a destination network. The *AS path* is a list of autonomous systems that a route passes through to reach its destination. Because BGP was designed to support the entire Internet routing table, BGP is not aware of individual router hops; instead, BGP stores information about the number of AS hops that are used to reach a destination. This is why BGP is referred to as a *path-vector protocol*, because BGP stores information about network paths, rather than distance-vector or link-state routing information. To decrease the number of networks advertised and to increase the believability of the routes, networks are usually aggregated, or summarized, at an AS border router. Aggregation of networks keeps BGP routing tables down in size, decreasing the number of routes that must be sent to neighboring routers and allowing for more controllable network policies.

NOTE

In later versions of Cisco IOS software, the Cisco implementation of BGP supports IPv4 and IPv6 unicast and multicast networks. This book only covers BGP for the unicast IPv4 protocol. When the term IP is used in the chapter, it refers to the IPv4 protocol. For more information on IPv6, see *Cisco Self-Study: Implementing IPv6 Networks (IPv6)*, by Regis Desmeules.

Routing policies are configured using BGP attributes. Attributes are generally assigned to individual network paths, or to an entire autonomous system at the AS border router. BGP speakers use the path attributes to select the best path to each destination network. There are different path selection criteria for interior and exterior BGP sessions. Because exterior BGP speakers must choose from routes that originated in other autonomous systems, these BGP speakers select the paths with the shortest AS path, along with other BGP attributes. I-BGP speakers forward and receive routes that belong to the same AS, so the autonomous system path for these routes is blank; therefore, these BGP speakers must use other BGP attributes to choose the best path. To prevent routing loops, all interior BGP speakers belonging to the same autonomous system do not accept routes that contain their own AS number in the AS path.

NOTE

BGP path attributes are covered in detail later in this chapter in the "[BGP Path Attributes](#)" section.

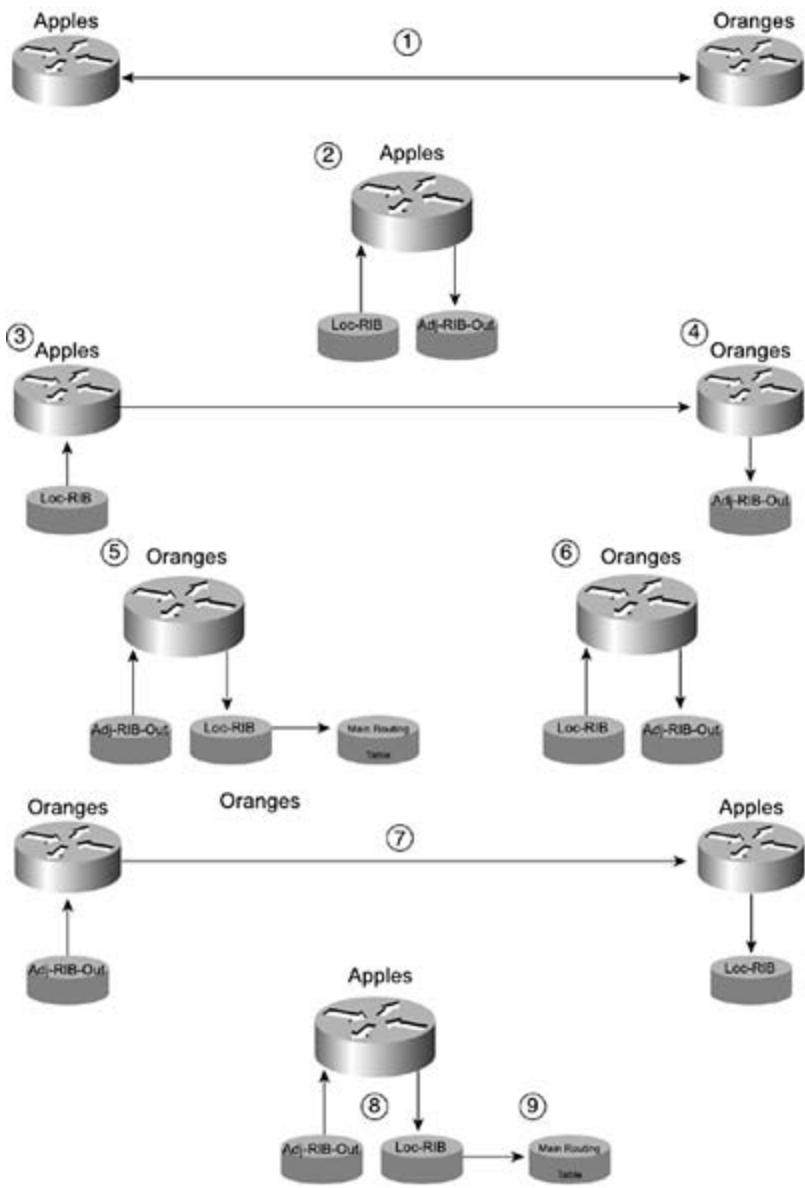
BGP Routing Tables

Routers running the BGP protocol use different routing tables for different purposes. The main IP routing table contains routes obtained through IGP routing processes, such as RIP or Open Shortest Path First (OSPF), static, or directly connected networks. There are also three other conceptual BGP tables, referred to as *Routing Information Bases* (RIBs), which contain only BGP-specific routing information. The BGP tables are used to store information about BGP paths. This information includes the best path to each destination network (used for local routing), the information to send to other BGP peers, and information obtained from other BGP peers. After BGP has selected the best path to a network, that path is added to the main IP routing table.

BGP uses two different routing tables to store incoming and outgoing network advertisements: Adj-RIB-In and Adj-RIB-Out. These tables store information received from other BGP speakers and information to be passed to other BGP peers. Each BGP speaker maintains one Adj-RIB-In and one Adj-RIB-Out per BGP peer relationship. The *Adj-RIB-In* table stores unprocessed BGP information learned from other BGP peers. The information contained in this table is used to determine the best path to the destination network, based on its BGP attributes, using the BGP route selection process. Information from this table is processed by the BGP finite-state machine (the local BGP routing process) and sent to the local BGP table. Information in the *Adj-RIB-Out* table is sent to other BGP peers.

After the local BGP decision process has finished selecting the best path to each destination network, information is stored in the local BGP table, which is known as the *Loc-RIB*. Loc-RIB stores information about paths that conform to the locally configured BGP policies. The BGP speaker learns these routes by means of local BGP configuration, or by learning the route through a BGP session with another BGP speaking router. Unlike the other two BGP routing tables, there is only one Loc-RIB per router (for IPv4 BGP routing). Each path in the Loc-RIB is accompanied by the following routing data: the next-hop IP address used to reach the networks, the metric applied to the network path, the local preference of the path, the weight assigned to the path, the AS path used to reach each of these networks, whether the path was learned through an interior or exterior BGP process or undetermined network origin. If a local router is able to verify that the next hop to the route is reachable—using an IGP route from the local routing table, a static route, or from a directly connected network—the BGP process selects the route and stores it in the main IP routing table. [Figure 7-2](#) illustrates how the BGP routing tables are used during the exchange of BGP routes between two BGP peers, the Apples and Oranges routers, while exchanging routes.

Figure 7-2. BGP Routing Tables



NOTE

The term *RIB* stands for Routing Information Base (database) and refers to a routing table.

Step 1. BGP speakers, Apples and Oranges, form a BGP peering session.

Step 2. The Apples router takes the routes from its local BGP table, Loc-RIB, processes the routes according to its outgoing BGP policy for the Oranges peer, and sends the routes that comply with the policy to the outgoing BGP table, Adj-RIB-Out.

Step 3. The Apples router sends the Oranges all BGP routes matching the local BGP routing policy conforming to the policies configured for the Oranges router, which the

Apples router has stored in the Adj-RIB-Out table for the Apples/Oranges peer session.

Step 4. The Oranges router receives the incoming routes from the Apples router and stores them in the Adj-RIB-In table for the Apples/Oranges peering session, to be processed by the BGP decision process.

Step 5. The Oranges router processes each of the new routes contained in the Adj-RIB-In table, and stores the best path for each network that conforms to the incoming BGP policies for the Apples peer in the Loc-RIB table. Although there is one Adj-RIB-In and one Adj-RIB-Out per BGP session, there is only one main BGP Loc-RIB table per router. After the Oranges router has verified that the next hop to the path is reachable, by searching the main IP routing table for a matching route, and assuming that the main IP routing table does not already have a route to that network via an IGP routing protocol with a lower administrative distance, the path is then stored in the main routing table where it can be used for routing decisions.

Step 6. The Oranges router takes the routes from its local BGP table, Loc-RIB, processes the routes according to the outgoing policy for the Apples router, and sends the routes to be advertised to the outgoing BGP table, Adj-RIB-Out.

Step 7. The Oranges router sends the routes from its outgoing BGP table, Adj-RIB-Out, that conform to the outgoing policy to the Apples router, which stores them in its incoming BGP route table, Adj-RIB-In.

Step 8. The Apples router processes the routes in its Adj-RIB-In table, according to its incoming policy for routes from the Oranges peer, and stores the best path to each destination (that conforms to the incoming policy for the Oranges peer) in the local BGP table, Loc-RIB.

Step 9. The Apples router then verifies that the next hop to each of the network paths contained in the Loc-RIB table is reachable, and, so long as another route to the destination network with a lower administrative distance is not already in the table, stores the reachable best path routes in its main IP routing table.

After the routers have completed the update process and the routes have been processed, only route additions, changes, and removals are sent. As long as the TCP session between the BGP peers is established, the peering routers only send route changes. If the TCP session is lost, all routes learned by means of that session are removed, and when the session is restored, the entire route exchange process takes place again.

BGP speakers do not advertise any networks, unless they are explicitly configured to do so. Before a BGP speaker advertises any network, that network must be explicitly configured as a BGP network. BGP networks can be configured in a number of ways: via the network command; as part of an aggregate network; by redistribution; or as a triggered network advertisement, which is created by configuring condition BGP advertisements. BGP network configuration creates the outgoing BGP policy that will apply to each BGP peer. While creating an outgoing BGP policy, you can specify the BGP attributes that will apply to each of the BGP networks you have created. The BGP attributes can be used to influence the way other routers see a particular route, making it more or less desirable.

Before a BGP speaker installs a route to a network in the main IP routing table, the router must know how to reach the next hop that is used to get to that network. Route reachability is verified by searching for a route to the next hop in the main IP routing table. Unlike IGP routing protocols, such as EIGRP and OSPF, which assume that a route is reachable if they learned it through a valid adjacency, BGP does not install routes that it cannot verify as reachable. If a

route to the next hop for a BGP network is found in the main IP routing table, BGP assumes that the network is reachable, and that the particular BGP route might be stored in the main IP routing table. If the router receives a route to a network that is not reachable, that route continues to be stored in the incoming BGP table, adj-RIB-In, and might be seen using the show ip bgp command, but is not placed in the main IP routing table. If a BGP route that has already been placed in the main IP routing table becomes unreachable (the next hop that is used to reach the network is removed from the main IP routing table), the route is removed. If another reachable route exists, that route is added to the main routing table in the other route's place. When the original route becomes reachable, it might replace the other route, assuming it is the best path to the destination network.

Neighbor Relationships

For two BGP speakers to exchange routing information, they must form a peer relationship, sometimes referred to as a *neighbor relationship*. Each BGP speaker must form a peer relationship with each router with which it is to exchange routes. There are two types of BGP neighbor relationships: internal and external. This section shows how TCP sessions are formed between BGP peers and describes how internal and external BGP peers form neighbor relationships.

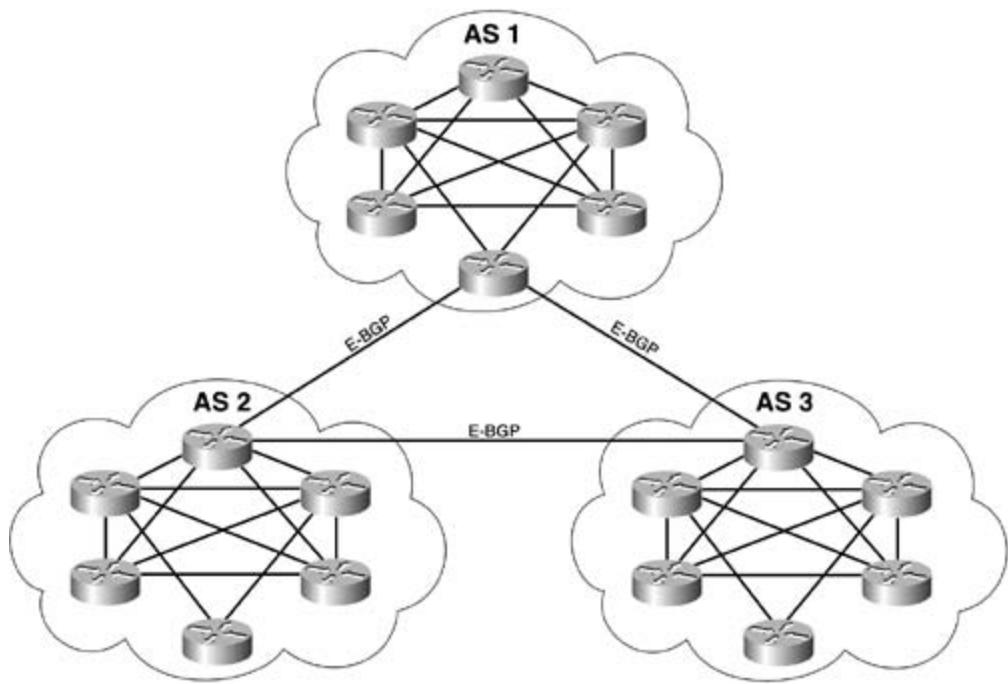
Internal and External BGP

As previously mentioned, there are two types of BGP sessions: external BGP sessions, which interconnect AS; and internal BGP sessions, which are used between BGP speakers within the same AS. Both external and internal BGP speakers forward information about BGP paths and rely on IGP routing protocols to maintain a routing table.

External BGP Operation

External BGP is used to exchange routing information between routers belonging to different ASs. Each AS has its own routing policies and is managed independently, usually by people in different organizations or departments. Because E-BGP peers belong to different networks, each E-BGP peer must be configured with policies to control the propagation of internal routes to external networks, filter internal networks that should not be advertised externally, aggregate routes as necessary, and provide session stability. Unless otherwise specified, E-BGP peering routers must be directly connected to each other. [Figure 7-3](#) shows how E-BGP is used to form external BGP sessions between AS 1, AS 2, and AS 3. Notice that only the AS border routers participate in E-BGP, and the E-BGP peers are directly connected to each other at the AS border.

Figure 7-3. E-BGP Logical Diagram



After BGP has been configured, each of the peers negotiates a BGP session and exchanges routes. When you connect a local BGP router to a service provider, you will, most likely, be using a serial, ATM, or Frame Relay connection that goes from your Internet border router directly to your service provider's customer-facing border router. In most cases, this connection is not made across other non-BGP-speaking routers.

NOTE

With the ever-present security threats that must be considered in today's networks, E-BGP connections might need to pass through a firewall or other security device before exiting the network. To overcome the rule that requires E-BGP peers to be directly connected, you can use the `ebgp-multihop` command to specify that the BGP session will be formed over more than one hop. [Chapter 8, "Introduction to BGP-4 Configuration,"](#) covers the use of the `ebgp-multihop` command.

When designing BGP networks, stable interfaces should be used to prevent route dampening. *Route dampening* occurs when an interface has repeatedly transitioned from an up to down state, and the BGP peering router dampens the route, temporarily suspending route advertisements from the flapping router until a certain period of stability has been exceeded. Most service providers provide their customers with their route-dampening policy and the policy violation penalties. When configuring a multihomed router for E-BGP peering, it is always a good practice to set the BGP router ID to that of a loopback interface, so that the BGP session is least affected by network instabilities and routes are not dampened.

NOTE

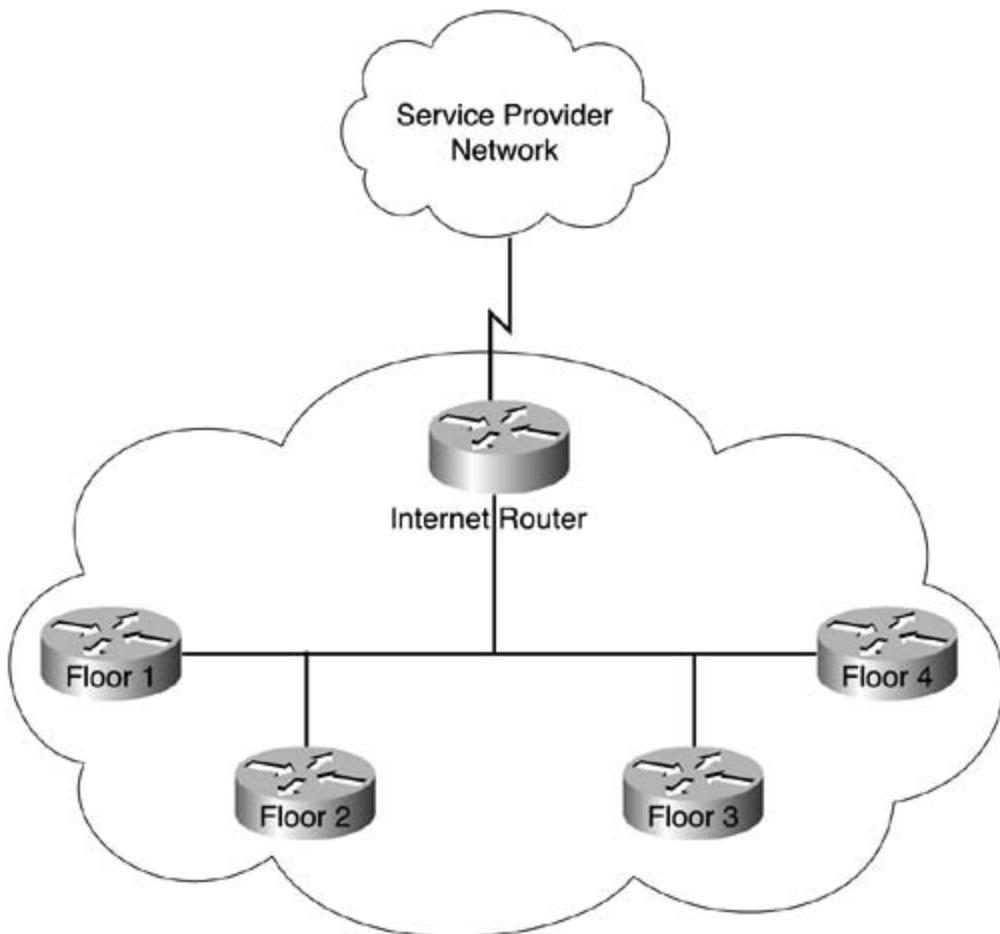
Many service providers require that customers that do not have multihomed routers must use the IP addresses of directly connected networks for BGP sessions. To work around this problem, you can set the IP address of the BGP router ID to that of a loopback interface, and change the BGP update source to the IP address of the directly connected interface. Multihoming is covered in detail in [Chapter 8](#).

NOTE

It is generally a good idea to use a loopback interface for the BGP router ID. When OSPF and BGP are both used on the same router, however, you must plan your BGP and OSPF router IDs even more carefully. RFC 1745 states, "The BGP/IDRP identifier *must* be the same as the OSPF router ID at all times that the router is up." If the OSPF and BGP router IDs do not match, BGP cannot synchronize with OSPF, causing BGP not to advertise any unsynchronized routes to any peers.

In most enterprise environments, I-BGP is generally used to connect two or more enterprise border routers to multihome a network to two or more service providers. However, some large enterprise networks might use I-BGP between core routers and E-BGP between the core routers in core sites to provide routing policy. On most enterprise networks, E-BGP sessions are more common than I-BGP connections. This is because E-BGP sessions are used to connect local autonomous systems to the Internet service providers using I-BGP. There are quite a few ways to connect private networks to the public Internet, the most common of which is to use a static route that provides a default route to any unknown network. When this configuration is used, the service provider provides all BGP routing from within their own network and advertises the customer's network from a block of addresses that the service provider has provided the customer. In this case, BGP is not needed on the customer's network. As shown in [Figure 7-4](#), the Internet router provides the only route to the Internet through the service provider's network. The customer's network runs its own IGP for interior routing for all internal traffic between floors on the local network, and the Internet router provides a default route to the Internet using the service provider's network to provide any Internet routing.

Figure 7-4. Single-Homed Networks



If your network has its own scope of public IP addresses that has been allocated by a public address registry, such as ARIN (American Registry for Internet Numbers), an organization that registers public IP addresses and AS numbers, you must obtain your own unique BGP AS number to advertise your public networks to the Internet.

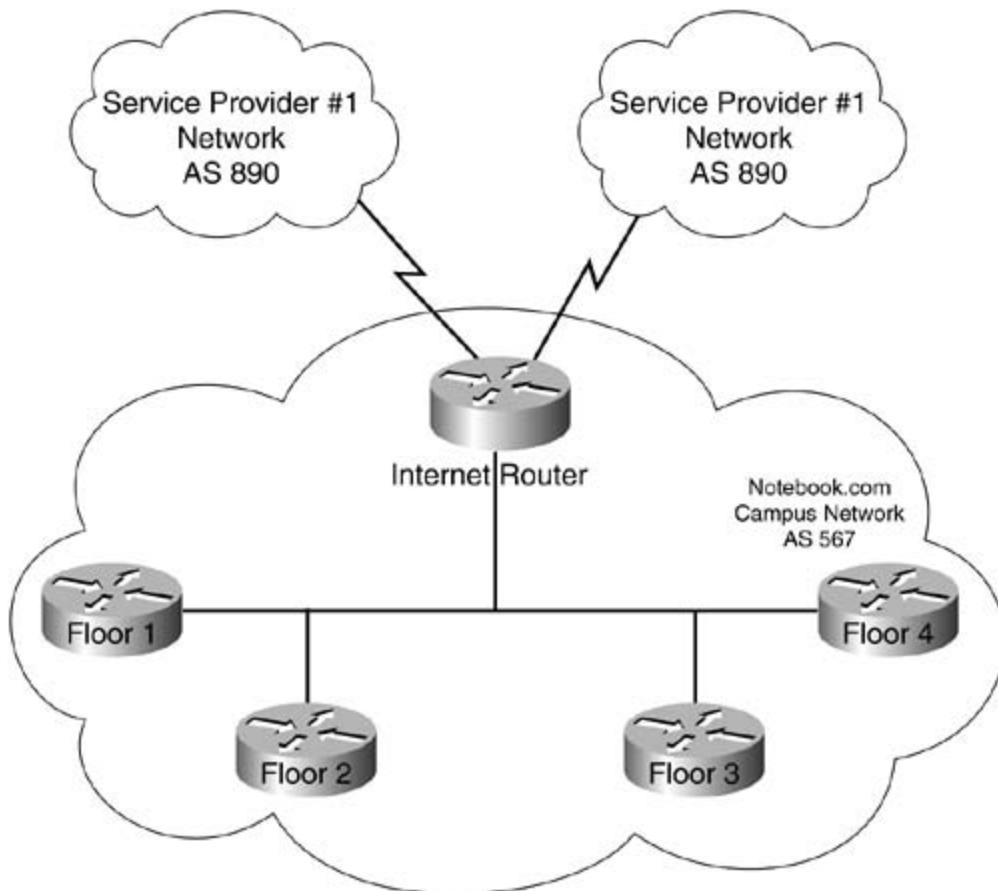
NOTE

For more information on Internet number registration in the United States, check out the ARIN website at www.arin.net. For European address registration, visit the Réseaux IP Européens Network Coordination Centre (RIPE NCC), www.ripe.net. For Asian network address registration, visit the Asia Pacific Network Information Centre (APNIC) at www.apnic.net. Each of these websites contains a great deal of information about Internet number allocation and assignment, policies for number assignment, and statistical information.

After you have been allocated a range of public IP addresses and have registered an AS number, you must then arrange to advertise this information to an upstream network service provider, following that service provider's policies. You can connect and advertise networks to upstream providers in a number of ways. The two most popular ways are single-homing a network, which

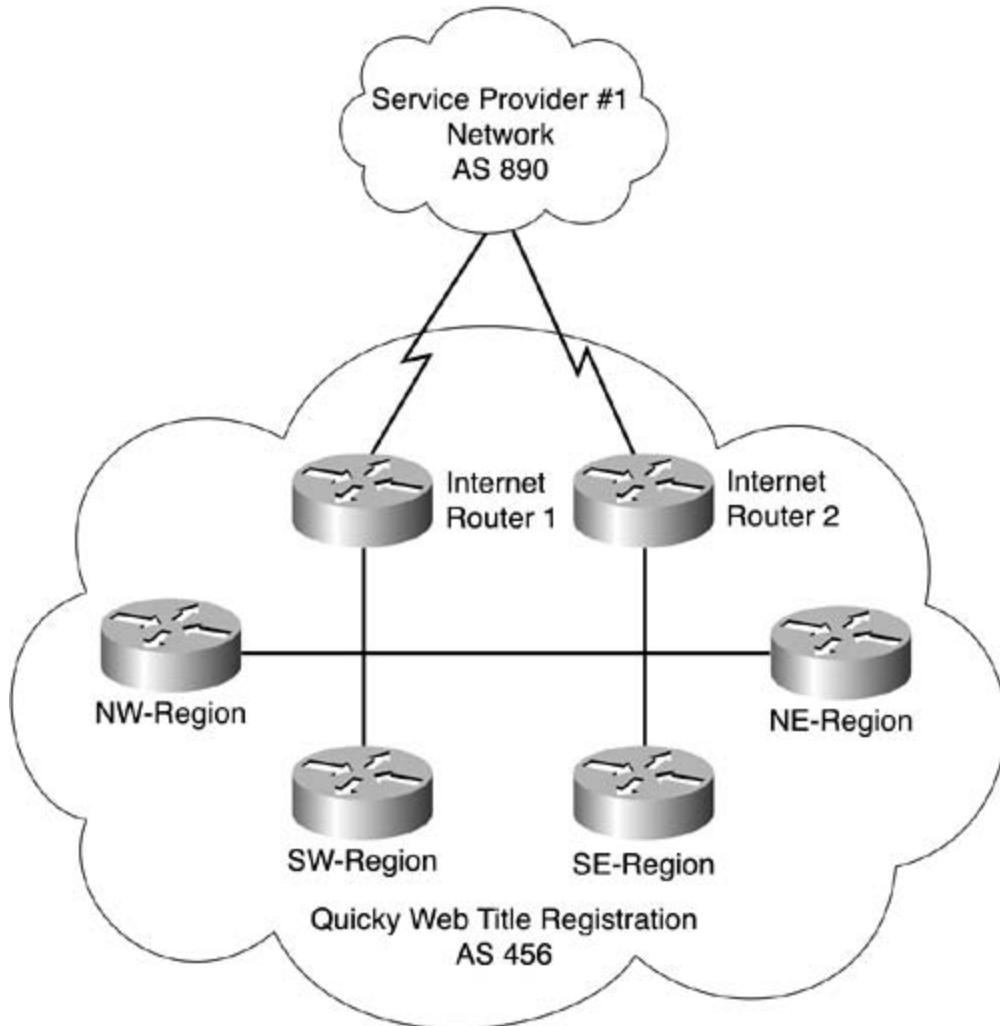
usually does not require an AS number or an RIR assigned public IP address allocation, and multihoming networks to more than one provider, which requires AS number and IP address assignments. [Figure 7-5](#) shows how one campus network is multihomed to two different service providers using BGP. In this example, Notebook.com is connected to Service Provider 1 (AS 890) and Service Provider 2 (AS 123). Notebook.com advertises its IP networks using AS 567. In this example, Internet connection redundancy is provided to different service providers connecting to one router; this might be a solution in some cases where budget constraints limit you to one Internet border router; be aware, however, that having only one router does create a single point of failure.

Figure 7-5. Single-Homed Campus to Multiple Providers



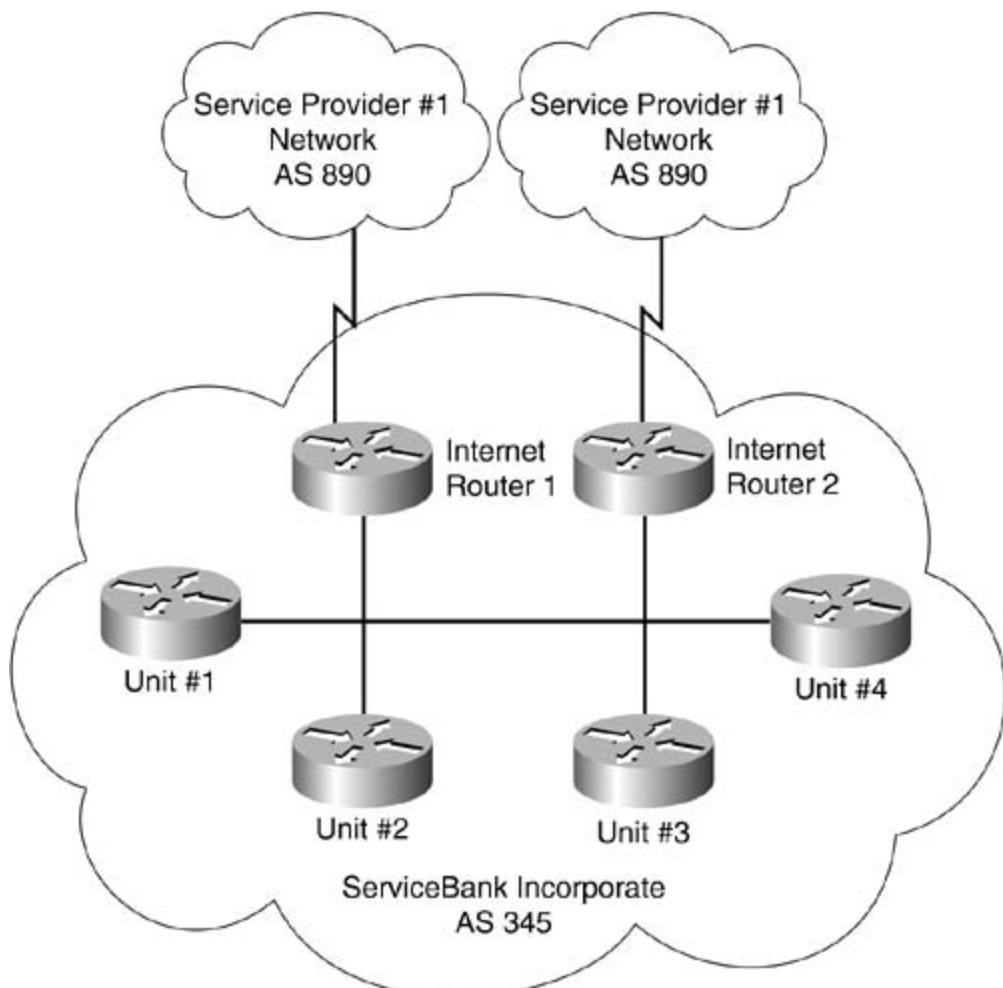
In the next example, shown in [Figure 7-6](#), Quicky Web Title Registration uses Internet Router 1 and Internet Router 2 to advertise its Northwestern, Southwestern, Northeastern, and Southeastern regions' networks to their upstream service provider's network. Quicky's network uses AS 456 to advertise its public networks, and the service provider uses AS 876 to connect to AS 456. In this example, Internet redundancy is provided by connecting two Internet border routers to one service provider, which provides two different routers, WAN interfaces, and circuits for hardware redundancy, but causes a single point of failure with the Internet service provider. In this example, if the service provider has an outage, Quicky's entire Internet connection would be lost.

Figure 7-6. Multihomed Campus to Single Provider



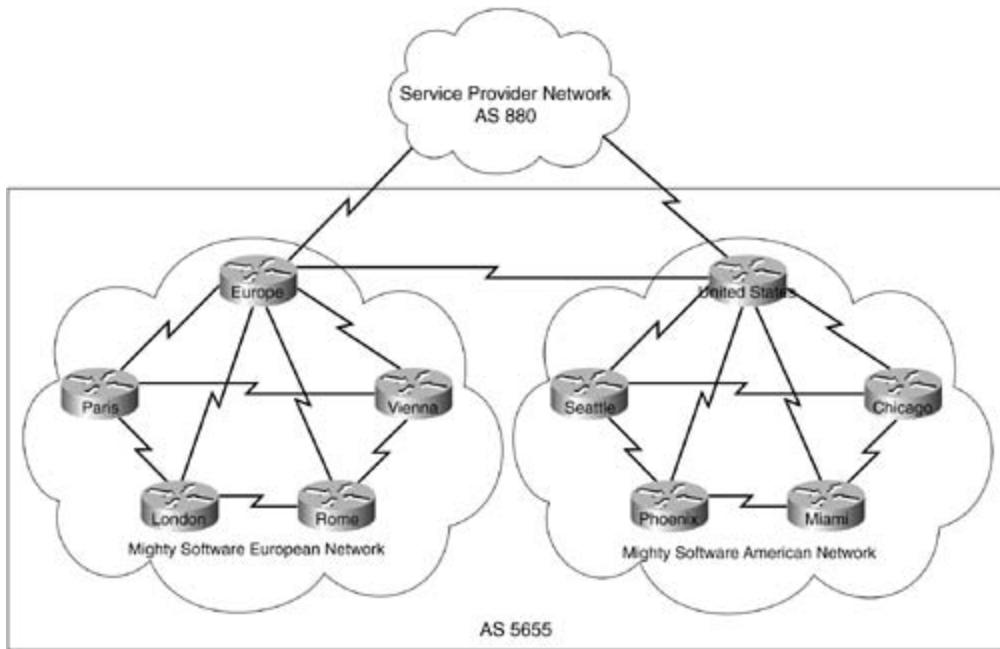
In [Figure 7-7](#), ServiceBank Incorporated uses AS 345 to connect to Service Provider 1 (AS 923) and Service Provider 2 (AS 159). In this example, ServiceBank uses two Internet routers, each connected to a different service provider, to multihome their network to multiple providers. In this case, I-BGP needs to be used to exchange routing information between the two E-BGP Internet routers. This example uses two routers, two circuits, and two service providers; this configuration eliminates any single points of failure. In this example, if ServiceBank has any one failure with any router, circuit, or service provider, they will still be connected to the Internet and able to pass traffic.

Figure 7-7. Multihomed Campus to Multiple Providers



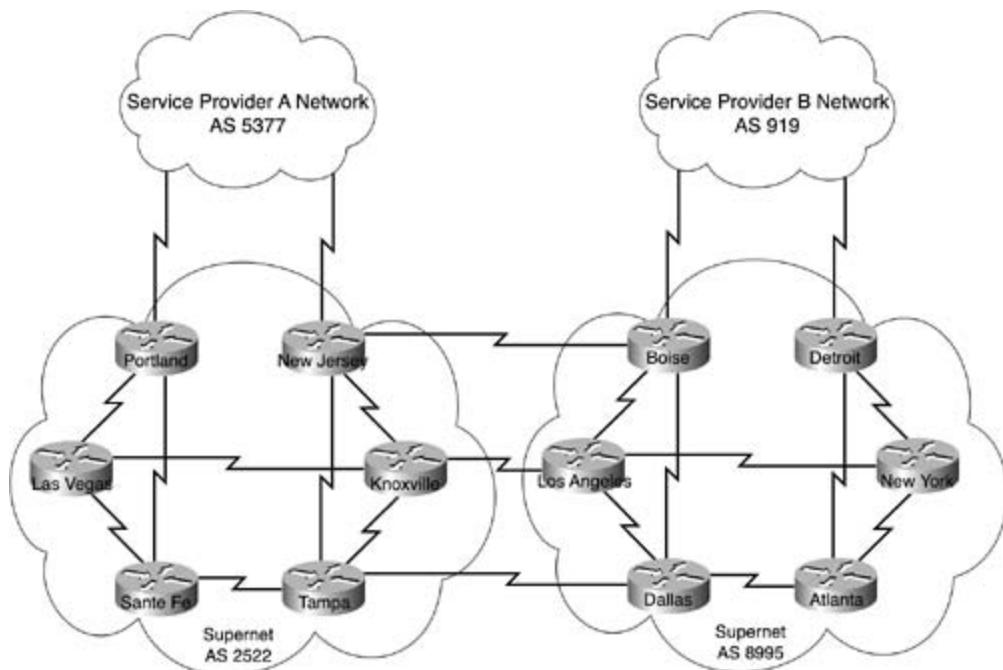
[Figure 7-8](#) shows how Mighty Software uses one BGP AS, AS 5655, to connect its European and American networks to the Internet. In this example, Mighty Software's Europe router forms an E-BGP connection, using AS 5655 with the service provider's AS 888. The Europe router is also connected to the Paris, Vienna, London, and Rome routers using a partial mesh of serial E1 WAN connections. The Paris, Vienna, London, and Rome routers are connected via E1 circuits, and they use an IGP routing protocol to route internal networks. The Europe router handles all BGP routing with the service provider for European Internet traffic, and all the other European routers use the Europe router to access the Internet. Likewise, on the American network, the United-States router handles all Internet traffic using an E-BGP connection to the service provider's network, and all U.S. routers form a partial mesh to route to the Internet, the Europe network, and to each other. In this example, there are very few points where a failure can affect Internet connectivity; the only real single point of failure is the single Internet provider.

Figure 7-8. Multihomed to Single-Provider International



In [Figure 7-9](#), Supernet has two divisions, each having its own AS number. Each AS is multihomed to a single provider's network for Internet traffic. AS 2522 uses the Portland and New Jersey routers for E-BGP to Service Provider A (AS 5377), and AS 8995 uses the Boise and Detroit routers for E-BGP connections to Service Provider B's network (AS 919). Each of these networks is partially meshed, and they all use an IGP routing protocol for internal routing. The New Jersey and Boise routers are also used to form an E-BGP connection between the two ASs. I-BGP connects are required for communication between the Portland and New Jersey routers and the Boise and Detroit routers. This example is the most redundant of all shown so far. Multiple sites have multiple connections to multiple service providers, limiting the number of failure points. Whenever the resources are available, it is always best to create the most redundant architecture possible, limiting the possible points of failure.

Figure 7-9. Multihomed to Multiple-Providers National

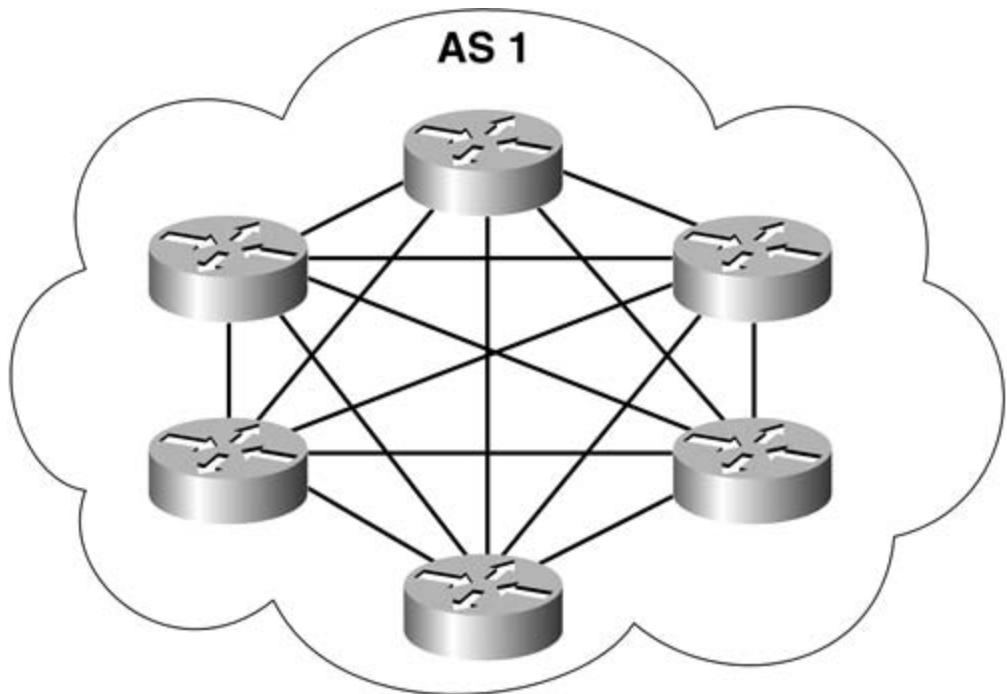


After an E-BGP peer relationship has been formed between an AS border router and an upstream service provider network, Internet border routers must run an internal BGP process to communicate with other BGP speakers within the local AS. The next section discusses I-BGP operation and I-BGP rules.

I-BGP Operation

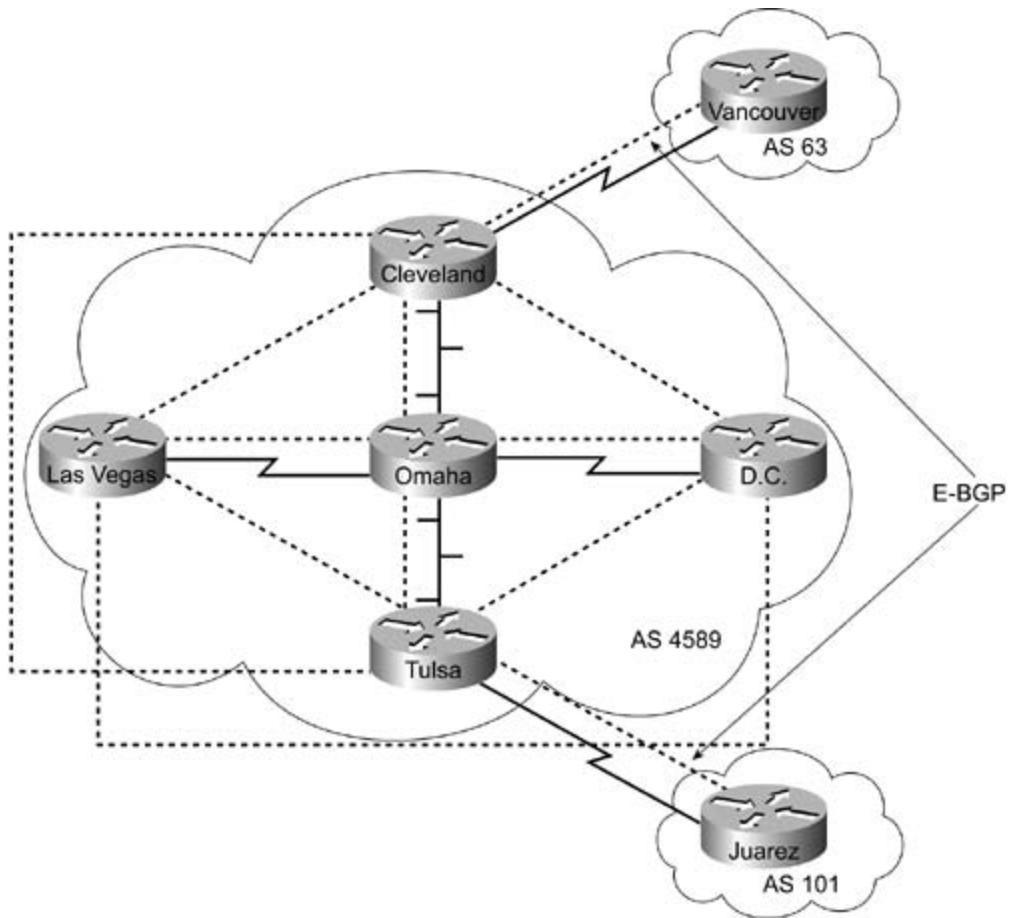
I-BGP is used between BGP peers within the same AS. As with E-BGP, each I-BGP speaker must be configured to peer with each of its neighboring BGP-speaking routers. BGP does not allow for automatic neighbor discovery. For I-BGP peering routers to provide a consistent view of the network, they must be configured in a full-mesh type of architecture, such as that shown in [Figure 7-10](#). Each router in an I-BGP peering relationship must be connected to all other I-BGP peers via local BGP configuration. Each I-BGP peer must also transition through the various BGP states, and send the same BGP messages and form an Established BGP connection to each of its neighboring peers to exchange routing information.

Figure 7-10. I -BGP Logical Diagram



Unlike E-BGP peering routers, I-BGP routers do not have to be directly connected. In [Figure 7-11](#), for example, AS 4589 contains five I-BGP peering routers: Las Vegas, Cleveland, Omaha, D.C., and Tulsa.

Figure 7-11. I -BGP Full-Mesh Versus E-BGP



Each I-BGP-speaking router in AS 4589 has an I-BGP peering connection with each other router within AS 4589, even if they are not directly connected. The E-BGP-speaking routers—Cleveland and Vancouver, and Tulsa and Juarez—have direct serial connections that are used to form the E-BGP sessions. Notice also that the other I-BGP-speaking routers do not form peer relationships with the E-BGP routers external to their AS. This is because each BGP session, either I-BGP or E-BGP, must be explicitly configured on each of the peering routers. [Table 7-1](#) shows the BGP peer connection types and the BGP peering neighbors.

Table 7-1. BGP Peer Connection

BGPRouter	I-BGPPeers	E-BGPPeers
Las Vegas	Cleveland Omaha Tulsa D.C.	None
Cleveland	Las Vegas Omaha D.C. Tulsa	Vancouver
D.C.	Cleveland Omaha Tulsa Las Vegas	None
Omaha	Cleveland Las Vegas D.C. Tulsa	None
Tulsa	Las Vegas Omaha D.C. Cleveland	Juarez

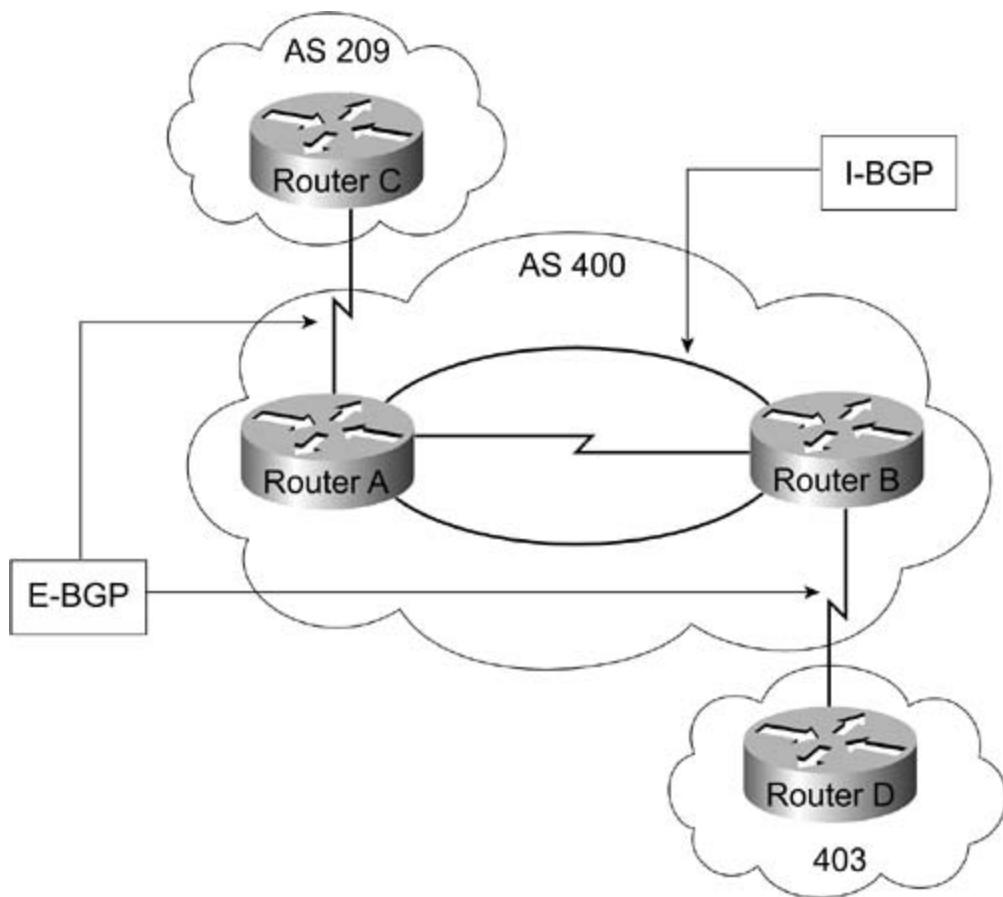
As mentioned earlier in this chapter, BGP is a path-vector routing protocol, which means that routers that participate in BGP routing processes route traffic based on AS paths, rather than individual router hops like distance-vector algorithms or other link-state metrics such as costs. For BGP to form loop-free paths, it uses an attribute referred to as *AS_PATH*, which contains the path that the BGP route traversed to reach a destination. Each E-BGP-speaking router adds its AS to the AS_PATH on each route it learns, and then forwards that information to downstream BGP routers, which use that information to determine the return path. I-BGP neighbors do not forward (or re-advertise) routes learned from within their own AS (contained in the AS_PATH) to other I-BGP peers, which prevent routing loops from forming within an AS. When two routers in the same AS are each connected to two other E-BGP routers in other autonomous systems, they do not include their internal BGP AS number in the AS_PATH when forwarding routes internally.

NOTE

The AS_PATH attribute is covered in detail later in the "[The AS_PATH Attribute](#)" section of this chapter.

As shown in [Figure 7-12](#), Router A is connected to Router C via E-BGP, and Router B is connected to Router D via E-BGP. Routers A and B also have I-BGP connections. When Router A learns of routes through its E-BGP session with Router C, the AS_PATH for each of those routes will include AS 209. When Router A forwards these routes to Router B, it does not include its AS number, AS 400, in the AS_PATH, because Routers A and B have an I-BGP peer relationship. When Router B forwards the routes to Router D, however, it includes its AS number 400, in the path because Router D is an E-BGP peer. Therefore, Router D sees an AS_PATH of 400 and 209 when in the path to Router C, but it is unaware that AS 400 had multiple routes in the path.

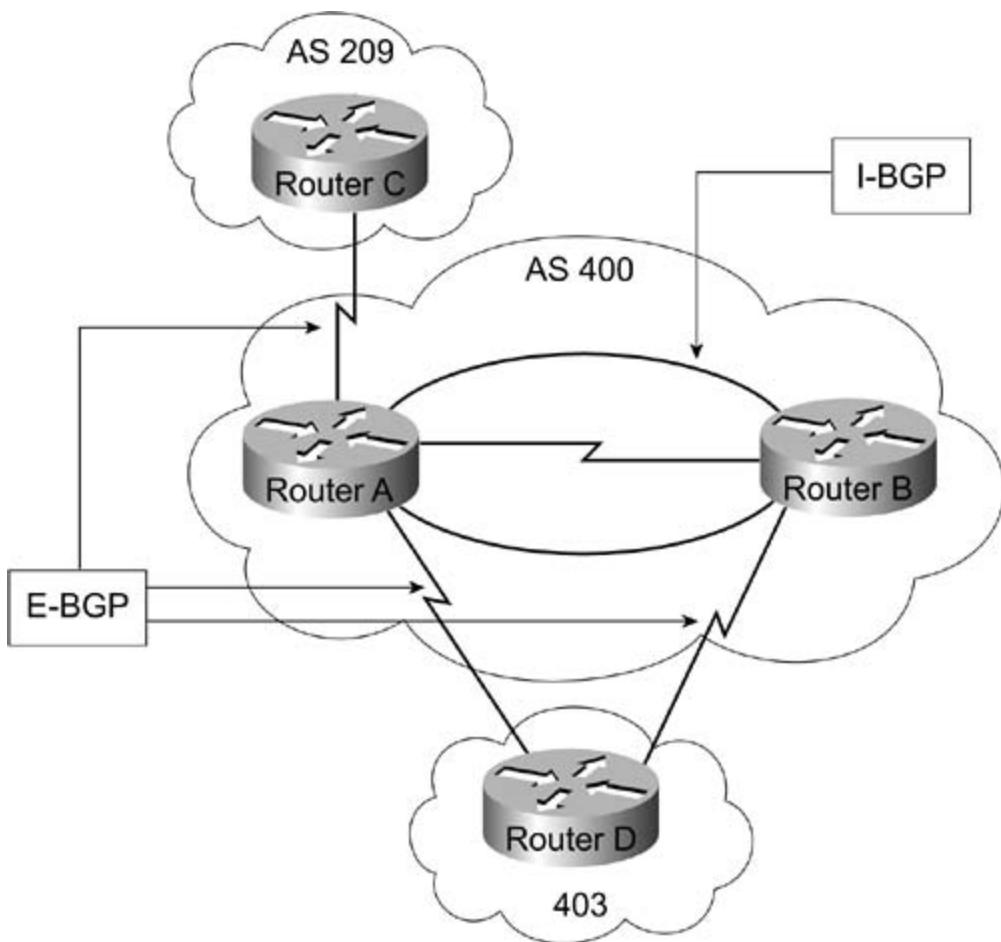
Figure 7-12. ASm Paths and I-BGP



In the preceding example, when Router A receives updates from Router C, these updates contain an AS_PATH value of 209. When Router A forwards the updates to Router B to tell it about networks advertised by Router C, the updates still contain an AS_PATH value of 209, because Routers A and B both belong to the same AS. When Routers A and B forward routes from Router C to Router D, however, they add their AS number, 400, to the AS_PATH, so Router D sees that routes from Router C contain an AS_PATH of 400 and 209. Likewise, Router C sees routes from Router D with an AS_PATH value of 400 and 403.

If this topology changes and Router D forms two E-BGP connections, one with Router A and one with Router B, Router D still has one AS path to follow to reach Router C in AS 209. So, routes cannot loop between Routers A and B in AS 400 to reach AS 209. [Figure 7-13](#) illustrates this. Router C uses Router A to reach Router D in AS 403. If the link between Routers A and D goes down, Routers A and D can still reach each other via Router B; and Router D can still reach router C in AS 209, if either of the links between itself and Routers A or B are down.

Figure 7-13. Adding a New E-BGP Connection to AS 400



For I-BGP-speaking routers to send internal BGP routes to E-BGP-speaking peers, the I-BGP-speaking router must first have an exact match for the BGP route in its IP routing table. Routes that are not present, or synchronized with the main IP routing table, are not advertised to any BGP peers, because the I-BGP-speaking peer cannot verify reachability for a route that is not found in the main IP routing table. If the router does have an exact match for the route in its main IP routing table, however—learned through an IGP routing process, via a static route, or a directly connected network—that route is advertised to other BGP peers. This is referred to as the *rule of synchronization*; routes in the BGP table must be synchronized with routes in the main IGP routing table (that is, an exact, valid, reachable match for the route must exist) before they can advertise routes to remote peers.

NOTE

One key concept to remember with BGP is the rule of synchronization. Paths in the local BGP table (Loc-RIB) must be synchronized with valid, reachable routes from the IGP routing table before the local BGP process will advertise paths to remote BGP peers or store the BGP routes in the main IP routing table. In other words, routes learned through I-BGP are validated against routes learned via IGP protocols when synchronization is enabled. Synchronization can be, and often is, disabled on BGP-speaking routers that run both I-BGP and E-BGP. If BGP synchronization is not disabled, and an IGP protocol is not providing routing information, the BGP speaker does not use or propagate routes that it does not know how to reach. The use of BGP synchronization is covered in detail in [Chapter 8](#).

To provide a consistent view of an AS to upstream BGP peers, by default, AS bordering routers do not advertise unsynchronized routes learned through I-BGP sessions to E-BGP peers. This is due to the rule of synchronization. BGP synchronization allows I-BGP peers to provide upstream peers with a consistent view of their networks. Because I-BGP-speaking routers that have synchronized BGP and IGP routing tables assume that all other internal peers have the same routing tables, there should not be any unsynchronized routes. As long as all the speakers in an I-BGP network are fully meshed and have a consistent view of the BGP network, IGP to BGP synchronization can be disabled. In [Figure 7-13](#), for example, Router A will not advertise the routes that it has learned from Router B to Routers C or D unless synchronization has been disabled or they are running an IGP routing protocol with synchronized IGP to BGP routes. Likewise, Router B will not advertise any routes it receives from Router A on to Router D unless the IGP and BGP routes are synchronized or BGP synchronization is disabled.

Now that basic BGP operation and terminology have been covered, it is time to move on to more advanced BGP operation. The next few sections cover the following topics in detail:

- BGP messages
- The BGP Finite-State Machine
- BGP attributes
- Route reflectors and confederations
- The BGP decision process

BGP Messages

BGP uses a series of messages to initiate BGP sessions with peering routers, verify that sessions are active, send routing updates, and notify peer routers of error conditions. Each of these messages is used for a particular type of action. [Table 7-2](#) shows a summary of the messages used for all BGP peering sessions.

Table 7-2. BGP Message Summary

Message Number	Message Type	Message Description
1	OPEN message	Used to open BGP sessions
2	UPDATE message	Carries route updates for established BGP sessions
3	NOTIFICATION message	Notifies a peer router of an error condition
4	KEEPALIVE message	Sent between BGP peering routers to verify BGP session
5	ROUTE-REFRESH message	An optional message (negotiated during capability advertisement) that is sent to request dynamic BGP route updates from the Adj-RIB-Out table of a remote BGP speaker

NOTE

BGP-4 protocol operation was originally defined in RFC 1771; the IETF Inter-Domain Routing (IDR) working group has been working on a draft that will update that RFC. That Internet draft should reach RFC status by late 2003. For more information about the IETF IDR working group, go to <http://www.ietf.org/html.charters/idr-charter.html>.

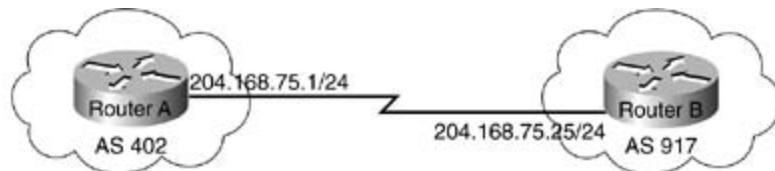
OPEN Message

To establish a BGP session, each BGP peer must send each of its neighboring peers an OPEN message. The OPEN message contains information about the local BGP speaker, and is used after a TCP session has been established. All fields in the OPEN message must be negotiated and accepted before a session can exchange routing information. [Table 7-3](#) describes the information that comprises the OPEN message.

[Figure 7-14](#) shows how Router A and Router B use BGP OPEN messages to form a BGP session. In this example, Router A sends an OPEN message to Router B containing its BGP version of 4, the My AS value of 402, a hold timer of 180 seconds, and the BGP ID of 204.168.75.1. Router B responds with its own OPEN message containing its local BGP version of 4, its My AS of 917, a hold timer of 180 seconds, and the BGP ID of 204.168.75.25. Notice that in this example, each

of the BGP speakers are in a different AS, identified by their My AS values; this indicates that they will participate in an E-BGP session.

Figure 7-14. Opening a BGP Session



Open Message	
Version	4
My AS	402
Hold Timer	180
BGP ID	204.168.75.1
Optional	None

Open Message	
Version	4
My AS	917
Hold Timer	180
BGP ID	204.168.75.25
Optional	None

Table 7-3. BGP OPEN Message Parameters

Message Parameter	Description
Version	<p>The version of BGP used by the local BGP speaker.</p> <p>The BGP version of the local router is usually the current version, but can be configured to an older version to be compatible with a peering router running an older BGP version.</p> <p>If the BGP versions do not match, a BGP session will not be opened. Each of the peering routers try to negotiate a compatible BGP version prior to opening a session.</p>
My AS	<p>The AS number used by the local BGP speaker.</p> <p>If the My AS value does not match that configured for the remote peer, a BGP session will not be opened.</p> <p>The My AS value also defines whether the BGP peers will be participating in an internal or external BGP session.</p>

Hold Timer	<p>The length of time a BGP speaker expects to wait before receiving either an UPDATE or KEEPALIVE message from its peer.</p> <p>BGP peering routers must negotiate and agree on a hold time to establish a BGP session. On Cisco routers, the default hold time for a BGP session is 180 seconds. However, the hold timer is configurable to a value between 0 and 4,294,967,295. If a hold timer of 0 is configured, KEEPALIVE messages will not be used to verify BGP session validity. If a hold time of 0 is not used, the hold timer must be configured to use a value greater than 3 seconds. Hold timers are configured using the default timers bgp command, which is covered in Chapter 8.</p> <p>It is very important to note that each of the BGP neighbors must agree on an acceptable hold timer before a BGP session can be established, so this value should not be changed unless the peering routers hold timer values will be changed as well.</p>
BGP ID	<p>The local BGP speaker's identification.</p> <p>The BGP ID is usually the local router ID that, like OSPF, is the highest IP address of a loopback interface. Loopback interfaces are used to provide the most stable interface for the router ID. The router ID can be changed to another local IP address using the bgp router-id command, which is covered in Chapter 8.</p> <p>The BGP ID value must match the values configured by both the local and remote BGP peers for each BGP peer relationship, and the remote peer must be reachable by the local BGP peer or the session will not be opened.</p>
Optional	<p>Contains optional BGP parameters, such as the Marker field, which contains authentication information; if authentication is not configured, the Marker field will contain all 1s.</p> <p>The optional <i>Capabilities</i> field contains information that allows for BGP feature negotiation; it is either supported or unsupported between BGP peers. If a Capability option is not supported, it will be ignored by the remote peer, and the session will be renegotiated without the capability.</p>

[Example 7-1](#) shows a packet capture that contains a BGP OPEN message. BGP uses the IP precedence value of Internetwork Control, shown as 110000, which is used for high-priority routing traffic. For more detailed information on the type of service (ToS) bits, refer to [Chapter 5](#), "Integrated and Differentiated Services." Notice in this message that the TCP session is using the destination port 179, the BGP destination port. The BGP header for this OPEN message (BGP message type 1) includes a Marker field containing all 1s, which indicates that MD-5 authentication is not in use, with a 45-byte header; the Version field specifies that the sending host is using BGP-4. The host belongs to AS number 1 and the hold time is 180 seconds, and the sending host's BGP ID is 192.168.5.1.

Example 7-1. BGP OPEN Message

Frame Status Source Address Dest. Address Size Rel. Time Delta Time Abs. Time

Summary

```
8 [10.50.4.1] [10.50.4.2] 99 0:00:37.326 0.003.216 04/28/2002 03:14:50 PM
BGP: type = Open
DLC: -----
DLC Header -----
DLC:
DLC: Frame 8 arrived at 15:14:50.2341; frame size is 99 (0063 hex) bytes.
DLC: Destination = Station 000427228197
DLC: Source = Station 0004272281D8
DLC: Ethertype = 0800 (IP)
DLC:
IP: ----- IP Header -----
IP:
IP: Version = 4, header length = 20 bytes
IP: Type of service = C0
IP: 110. .... = internetwork control
IP: ...0 .... = normal delay
IP: .... 0... = normal throughput
IP: .... .0.. = normal reliability
IP: .... ..0. = ECT bit - transport protocol will ignore the CE bit
IP: .... ...0 = CE bit - no congestion
IP: Total length = 85 bytes
IP: Identification = 2
IP: Flags = 0X
IP: .0... .... = might fragment
IP: ..0. .... = last fragment IP: Fragment offset = 0 bytes
IP: Time to live = 1 seconds/hops
IP: Protocol = 6 (TCP)
```

IP: Header checksum = 9C7B (correct)

IP: Source address = [10.50.4.1]

IP: Destination address = [10.50.4.2]

IP: No options

IP:

TCP: ----- TCP header -----

TCP:

TCP: Source port = 11002

TCP: Destination port = 179 (BGP)

TCP: Sequence number = 3817488861

TCP: Next expected Seq number= 3817488906

TCP: Acknowledgment number = 3816595146

TCP: Data offset = 20 bytes

TCP: Flags = 18

TCP: ..0. = (No urgent pointer)

TCP: ...1 = Acknowledgment

TCP: 1.... = Push

TCP:0.. = (No reset)

TCP:0. = (No SYN)

TCP:0 = (No FIN)

TCP: Window = 16384

TCP: Checksum = 97C3 (correct)

TCP: No TCP options

TCP: [45 Bytes of data]

TCP:

BGP: ----- BGP Message -----

BGP: BGP: 16 byte Marker (all 1's)

BGP: Length = 45

BGP Capabilities Advertisement

Starting with BGP-4, BGP peer capabilities can be negotiated during session BGP initialization, using the Optional Capabilities parameter, which is contained in the OPEN message. BGP capabilities negotiation is described in RFC 2842. This element was added into BGP so that new features could be added into the BGP specification without requiring upgrades to newer versions of the protocol.

Using capabilities advertisement, peers can exchange capabilities and negotiate a session using the most agreed-upon features. If one of the peers does not support an optional parameter, it sends the advertiser a NOTIFICATION message with the error "Unsupported Optional Parameter." After receiving the NOTIFICATION message, the advertising peer resends the message without the unsupported parameter and so on, until both peers agree on a set of parameters. [Table 7-4](#) describes the IANA-defined BGP capabilities codes.

Table 7-4. BGP Capabilities Codes

Capabilities Code	Description
0	Reserved
1	Multiprotocol extensions for BGP-4
2	ROUTE-REFRESH capability for BGP-4
3	Cooperative route filtering capability
4	Multiple routes to a destination capability
5–63	Unassigned
64	Graceful restart capability
65	Support for 4-octet AS number capability
66	Support for dynamic capability
128–255	Vendor specific

UPDATE Message

After a BGP session has been established, the peering routers begin to exchange routing information using UPDATE messages. UPDATE messages contain information about each route advertised to the peering router. In BGP routing, network prefixes are also referred to as *Network Layer Reachability Information (NLR)*. [Table 7-5](#) shows the information contained in BGP UPDATE messages and descriptions of the BGP UPDATE message fields.

Table 7-5. BGP UPDATE Message Information

Message Parameters	Description
Unfeasible Route Length	This field contains the total number of routes that are to be withdrawn from the BGP routing tables. If this value is 0, no routes are to be withdrawn in this message.
Withdrawn Routes	The Withdrawn Routes field contains prefixes that are to be removed from the BGP tables. This information is stored in a [<i>length, prefix</i>] format. Each route that is to be removed from an established BGP session is sent to the neighboring router in this format.
Total Path Attribute Length	This field identifies the total length of the Path Attributes field (in octets).

Path Attributes	<p>BGP path attributes (attribute type codes) are basically the metrics that are to be used by the decision process. There are 19 BGP path attributes defined by IANA, the top 10 of which are as follows:</p> <ol style="list-style-type: none"> 1. ORIGIN 2. AS_PATH 3. NEXT_HOP 4. MULTI-EXIT-DISC 5. LOCAL-PREF 6. ATOMIC-AGGREGATE 7. AGGREGATOR 8. COMMUNITY 9. ORIGINATOR_ID 10. CLUSTER_LIST <p>The Path Attributes field contains three values:</p> <ul style="list-style-type: none"> • Attribute Type— Contains two subsections that describe each attribute type code (listed here) and the flags that apply to those attributes • Attribute Length— Defines the length of the attribute • Attribute Value— Contains the value belonging to the attribute type code
Attribute Type (a subsection of the Path Attributes field)	<p>The Attribute Type field contains two items: the Attribute Flags and the Attribute Type Code. Each of the attributes from the Attribute Type Code section of the Path Attributes field has an associated Attribute Type category, which defines how the attribute is to be forwarded by other BGP routers. There are four attribute types:</p> <ol style="list-style-type: none"> 1. Well-known mandatory 2. Well-known discretionary 3. Optional transitive 4. Optional nontransitive <p>The Attribute Flags field is covered shortly.</p>

NLRI	<p>The NLRI field is the part of the UPDATE message field that contains paths that are to be advertised as reachable (network layer reachability information).</p> <p>The NLRI field contains the prefixes for each of the paths to be advertised in a [<i>length, prefix</i>] format. This is the information that was taken from the local routers' Adj-RIB-Out database and will be added to the neighboring routers' Adj-RIB-In database.</p>
------	---

After two BGP peers have formed an established BGP session, they can exchange routing information in the form of UPDATE messages. The UPDATE messages contain information about new routes that are to be added to the BGP table, routes that are no longer reachable (and are to be removed from the BGP table), and path attributes for the routes.

As shown in the preceding table, the Unfeasible Route Length field contains the number of routes that are to be removed from the BGP table. The Withdrawn Routes field contains the actual routes that are to be removed, in the [*length, prefix*] format. The Path Attributes field contains the attribute type codes for the paths sent in the update, and the Attribute Flags field specifies how attributes are to be handled by the routing process. And, finally, the NLRI field contains the new or changed routes that are being advertised.

In BGP, each routing update contains attributes that belong to all the NLRI paths in the message. The 10 basic attribute type codes and attribute values you will most likely encounter when working with BGP-4 in an IP environment are as follows:

1. ORIGIN— Specifies the origin of the route: I-BGP, E-BGP, or Incomplete.
2. AS_PATH— Contains a list of ASs that the route traversed in its path.
3. NEXT_HOP— The next hop taken to reach the destination route.
4. MULTI-EXIT-DISC— Multiple Exit Discriminator is a metric used to determine which path to take if there are multiple exit points to an AS.
5. LOCAL-PREF— Indicates preference for one path over others within an AS.
6. ATOMIC-AGGREGATE— Indicates that the local process chose a less-specific path to a destination over one that is more specific.
7. AGGREGATOR— This attribute is used to indicate the IP address of a router that has aggregated a number of routes together.
8. COMMUNITY— Specifies the local BGP COMMUNITY value; by default, all community-aware routers belong to the Internet community.
9. ORIGINATOR_ID— Specifies a route reflection with a route reflector cluster.
10. CLUSTER_LIST— Contains a reflection path that shows through which path a reflected route has passed.

Each of these attribute code types is accompanied by an *attribute flag* that specifies how the attribute is to be treated when it is processed by a peer router. [Table 7-6](#) shows the four attribute flags and their associated flags; these are covered in detail later in this chapter.

Table 7-6. BGP Attribute Flags

Attribute Flag	Flag Name	Description
Highest bit	Optional bit	Defines whether an attribute is well known (0) or optional (1).
Second highest bit	Transitive bit	Defines whether an optional attribute is nontransitive (0) or transitive (1).
Third highest bit	Partial bit	Defines whether an optional transitive attribute is complete (0) or partial (1).
Fourth highest bit	Extended Length bit	Defines whether the attribute length is 1 octet (0) or 2 octets (1). This flag is only used (set to 1) when the attribute length is greater than 255 octets.

[Example 7-2](#) shows a protocol analysis of an UPDATE message. Notice in the example that this message is a 68-byte BGP type 2 UPDATE message, with a Marker field of all 1s, indicating no authentication is taking place. This update does not contain any withdrawn routes, indicated by the 0 Unfeasible Routes Length. The first attribute in this message is the well-known transitive type 1 ORIGIN attribute value of 0-IGP, indicating that the message came from an I-BGP session. The next well-known transitive attribute is the type 2 AS_PATH attribute; this attribute lists the ASs through which the route has passed. The Path Segment Type field value of 2 (AS-SEQUENCE) means that this update contains an ordered list of autonomous systems. The Path Segment Length field value of 1 indicates that there is only one AS in the path, and the AS Identifier field value indicates that the packet originated from AS 2. The next well-known transitive attribute is the type 3 NEXT-HOP attribute that contains the next hop of 10.50.4.2. The final optional nontransitive attribute is the type 4 MED attribute. This attribute is used to determine which route to take if there are multiple exit points to an AS. The MED for this update is 0.

The next field in this update contains the NLRI information. The NLRI field contains new or changed routes that are being advertised in this message. This message contains routes to the networks 192.168.11.0/24, 192.168.12.0/24, 192.168.13.0/24, 192.168.14.0/24, and 192.168.15.0/24. Each of these routes is presented in [prefix length, subnet mask, IP address] format.

Example 7-2. BGP UPDATE Message

```
Frame Status Source Address Dest. Address Size Rel. Time Delta Time Abs. Time
```

Summary

```
13 [10.50.4.2] [10.50.4.1] 141 0:00:37.537 0.001.028 04/28/2002 03:14:50 PM
```

BGP: type = Update

```
DLC: ----- DLC Header -----
```

DLC:

DLC: Frame 13 arrived at 15:14:50.4449; frame size is 141 (008D hex) bytes.
DLC: Destination = Station 0004272281D8
DLC: Source = Station 000427228197
DLC: Ethertype = 0800 (IP)
DLC:
IP: ----- IP Header -----
IP:
IP: Version = 4, header length = 20 bytes
IP: Type of service = C0
IP: 110. = internetwork control
IP: ...0 = normal delay
IP: 0... = normal throughput
IP:0.. = normal reliability
IP:0. = ECT bit - transport protocol will ignore the CE bit
IP:0 = CE bit - no congestion
IP: Total length = 127 bytes
IP: Identification = 3
IP: Flags = 0X
IP: .0.. = might fragment
IP: ..0. = last fragment
IP: Fragment offset = 0 bytes
IP: Time to live = 1 seconds/hops
IP: Protocol = 6 (TCP)
IP: Header checksum = 9C50 (correct)
IP: Source address = [10.50.4.2]
IP: Destination address = [10.50.4.1]
IP: No options

IP:

TCP: ----- TCP header -----

TCP:

TCP: Source port = 179 (BGP)

TCP: Destination port = 11002

TCP: Sequence number = 3816595210

TCP: Next expected Seq number= 3816595297

TCP: Acknowledgment number = 3817488925

TCP: Data offset = 20 bytes

TCP: Flags = 18

TCP: ...0. = (No urgent pointer)

TCP:1 = Acknowledgment

TCP:1.... = Push

TCP:0... = (No reset)

TCP:0. = (No SYN)

TCP:0 = (No FIN)

TCP: Window = 16320

TCP: Checksum = 19F9 (correct)

TCP: No TCP options

TCP: [87 Bytes of data]

TCP:

BGP: ----- BGP Message -----

BGP:

BGP: 16 byte Marker (all 1's)

BGP: Length = 68

BGP:

BGP type = 2 (Update)

BGP:

BGP: Unfeasible Routes Length = 0

BGP: No Withdrawn Routes in this Update

BGP: Path Attribute Length = 25 bytes

BGP: Attribute Flags = 4X

BGP: 0... = Well-known

BGP: .1.. = Transitive

BGP: ..0. = Complete

BGP: ...0 = 1 byte Length

BGP: Attribute type code = 1 (Origin)

BGP: Attribute Data Length = 1

BGP: Origin type = 0 (IGP)

BGP: Attribute Flags = 4X

BGP: 0... = Well-known

BGP: .1.. = Transitive

BGP: ..0. = Complete

BGP: ...0 = 1 byte Length

BGP: Attribute type code = 2 (AS Path)

BGP: Attribute Data Length = 4

BGP: Path segment type = 2 (AS_SEQUENCE)

BGP: Path segment length = 1

BGP: AS Identifier = 2

BGP: Attribute Flags = 4X

BGP: 0... = Well-known

BGP: .1.. = Transitive

BGP: ..0. = Complete

BGP: ...0 = 1 byte Length

BGP: Attribute type code = 3 (Next Hop)

BGP: Attribute Data Length = 4

BGP: Next Hop = [10.50.4.2]

BGP: Attribute Flags = 8X

BGP: 1.... = Optional

BGP: .0... = Non-transitive

BGP: ..0. = Complete

BGP: ...0 = 1 byte Length

BGP: Attribute type code = 4 (Multi Exit Disc)

BGP: Attribute Data Length = 4

BGP: Multi Exit Disc Attribute = 0

BGP:

BGP: Network Layer Reachability Information:

BGP: IP Prefix Length = 24 bits, IP subnet mask [255.255.255.0]

BGP: IP address [192.168.11.0]

BGP: IP Prefix Length = 24 bits, IP subnet mask [255.255.255.0]

BGP: IP address [192.168.12.0]

BGP: IP Prefix Length = 24 bits, IP subnet mask [255.255.255.0]

BGP: IP address [192.168.13.0]

BGP: IP Prefix Length = 24 bits, IP subnet mask [255.255.255.0]

BGP: IP address [192.168.14.0]

BGP: IP Prefix Length = 24 bits, IP subnet mask [255.255.255.0]

BGP: IP address [192.168.15.0]

BGP:

BGP: 16 byte Marker (all 1's)

BGP: Length = 19

BGP:

BGP type = 4 (KEEPALIVE)

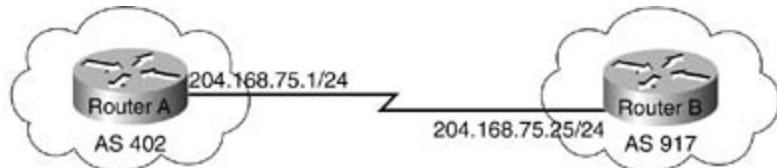
BGP:

DLC: --- Frame too short

ADDR	HEX	ASCII
0000:	00 04 27 22 81 d8 00 04 27 22 81 97 08 00 45 c0 ..'".....'"....E.	
0010:	00 7f 00 03 00 00 01 06 9c 50 0a 32 04 02 0a 32 P.2....2	
0020:	04 01 00 b3 2a fa e3 7c 9f 0a e3 8a 42 1d 50 18 *...B.P.	
0030:	3f c0 19 f9 00 00 ff ?...ù.....	
0040:	ff ff ff ff ff ff 00 44 02 00 00 00 19 40 01 01 D.....@..	
0050:	00 40 02 04 02 01 00 02 40 03 04 0a 32 04 02 80 .@.....@...2...	
0060:	04 04 00 00 00 18 c0 a8 0b 18 c0 a8 0c 18 c0 	
0070:	a8 0d 18 c0 a8 0e 18 c0 a8 0f ff ff ff ff ff ff 	
0080:	ff ff ff ff ff ff ff ff ff 00 13 04 	

In [Figure 7-15](#), for example, Routers A and B have an established BGP session and are now exchanging routing information using UPDATE messages. Router A sends an update removing two routes: one to 50.1.1.0/24, and one to 50.2.2.0/24. This routing update also contains four new routes: 51.3.3.0/24, 51.4.4.0/24, 51.5.5.0/24, and 60.1.1.0/24. These routes are sent out as routes learned through E-BGP, but originating from an I-BGP session (indicated by the Type 1 IGP path attribute), with an AS path of AS 402, AS 10, and AS 30, with a next hop of 51.5.2.4. Router B receives the UPDATE message, removes the routes to 50.1.1.0/24 and 50.2.2.0/24 from its Adj-RIB-In table, and then adds the routes to the 51.3.3.0/24, 51.4.4.0/24, 51.5.5.0/24, and 60.1.1.0 networks to its Adj-RIB-In table to be processed by its BGP decision process.

Figure 7-15. Routers Exchanging BGP Updates



Update Message		Update Message	
Unfeasible Route Length	2	Unfeasible Route Length	0
Withdrawn Routes	[24, 50.1.1.0] [24, 50.2.2.0]	Withdrawn Routes	None
Path Attributes	1 - IGP 2 - [402, 10, 30] 3 - 51.5.2.4	Path Attributes	1 - IGP 2 - [917, 40, 29] 3 - 197.61.1.1
NLRI	[24, 51.3.3.0] [24, 51.4.4.0] [24, 51.5.5.0] [24, 60.1.1.0]	NLRI	[24, 197.62.59.0] [24, 197.63.59.0] [24, 197.64.59.0]

Router B then takes its routes from the local Adj-RIB-Out table, and sends an update to Router A containing new routes to networks 197.62.59.0/24, 197.63.59.0/24, and 197.64.59.0/24. The new routes all came from an E-BGP session, but originated from an I-BGP session, using an AS path of AS 917, AS 40, and AS 29, and have the next hop of 197.61.1.1. Router A takes these new routes and adds them to its Adj-RIB-In table to be processed by the BGP decision process, and then adds the best routes to its local BGP routing table Loc-RIB. Until there are any route changes, Routers A and B will not send any further routing updates; they will only send KEEPALIVE messages back and forth, notifying each other that the BGP session is still active.

NOTIFICATION Message

BGP NOTIFICATION messages are used to indicate an error condition resulting in BGP session termination. NOTIFICATION messages are always immediately followed by session termination. Upon termination of a BGP connection, the TCP session between the BGP peers is torn down, all resources are released, "route withdrawal" messages are sent to peering BGP peers, and all BGP routes are removed from the table. A BGP session might terminate in an error condition for a number of reasons. [Table 7-7](#) describes the six major NOTIFICATION error messages.

Table 7-7. BGP NOTIFICATION Messages

MessageNumber	Message Type	Description
1	Message Header Error	Indicates that an error was found processing a BGP message header. Message header errors include a subcode that indicates the reason for the error.
2	OPEN Message Error	Indicates a message found in an OPEN message. OPEN message errors include an error subcode that indicates the cause of the error.
3	UPDATE Message Error	Indicates a message found in an UPDATE message. UPDATE message errors are accompanied by an error subcode that indicates the cause of the error.
4	Hold Timer Expired	This error type indicates that the local system did not receive a KEEPALIVE or UPDATE message within the negotiated time interval.
5	Finite-State Machine Error	When an unexpected error occurs, a finite-state machine error is sent to the peering router, terminating the BGP session.
6	Cease	Indicates the immediately terminated BGP session.

Each NOTIFICATION message contains three fields: Error Code, Error Subcode, and Data. The *Error Code* field specifies the type of NOTIFICATION error. The *Error Subcode*, if provided, gives a more detailed explanation of the error. One or more error subcodes might be included in a NOTIFICATION message. The *Data* field includes any diagnosis information that is related to the error. Not all NOTIFICATION messages include a value in the Data field.

When an error is found while processing a BGP header, a message header error NOTIFICATION message is generated. This message is generated in the event that a BGP header is received with an invalid Marker field, if the value of the length of a message header is greater or less than the required value, or if the type of the message header is unknown. [Table 7-8](#) shows Message Header Error Notification subcodes and their descriptions.

Table 7-8. Message Header Error NOTIFICATION Subcodes

Message Number	Message Subcode Type	Description
0	No error subcode	Null field.
1	Connection Not Synchronized	<p>Indicates that the Marker field in a BGP message is not the expected value.</p> <p>OPEN message— All 1s, unless TCP MD-5 authentication is in use</p> <p>All others— Negotiated in OPEN messages</p>
2	Bad Message Length	<p>The length of a message header is greater or less than the required value. This message contains the bad value in the Data field.</p> <p>OPEN— Minimum 29 octets, maximum 4096 octets</p> <p>UPDATE— Minimum 23 octets, maximum 4096 octets</p> <p>KEEPALIVE— No greater or less than 19 octets (the size of an empty BGP KEEPALIVE message)</p>
3	Bad Message Type	Indicates that an unrecognized message type was received. The value of the Type field is included in the Data field of this message.

BGP OPEN message errors can be caused by failed or misconfigured TCP MD-5 authentication attempts, corrupt TCP packets, or other BGP configuration problems. OPEN message errors include a message subcode that describes the reason for the error message. [Table 7-9](#) shows possible subcode messages and their descriptions.

Table 7-9. OPEN Message Error NOTIFICATION Subcodes

Message Number	Message Subcode Type	Description
1	Unsupported Version	The BGP peer is using an unsupported BGP version. The Data field in this message includes the largest locally supported BGP version.
2	Bad Peer AS	The peering router's My AS value is not as expected. This error might be caused by a misconfiguration on one of the peering routers.
3	Bad BGP ID	The peering router's BGP ID value is not as expected. This error might be caused by a misconfiguration on either router. This value must be a valid IP address.
4	Unsupported Optional	The local router received an unsupported Optional value.
5	Authentication Failure	This message is generated upon BGP authentication failure.
6	Unacceptable Hold Time	The hold-timer value is not acceptable to the local system, any hold time might be rejected; hold timers must be negotiated on both BGP peers.

After the OPEN messages have been received and the routers have established a valid BGP session, they begin to send UPDATE messages. A number of different errors might occur when processing UPDATE messages. These errors are generally the result of a misconfiguration on one of the peer routers. [Table 7-10](#) shows the various UPDATE message error NOTIFICATION messages and their descriptions.

Table 7-10. UPDATE Message Error NOTIFICATION Subcodes

Message Number	Message Subcode Type	Description
1	Malformed Attribute List	<p>The length of the Unfeasible Route Length and/or Total Attribute Length plus the fixed UPDATE header size (the fixed size of the UPDATE header [19] plus the size of the Total Path Attribute Length field [2] plus the Unfeasible Route Length field [2]) is too large.</p> <p>This message might also be sent if the same attribute appears more than once in the same UPDATE message.</p>
2	Unrecognized Well-Known Attribute	Indicates an unknown well-known mandatory attribute. The value of this attribute is included in the Data field of the message.
3	Missing Well-Known Attribute	Indicates that a well-known mandatory attribute is missing. The Data field includes the missing attribute.

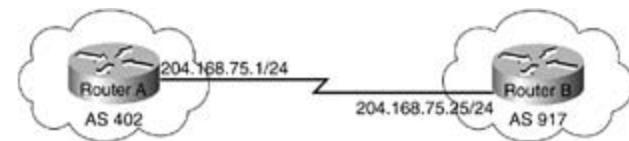
4	Attribute Flag Error	The Attribute Flag field and Attribute Code field do not match. This might be a bad attribute, flag, code, or value. This information is included in the Data field for the message.
5	Attribute Length Error	The actual attribute length does not match the length specified by the Attribute Length field. The attribute data (attribute type, length, and value) is included in the Data field for the message.
6	Invalid Origin Attribute	The ORIGIN value is not defined or is unrecognized. The value of the ORIGIN field is included in the error message.
7	AS Routing Loop	The local AS number has been seen in an UPDATE message—an AS routing loop is assumed.
8	Invalid Next-Hop Attribute	The next-hop value is not a valid IP address; this is a syntax error. The value is included in the message.
9	Optional Attribute Error	Indicates an error in the value of a recognized optional attribute. The value of this error appears in the Data field of this message.
10	Invalid Network Field	Indicates a syntax error in the NLRI field for a message.
11	Malformed AS_PATH	The AS_PATH is syntactically incorrect.

If a BGP session has no errors, you will not see any NOTIFICATION messages unless an interface goes down or the BGP configuration has changed. After two BGP peers have formed a BGP session, they exchange KEEPALIVE messages to verify session BGP integrity. The next section discusses the BGP KEEPALIVE message type.

KEEPALIVE Message

After the BGP session has been successfully established, and BGP updates have been sent and received, the BGP peers send each other periodic KEEPALIVE messages. KEEPALIVE messages are sent by the peering routers every 60 seconds, by default, to notify neighboring peers that the BGP connection is active. The KEEPALIVE message interval can be changed from the default value to any other value between 3 and 4,294,967,295 or set to 0 to signify that KEEPALIVE messages will not be exchanged. KEEPALIVE values of 1 or 2 seconds are not valid. If invalid KEEPALIVE values are used, the BGP session will fail with the NOTIFICATION message "Open failed: Connection refused by remote host." KEEPALIVE timers might also be set to 1/3 the negotiated hold-timer value, which is, by default, 180 seconds. [Figure 7-16](#) shows the process, followed by each of the three BGP messages, including the KEEPALIVE messages sent during a successful BGP session.

Figure 7-16. BGP Messages



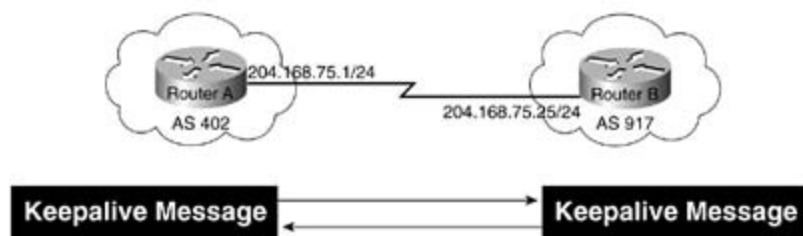
Open Message	
Version	4
My AS	402
Hold Timer	180
BGP ID	204.168.75.1
Optional	None

Open Message	
Version	4
My AS	917
Hold Timer	180
BGP ID	204.168.75.25
Optional	None

Update Message

Update Message	
Unfeasible Route Length	2
Withdrawn Routes	[24, 50.1.1.0] [24, 50.2.2.0]
Path Attributes	1 - IGP 2 - [402, 10, 30] 3 - 51.5.2.4
NLRI	[24, 51.3.3.0] [24, 51.4.4.0] [24, 51.5.5.0] [24, 60.1.1.0]

Update Message	
Unfeasible Route Length	0
Withdrawn Routes	None
Path Attributes	1 - IGP 2 - [917, 40, 29] 3 - 197.61.1.1



The KEEPALIVE message contains no data; it is just a 19-byte BGP header, as shown in the protocol analysis contained in [Example 7-3](#).

Example 7-3. BGP KEEPALIVE Message

Frame	Status	Source Address	Dest. Address	Size	Rel. Time	Delta Time	Abs. Time	Time
10	[10.50.4.1]	[10.50.4.2]	73	0:00:37.336	0.008.155	04/28/2002	03:14:50	PM
Summary								
BGP: type =								

KEEPALIVE

DLC: ----- DLC Header -----

DLC:

DLC: Frame 10 arrived at 15:14:50.2443; frame size is 73 (0049 hex) bytes.

DLC: Destination = Station 000427228197

DLC: Source = Station 0004272281D8

DLC: Ethertype = 0800 (IP)

DLC:

IP: ----- IP Header -----

IP: IP: Version = 4, header length = 20 bytes

IP: Type of service = C0

IP: 110. = internetwork control

IP:0 = normal delay

IP: 0... = normal throughput

IP:0.. = normal reliability

IP:0. = ECT bit - transport protocol will ignore the CE bit

IP:0 = CE bit - no congestion

IP: Total length = 59 bytes

IP: Identification = 3 IP: Flags = 0X

IP: .0... = might fragment

IP: ..0. = last fragment

IP: Fragment offset = 0 bytes

IP: Time to live = 1 seconds/hops IP: Protocol = 6 (TCP)

IP: Header checksum = 9C94 (correct)

IP: Source address = [10.50.4.1]

IP: Destination address = [10.50.4.2]

IP: No options

IP:

TCP: ----- TCP header -----

TCP:

TCP: Source port = 11002

TCP: Destination port = 179 (BGP)

TCP: Sequence number = 3817488906

TCP: Next expected Seq number= 3817488925

TCP: Acknowledgment number = 3816595191

TCP: Data offset = 20 bytes

TCP: Flags = 18 TCP: ..0. = (No urgent pointer)

TCP: ...1 = Acknowledgment

TCP: 1.... = Push

TCP:0... = (No reset)

TCP:0. = (No SYN)

TCP:0 = (No FIN)

TCP: Window = 16339

TCP: Checksum = 7BB6 (correct)

TCP: No TCP options

TCP: [19 Bytes of data]

TCP: BGP: ----- BGP Message -----

BGP:

BGP: 16 byte Marker (all 1's)

BGP: Length = 19 BGP: BGP type = 4 (KEEPALIVE)

BGP:

BGP:

ADDR HEX	ASCII
0000: 00 04 27 22 81 97 00 04 27 22 81 d8 08 00 45 c0	..'".....!".....E.
0010: 00 3b 00 03 00 00 01 06 9c 94 0a 32 04 01 0a 32	..;.....2....2
0020: 04 02 2a fa 00 b3 e3 8a 42 0a e3 7c 9e f7 50 18	..*.....B.. ..P.

```
0030: 3f d3 7b b6 00 00 ff | ?.{.....
```

```
0040: ff ff ff ff ff ff 00 13 04 | .....
```

ROUTE-REFRESH Message

Prior to Cisco IOS Software Release 12.0(6)T, all BGP-speaking routers used to require a manual BGP session reset each time the local routing policy changed. This session reset allowed peers to apply new policies as the routers processed and received the incoming routing updates from their remote peers. In legacy versions of Cisco IOS software, this problem was solved, on a peer-by-peer basis, using BGP *soft reconfiguration*. After BGP soft reconfiguration has been configured on a legacy peer, that router stores the full, unmodified copy of the incoming Adj-RIB-In table that it received from each remote peer in memory. Although this feature promotes network stability by preventing BGP session interruptions, it also consumes large amounts of system resources. Soft configuration is triggered each time a soft-reconfiguration request is issued using the `clear ip bgp { * | ip-address | peer-group} soft [in | out]` command; the use of this command is covered later in [Chapter 9](#), "Advanced BGP Configuration." When this command is issued, the local BGP peer acts as though it has just received a full routing update from the remote peer by refreshing routes stored in the Loc-RIB table using the Adj-RIB-In information stored in memory.

The BGP ROUTE-REFRESH capability, specified in RFC 2918, also referred to in Cisco IOS Software as the BGP *soft reset enhancement*, which is automatically enabled in later releases of Cisco IOS Software, is negotiated between BGP speakers during the capabilities exchange portion of BGP session initialization. This capability allows BGP peers to either request dynamic inbound updates or send outbound route updates to a peer without the soft reconfiguration. The IANA-assigned ROUTE-REFRESH capability (2) is contained in the Optional Capabilities field of the BGP OPEN messages. For ROUTE-REFRESH messages to be sent and understood, each of the peers negotiating a BGP session must support the capability. If a peer that does not understand this capability receives a ROUTE-REFRESH request message from a remote peer, that peer ignores the message, logging an "Unsupported OPEN Parameter" error, and continues on uninterrupted. When the ROUTE-REFRESH capability is not supported by both peers in a BGP peer relationship, neither of the peers will be able to use the capability, and either soft reconfiguration or manual session re-initialization has to take place to refresh the Adj-RIB-In table. If the ROUTE-REFRESH capability is successfully negotiated during session initialization, and a ROUTE-REFRESH request is, for some reason, unsuccessful, the session can still be manually cleared.

BGP Finite-State Machine Operation

BGP peers transition through several states before becoming adjacent neighbors and exchanging routing information. During each of the states, the peers must send and receive messages, process message data, and initialize resources before proceeding to the next state. This process is known as the BGP *Finite-State Machine (FSM)*. If the process fails at any point, the session is torn down and the peers both transition back to an Idle state and begin the process again. Each time a session is torn down, all routes from the peer who is not up will be removed from the tables, which causes downtime. If configuration issues exist on one of the BGP peers, the peering routers continuously transition between unestablished states until the issue has been resolved. BGP peers transition through all the following states until an established BGP session has been created:

- Idle
- Connect
- Active
- OpenSent
- OpenConfirm
- Established

Each of these states also has accompanying *input events* (IEs). Input events are events occurring during a BGP session that trigger an action. [Table 7-11](#) shows the BGP IEs.

Table 7-11. BGP Input Events

Event ID	Event Name	Description
1	BGP Start	Occurring during the Idle state, the BGP start event signals the beginning of a BGP session. It also initializes the resources for the BGP process. The BGP start event is only listened for during the Idle state. If the local speaker receives a start event and it is not in the Idle state, that event is ignored.
2	BGP Stop	The BGP Stop signals the termination of a BGP session.
3	BGP Transport Connection Open	This event notifies the local speaker that the TCP connection is open and the BGP resource initialization is complete.
4	BGP Transport Connection Closed	This event notifies the local speaker that the remote BGP speaker has closed the TCP session. This message also triggers the release of BGP resources and causes the local speaker to return to the Idle state.

5	BGP Transport Connection Failed	This event notifies the local speaker that the TCP session to the remote BGP peer has failed. This message also triggers the release of BGP resources and causes the local speaker to return to the Idle state.
6	BGP Transport Fatal Error	This event notifies the local speaker that the TCP session to the remote BGP peer has resulted in a fatal error. This message also triggers the release of BGP resources and causes the local speaker to return to the Idle state.
7	ConnectRetry Timer Expired	This event occurs when the ConnectRetry timer has expired. When the ConnectRetry timer expires, it is restarted.
8	Hold Timer Expired	This event occurs when the hold timer has expired, meaning that the remote peer has not responded to a message from the local peer.
9	KEEPALIVE Timer Expired	This event indicates that the KEEPALIVE timer expired, signaling that a KEEPALIVE has not been received from the remote peer within the timeout period.
10	Receive Open Message	This event notifies the local system that a BGP OPEN message has been received by the remote peer, and the BGP session can move on to the OpenConfirm state.
11	Receive KEEPALIVE Message	This event notifies the local system that a BGP KEEPALIVE message has been received by the remote peer, and the BGP session can move on to the Established state.
12	Receive Update Message	This event notifies the local system that the remote peer has received a BGP UPDATE message.
13	Receive Notification Message	This event notifies the local system that a BGP NOTIFICATION message has been received, and the BGP session should be terminated immediately.

Idle State

According to RFC 1771, at the beginning of each BGP peer session, each of the peer routers must pass through various BGP states. The first state that a router enters when configured for BGP is the Idle state. In the Idle state, the BGP-speaking router refuses incoming BGP session requests. At this point, the router has not allocated any resources to the BGP process and does not do so until a BGP start event has either been initiated by the router's BGP process or by manual user intervention. [Table 7-12](#) summarizes the Idle state behaviors and the reasons for those behaviors.

Table 7-12. Idle State Behaviors

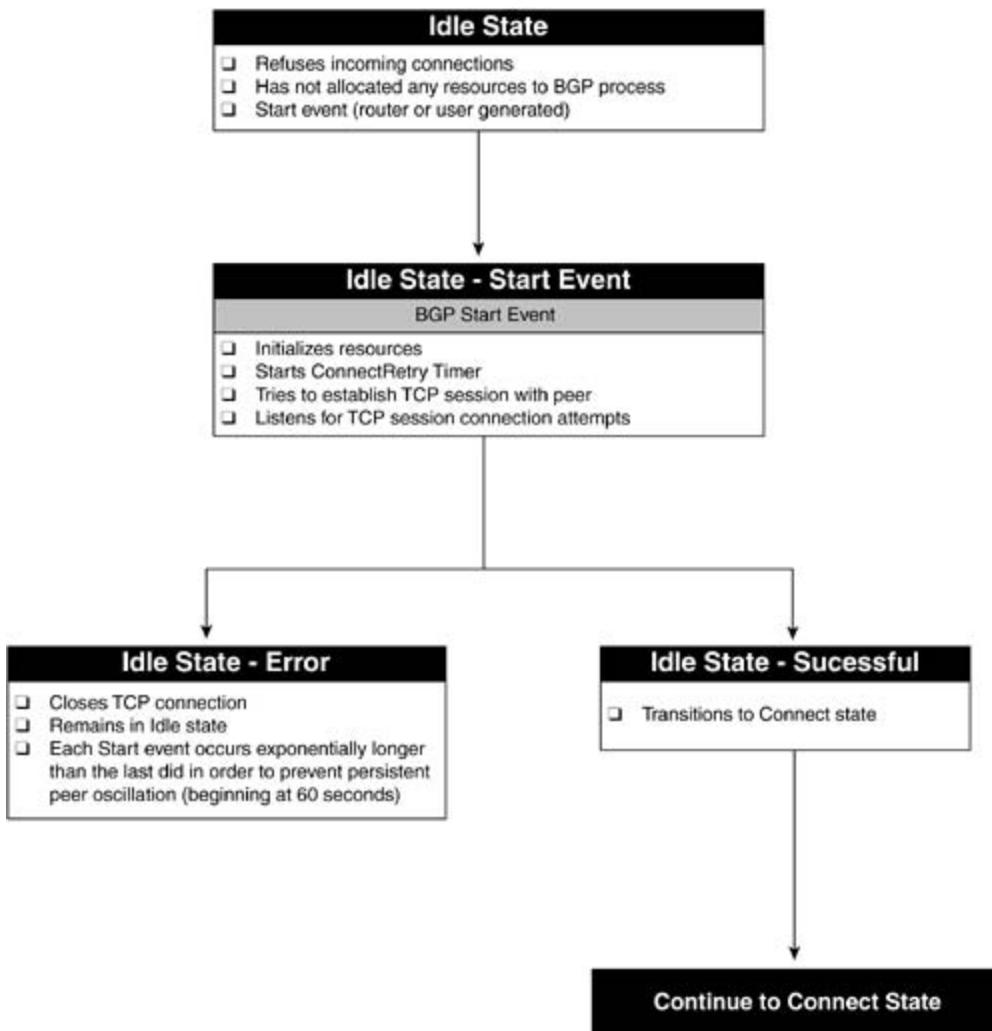
Idle State Behavior	Reasons

Refuses incoming sessions	The router has either just been configured and has not established a BGP session with this peer before, or the BGP session has been reset. Incoming sessions are refused until a BGP start event has been issued.	
No BGP resource allocation	<p>Newly configured peer session.</p> <p>Reset session.</p> <p>Resources are allocated after a start event has been received.</p>	
BGP start event either sent or received	After the start event has been issued, the BGP peer initializes its resources, starts the ConnectRetry timer, attempts to establish a TCP connection with the peer, and listens for incoming TCP connection attempts.	
Upon error	<p>TCP sessions will be closed.</p> <p>The router will remain in Idle state and the start event will re-occur; each time a start event is generated, the time between the current and last start event exponentially increases.</p>	
Transition from other state to Idle state	Active state	Returns to Idle state upon other undefined error.
	OpenSent state	<p>Returns to Idle state upon:</p> <p>OPEN message error</p> <p>BGP stop event (sent or received)</p> <p>Hold timer expired</p> <p>Other undefined error</p>
	OpenConfirm state	<p>Returns to Idle State upon:</p> <p>Receiving disconnect notification from TCP</p> <p>Hold timer expired</p> <p>NOTIFICATION message received</p> <p>BGP stop event</p> <p>Other undefined error</p>
	Established state	<p>Returns to Idle state upon:</p> <p>UPDATE message error</p> <p>Receiving disconnect notification from TCP</p> <p>NOTIFICATION message received</p> <p>BGP stop event</p> <p>Hold timer expired</p> <p>Other undefined error</p>

BGP start events initially occur after initial BGP configuration, or, if the FSM has recently transitioned from another state to the Idle state, the next start event will occur after 60 seconds. To prevent routers from continuously bringing up and tearing down BGP sessions, each start event is issued at an exponentially increasing interval.

After the start event has been issued, the router initializes its BGP resources and starts the ConnectRetry timer, which controls the frequency between TCP connection attempts. At this point, the router tries to establish a TCP session with its configured BGP peer, and also listens for TCP session requests from that peer. If the TCP connection is closed or fails for any other reason, the FSM remains in the Idle state, and the time between BGP start events increases exponentially, which greatly increases the time between BGP start events. Otherwise, the FSM transitions to the Connect state. [Figure 7-17](#) shows the logical flow between steps that the FSM follows during the BGP Idle state. In this figure, the black text boxes display the actions taking place, the gray text boxes display BGP events that might be associated with the actions taking place, and the white text boxes show the detail for each action that takes place.

Figure 7-17. BGP Idle State



NOTE

Connection collisions occur when two BGP peering routers attempt to establish a TCP connection at the same time; or when a BGP session has already started, and the remote peer tries to restart a new connection. When connection collisions occur, the two peers compare BGP IDs, and the connection opened by the peer with the highest BGP ID is opened; the other connection is closed. In the case that the connection collision occurs on a BGP session that has already started, the new BGP session request is closed. Connection collisions can only be detected in the OpenSent, OpenConfirm, or Established state.

If you notice that a router is constantly remaining in the Idle state, you can check the following:

- Verify that the remote peer has the correct IP address and AS number configured for the local peer. You might need to change the BGP update source or the BGP router ID so that the peer will see BGP requests coming from the right IP address. Remember that BGP does not accept connections from unknown BGP peers.
- Verify that you have the correct IP address and AS number configured for the remote peer. Remember, BGP verifies the contents of BGP OPEN messages; if the contents of the OPEN message received from a remote peer do not match the local BGP configuration for that peer, the routers will not form a BGP peer relationship.
- Make sure the routers can reach each other using the configured IP address and TCP port number 179. You might need to add routes or change access lists or firewall rule sets to allow BGP peers to communicate.

Connect State

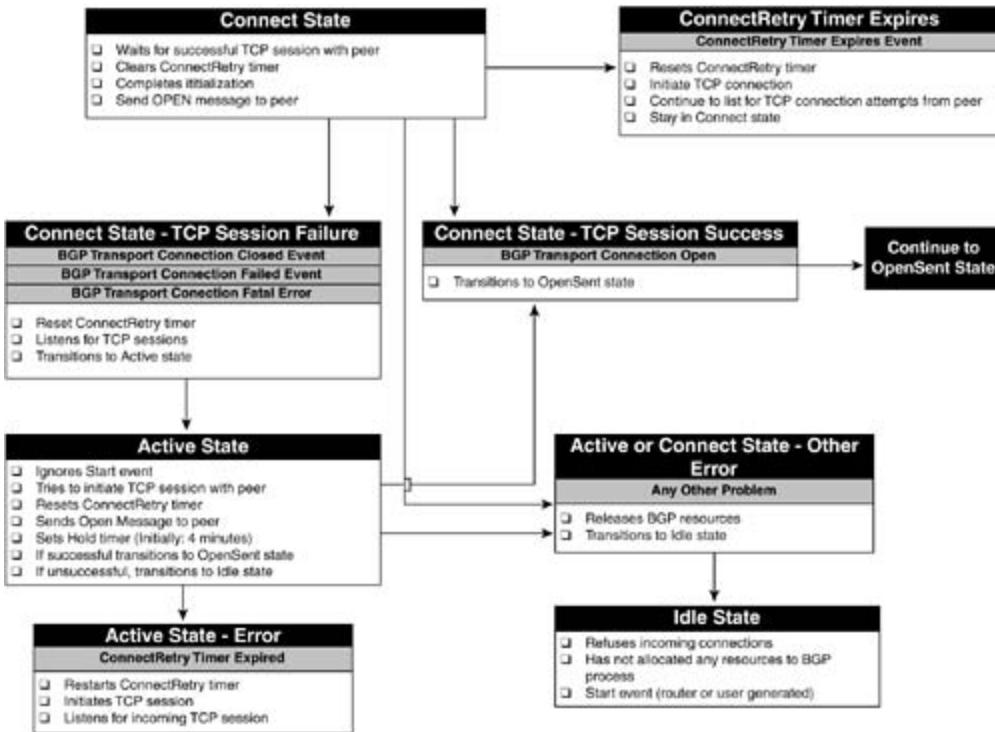
During the Connect state, the router is waiting for a successful TCP connection with its BGP peer. After a TCP session has successfully been established, the FSM clears the ConnectRetry timer, finishes initializing BGP resources, and sends an OPEN message to its peer. [Table 7-13](#) shows the various Connect state behaviors, their associated events, and the associated state transitions.

Table 7-13. Connect State Behaviors

Connect State Behavior	Reasons	
Ignores incoming start events	Start events are only received and acknowledged in the Idle state. Any start events received during the Connect state are ignored.	
BGP resource allocation is completed	The BGP process begins on the router; however, routing does not occur until the FSM has entered the Established state.	
OPEN message is sent to peer	After an OPEN message has been sent to the BGP peer, the router enters OpenSent state.	
Upon TCP connection error	The ConnectRetry timer is reset. The router still listens for a TCP session request from its peer, but it transitions from the Connect state to the Active state.	
ConnectRetry timer expires	The ConnectRetry timer is reset. The router tries to initialize a TCP session with its peer, listens for connection attempts from its peer, and stays in the Connect state.	
An undefined event occurs	If any other event occurs, the router releases its BGP resources and transitions back to the Idle state.	
Transition from other state to Connect state	Active state	If the ConnectRetry timer expires while a router is in the Active state, that peer does the following: Resets the ConnectRetry timer Attempts to initialize a TCP connection with its peer Listens for a TCP connection from its remote peer

During successful BGP peer sessions, the peering routers typically do not spend much time in the Connect state before they transition to the OpenSent state. [Figure 7-18](#) shows the BGP Connect state behaviors and the reasons for these behaviors. In this figure, the black text boxes display the actions taking place, the gray text boxes display BGP events that might be associated with the actions taking place, and the white text boxes show the details for each action that takes place.

Figure 7-18. BGP Connect State



If the TCP session between two BGP peers in Connect state is closed or fails for any reason, the FSM resets the ConnectRetry timer, continues to listen for a TCP session request from its peer, and enters the Active state.

When BGP peers get stuck in the Connect state, it is usually because of a configuration error:

- Always make sure that you have inbound and outbound TCP connectivity on port 179 (and a random TCP port greater than 1023 on the source side) so that BGP sessions can be formed in each direction. BGP TCP sessions are opened using a random source port, and a TCP destination port of 179.
- Verify the local and remote BGP configurations. Check the IP addresses and AS numbers for typos, and make sure the BGP routing process is numbered correctly.

Active State

If a router has entered the Active state, it is because it was unable to establish a successful TCP connection with one of its BGP peers. While in the Active state, a BGP speaker ignores the start event (remember, it is only listened for during the Idle state), attempts to initiate a TCP session with its peer, and resets the ConnectRetry timer.

If a successful TCP session is established while the BGP speaker is in the Active state, it sends an OPEN message to its peer, sets the hold timer, which is used to determine the time that a peer should wait for a return message from its peer, and transitions to the OpenSent state. The hold timer's initial value is set to 4 minutes, and later, upon a successful BGP session establishment, it is changed to the value negotiated during the OPEN message processing.

If the TCP session is not successfully established before the ConnectRetry timer expires, the FSM

restarts the ConnectRetry timer, attempts to initiate a TCP session, and continues to listen for a TCP session request from its peer while transitioning back to the Connect state.

You might notice routers cycling between the Idle and Active states under the following conditions:

- The BGP peer ID is entered incorrectly during configuration.
- The BGP peer is not reachable via TCP port 179.
- Network congestion is causing the ConnectRetry timer to expire.
- A flapping network interface.

OpenSent State

In the OpenSent state, the BGP peer waits for an OPEN message from its peer. After an OPEN message has been received, it is checked for validity. At this time, all fields in the OPEN message are checked against the local BGP configuration. Any fields that do not match the expected values cause an OPEN message error to occur. At this time, the BGP peer also checks to verify that a connection collision has not occurred. If the message is valid, the peer sends a KEEPALIVE message to its peer, sets the KEEPALIVE timer, sets the hold timer, and transitions to the OpenConfirm state. [Table 7-14](#) shows the OpenSent state behaviors and their descriptions.

Table 7-14. OpenSent State Behaviors

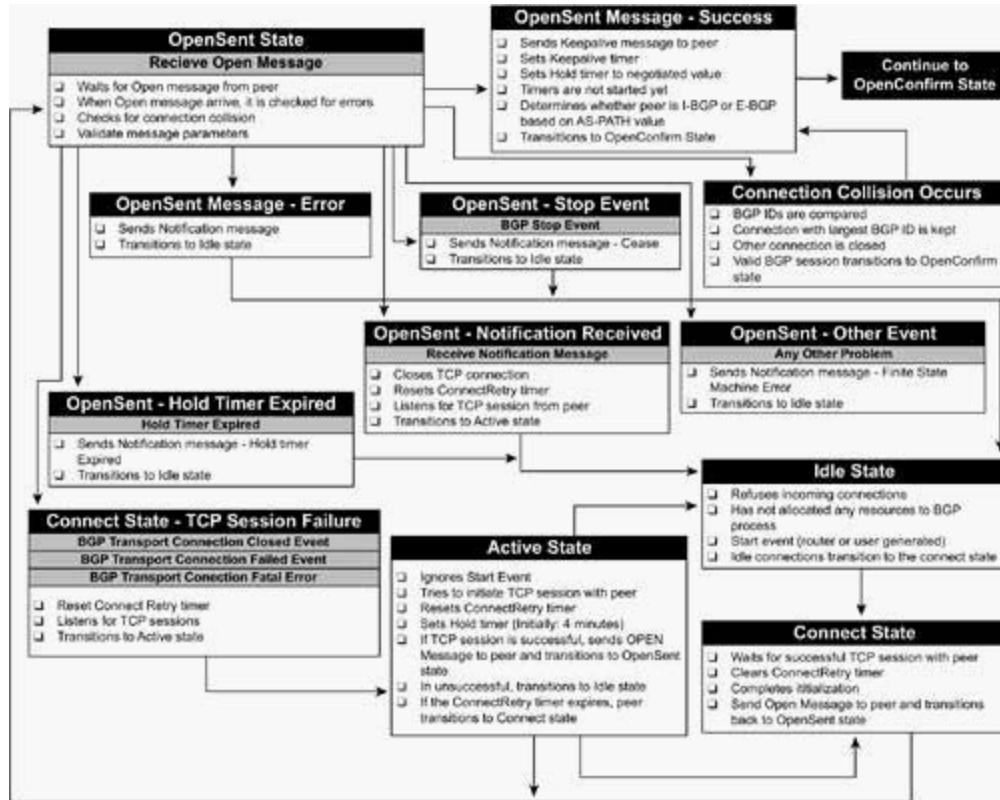
OpenSent State Behavior	Reasons
Ignores incoming start events	Start events are only received and acknowledged in the Idle state. Any start events received during the Connect state are ignored.
Waits for OPEN message from peer	The BGP peer remains in the OpenSent state until the following occurs: <ul style="list-style-type: none">• A valid OPEN message is received.• A TCP disconnect event occurs.• A NOTIFICATION message is received.• A stop event occurs.• The hold timer expires.• Any other undefined event occurs.

A number of events can cause a BGP speaker to transition from the OpenSent state to the Idle state. As mentioned previously, if the speaker receives an invalid OPEN message from its peer, an OPEN message error will occur. Upon an OPEN message error, the local router sends out a NOTIFICATION message specifying the cause of the error and transitions to the Idle state where

the connection process starts again. If a NOTIFICATION message is received from another peer router, the local router closes its TCP connection, resets the ConnectRetry timer, and transitions to the Active state.

Upon receipt of a BGP stop event, hold-timer expiration, or other unexpected event, the local router also sends a NOTIFICATION message and transitions back to the Idle state. From the Idle state, the peering BGP routers once again try to launch a successful BGP session. [Figure 7-19](#) shows the various events that might occur in the OpenSent state.

Figure 7-19. BGP OpenSent State



BGP peers rarely appear to wait in the OpenSent state for long amounts of time. After the local router receives an OPEN message from its peer, it sends its peer a KEEPALIVE message and transitions to the OpenConfirm state.

OpenConfirm State

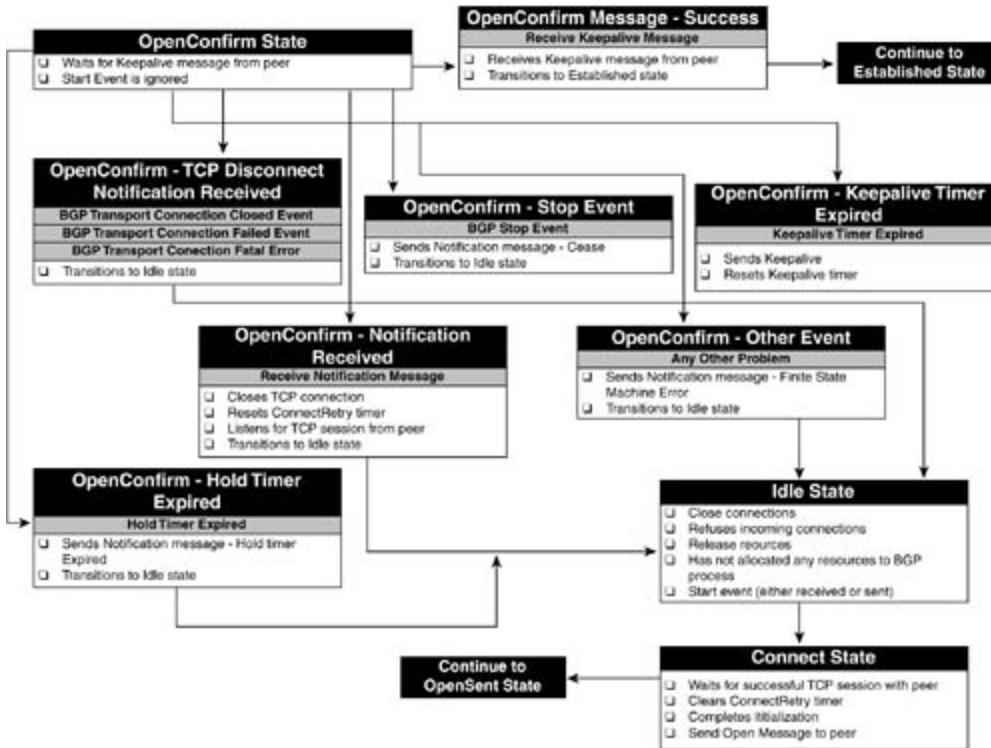
In the OpenConfirm state, the local router is waiting for the receipt of a KEEPALIVE message from its peer. Upon receipt of a KEEPALIVE message, the BGP session transitions to the Established state. As with the OpenSent state, BGP peers might transition to the OpenConfirm state for a number of reasons. [Table 7-15](#) shows these state transitions and other behaviors of the OpenConfirm state.

Table 7-15. OpenConfirm State Behaviors

OpenConfirm State Behavior	Reasons
Ignores incoming start events	Start events are only received and acknowledged in the Idle state. Any start events received during the OpenConfirm state are ignored.
Waits for KEEPALIVE message from peer	The BGP peer remains in the OpenConfirm state until the following occurs: <ul style="list-style-type: none"> • A KEEPALIVE message is received. • A TCP disconnect message is received. • A NOTIFICATION message is received. • A stop event occurs. • The hold timer expires. • Any other undefined event occurs.
If the KEEPALIVE timer expires	The KEEPALIVE timer might be reset up to three times the length of the hold timer before the hold timer will expire, and the local peer will transition to the Idle state.
If a peer returns from the OpenConfirm to Idle state	The BGP connection is closed. All BGP resources for that BGP peering session are released.

[Figure 7-20](#) shows the actions that can occur during the OpenConfirm state. The local router can successfully transition to the Established state, after receiving a KEEPALIVE message or transition back to the Idle state upon a Disconnect, Stop, or Notification event.

Figure 7-20. BGP OpenConfirm State

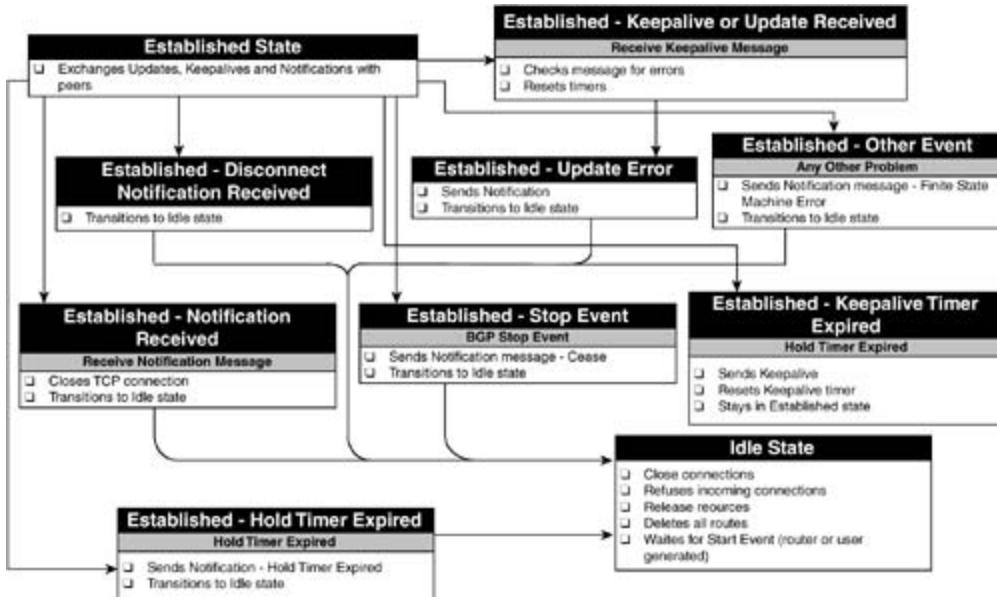


BGP peers only stay in the OpenConfirm state long enough to receive a KEEPALIVE message. If the KEEPALIVE is not received within the space of the hold timer, the session transitions back to the Idle state.

Established State

BGP peers reach the Established state after they have successfully exchanged OPEN and KEEPALIVE messages. After the peers reach the Established state, they begin to send UPDATE messages containing routing information and KEEPALIVE messages to verify the TCP Connection state. If an error is encountered at any time while a peer is in the Established state, the local peer sends a NOTIFICATION message with the reason for the error and transitions back to the Idle state. [Figure 7-21](#) shows the various events that might occur while a speaker is in the Established state.

Figure 7-21. BGP Established State



Now that the basic BGP operations have been covered, it is time to discuss the various attributes that are exchanged within BGP UPDATE messages.

BGP Path Attributes

BGP path attributes describe the values that belong the paths sent in a BGP UPDATE message. All attributes contained in an UPDATE message apply to all paths specified by the NLRI field of the UPDATE.

ORIGIN Attribute

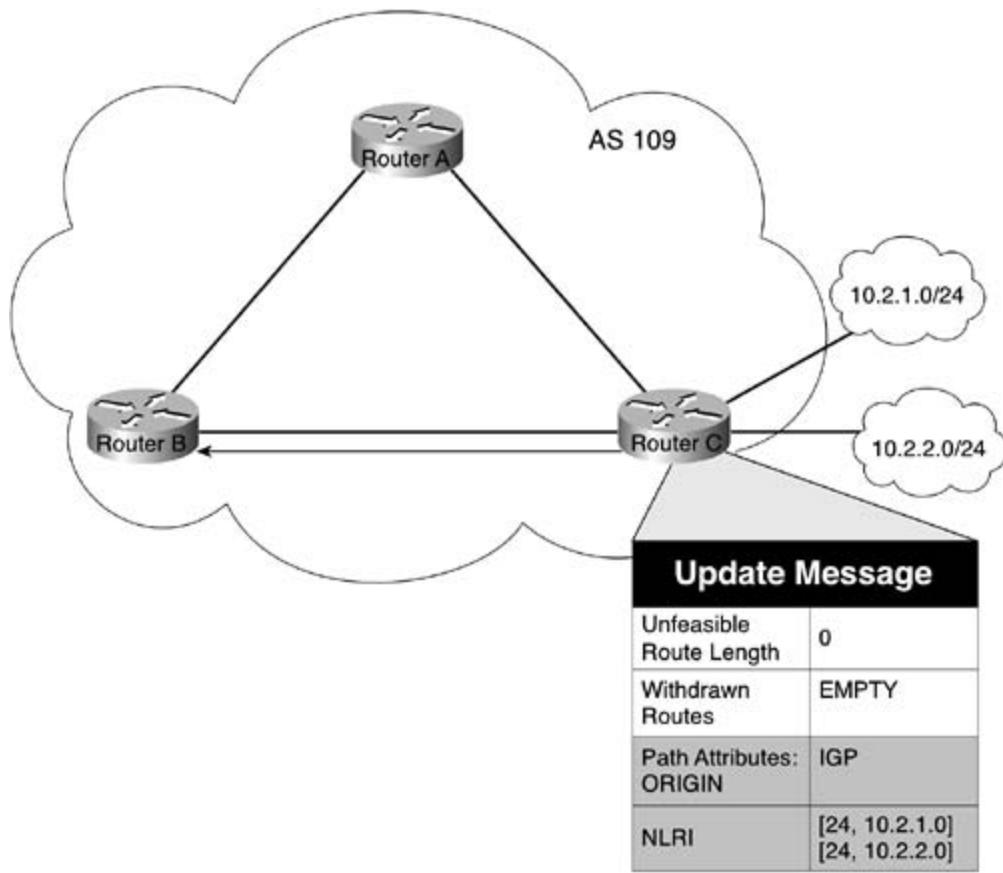
The *ORIGIN* of a route describes the way that the path was introduced into the BGP path. ORIGIN is a well-known mandatory attribute, meaning all BGP implementations must accept and understand the value of the ORIGIN attribute, and it is passed to other BGP peers. [Table 7-16](#) shows three BGP ORIGIN codes. If a route entered BGP from an I-BGP session, the route will have the ORIGIN type 0, IGP. If the route was originally introduced into BGP by an Exterior Gateway Protocol (EGP) session, it is type 1, EGP. If the route entered BGP from an unknown (external to BGP) routing process, then the ORIGIN value is type 3, Incomplete.

Table 7-16. BGP ORIGIN Codes

ORIGIN Code	ORIGIN Code Name	Description
0	IGP	<p>The route originated on a BGP router. This route type includes any route that originated from the BGP process on a BGP-speaking router.</p> <p>The IGP ORIGIN type is the most preferred ORIGIN for a route and is selected before EGP or Incomplete.</p>
1	EGP	<p>The route originated from an EGP (not E-BGP) session.</p> <p>The EGP ORIGIN type is more desirable than the Incomplete ORIGIN type.</p>
2	Incomplete	<p>The route originated from a routing process other than BGP, and entered BGP by means of manual redistribution, such as redistribution from an IGP protocol, static route, or connected route.</p> <p>The Incomplete ORIGIN type is not preferred over IGP or EGP.</p>

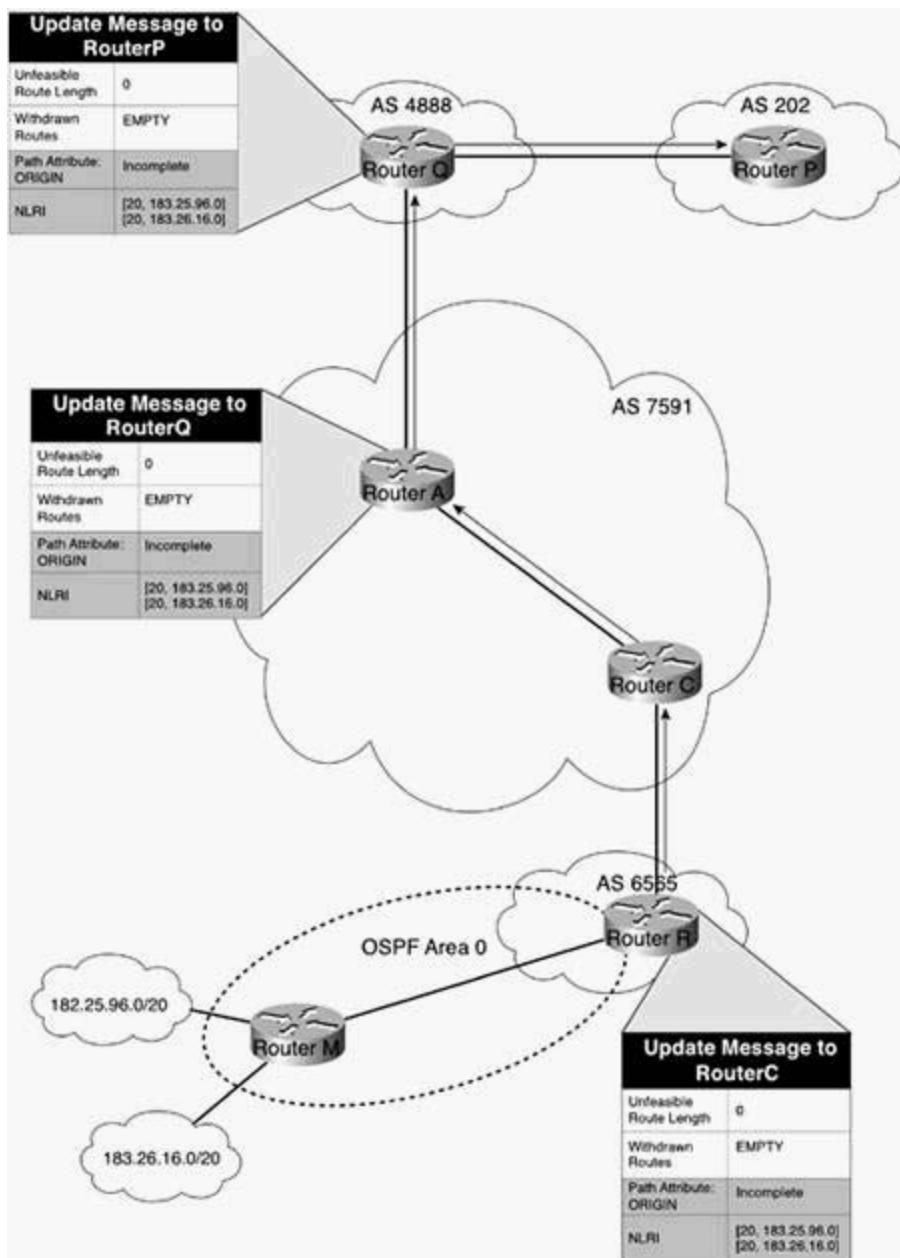
[Figure 7-22](#) shows a route with the attribute type 1, IGP. This route originated from an I-BGP session. As you can see, Router C originated the routes to networks 10.2.1.0/24 and 10.2.2.0/24, so Router C will assign these routes the IGP ORIGIN attribute as it does in the UPDATE message to Router B.

Figure 7-22. BGP ORIGIN Code IGP



[Figure 7-23](#) illustrates how the Incomplete ORIGIN type is used to mark paths whose origins are unknown. In this figure, Router R originates the route in AS 6565, but because the router was learned by means of a redistributed OSPF process, the paths are sent out with the Incomplete ORIGIN type. Each downstream router that forwards these paths includes the Incomplete ORIGIN value as well.

Figure 7-23. BGP ORIGIN Code Incomplete



AS_PATH Attribute

The AS_PATH is a well-known mandatory attribute. It describes the path that the route has taken on the way to its destination. The primary reason for the BGP AS_PATH attribute is to prevent routing loops. BGP peers know that they have encountered a routing loop if they receive an UPDATE message that contains their local AS number in the AS_PATH. If a looped update is received, the UPDATE is ignored.

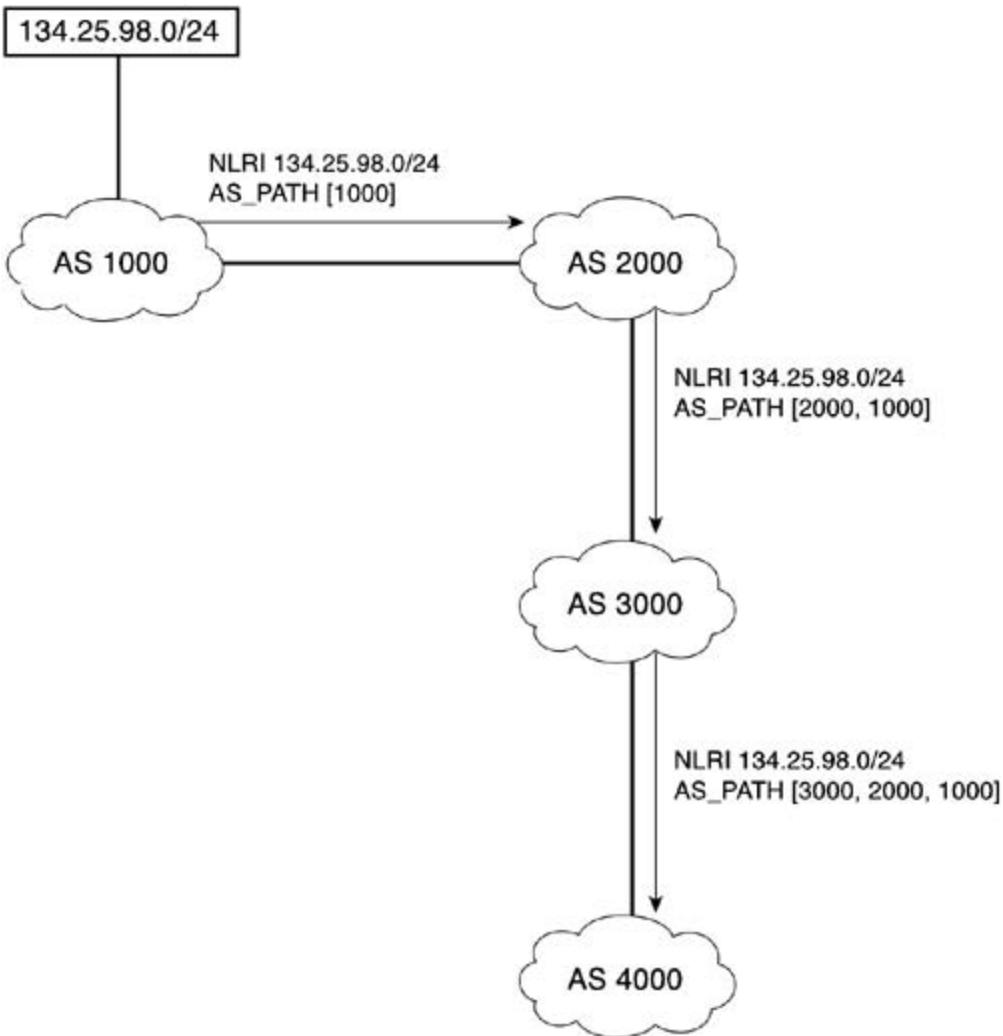
Each AS border router that sends an update for a given path to an E-BGP peer prepends its AS number to the AS_PATH. The AS_PATH field contains three values:

- The *path segment type*, which has two possible values: AS_SET and AS_SEQUENCE.

- The *path segment length* value contains the number of ASs in a segment.
- The *path segment* value contains the list of AS numbers.

The AS_PATH Path Segment Type is generally of the AS_SEQUENCE type, where each E-BGP router prepends its AS number to the leftmost side of the AS_SEQUENCE field. The AS_PATH contains the path of AS numbers that the path has traversed to reach the current AS. [Figure 7-24](#) shows how the AS_PATH value is used with the AS_SEQUENCE path segment type.

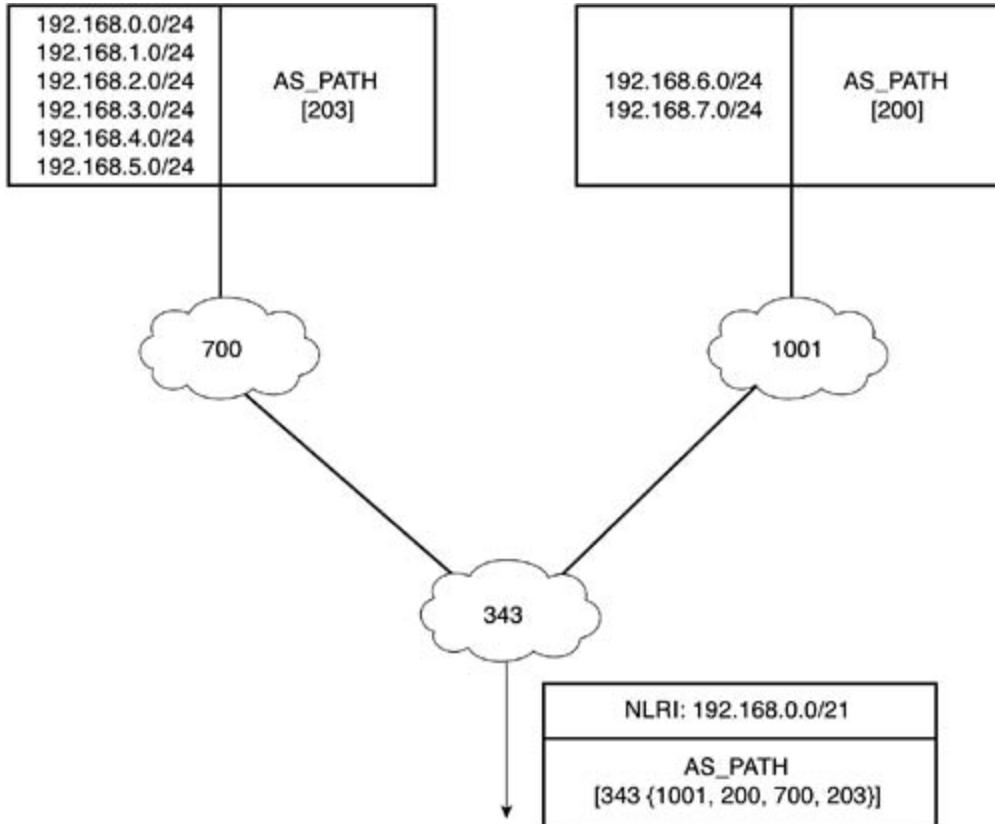
Figure 7-24. AS_PATH Attribute with an AS_SEQUENCE



In this example, AS 1000 originates the route to the 134.25.98.0/24 network. Because this route is originated in AS 1000, the AS_PATH value for this NLRI contains only the local AS number of 1000. When AS 2000 receives the UPDATE and its AS 3000 bordering router sends the UPDATE off to its E-BGP peer in AS 3000, it prepends its own AS number to the AS_PATH, and the AS 3000 border router does the same for its E-BGP peer in AS 4000. The AS_PATH contains the sequence of AS numbers that must be traversed to reach the 134.25.98.0/24 network. The leftmost value is the closest AS number, and each number in between the leftmost and rightmost numbers is an AS along the path to the originating AS—the rightmost AS number.

The AS_SET value is used with aggregation. The AS_PATH path segment type is used when routes that have differing AS_PATH values have been aggregated. [Figure 7-25](#) shows how the AS_SET value is used within the AS_PATH sequence to show that two paths are required to reach all the networks for the 192.168.0.0/21 aggregate.

Figure 7-25. AS_PATH Attribute with an AS_SET

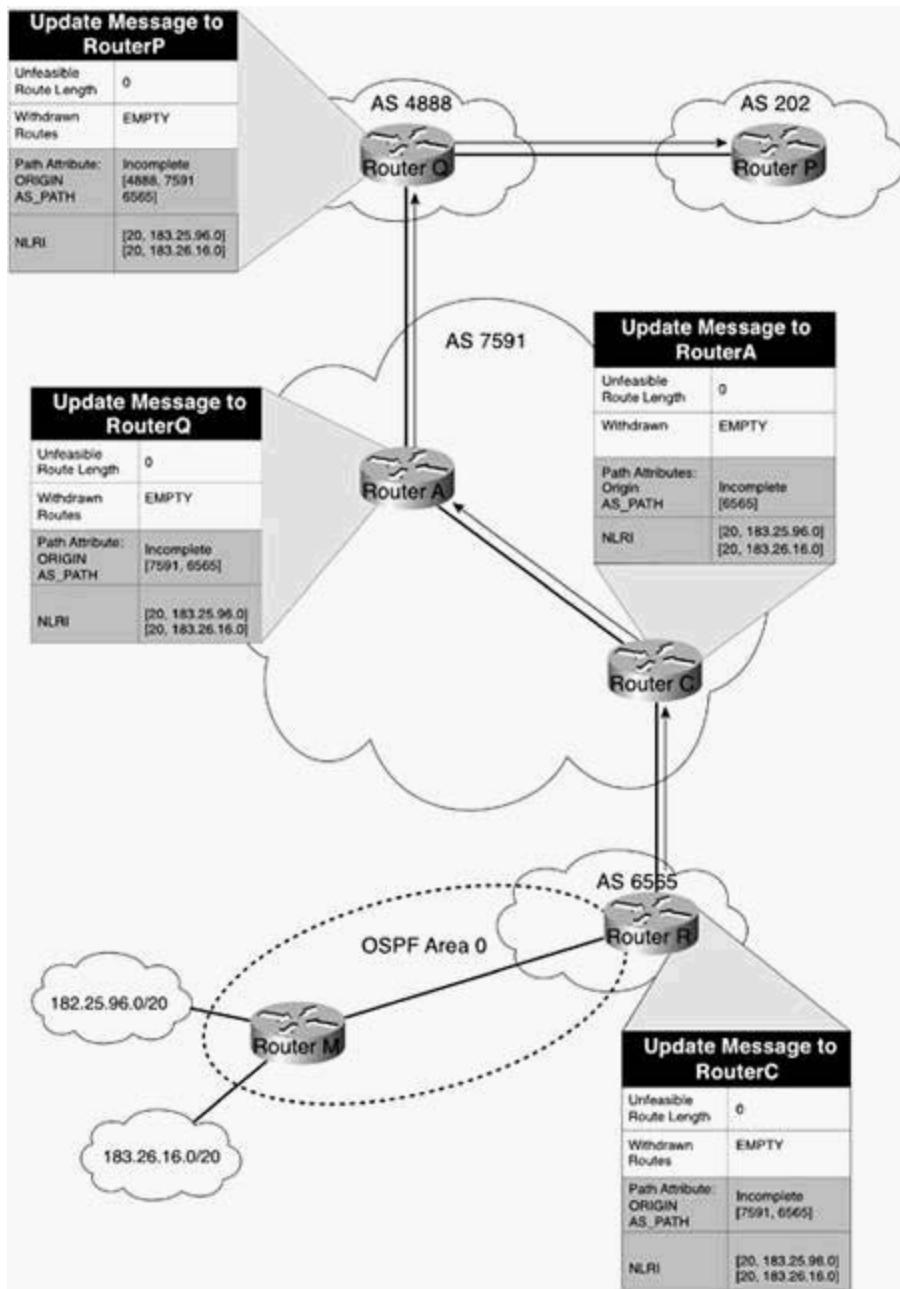


In this example, AS 700 has six routes—192.168.0.0/24, 192.168.1.0/24, 192.168.2.0/24, 192.168.3.0/24, 192.168.4.0/24, and 192.168.5.0/24—which it is advertising to its E-BGP peer in AS 343. Each of these networks originated in AS 203. When the AS 700 border router sends this update to its E-BGP neighbor in AS 343, it prepends its AS number to the AS_PATH, so the full AS_PATH that AS 343 will use to reach the 192.168.0 through 5 networks is [700, 203]. AS 1001 also advertises 192.168.6.0/24 and 192.168.7.0/24 with an AS_PATH of [1001, 200].

To preserve the AS information for the aggregated routes when AS 343 aggregates the 192.168.0.0/21 range of addresses, it must use an AS_SET AS_PATH segment code type to list the unordered path that is used to reach the networks.

[Figure 7-26](#) shows how the AS_PATH attribute is modified for the path to networks 183.25.96.0/20 and 183.25.16.0/20, as they cross various ASs.

Figure 7-26. Using the ORIGIN and AS_PATH Attributes

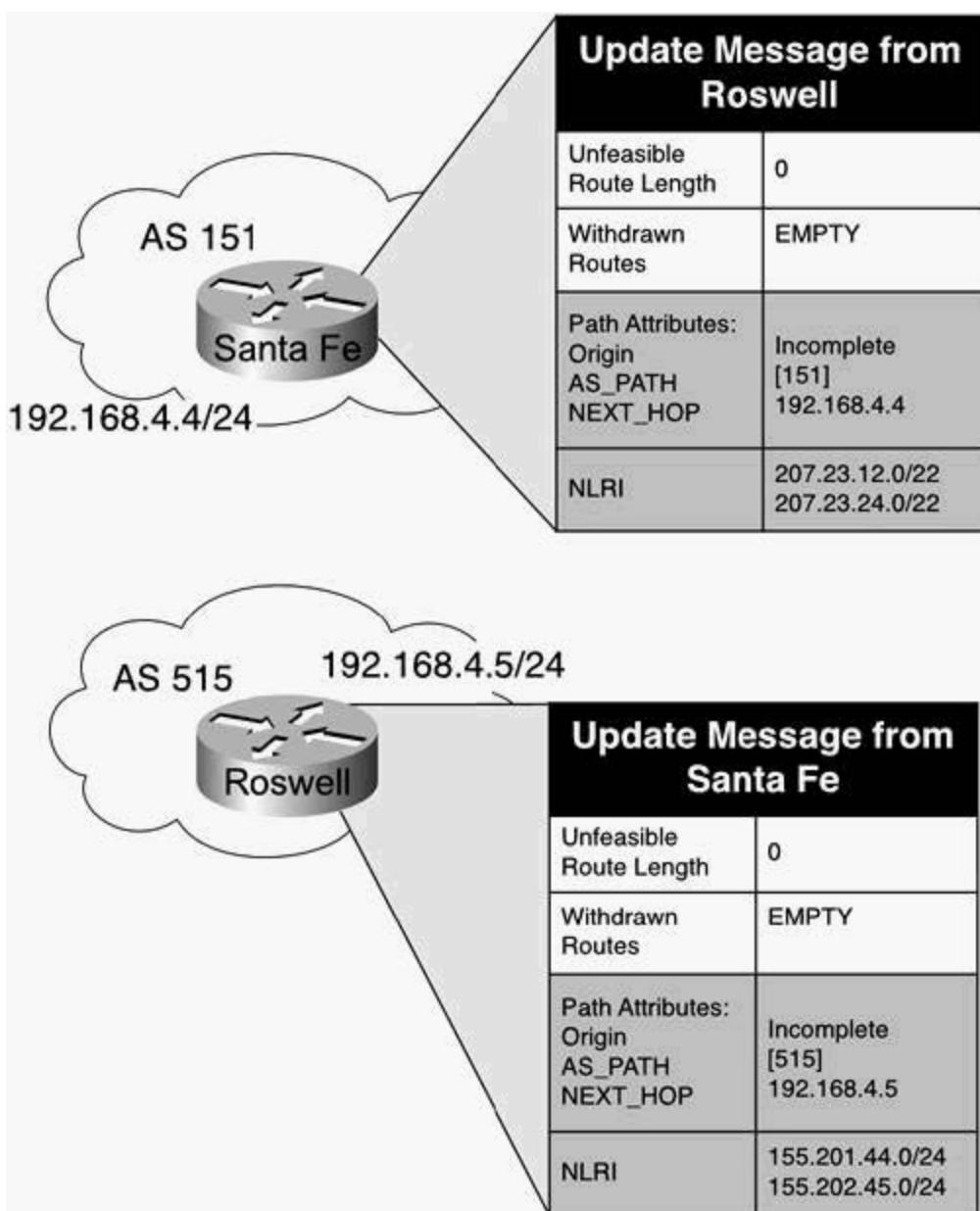


This example shows how Router R originates the route to the 183.25.96.0/20 and 183.26.16.0/20 networks that it learned through its local OSPF routing process, originates the routes as having an Incomplete ORIGIN, and sends them off to AS 7591 with the AS_PATH value 6565, Router R's local AS number. Because Router C and Router A both belong to AS 7591, Router C does not prepend its AS number to the route as it advertises it to Router A. Because Router A is sending the route to its E-BGP peer Router Q, however, it does prepend AS number 7591 to the AS_PATH as it sends it out. Then Router Q receives the route, which still contains the Incomplete ORIGIN code with the AS_PATH of [7591, 6565] and prepends its AS number, 4888, to the AS_PATH and sends it to Router P in AS 202. When a router in AS 202 wants to reach the 183.25.96.0/20 or 183.26.16.0/20 networks, it follows the AS_PATH 4888, 7591, 6565, and its packets arrive at Router R, where the local OSPF process sends them to Router M.

NEXT_HOP Attribute

The NEXT_HOP is a well-known mandatory attribute that specifies the IP address of the next hop that is taken to reach a path. The NEXT_HOP attribute is treated differently in I-BGP and E-BGP. Because of the rule of synchronization, mentioned earlier, I-BGP routers do not modify the NEXT_HOP attribute unless they are specifically told to do so using the next-hop-self command. E-BGP neighbors modify the next hop to be the egress interface used to reach their E-BGP peer. In [Figure 7-27](#), for the Santa Fe router to reach any of the networks advertised by the Roswell router, it must use the next-hop address of 192.168.4.5. Likewise, the Roswell router must use the 192.168.4.4 next-hop address to reach networks 207.23.12.0/22 and 207.23.24.0/22.

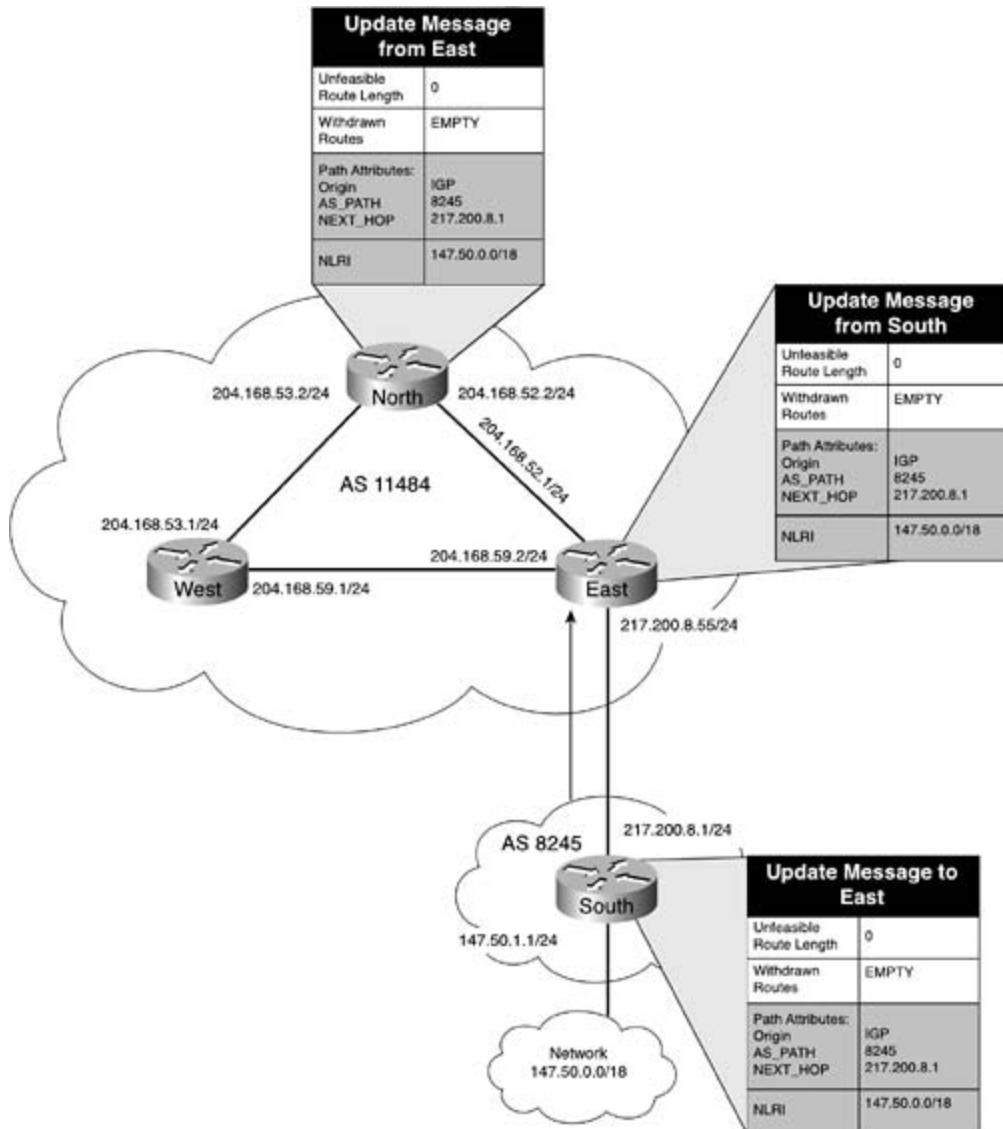
Figure 7-27. NEXT_HOP with E-BGP Peers



For an I-BGP peer to reach the next hop advertised by another I-BGP peer, it must be reachable using a route from the main routing table. If, for some reason, the I-BGP peer does not have a route to reach the next-hop address, the `next-hop-self` command can be used to alter the next-hop address specified in the outgoing UPDATE messages to that peer.

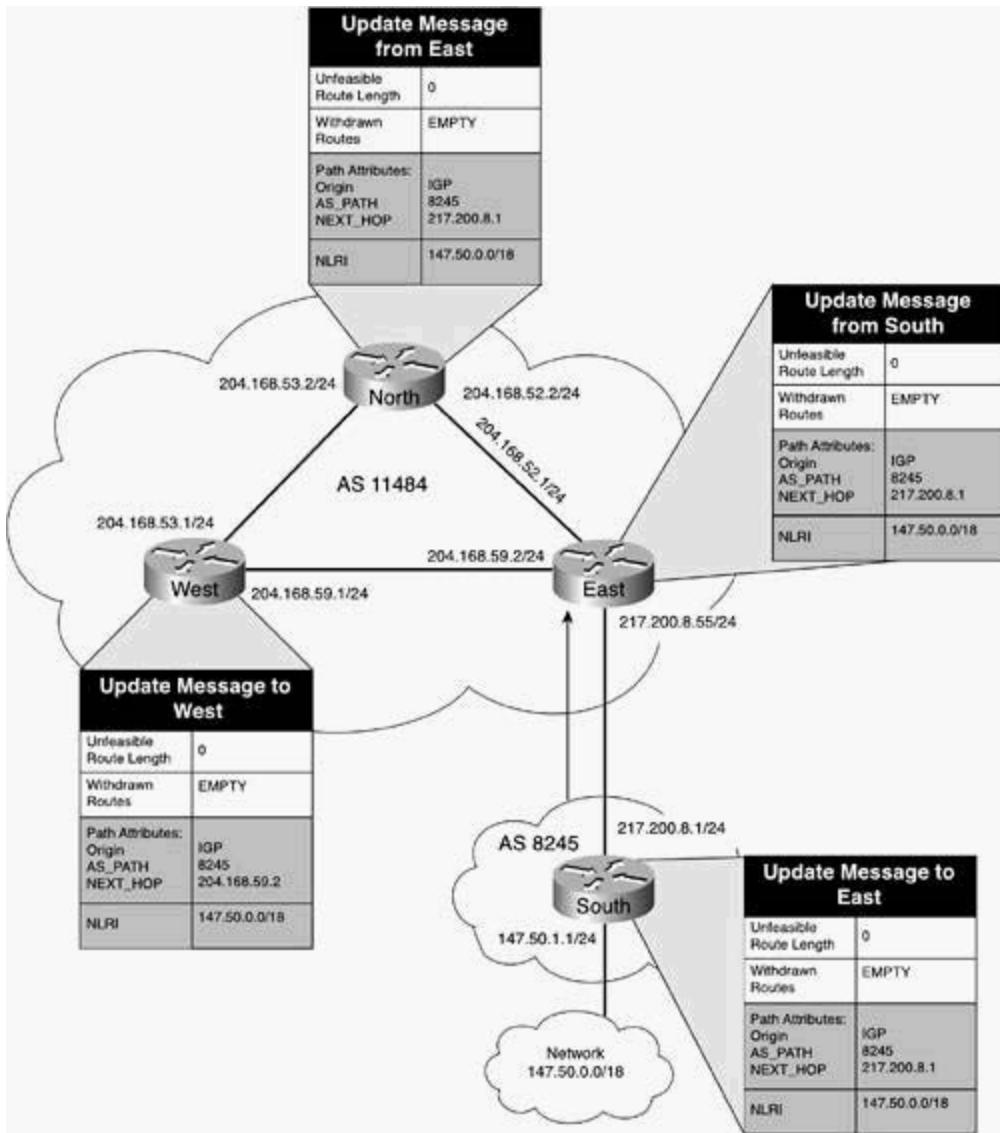
[Figure 7-28](#) illustrates how the `NEXT_HOP` attribute is used between I-BGP peering routers. In this example, the East router peers with the North and West routers in AS 7995, and forms an E-BGP session with the South router in AS 8245. The South router advertises the network 147.50.0.0/18 to the East router, which receives the UPDATE and sends the route, unchanged, to its I-BGP peer, the North router. In this case, because the East router does not change the `NEXT_HOP` attribute for the NLRI 147.50.0.0/18, the next hop for this route sent will be 217.200.8.1, the egress interface for AS 8245. Therefore, the North and West routers will see the route to the 147.50.0.0/18 network with a `NEXT_HOP` of 217.200.8.1, and will consider this route unreachable. These routers will not advertise unreachable routes to E-BGP peers, and will not store the route in their main routing tables.

Figure 7-28. `NEXT_HOP` Attribute and I-BGP Peers



However, [Figure 7-29](#) shows how this situation can be prevented using the next-hop-self command on the East router. After this command has been issued, the East router advertises the 147.50.0.0/18 route to the North router with a next hop of 204.168.52.1, and it advertises the same network to the West router with a next hop of 204.168.59.2. Because these are both reachable next hops, the North and West routers accept this route, advertise it to neighboring E-BGP routers, and store it in the main routing table.

Figure 7-29. NEXT_HOP Attribute and I-BGP Peers



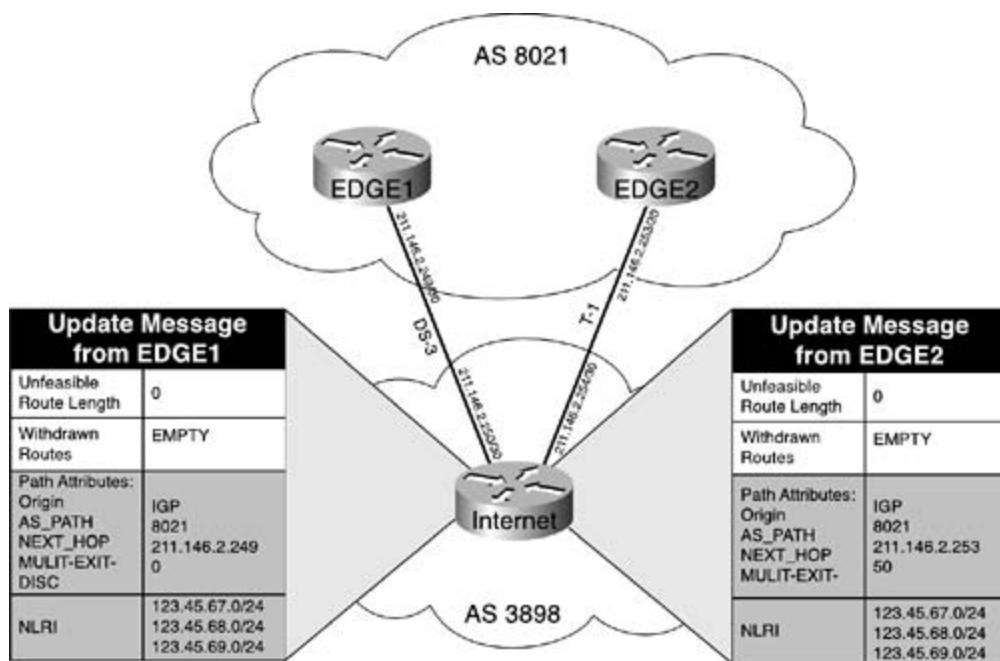
MED Attribute

The MULTI_EXIT_DISC (MED), or Multi Exit Discriminator, attribute is an optional nontransitive

attribute used as a metric to specify the preferred entry path when there is more than one point of entry into a network. The MED attribute is basically a metric used to send other bordering autonomous systems information about the preferred network entry point. The MED value ranges from 0 to 4,294,967,295, with the lowest value being the preferred value, and is configured on a per-neighbor basis. The default MED value is 0. The MED attribute is not passed beyond the neighboring AS and is only compared when both external peers belong to the same neighboring AS; this metric applies only to the connection between externally configured peers. Before considering the use of the MED attribute, consult your service provider and inquire whether they accept the MED attribute, and how they prefer that it is used.

[Figure 7-30](#) shows how the MED attribute is used between AS 3898 and AS 8021. In this example, AS 3898 has two exit points—one between the Edge 1 and Internet routers, network 211.146.2.248, which uses a DS3 connection; and another connection between the Internet and Edge 2 routers, network 211.146.2.252, which only uses a T1 connection. For the Internet router in AS 8021 to prefer the DS3 connection to the 123.45.67.0/24, 123.45.68.0/24, and 123.45.69.0/24 networks via the path advertised by the Edge 1 router, the Edge 2 router, which is connected to the Internet router via a T1 connection on the 211.146.2.252 network, advertises with a MED value of 50. The Edge 1 router advertises the same routes with the default MED value of 0. When the Internet router receives the routes from the Edge 1 and Edge 2 routers, it prefers the route from the Edge 1 router because it has a lower MED attribute.

Figure 7-30. Using the MED Attribute to Select Paths



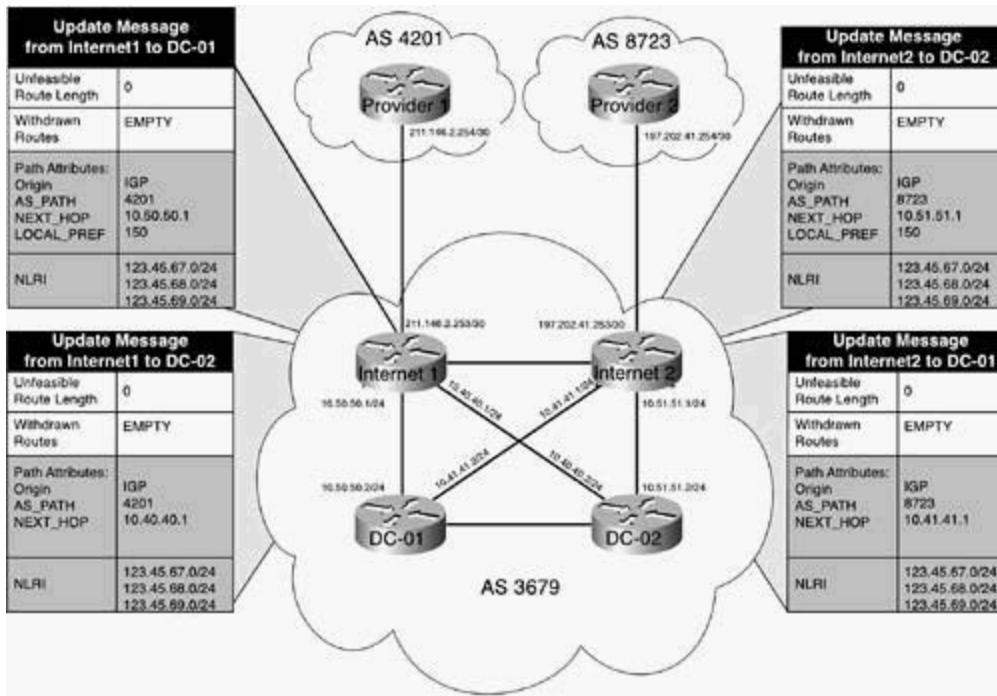
LOCAL_PREF Attribute

The LOCAL_PREF, or Local Preference, attribute is a well-known discretionary attribute used between I-BGP peers as a metric to specify a preferred path to a destination when there is more than one path to that network. The LOCAL_PREF attribute is used to specify a degree of preference to a network that has more than one path to an external destination network. The LOCAL_PREF value ranges from 0 to 4,294,967,295, and, like the MED attribute, is also

configured on a per-neighbor basis. The default value of the LOCAL_PREF attribute is 100; this attribute is not passed to E-BGP peers.

[Figure 7-31](#) illustrates how the LOCAL_PREF attribute is used to specify a more desirable path to the Internet through multiple providers. AS 3679 has two Internet border routers, Internet 1 and Internet 2. Each Internet border router is connected to a different Internet service provider, shown in the figure as Provider 1 and Provider 2.

Figure 7-31. Using LOCAL_PREF to Select Paths



The Provider 1 and Provider 2 routers advertise the same three routes: 123.45.67.0/24, 123.45.68.0/24, and 123.45.69.0/24. The Internet border routers, Internet 1 and Internet 2, forward these routes to the directly connected BGP peer routers DC-01 and DC-02; however, Internet 1 is geographically closer to DC-01 and Internet 2 is closer to DC-02. Therefore, unless the connection from DC-01 to Internet 1 is down, DC-01 should prefer and use the routes originating from Internet 1, and the exact same applies for Internet 2, and DC-02. To achieve this effect, when Internet 1 sends routes to DC-01, it alters the LOCAL_PREF value from 0 to 150, and leaves the LOCAL_PREF value for the DC-02 router at the default value of 100. That way, unless the connection between Internet 1 and DC-01 is broken, DC-01 always prefers routes from the Internet 1 router; and if the connection does go down, routes from the Internet 2 router are used. This also applies to the DC-02 and Internet 2. The I-BGP peers always prefer the route with the largest local preference. Because the LOCAL_PREF values for the connection between Internet 1 and Internet 2 are not changed, those two routers always prefer to get the routes to the 123.45.67.0/24, 123.45.68.0/24, and 123.45.69.0/24 networks from their upstream providers (Provider 1 and Provider 2).

WEIGHT Attribute

The WEIGHT attribute is the only attribute covered in this book that applies only to Cisco routers. The WEIGHT attribute is another means to specify a preferred path to a destination network when more than one path exists. Larger weights are preferred to smaller weights, with 0 being the default value for a route received from a neighboring peer, and 32,768 being the default for locally generated routes. WEIGHT values range from 0 to 65,535. The WEIGHT attribute is not passed to *any routers*, E-BGP, or I-BGP; it is strictly a local BGP policy that applies to routes in the local BGP table.

NOTE

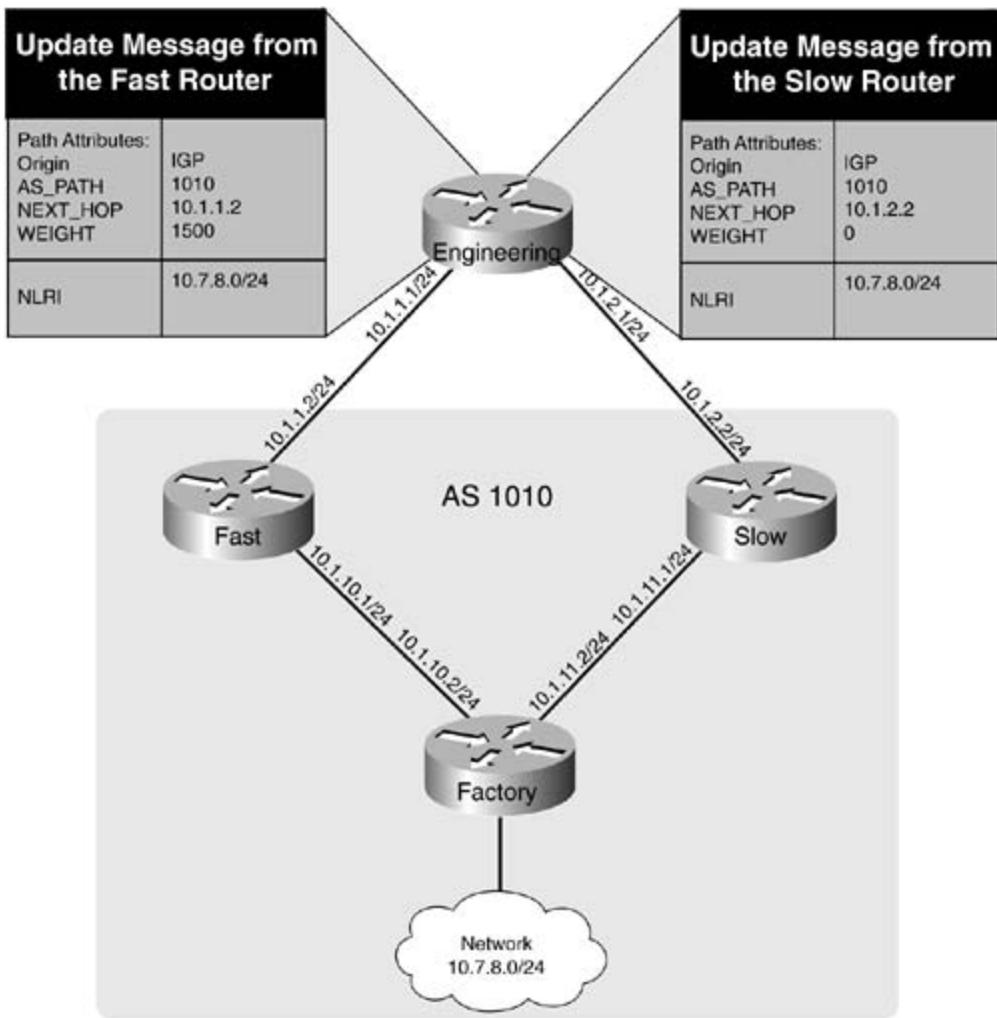
Because the WEIGHT attribute is the first item considered during the BGP path selection process, WEIGHT attribute modification can be a very useful tool that you can use when creating a local BGP routing policy.

NOTE

It is possible to use more than one route to a destination network and load balance over these routes. With the maximum-paths command, you can use up to six paths to a destination network.

[Figure 7-32](#) shows how the WEIGHT attribute is modified to specify a preferred route to a network when more than one route exists in the BGP table. In this example, the Engineering router has two possible paths to reach the 10.7.8.0/24 network advertised by the Factory router. In this case, the Engineering router should prefer the path through the Fast router over the path that passes through the Slow router. Because the decision to prefer the path over the Fast router more than the path using the Slow router is local to the Engineering Router, the WEIGHT attribute for the 10.7.8.0/24 route from the Fast router is changed to 1500. If the Fast router were to fail, traffic between the Engineering and Factory routers would still be passed using the path through the Slow router because its WEIGHT was left at the default value of 0.

Figure 7-32. Locally Preferring Routes with WEIGHT

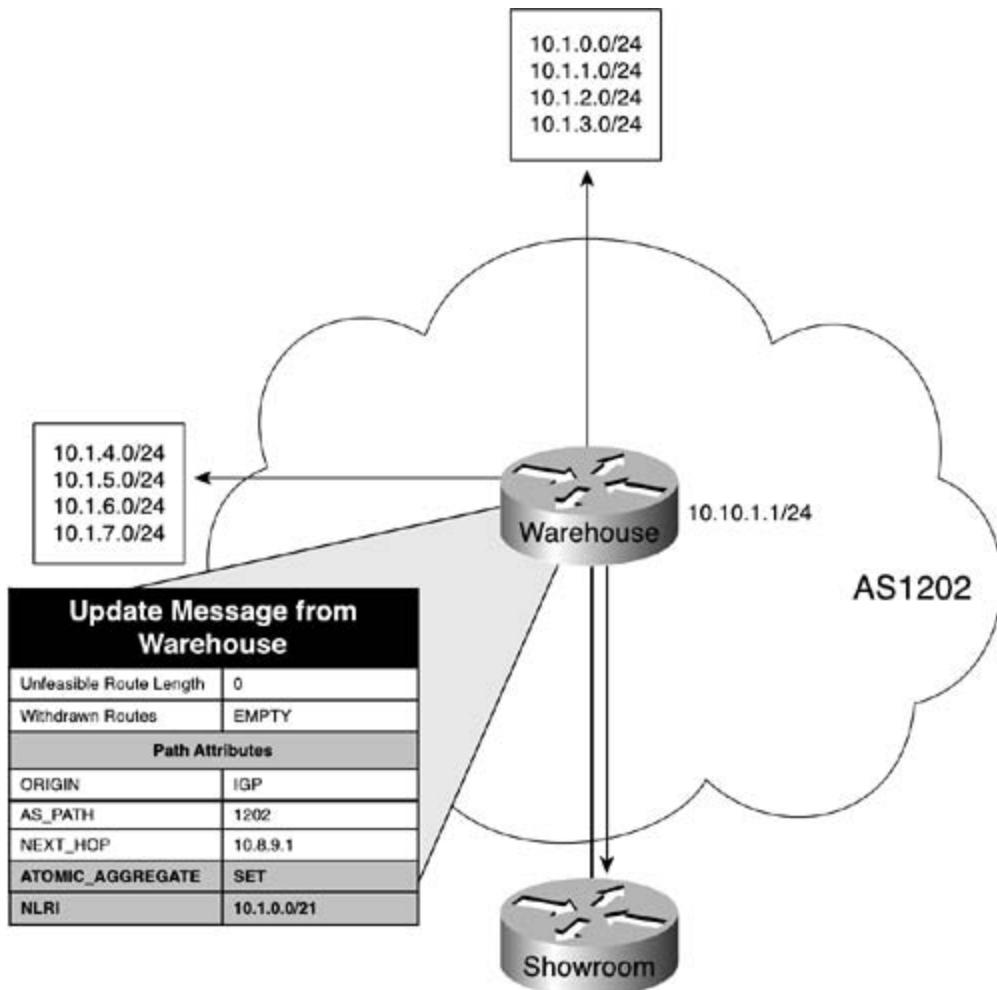


ATOMIC_AGGREGATE Attribute

The ATOMIC_AGGREGATE is a well-known discretionary attribute used to notify downstream neighbors that path information for a specific route has been lost. This information loss is caused when more specific paths are aggregated into a less-specific path. The ATOMIC_AGGREGATE attribute is just a flag set in the UPDATE packet that notifies the downstream routers that some path information has been lost during the aggregation. When the ATOMIC_AGGREGATE attribute is set, the downstream routers must not remove the attribute or send a more specific route to that network.

[Figure 7-33](#) shows an example of the how the ATOMIC_AGGREGATE attribute is used to notify the Showroom router that the Warehouse router aggregated the NLRI to network 10.1.0.0/21. The ATOMIC_AGGREGATE flag is set to notify the Showroom router that it must not send more specific routes to the 10.1.0.0/21 network because path information was lost.

Figure 7-33. ATOMIC_AGGREGATE Attribute

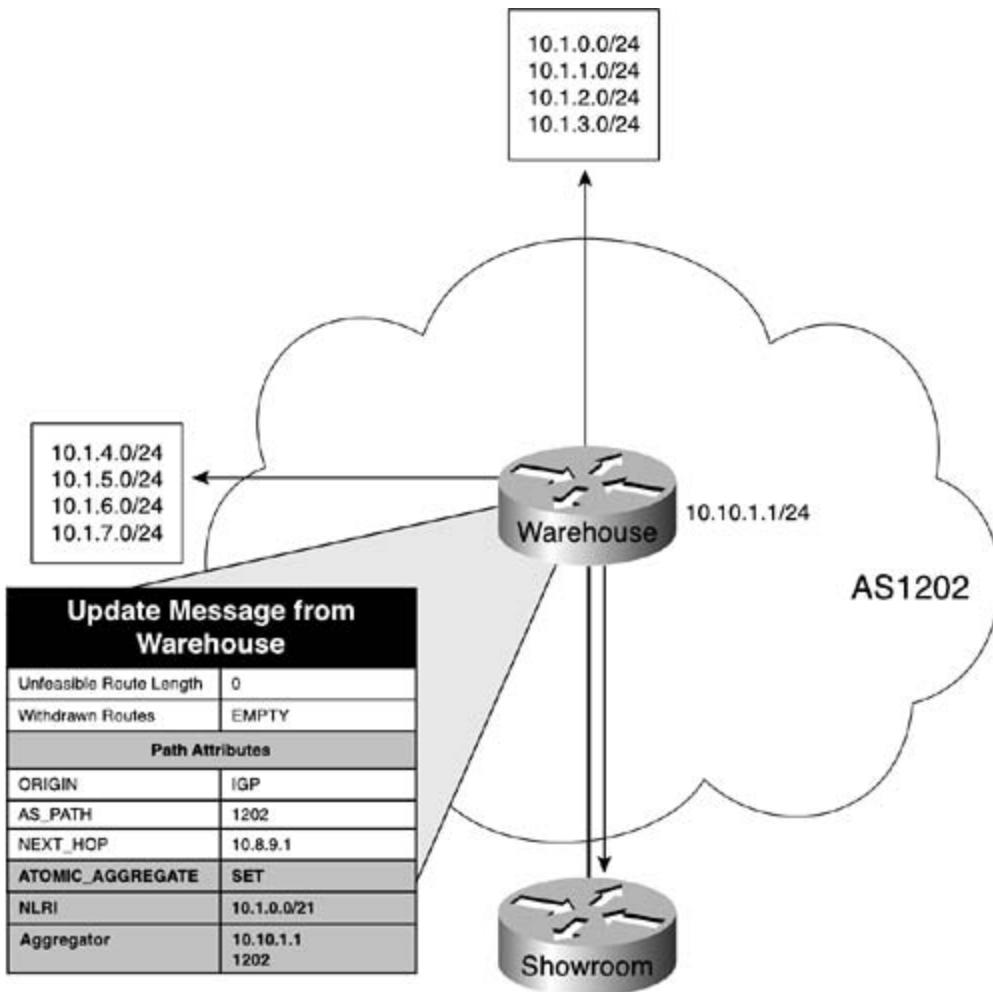


AGGREGATOR Attribute

The AGGREGATOR attribute is an optional transitive attribute that might be used if the ATOMIC_AGGREGATE attribute has been used on an NLRI. The AGGREGATOR attribute contains information about the speaker that aggregated the route. This attribute contains the BGP ID and AS number of the router that created the aggregate marking that route with the ATOMIC_AGGREGATE attribute. This information specifies the source of the less-specific aggregate route, which can be used to find where the more specific routes originated.

[Figure 7-34](#) shows the AGGREGATOR in use for the route to the 10.1.0.0/21 network from [Figure 7-33](#). In this example, the AGGREGATOR attribute was added to show that the router (BGP_ID 10.10.1.1 in AS 1202) aggregated the route.

Figure 7-34. AGGREGATOR Attribute



BGP COMMUNITY Attribute

BGP communities, defined in RFC 1997 (usages defined in RFCs 1998 and 2519), are an optional transitive attribute that define groups that follow the same policies. The policies assigned to communities affect the way routers belonging to the communities accept or deny incoming routes. They might also be used to specify a preference for particular routes. For a route to belong to a community, it must be locally configured to do so. All community-aware BGP speakers belong to the */Internet* COMMUNITY by default. If a route with an unspecified COMMUNITY attribute is received, a new community might be added. If a route with a COMMUNITY attribute set is received, that COMMUNITY attribute might be modified. Because the COMMUNITY attribute is not automatically forwarded by BGP speakers, before sending the COMMUNITY attribute to an E-BGP peer, you should first coordinate the proposed community uses to the appropriate persons in that organization.

The BGP COMMUNITY attribute is a 32-bit, 4-octet value that contains the local AS number in the first 2 octets and the locally defined value in the last 2 octets. Communities might be defined in three ways: as a decimal, with a value ranging from 1 to 4,294,967,295; as a hexadecimal value in an *aa:nn* format with the first decimal number as the local AS number, and the last 2 octets as the local defined value; or third by name, using one of the well-known BGP COMMUNITY names.

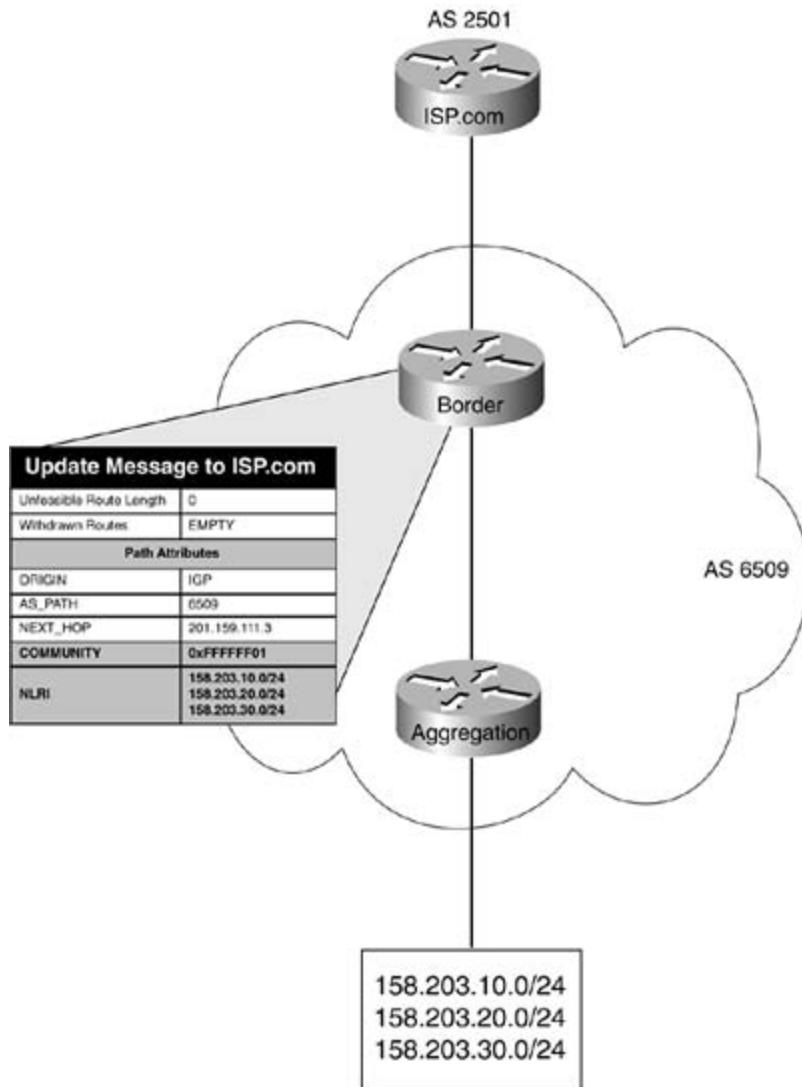
[Table 7-17](#) shows the various COMMUNITY values and their descriptions.

Table 7-17. Well-Known BGP COMMUNITY Values

COMMUNITY Value (Hex)	COMMUNITY Value (Decimal)	COMMUNITY Name	Description
0x00000000 to 0x0000FFFF	0 to 65535	Reserved	This range of COMMUNITY attributes has been reserved by IANA.
0xFFFFF0000 to 0xFFFFFFFF	4294967041 to 4294967295	Reserved	This range of COMMUNITY attributes has been reserved by IANA.
0	0	Internet	The default community, which all BGP-Community aware routers belong to by default.
0xFFFFF01	4294967041	NO_EXPORT	Routes with this COMMUNITY attribute must not be advertised outside of the local AS or confederation.
0xFFFFF02	4294967042	NO_ADVERTISE	Routes with this COMMUNITY attribute must not be advertised to <i>any</i> peer.
0xFFFFF03	4294967043	LOCAL_AS	Routes with this COMMUNITY attribute must not be advertised to any external confederation peer, referred to as NO_EXPORT-SUBCONFED in RFC 1997.

[Figure 7-35](#) shows how the NO_EXPORT (0xFFFFF01) community is used to keep internal network routes from being advertised to the public Internet. In this example, the Border router marks the 158.203.10.0/24, 158.203.20.0/24, and 158.203.30.0/24 routes as COMMUNITY NO_EXPORT and sends them to the ISP.com router. When the ISP.com router receives these routes, it might forward them to any router within its local AS, AS 2501, but no router within AS 2501 can forward that route beyond its local AS.

Figure 7-35. Using the NO_EXPORT Community

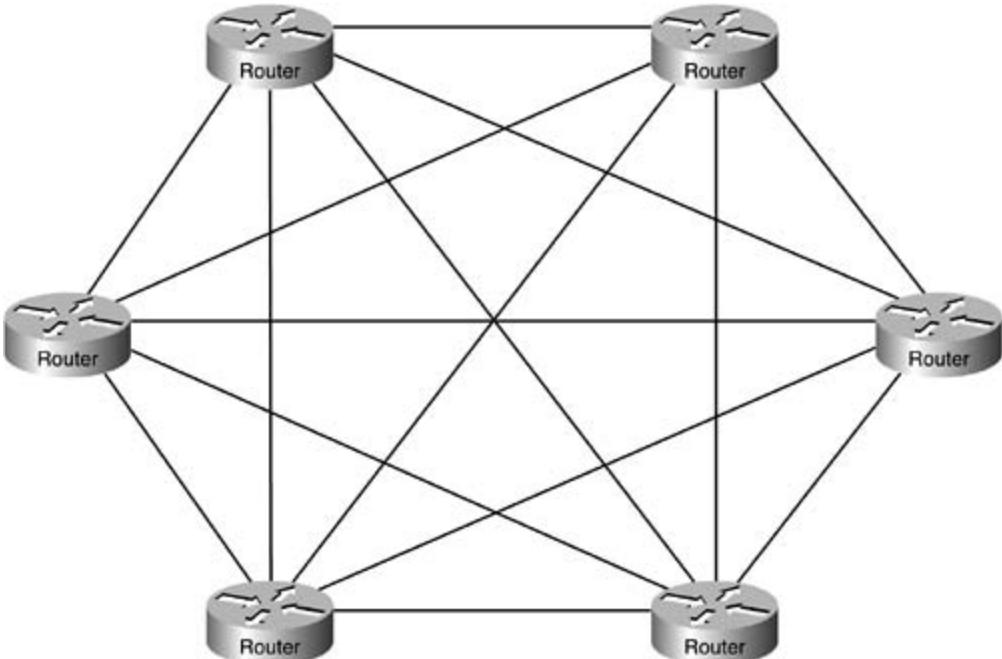


Two more BGP attributes are covered later in this chapter—the CLUSTER_LIST attribute, and the ORIGINATOR_ID attribute—both of which apply only to route reflectors. Each of these attributes is covered after an overview of BGP route reflector operation.

Route Reflectors

As mentioned earlier in this chapter, the BGP-4 protocol requires that all BGP peers belonging to the same AS form an I-BGP session with all other peers in that AS. The original BGP specifications assumed that an IGP protocol was running within each AS to synchronize all I-BGP sessions. Since the specification was written, however, more and more BGP users are no longer using IGP synchronization, and it has become very difficult for large networks running I-BGP to have I-BGP-speaking routers form a full-mesh topology. [Figure 7-36](#) shows how many connections would be required between six routers if I-BGP were to run in a full mesh, without route reflectors or confederations.

Figure 7-36. I-BGP Full Mesh Without Route Reflectors

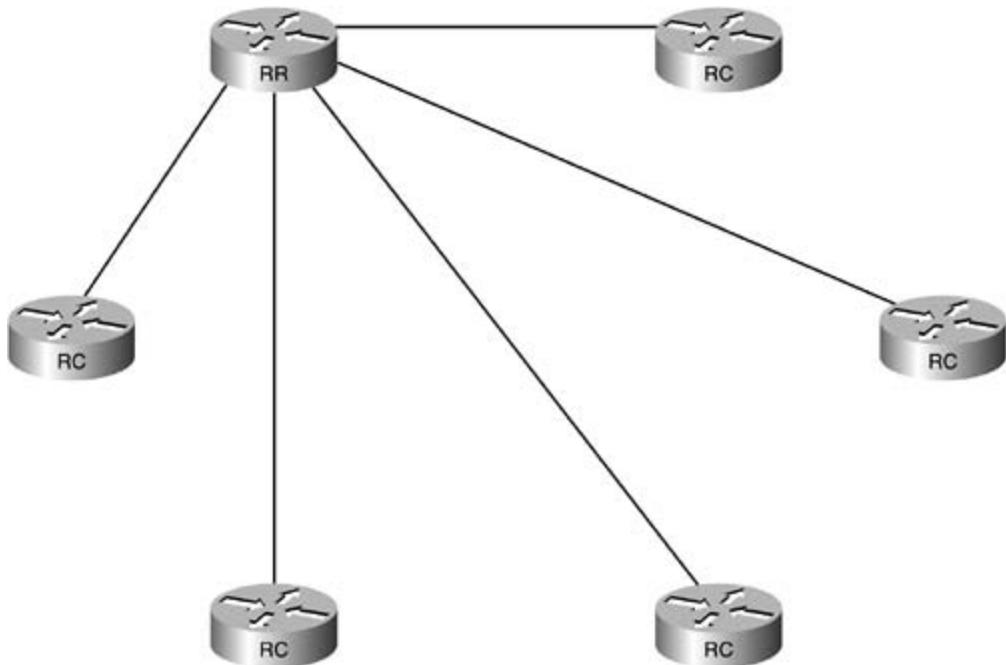


In this example, each of the six I-BGP speakers must form an I-BGP session with each peer in the local AS. As you can see, this configuration requires $n * (n - 1) / 2$, or 15 connections, which becomes unmanageable and unacceptable over large wide-area networks with expensive WAN connections. Each I-BGP session adds to the overall BGP memory and processor utilization load that each I-BGP router will have to support, and adds to the administrative headaches for the people who have to support the BGP routers. In an effort to solve this problem, route reflectors (specified in RFC 2796) and confederations (specified in 3065) were created. Confederations are covered later in this chapter.

Route reflectors are basically fully functional I-BGP speakers that form I-BGP sessions with other I-BGP speakers. However, router reflectors perform a second function: They forward routes from other I-BGP speakers to *route reflector clients*. Route reflector clients are BGP-speaking routers that only form I-BGP sessions with the route reflector, decreasing the number of I-BGP peering sessions and simplifying the BGP routing process. [Figure 7-37](#) shows the same network previously shown in [Figure 7-36](#). In the new figure, route reflectors are used to decrease the

number of I-BGP sessions.

Figure 7-37. Using Route Reflectors to Decrease the Number of I-BGP Sessions



Notice in this figure that five of the six I-BGP peers, labeled RC, now form one I-BGP session with the route reflector, labeled RR.

In review, route reflectors advertise I-BGP routes to I-BGP neighbors, both the fully meshed neighbors who are not route reflector clients, and the route reflector clients, which they serve. Although route reflectors forward routes to route reflector clients, route reflector clients cannot forward routes to route reflector servers unless they are specifically configured to do so. The route reflector and the route reflector clients form *clusters*. More than one cluster can exist within an AS. Any I-BGP speakers that do not support route reflection must form I-BGP sessions with all other I-BGP routers, with the exception of route reflector clients, which behave as though they are fully meshed I-BGP peers with their route reflector. Route reflector clients require only I-BGP sessions with their route reflector, and the route reflector forms I-BGP connections with any routers that are not route reflector clients.

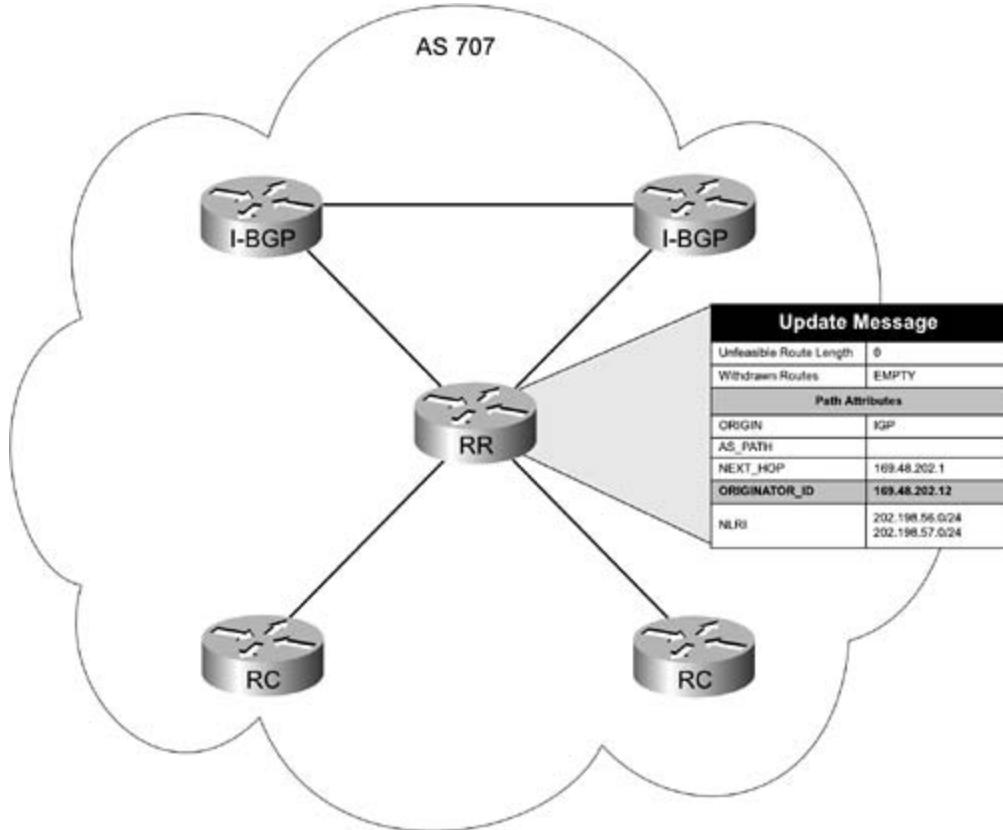
ORIGINATOR_ID Attribute

Route reflector clusters are identified by a 4-byte (32-bit) ORIGINATOR_ID attribute, which is the BGP ID for the route reflector. The ORIGINATOR_ID is a loop-prevention device that identifies a route reflector cluster by the IP address of the route reflector. If a route reflector finds its own ORIGINATOR_ID in an UPDATE message, it assumes that a routing loop has occurred and that message is ignored.

The ORIGINATOR_ID is an optional nontransitive attribute, described in RFC 2796 as the identifier for a route reflector cluster, which is used to prevent routing loops. If a route reflector

receives a route without an existing ORIGINATOR_ID value, it adds its own BGP ID to the ORIGINATOR_ID. If the route reflector sees its own IP address in the ORIGINATOR_ID field, it ignores the update. [Figure 7-38](#) shows how the ORIGINATOR_ID attribute is used with route reflectors within an AS.

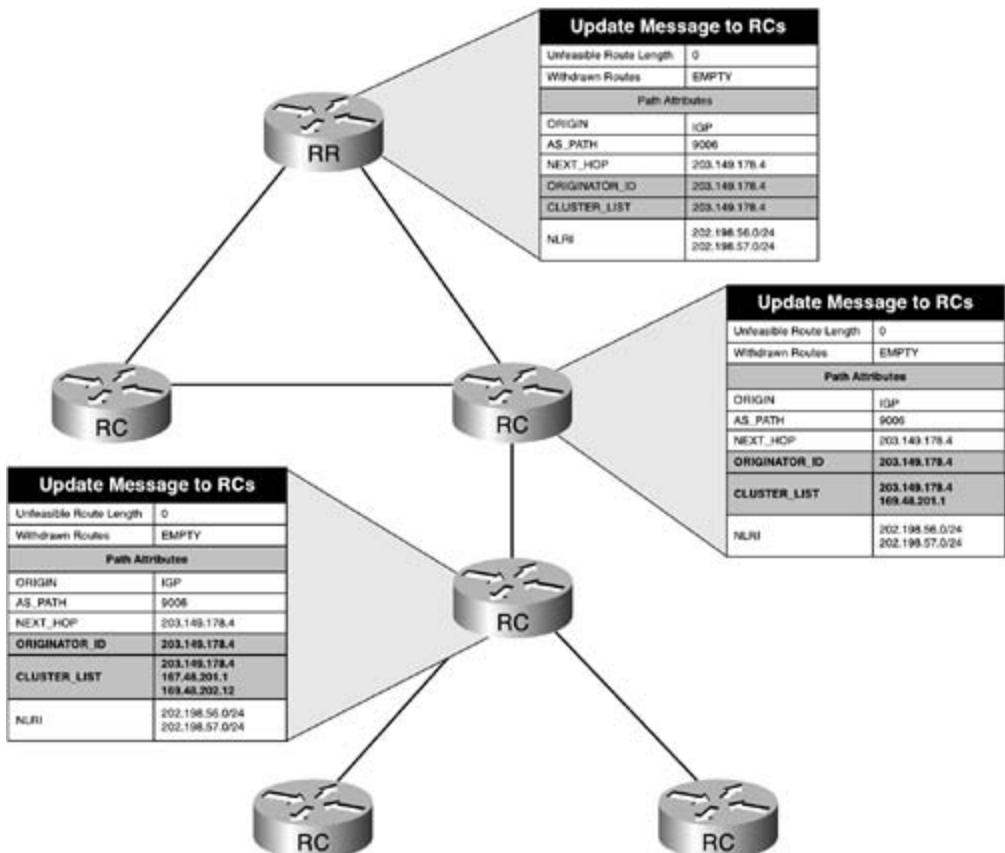
Figure 7-38. ORIGINATOR_ID and Route Reflectors



CLUSTER_LIST Attribute

The CLUSTER_LIST attribute, also defined in RFC 2796, is an optional nontransitive attribute used to prevent loops when more than one route reflector cluster exists within an AS. The CLUSTER_LIST is a 4-byte value that contains a list of CLUSTER_ID values that describe the reflection path that a route passed through, similar to the AS_PATH attribute. Similar to the ORIGINATOR_ID, the CLUSTER_ID is the BGP ID of the router. When a route reflector receives an update, it checks the value of the CLUSTER_LIST attribute. If the CLUSTER_LIST field is empty, it adds its CLUSTER_ID to the field. If the field contains other entries, it prepends its local CLUSTER_ID to the list. If a route reflector receives an update with its own CLUSTER_ID in the CLUSTER_LIST, it assumes a routing loop exists and ignores the update. [Figure 7-39](#) demonstrates how the CLUSTER_ID is prepended to the CLUSTER_LIST to prevent routing loops within an AS.

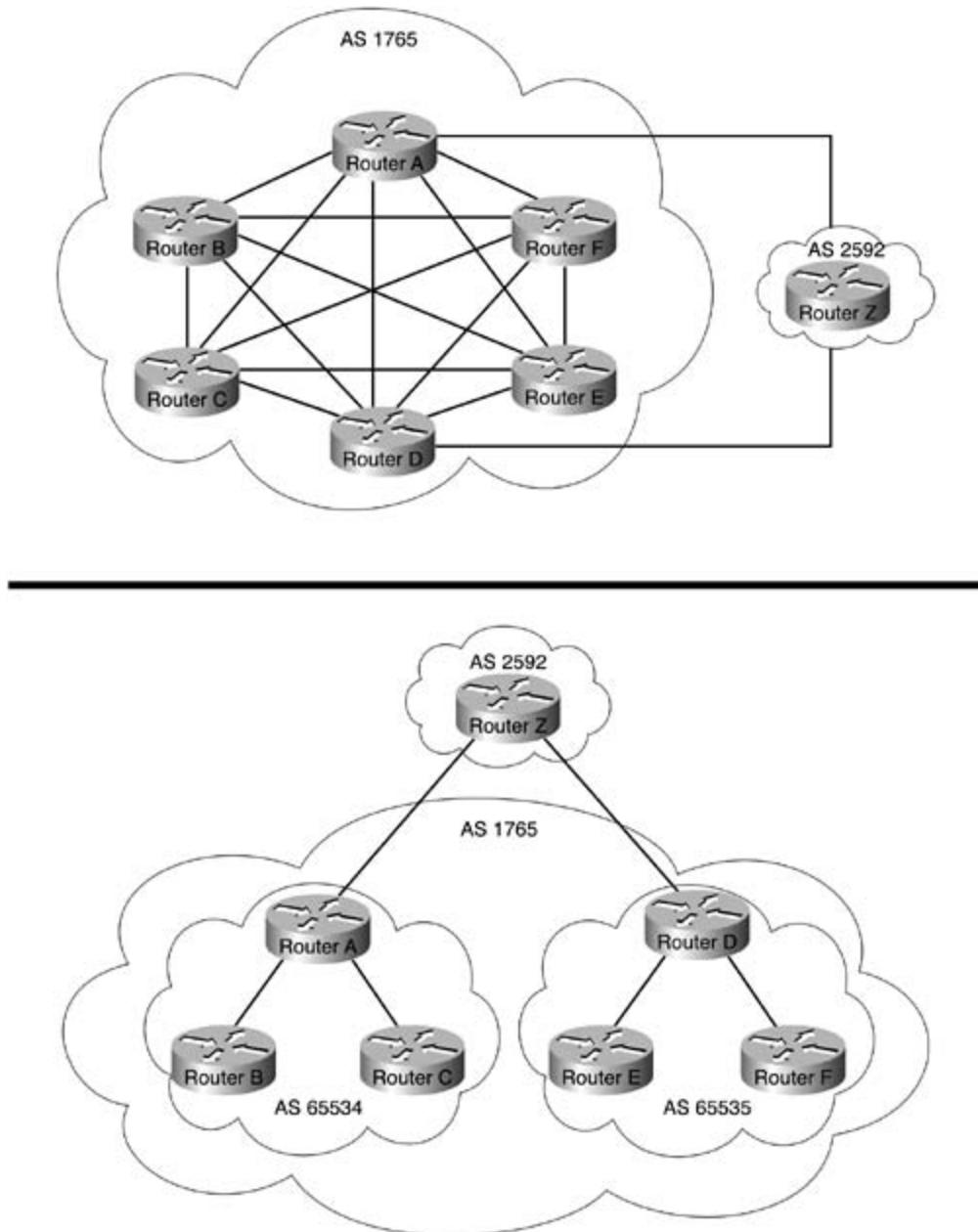
Figure 7-39. CLUSTER_LIST Attribute



Confederations

Another way to solve the I-BGP full-mesh requirement is to use *confederations*. Defined in RFC 3065, BGP confederations are smaller sub-autonomous systems that can be created within a primary AS to decrease the size of BGP peer connections that are required between I-BGP peers. [Figure 7-40](#) shows six routers before and after the creation of AS confederations.

Figure 7-40. Before and After AS Confederations

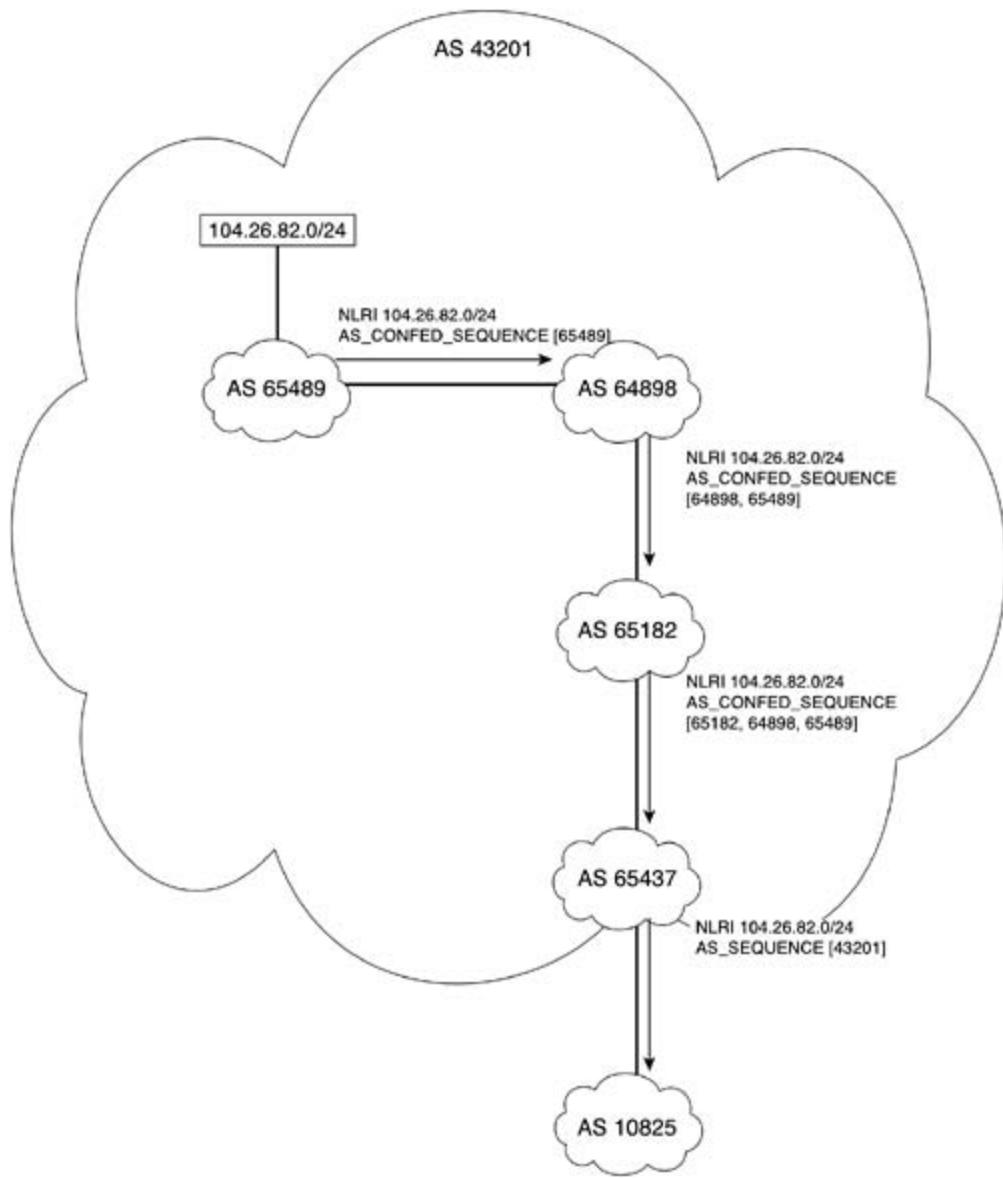


In the top diagram, all 6 peers in AS 1765 form a I-BGP full mesh, resulting in $6 * (6 - 1) / 2 = 15$, $n * (n - 1) / 2$, I-BGP peering sessions between those 6 hosts, with Routers A and D forming E-BGP sessions with Router Z in AS 2592. The bottom diagram shows how two sub-autonomous systems, 65,534 and 65,535, are formed within AS 1765, decreasing the number of I-BGP peer sessions to three per sub-AS, with an E-BGP session between the sub-autonomous systems. Routers A and D still form an E-BGP session with Router Z in AS 2592, but Router Z is completely unaware of the existence of the AS confederations within AS 1756, the parent AS for the two sub-autonomous systems 65,534 and 65,535.

All BGP confederation peers follow the same rules that apply to I-BGP peers that do not belong to confederations. Each peer must have an I-BGP session with all other I-BGP peers in the sub-AS, and the NEXT_HOP, AS_PATH, MED, and LOCAL_PREF attributes remain unchanged as they are passed between peers belonging to the same sub-AS. Any AS containing confederations appears as one AS to all external BGP peers. Each sub-AS is assigned its own AS number, a private AS number that is invisible to peers outside the sub-AS. This private AS number is called a *member AS number*. The sub-autonomous systems belonging to an AS confederation are referred to as *member autonomous systems*. The parent AS containing the sub-AS confederations still maintains its own AS number. When confederations are in use, this number is referred to as a *confederation ID*. Because the peers within the sub-AS have a separate My AS value than other peers belonging to the parent AS, to facilitate communication with other routers within the parent AS, at least one peer that is a member of a confederation must form an E-BGP session with other peers belonging to any AS number other than that of the confederation. When a BGP update is sent from a peer belonging to a confederation to a peer outside the sub-AS, the sending peer uses its own sub-AS number. When the confederation peer sends an update to an E-BGP peer, it identifies itself using the AS confederation ID of the parent AS.

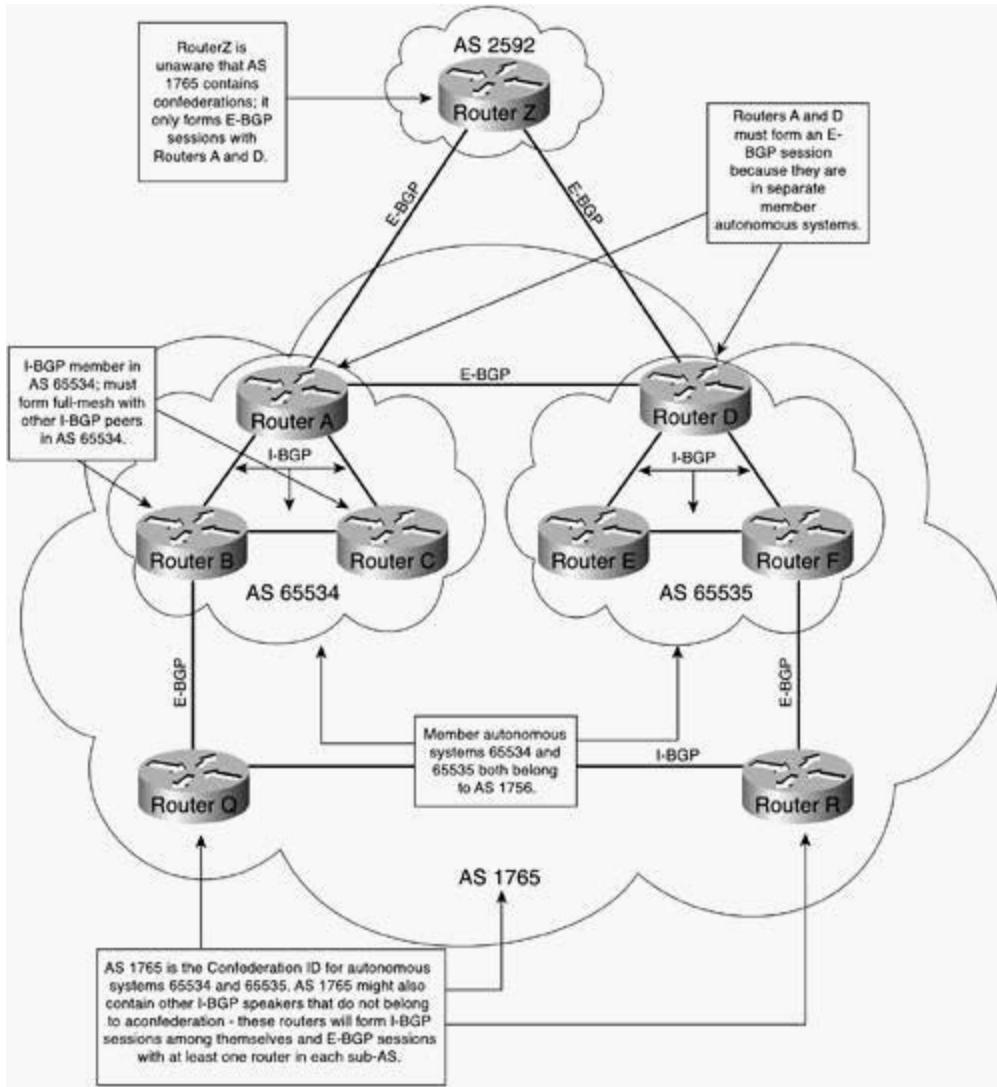
When confederations are in use, one of two new AS_PATH attributes apply. The AS_CONFED_SET and AS_CONFED_SEQUENCE AS_PATH path segment types are used to describe the path that a route followed as it passed through confederations. The AS_CONFED_SET segment type is an unordered list of sub-autonomous systems that a route has traversed, similar to the AS_SET segment type, and the AS_CONFED_SEQUENCE segment type contains an ordered list of member ASs that a route travels through. When updates are sent to external peers, the AS_CONFED_SET and AS_CONFED_SEQUENCE path segment types are replaced with the confederation ID belonging to the parent AS. [Figure 7-41](#) illustrates how the AS_CONFED_SEQUENCE path segment type is used for an advertisement spanning multiple sub-autonomous systems before exiting the parent AS.

Figure 7-41. AS_CONFED_SEQUENCE Path Segment Type



[Figure 7-42](#) illustrates the various parts of a configuration and the roles that routers play, both inside and outside the confederation.

Figure 7-42. How Confederations Work



This figure identifies the basic characteristics of an AS containing confederations. Sub-AS 65,534 contains Routers A, B, and C. Each router in this sub-AS forms an I-BGP session with the other routers, forming a full mesh. Likewise sub-AS 65,535 contains Routers D, E, and F, which also form an I-BGP full mesh. Routers A and D form an E-BGP session across the two sub-autonomous systems, linking them together, and Routers B and F also form E-BGP with Routers Q and R. All of these routers belong to AS 1765, the confederation ID for ASs 65,534 and 65,535.

Routers A and D are also the only routers in AS 1765 that interface with Router Z in AS 2592, the only peer relationship formed outside of AS 1765. Before routes that originated within AS 1765 can be passed to AS 2592, Routers A and D must modify the AS_PATH and replace the AS_CONFED_SEQUENCE value of either [65534] or [65535] with an AS_SEQUENCE value of [1765].

Peer Groups

When configuring one router with BGP multiple peer relationships, configurations can get quite complicated. Peer groups were created to simplify the configuration and troubleshooting process. Peer groups are created by making groups and assigning neighbors with the same policies to the groups. Peer group members inherit the policies assigned to the group. [Chapter 9](#) covers peer group configuration and examples.

Route Selection Process

So, now that you know how BGP operates, how attributes influence routing decisions, and when to consider more complicated configurations, it is time to put this information together and use it to install routes in the main routing table. For a BGP speaker to move a route from its Adj_RIB_In to the Loc-RIB table, BGP performs a quite complicated route selection process. Unless the use of multiple paths has explicitly been configured, BGP speakers store only one route, the best route, in the main routing table. Only routes that the BGP process knows are reachable (from an IGP or directly connected) are considered for the BGP route selection process. The following BGP route selection process is described at the Cisco.com website at <http://www.cisco.com/warp/public/459/25.shtml>.

Step 1. Select the path with the *largest WEIGHT* (ranging from 0 to 65,535). Remember, WEIGHT is a Cisco proprietary attribute, is not forwarded to *any* peers, and only applies to the local router.

Step 2. If the WEIGHT attributes are equal, select the path with the *largest LOCAL_PREF* value (ranging from 0 to 4,294,967,295).

Step 3. If the WEIGHT and LOCAL_PREF values are equal, select the path that originated from the local router, either by local configuration or redistribution.

Step 4. If the WEIGHT, LOCAL_PREF, and local origination of the route are equal, select the route with the *shortest AS_PATH*.

Step 5. If all the previous attributes are equal, select the path with the *most desirable ORIGIN*. Remember, IGP is preferred, and EGP is considered before Incomplete.

Step 6. If the previous attributes are equal and there is more than one exit path to a network, prefer the path with the *lowest MED* value (ranging from 0 to 4,294,967,295).

Step 7. If the MED value is equal or not used, prefer E-BGP paths to I-BGP paths.

Step 8. If both paths are E-BGP (or both paths are not E-BGP), prefer the path with the lowest IGP metric.

If BGP multipath is enabled, and there are multiple external or confederation-external paths from the same neighboring AS or sub-AS, multiple paths are added to the Loc-RIB table at this point. The oldest path is considered the best path when forwarding updates to other routers.

Step 9. If the paths are external, select the *oldest* path (the path that was received first).

Step 10. If the paths were received at the same time, prefer the path that came from the peer with the *lowest BGP-ID*.

Step 11. If the route was received from a route reflector, select the path with the *lowest CLUSTER_ID* (BGP_ID of the route reflector) length.

Step 12. If the path was received from the same host, either peer or route reflector, select the path that came from the neighbor with the *lowest peer IP address* (the address of the directly [or nearest indirectly connected if not directly connected] connected interface).

After the most desirable route has been selected, it is put into the main routing table and can be used to route packets.

Summary

BGP is an Exterior Gateway protocol that uses a path-vector algorithm to define the best path to a destination network. There are two types of BGP relationships, External BGP and Internal BGP—each type operates differently. Paths are not selected until BGP peers have transitioned through several states and established a peer relationship. OPEN messages are used during the peer session Establishment stage. After the neighboring routers have become peers, they exchange KEEPALIVE messages to verify connectivity and UPDATE messages to exchange routes. Upon a critical error, the peer experiencing the error condition sends a NOTIFICATION message to its peer, specifying the cause for the error and closing the BGP session. During the UPDATE process, BGP uses several attribute types to determine the best path to a destination network. After the best path has been selected, that path is stored in the main routing table and is ready for use.

Further Reading

Internet Routing Architectures, Second Edition, by Sam Halabi.

Routing TCP/IP, Volume II, by Jeff Doyle and Jennifer Dehaven Carroll.

Cisco BGP-4 Command and Configuration Handbook, by Dr. William R. Parkhurst.

BGP4 Inter-Domain Routing in the Internet, by John W. Stewart III.

RFC 1771, *A Border Gateway Protocol 4 (BGP-4)*, by Yakov Rekter and Tony Li.

RFC 1997, *BGP Communities Attribute*, by Ravi Chandra and Paul Triana.

RFC 1998, *An Application of the BGP COMMUNITY Attribute in Multi-Home Routing*, by Enke Chen and Tony Bates.

RFC 2395, *Protection of BGP Sessions via the TCP MD5 Signature Option*, by Andy Hefferman.

RFC 2519, *A Framework for Inter-Domain Route Aggregation*, by Enke Chen and John W. Stewart, III.

RFC 2892, *Capabilities Advertisement with BGP-4*, by Ravi Chandra and John G. Scudder.

RFC 2918, *Route Refresh Capability for BGP-4*, by Enke Chen.

RFC 2796, *BGP Route Reflection—An Alternative to Full Mesh IBGP*, by Tony Bates, Ravi Chandra, and Enke Chen.

Chapter 8. Introduction to BGP-4 Configuration

Configuring Border Gateway Protocol (BGP) in a production environment can be one of the most daunting tasks that network professionals encounter in their career. Depending on your BGP protocol and configuration knowledge, the BGP peering requirements, the network policy, and general network stability, designing and implementing a solid BGP network might be one of the largest design challenges that you face. BGP router configuration mode contains hundreds of possible commands, which makes it one of the most customizable routing protocols available today. BGP also uses several other features in Cisco IOS Software that complement the commands available in BGP router configuration mode, such as access lists, route maps, autonomous system path (AS path) access lists, IP prefix lists, community lists, and regular expressions. These features combined with the other BGP configuration commands create a large toolbox for use in BGP configuration. Over the next two chapters, this book covers many of these commands and shows you how to use them to create and implement solid BGP network models.

This chapter covers the basic BGP configuration prerequisites and briefly covers some of the BGP processes that run on a Cisco router. The chapter then takes you through a detailed step-by-step BGP neighbor configuration and network advertisement, using some hands-on practical examples. While configuring BGP in this chapter, you have the opportunity to analyze and verify the BGP configuration using BGP show and debug commands as troubleshooting tools. This chapter also introduces several BGP configuration tips and other tools that you can use to decrease troubleshooting time and to help you get more use from Cisco IOS Software. These tools are used to take a close look at BGP operation and can also be used to troubleshoot common BGP problems. The output of each command is listed in detail so that you can see exactly what the router is doing and read the command output like a pro.

This chapter provides the foundation for the final BGP chapter, [Chapter 9](#), "Advanced BGP Configuration," which covers topics such as route reflectors, confederations, redistribution, route aggregation, and BGP tuning.

BGP Configuration Prerequisites

When modeling a BGP network, you need to consider many configuration prerequisites. You must consider the amount of memory and processor available on your routers and the software feature sets required to create the scenarios that properly model the network. As a best practice, before configuring BGP, always make sure that the routers running BGP are capable of doing so. Get a snapshot of the current operating environment, and check the available and used memory to verify that debugging BGP does not crash the router.

If the router does not have enough memory, and there is no way to increase the amount of memory on the router, you can do a few things to prevent configuration disasters. First, check your feature set using the show version command. If you are running an enterprise feature set and you will not be using all the other features, such as IPX, AppleTalk, or DEC protocols, try using a more scaled-down version of Cisco IOS Software such as the IP feature sets. Second, display the running processes and the running configuration, and find some protocols or features that can be disabled to make more memory available to BGP. Third, disable console logging (log to the buffer or syslog), and use the scheduler allocate command to prevent router reloads. Finally, save your configuration before debugging; that way, in the event that the router does reload, you still have your configuration.

Assessing the Router's Capacity for BGP

After BGP has been configured on a Cisco router, four processes are started: BGP Open, BGP Scanner, BGP Router, and BGP I/O. The *BGPOpen* process is used to establish the TCP session between BGP speakers. The BGP Open process ends after a TCP session for the BGP peers has been established and is only visible at the beginning of BGP session establishment. The *BGPI/O* process performs all BGP packet processing and performs the queuing of BGP UPDATE and KEEPALIVE messages. The *BGPScanner* process scans, or walks, the BGP table, a data structure called a *Radix Trie*, for next-hop reachability changes. By default, the scanner runs every 60 seconds and is shown while debugging BGP as *nettable_scan* and *nettable_walker*. Finally, the *BGPRouter* process handles the establishment of peer sessions. The BGP Router process also handles the actual BGP decision process, determining which routes are stored in the main IP routing table; it also processes new routes and advertises routes to peers. [Example 8-1](#) shows the four BGP processes as displayed using the show processes cpu | includeBGP command.

Example 8-1. Four BGP Processes

```
Alki#show processes cpu | include BGP

CPU utilization for five seconds: 0%/0%; one minute: 0%; five minutes: 0%

PID Runtime(ms)    Invoked      uSecs     5Sec   1Min   5Min TTY Process
 21          0         1           0  0.00%  0.00%  0.00%  0 BGP Open
 84        81       6085          13  0.00%  0.02%  0.00%  0 BGP Router
 85       693      13436          51  0.00%  0.00%  0.00%  0 BGP I/O
```

```
86      2547      201      12671  0.00%  0.06%  0.06%  0 BGP Scanner
```

Notice in the prior example that there were four BGP processes running at the time that the show processes cpu snapshot was taken. The BGP Router, BGP I/O, and BGP Scanner processes always run after BGP has been configured. The BGP Open process only runs when BGP triggers the initial TCP session, and only runs until the TCP session is established, so you can tell that this command was issued at the beginning of a BGP session, right after BGP was configured. The show processes history command enables you to display a summarized graphical representation of the CPU utilization history. This command might prove useful when troubleshooting performance problems on a production router.

TIP

Output modifiers, like the one shown in [Example 8-1](#), enable you to display more concise information from a command. In the preceding example, the | includeBGP output modifier was used to limit the output of the show processes cpu command to include items containing the string "BGP." Output modifiers are case sensitive, and you might need to experiment with the output string to find the information that you want to display. When commands used with output modifiers are combined with command aliases, you have yet another tool that can help you customize your use of Cisco IOS Software. Use of aliases and output identifiers is covered in more detail later in this chapter.

The highlighted section of the command output was added into this example to show the command output description. It does not normally appear, unless specified, when output modifiers are used. [Example 8-2](#), using the show processes memory | includeBGP command, shows the BGP processes that are currently utilizing memory.

Example 8-2. Output from the show processes memory | include bgp Command

```
Alki#show processes memory | include BGP
```

```
Total: 29184828, Used: 5148284, Free: 24036544
```

PID	TTY	Allocated	Freed	Holding	Getbufs	Retbufs	Process
21	0	0	0	6928	0	0	0 BGP Open
84	0	52560	492	10324	0	0	0 BGP Router
85	0	0	0	6868	0	0	0 BGP I/O
86	0	116	0	9992	0	0	0 BGP Scanner

In the preceding example, you can see the amount of memory that the Alki router has allocated to the BGP processes that are currently running. Once again, the highlighted section of the command was added into the command output to show the descriptions for the items displayed for the command. If the entire contents of the show processes memory command had been included in the command, the output would have been quite a few pages, so the output modifier was used to constrain the output of the show command to display only BGP processes. The show memory | includeBGP command enables you to display the current memory allocation for BGP processes, as shown in [Example 8-3](#). The highlighted section of the command output was added to display the output description.

Example 8-3. BGP Memory Utilization

```
Alki#show memory | include BGP

Address      Bytes      Prev      Next Ref      PrevF      NextF Alloc PC      what
823A2F8C 0000000044 823A2D10 823A2FE4 001 ----- ----- 813BC2E0 BGP Router
823C1C5C 0000005000 823C1830 823C3010 001 ----- ----- 805A124C BGP rcache-
chunk
823C3010 0000005000 823C1C5C 823C43C4 001 ----- ----- 805A1280 BGP fcache-
chunk
823C4408 0000060496 823C43C4 823D3084 001 ----- ----- 805A12E8 BGP (0) attr
823D3084 0000000044 823C4408 823D30DC 001 ----- ----- 813BC2E0 BGP Router
8241C8D4 0000000032 8241C7F8 8241C920 001 ----- ----- 8045F35C BGP Router
8241D100 0000000072 8241D08C 8241D174 001 ----- ----- 813B0548 BGP Router
8241D358 0000000072 8241D250 8241D3CC 001 ----- ----- 813B0548 BGP Scanner
8241D704 0000032768 8241D6C0 82425730 001 ----- ----- 805A12E8 BGP (1) attr
82425774 0000020000 82425730 8242A5C0 001 ----- ----- 805A12E8 BGP (2) attr
8242A604 0000032768 8242A5C0 82432630 001 ----- ----- 805A12E8 BGP (3) attr
82432630 0000003000 8242A604 82433214 001 ----- ----- 805A1330 BGP attrlist
-chunk
82433214 0000001500 82432630 8243381C 001 ----- ----- 805A1364 BGP worktype
-chunk
```

8243381C 0000005000 82433214 82434BD0 001 ----- ----- 805A1398 BGP gwcache
-c

hunk

82434BD0 0000002000 8243381C 824353CC 001 ----- ----- 805A13CC BGP NLRI-

chunk

824353CC 0000000432 82434BD0 824355A8 001 ----- ----- 805A1400 BGP SNPA-

chunk

824355EC 0000065536 824355A8 82445618 001 ----- ----- 805A146C BGP (0)
update

8244565C 0000065536 82445618 82455688 001 ----- ----- 805A146C BGP (1)
update

824556CC 0000065536 82455688 824656F8 001 ----- ----- 805A146C BGP (2)
update

8246573C 0000065536 824656F8 82475768 001 ----- ----- 805A146C BGP (3)
update

824757AC 0000065536 82475768 824857D8 001 ----- ----- 805A146C BGP (4)
update

8248581C 0000065536 824857D8 82495848 001 ----- ----- 805A146C BGP (5)
update

8249588C 0000065536 82495848 824A58B8 001 ----- ----- 805A146C BGP (6)
update

824A58FC 0000065536 824A58B8 824B5928 001 ----- ----- 805A146C BGP (7)
update

824B5928 0000065536 824A58FC 824C5954 001 ----- ----- 805A14D4 BGP batr
chunk

824C5954 0000000264 824B5928 824C5A88 001 ----- ----- 805A1508 BGP vpnv4
soo

The output of the preceding command shows the memory addresses used by the BGP processes. In this example, the Alki router only had one peer relationship, and BGP only had four routes in the table. When routers have many peers, with many routes containing many attributes, the show memory | includeBGP command displays pages of information. If a router in a network model is to have multiple peers, it is a good idea to have plenty of memory available to BGP. In a lab environment, BGP will run on just about any router that is running a feature set that includes BGP; however, BGP performance depends greatly on the selected router platform, the processor(s), the amount and type of memory, the speed of the backplane, the number of routes received by peering routers, and the router configuration itself. If you are modeling a BGP network for production use, carefully select the router platform you intend to use in production to support BGP process and memory utilization. If you are configuring a production router to run BGP with full Internet tables, it is a good rule to check the current BGP Internet table size. Make sure that you have at least twice the amount of memory as the full Internet table so that you will be able to run BGP uninterrupted until the tables double in size.

BGP Configuration Tips

When configuring and troubleshooting BGP, you will use a number of commands on a regular basis. You can use quite a few tricks to help you become more efficient with Cisco IOS Software. For instance, you can use the Control (Ctrl) key in combination with other characters on the keyboard as editing shortcuts. These shortcuts can save you time when you are in a hurry or are having a bad day and you just can't type. These commands are also helpful in the event that you are required to use a terminal-emulation program that does not support the use of up and down arrows or other commands that you would normally use. [Table 8-1](#) shows some of the most popular commands.

Table 8-1. Cisco IOS Software Shortcuts

Command	Description
Ctrl+A	Goes to beginning of line
Ctrl+B	Moves back one character
Ctrl+E	Goes to end of line
Ctrl+F	Moves forward one word
Ctrl+P	Repeats previous line
Ctrl+R	Repaints line
Ctrl+U	Deletes entire line
Ctrl+W	Deletes last word

Another commonly overlooked command that can help you customize your use of Cisco IOS Software is the alias command. The alias command enables you to create command aliases, which are used to represent commonly used commands. You create aliases in global configuration mode using the following command:

```
aliasmode alias-name alias-string
```

In [Example 8-4](#), you can see several command aliases used as shortcuts for various commonly used commands.

Example 8-4. Command Aliases

```
Alki#show alias
```

```
Exec mode aliases:
```

h	help
lo	logout
p	ping
r	resume
s	show
u	undebbug
un	undebbug
w	where
cib	cle ip bgp *
sb	show ip bgp sum

```
Router configuration mode aliases:
```

net	network
-----	---------

Notice that there are several default aliases—h, lo, p, r, s, u, un, and w—and that I added three other aliases, cib, which represents the command clear ip bgp *; sb, which represents the command show ip bgp summary; and net, which represents the router configuration mode command network. Aliases are never necessary, but they can be valuable tools for the ever-efficient network engineer.

Another tool that was briefly mentioned earlier in the chapter is the output modifier. Output modifiers have been around for a long time but are rarely ever used. Output modifiers change the way output from a show command is displayed and are available for just about every show command in existence. [Table 8-2](#) shows some examples.

Table 8-2. Output Modifiers

Output Modifier	Description
beginstring	Displays the command output from the point specified by the string
excludestring	Displays everything, excluding information specified by the string
includestring	Displays only items matching the string

[Example 8-5](#) shows how each of the output modifiers are used to show specific output from the show ip bgp command. The first line shows the unmodified output of the command. The second highlighted line shows how the include statement was used to specify only the best reachable routes marked with the *> characters. Notice in this example that the use of the * with the *> characters were preceded by a slash /*>. If the slash had not been used, the router would have shown an error condition, % Failed to compile regular expression because the * character itself is a regular expression, which matches a series of characters, much like *.* does in DOS. The second highlighted example shows how the exclude command was used to exclude the display of routes with 600 in their AS_PATH. The final highlighted area shows how the begin modifier was used to prevent the output description information from being shown in the command output.

Example 8-5. Examples of Output Modifiers

```
Alki#show ip bgp
```

```
BGP table version is 4, local router ID is 1.1.1.1
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.1.1.0/24	192.168.32.2	0	0	600	i
*> 10.2.2.0/24	192.168.32.2	0	0	600	i
*> 192.168.32.0/30	0.0.0.0	0	32768	I	

```
Alki#show ip bgp | include /*
```

```
BGP table version is 4, local router ID is 1.1.1.1
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.1.1.0/24	192.168.32.2	0	0	600	i
*> 10.2.2.0/24	192.168.32.2	0	0	600	i
*> 192.168.32.0/30	0.0.0.0	0	32768	I	

```
Alki#show ip bgp | exclude 600
```

```
BGP table version is 4, local router ID is 1.1.1.1
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 192.168.32.0/30	0.0.0.0	0	32768	I	

```
Alki#show ip bgp | begin Network
```

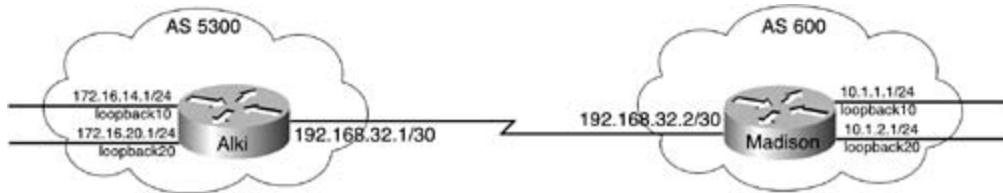
Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.1.1.0/24	192.168.32.2	0	0	600	i
*> 10.2.2.0/24	192.168.32.2	0	0	600	i
*> 192.168.32.0/30	0.0.0.0	0	32768	i	

Now that you have some tips that make BGP easier to configure, it is time to put your knowledge of Cisco IOS Software and skill together and learn to configure BGP on a Cisco router.

Configuring and Troubleshooting BGP Neighbor Relation

Five major tasks must be completed for each BGP session. In this section, each of these tasks is explained and a practical example is used to show all the items included in each task. [Figure 8-1](#) shows the network used for the examples in this section.

Figure 8-1. BGP Neighbor Configuration



Prior to the configuration of a BGP neighboring session, the following tasks must be completed:

- If the remote BGP peer is not under your administrative control, you must find the IP address of the remote interface and the remote autonomous system number (ASN) for the remote peer, which BGP is usually directly connected to your network's egress interface.
- The local and remote BGP peers must be able to reach each other using TCP port 179; therefore, the interface on the local router must be configured with an IP address, and the router must have a route to its remote peer.
- If the local router is not directly connected to its remote peer, another IGP or static route must be provided to provide the routing information required to form a TCP session.

NOTE

Both sides of the BGP session must be fully configured before a BGP session can be established.

In this example, you configure an E-BGP session between the Alki router and the Madison router across a direct serial connection. The Alki router's serial 0/0 interface is configured to use the IP address 192.168.32.1/30, and the Madison router's serial 0 interface is 192.168.32.2/30. The Alki router will be advertising networks 172.16.14.0/24 and 172.16.20.0/24, so configure loopback 10 to use 172.16.1.1/24 and loopback 20 to use 172.16.20.1/24. The Madison router will advertise networks 10.1.1.0/24 and 10.1.2.0/24, so configure loopback 10 to use 10.1.1.1/24 and loopback 20 to use 10.1.2.1/24.

Step 1. Verify that the local BGP router can reach the remote router. The ping command enables you to verify connectivity to the remote router; if access lists or a firewall exist between the local and remote routers, however, you must verify that the packet filters will allow TCP traffic on port 179.

At this time, it is also a good idea to verify the IP addresses on both of the routers' serial interfaces.

using the `show ip interface brief` and `show interface serial<interface-number>` commands on routers. Make sure that both interfaces are in the `interface is up, line protocol is up` state continuing on to the next step.

Verify that the Alki and Madison routers can reach each other. Because there are no access links between the two routers, you can safely assume that a ping test will verify the connection. [Example 6](#) shows the serial interface configurations and the results of the ping tests.

Example 8-6. Interface Configuration and Ping Tests

```
Alki#show run | begin Serial0/0

interface Serial0/0
  ip address 192.168.32.1 255.255.255.252

Alki#ping 192.168.32.2

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 192.168.32.2, timeout is 2 seconds:
!!!!!

Madison#show run | begin Serial0

interface Serial0
  ip address 192.168.32.2 255.255.255.252

Madison#ping 192.168.32.1

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 192.168.32.1, timeout is 2 seconds:
!!!!!
```

After both interfaces are up and operating on Layer 3, it is time to configure BGP on each of the routers.

Step 2. To enable BGP in Cisco IOS Software, use the `router bgp<as-number>` command in global configuration mode. The `as-number` keyword identifies the local ASN. The values for the `as-number` variable range from 1 to 65,535, with 64,512 to 65,535 reserved for private autonomous systems.

```
router bgpas-number
```

This command starts the following BGP processes (listed using the show processes cpu command) and allocates memory to those processes (listed using the show processes memory command) on the Alki router.

- BGP Router
- BGP I/O
- BGP Scanner

Configure BGP on the Alki router; the Alki router is in AS 5300.

```
Alki(config)#router bgp 5300
```

```
Alki(config-router)#
```

You can use the show processes cpu | includeBGP command to see that the BGP processes have been started.

```
Alki(config-router)#do show processes cpu | include BGP
```

80	4	111	36	0.00%	0.00%	0.00%	0	BGP Router
84	0	1	0	0.00%	0.00%	0.00%	0	BGP I/O
85	44	4	11000	0.00%	0.06%	0.01%	0	BGP Scanner

NOTE

In the preceding example, the do show processes cpu | includeBGP command was used to display the current BGP processes. If this same command were issued on a router with a failed session between BGP peers, you would see instances of the BGP Open process, as shown here:

```
r2(config)#do show processes cpu | include BGP

    78          0      179          0  0.00%  0.00%  0.00%  0 BGP Open
    89          0      179          0  0.00%  0.00%  0.00%  0 BGP Open
    99          0      179          0  0.00%  0.00%  0.00%  0 BGP Open
   104      165252  3566960        46  0.00%  0.00%  0.00%  0 BGP Router
   105          0      1          0  0.00%  0.00%  0.00%  0 BGP I/O
   106      7108      890        7986  0.00%  0.03%  0.00%  0 BGP Scanner
   107          0      179          0  0.00%  0.00%  0.00%  0 BGP Open
```

If you were to issue the show tcp brief all command, you would notice that the router currently has established TCP sessions but is listening for incoming TCP sessions. This is because no BGP peers have been configured on the Alki router, and the Madison router has not been configured yet.

```
Alki#show tcp brief all

TCB      Local Address          Foreign Address          (state)
8241BE64  *.*                  *.*                  LISTEN
```

Configure BGP on the Madison router; the Madison router is in AS 600.

```
Madison(config)#router bgp 600
```

After the router `bgp as-number` command has been issued, the router enters the BGP router config mode, where you can use the BGP commands shown in [Example 8-7](#). These commands are covered in this chapter and in [Chapter 9](#).

Example 8-7. BGP Commands Available in Cisco IOS Software 12.2(7)T

```
Madison(config-router)#?
```

Router configuration commands:

address-family	Enter Address Family command mode
aggregate-address	Configure BGP aggregate entries
auto-summary	Enable automatic network number summarization
bgp	BGP specific commands
default	Set a command to its defaults
default-information	Control distribution of default information
default-metric	Set metric of redistributed routes
distance	Define an administrative distance
distribute-list	Filter networks in routing updates
exit	Exit from routing protocol configuration mode
help	Description of the interactive help system
maximum-paths	Forward packets over multiple paths
neighbor	Specify a neighbor router
network	Specify a network to announce via BGP
no	Negate a command or set its defaults
redistribute	Redistribute information from another routing protocol
synchronization	Perform IGP synchronization

table-map	Map external entry attributes into routing table
timers	Adjust routing timers
traffic-share	How to compute traffic share over alternate paths

Step 3. Specify information about the remote peer(s). The remote peer information is entered with the **neighbor ip-address remote-as remote-as-number** command as shown here:

```
neighbor ip-address remote-as remote-as-number
```

This command specifies the IP address used to reach the remote BGP peer and the AS number to which the remote peer belongs.

Configure the Alki and Madison routers with their remote peer information using the neighbor command to specify the remote peer's IP address and remote AS number.

```
Alki(config-router)#neighbor 192.168.32.2 remote-as 600
```

```
Madison(config-router)#neighbor 192.168.32.1 remote-as 5300
```

Step 4. After configuring the local and remote peer autonomous systems, configure the network command so that each of the BGP speakers will be advertising to its remote peer using the network command as shown here:

```
network network-address [mask subnet-mask] [route-map route-map-name] [backdoor]
```

The command enables you to specify the networks, and if the network is not classful, you can specify the subnet mask for the network. The *route-map* option allows for BGP attribute manipulation, and the *backdoor* keyword specifies the use of a BGP backdoor, both of which are covered later in this chapter.

Use the **network** command to configure the Alki router to advertise networks 172.16.14.0/24 and 172.16.20.0/24. Then use the same commands to configure the Madison router to advertise networks 10.1.1.0/24 and 10.1.2.0/24.

```
Alki(config-router)#network 172.16.14.0 mask 255.255.255.0
```

```
Alki(config-router)#network 172.16.20.0 mask 255.255.255.0
```

```
Madison(config-router)#network 10.1.1.0 mask 255.255.255.0
```

```
Madison(config-router)#network 10.1.2.0 mask 255.255.255.0
```

Step 5. After configuring the local and remote BGP peers, you can monitor the BGP status using several different BGP show and debug commands.

At this point, you should be able to verify several items on each of the routers. Using the **show tcp** command, as shown in [Example 8-8](#), you should see an established TCP session between the Alki and Madison routers on port 179, and you should also see the routers listening for TCP activity on port 179.

Example 8-8. Using the **show tcp brief all** Command to Display TCP Connection State

```
Alki#show tcp brief all
```

TCB	Local Address	Foreign Address	(state)
8248F4BC	192.168.32.1.11003	192.168.32.2.179	ESTAB
820E59F0	*.179	192.168.32.2.*	LISTEN

By issuing the show ip bgp command, shown in [Example 8-9](#), you should see information about the session and networks that are advertised by both peers.

Example 8-9. Display BGP Routes Using the show ip bgp Command

```
Alki#show ip bgp
```

```
BGP table version is 5, local router ID is 1.1.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

Network          Next Hop            Metric LocPrf Weight Path
*> 10.1.1.0/24    192.168.32.2      0        0 600 i
*> 10.1.2.0/24    192.168.32.2      0        0 600 i
*> 172.16.14.0/24 0.0.0.0          0        32768 i
*> 172.16.20.0/24 0.0.0.0          0        32768 i
```

On the Alki router, notice that you can see networks 10.1.1.0/24 and 10.1.2.0/24 with a NEXT_HOP of 192.168.32.2 using the default MED, LOCAL_PREF, and WEIGHT attributes. You can also see that it originated in AS 600 and has an ORIGIN attribute of i for IGP because it originated locally on the router. To the left of each of the routes, you can see the asterisk (*) symbol, which means that the route has been verified as reachable by the BGP Scanner process, and the greater than (>) symbol means that this route is the best route to that network. When BGP has a valid best-path route to a network, it places the route in the main IP routing table and advertises it to any other external BGP peers.

You should also be able to issue the show ip route command to see the BGP routes in the main IP routing table and ping each of the loopback interfaces. [Example 8-10](#) shows the output of the show ip route command from the Alki router, and [Example 8-11](#) shows the ping tests from the Alki and Madison routers.

Example 8-10. Displaying the Main IP Routing Table with the show ip route Command

```
Alki#show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
```

E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

```
172.16.0.0/24 is subnetted, 2 subnets
C         172.16.20.0 is directly connected, Loopback20
C         172.16.14.0 is directly connected, Loopback10

10.0.0.0/24 is subnetted, 2 subnets
B         10.1.2.0 [20/0] via 192.168.32.2, 00:05:30
B         10.1.1.0 [20/0] via 192.168.32.2, 00:05:30

192.168.32.0/30 is subnetted, 1 subnets
C         192.168.32.0 is directly connected, Serial0/0
```

Example 8-11. Successful ping Tests on the Alki and Madison Routers

```
Alki#ping 10.1.1.1
```

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 10.1.1.1, timeout is 2 seconds:

!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 32/35/36 ms

```
Alki#ping 10.1.2.1
```

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 10.1.2.1, timeout is 2 seconds:

!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 36/36/36 ms

To see the process that the routers used to set up the BGP session, advertise networks, and install the BGP table, use the debug ip bgp command. Because BGP only sends new or changed routes in messages, you need to clear the BGP session using the clear ip bgp command. Because there is one BGP session on this router, you can use the * character to tell BGP to clear all sessions, as shown in Example 8-12.

TIP

Be very careful with your use of the clear ip bgp * command on production routers; this command closes all BGP sessions and will result in a network disruption if it is used on a production network.

Example 8-12. Debugging BGP

```
Alki#debug ip bgp
BGP debugging is on
Alki#clear ip bgp *
01:10:18: BGP: 192.168.32.2 went from Established to Idle
Comment: BGP cleared session
01:10:18: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Down User reset
Comment: the ADJCHANGE message indicates the session with the 192.168.32.2
neighbor is down due to a user reset
01:10:18: BGP: 192.168.32.2 closing
Comment: The BGP session is being closed
01:10:38: BGP: 192.168.32.2 went from Idle to Active
01:10:38: BGP: 192.168.32.2 open active, delay 26900ms
Comment: The router sent an active host TCP open message
connection request and is awaiting a TCP session request from its passive
neighbor.
01:10:48: BGP: Applying map to find origin for 172.16.14.0/24
01:10:48: BGP: Applying map to find origin for 172.16.20.0/24
Comment: BGP is finding the ORIGIN for the 172.16.14.0/24 and 172.16.20.0/24
```

routes, which will be i for I-BGP

01:11:05: BGP: 192.168.32.2 open active, local address 192.168.32.1

01:11:05: BGP: 192.168.32.2 went from Active to OpenSent

Comment: The remote BGP session transitioned from Active to OpenSent meaning a TCP session has been established and OPEN message has been sent, the router is now waiting to receive an OPEN message from its peer.

01:11:05: BGP: 192.168.32.2 sending OPEN, version 4, my as: 5300

Comment: The router sent an OPEN message to its peer, 192.168.32.2, and the message contained the BGP version: 4 and the MY_AS value 5300

01:11:05: BGP: 192.168.32.2 send message type 1, length (incl. header) 45

01:11:05: BGP: 192.168.32.2 rcv message type 1, length (excl. header) 26

Comment: The remote router sent an OPEN (type-1) message to this peer and it was successfully received

01:11:05: BGP: 192.168.32.2 rcv OPEN, version 4

01:11:05: BGP: 192.168.32.2 rcv OPEN w/ OPTION parameter len: 16

01:11:05: BGP: 192.168.32.2 rcvd OPEN w/ optional parameter type 2 (Capability) len 6

01:11:05: BGP: 192.168.32.2 OPEN has CAPABILITY code: 1, length 4

01:11:05: BGP: 192.168.32.2 OPEN has MP_EXT CAP for afi/safi: 1/1

01:11:05: BGP: 192.168.32.2 rcvd OPEN w/ optional parameter type 2 (Capability) len 2

01:11:05: BGP: 192.168.32.2 OPEN has CAPABILITY code: 128, length 0

01:11:05: BGP: 192.168.32.2 OPEN has ROUTE-REFRESH capability(old) for all address-families

01:11:05: BGP: 192.168.32.2 rcvd OPEN w/ optional parameter type 2 (Capability) len 2

01:11:05: BGP: 192.168.32.2 OPEN has CAPABILITY code: 2, length 0

01:11:05: BGP: 192.168.32.2 OPEN has ROUTE-REFRESH capability(new) for all

```
address-families
```

Comment: The remote peer's OPEN message contained the following data:

Comment: BGP version - 4

Comment: With Multiprotocol BGP and Route Refresh capabilities

```
01:11:05: BGP: 192.168.32.2 went from OpenSent to OpenConfirm
```

Comment: The session transitioned from OpenSent to OpenConfirm, the router is waiting on a KEEPALIVE message from its peer.

```
01:11:05: BGP: 192.168.32.2 send message type 4, length (incl. header) 19
```

```
01:11:05: BGP: 192.168.32.2 rcv message type 4, length (excl. header) 0
```

Comment: the router sent and received a KEEPALIVE (type-4) message and received a message from its peer.

```
01:11:05: BGP: 192.168.32.2 went from OpenConfirm to Established
```

Comment: The session transitioned from OpenConfirm to Established, now routes can be exchanged using UPDATE messages

```
01:11:05: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Up
```

Comment: The ADJCHANGED message indicating the BGP session with peer 192.168.32.2 is up

The debug ip bgp event command shows detailed information about internal BGP events as they occur on the router, and the debug ip bgp updates command, shown in [Example 8-13](#), displays detailed information on UPDATE messages as they are received.

Example 8-13. Debugging BGP Updates

```
Alki#debug ip bgp updates
```

BGP updates debugging is on

```
Alki#clear ip bgp *
```

```
01:33:30: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Down User reset
```

Comment: The session was reset upon user request

01:34:12: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Up

Comment: The BGP session with peer 192.168.32.2 is back up

01:34:12: BGP(0): 192.168.32.2 rcvd UPDATE w/ attr: nexthop 192.168.32.2, origin i, metric 0, path 600

Comment: The router received an update from peer 192.168.32.2 containing the BGP attributes

Comment: NEXT_HOP 192.168.32.2

Comment: ORIGIN: i

Comment: MED: 0

Comment: AS_PATH 600

01:34:12: BGP(0): 192.168.32.2 rcvd 10.1.1.0/24

01:34:12: BGP(0): 192.168.32.2 rcvd 10.1.2.0/24

Comment: The update contained NLRI paths 10.1.1.0/24 and 10.1.2.0/24

01:34:12: BGP(0): Revise route installing 10.1.1.0/24 -> 192.168.32.2 to main IP table

01:34:12: BGP(0): Revise route installing 10.1.2.0/24 -> 192.168.32.2 to main IP table

Comment: BGP found the routes to networks 10.1.1.0/24 and 10.1.2.0/24 valid best paths and is installing them in the main IP routing table

01:34:12: BGP(0): nettable_walker 172.16.14.0/24 route sourced locally

01:34:12: BGP(0): nettable_walker 172.16.20.0/24 route sourced locally

Comment: The BGP Scanner (nettable_walker) found networks 172.16.14.0/24 and 172.1
724 sourced locally

01:34:12: BGP(0): 192.168.32.2 computing updates, afi 0, neighbor version 0, table version 5, starting at 0.0.0.0

01:34:12: BGP(0): 192.168.32.2 send UPDATE (format) 172.16.14.0/24, next 192.168.32.1, metric 0, path

Comment: The router is sending an UPDATE message to 192.168.32.2 containing the route 172.16.14.0/24 with the attributes of NEXT_HOP: 192.168.32.2, MED: 0

```

01:34:12: BGP(0): 192.168.32.2 send UPDATE (prepend, chgflags: 0x208)
172.16.20.0/24, next 192.168.32.1, metric 0, path
Comment: The router is sending an UPDATE message to 192.168.32.2 containing the
route 172.16.20.0/24 with the attributes of NEXT_HOP: 192.168.32.2, MED: 0
01:34:12: BGP(0): 192.168.32.2 1 updates enqueued (average=56, maximum=56)
01:34:12: BGP(0): 192.168.32.2 update run completed, afi 0, ran for 4ms, neighbor
version 0, start version 5, throttled to 5
Comment: UPDATE messages were enqueued for transport and then sent successfully
the BGP table version has been changed to 5
01:34:12: BGP: 192.168.32.2 initial update completed
Comment: The update is complete

```

If the BGP peers are not able to reach each other using TCP port 179, you can use a number of TCF troubleshooting commands to troubleshoot the connection. As a best practice (that will save you m headache), however, it is better to verify the router configuration for inaccuracies before troubleshooting problem that might end up being a typo.

- Verify that the local BGP ASN is entered correctly.
- Verify that the remote peer's BGP ASN and IP address are entered correctly.
- Verify that the interfaces connecting the two peers are up and operational.
- If the peers are not directly connected, verify that they have a valid route (to and from) to each other.
- Check routers along the path between the peers for access lists or route policies that might be impacting or rerouting BGP traffic.
- Check logs for interface instabilities. Are routes flapping along the route between the BGP peers? Are any of the interfaces heavily congested or dropping packets? Keep in mind that BGP uses rather small packets for OPEN and KEEPALIVE messages. These packets are delayed if other larger packets are monopolizing a congested interface.
- If something has changed in the path between the two BGP peers, verify that it is not affecting the session—for example, a new switch configuration, new access lists, a firewall, new routing policies, and so on.

Don't spend time troubleshooting BGP when it is not the problem! Establish a general layered troubleshooting methodology; it will be the number one troubleshooting tool and your best friend when you encounter a problem.

Step 1. Layer 1

- Check your cabling; verify that all cables are connected and that the interface is in a good state. Don't spend time troubleshooting BGP when you have a Layer 1 connection.
- If you are using a serial link, make sure that you have set the correct clock rate. If you are using a channel service unit/data service unit (CSU/DSU), make sure it is properly connected and the line is up.
- If you are using an Ethernet interface, make sure that the speed and duplex are set correctly on the router and switch.
- Check the router and switch interfaces for errors; if there are errors, fix the error and proceed with your troubleshooting.

If you are using a Token Ring interface, make sure the router is configured to use the right speed, and that it has a good connection to the multistation access unit (MSAU) or switch.

Step 2. Layer 2

- If you are using an Ethernet connection, make sure that the switch port has been assigned to the proper VLAN.
- Make sure that the VLAN is properly configured, and that there are no spanning-tree problems on the switch.
- On an ATM interface, verify that the maximum transmission unit (MTU) is properly configured on both sides of the connection.
- Verify that you are using the correct virtual path identifier/virtual channel identifier (VPI/VCI) pair, and that you have configured a valid ATM map for Layer 2 to Layer 3 connectivity.

On a Frame Relay connection, verify that your local and remote data-link connection identifiers (DLCIs) and Local Management Interface (LMI) type are correctly set to match the values generated on the switch.

- Verify that LMI is up and that the interface is not flapping.
- If you are making a PPP connection, make sure PPP is configured on both sides of the connection.
- Before proceeding to the next step, verify that your interface is not in a line up protocol state.

Step 3. Layer 3

- Verify that you have configured the right IP address and subnet mask on the interface on the other side of the connection, and verify that it is on the same subnet (if directly connected, make sure that it is what you think it is).
- Make sure there is a valid route to reach your destination in the IP routing table. Trace the connection through any routers along the path, and verify that they have a path to and from each of the routers that they must reach for packets to reach your source and destination networks.
- Check static routes for typos; make sure that any redistributed routes are actually being properly propagated.

- If multiple paths are in use, verify that there are no routing loops.
- If authentication is in use by any routing protocols, make sure that they are both using correct passwords.
- On nonbroadcast multiaccess (NBMA) networks, such as ATM or Frame Relay, make sure you have proper support for Layer 2 to Layer 3 mappings, and that protocols such as Cisco Shortest Path First (OSPF) are configured for the proper network type.
- Before proceeding to the next step, verify that you are able to reach the destination router from the source network and vice versa.

Step 4. Layer 4

- Check for any access lists or firewalls that might be dropping TCP packets.
- Verify that you have connectivity on TCP port 179. One BGP speaker, the passive TCP host, receives a TCP request on port 179, and the other speaker, the active TCP host, will use TCP source port (beginning at 11,000) to initiate the TCP session.
- Check for retransmissions, out-of-order packets, or other TCP symptoms that might point to network congestion or invalid configurations.

After verifying that all the prior conditions are not affecting the BGP session, use TCP show and debug commands to help narrow down the culprit. These commands, your BGP TCP connection troubleshooting tools, are listed in [Table 8-3](#).

Table 8-3. TCP Connection Troubleshooting Tools

TCP Command	Command Description
show tcp	This command displays detailed information on each TCP session that the router has formed with a remote peer. It can be used with BGP to show whether the local and remote BGP peers have formed an established TCP session, details about that session.
show tcp [brief][all] [include 179]	This command displays a brief status of each of the TCP sessions that the router has formed with a remote router. This is a basic summary command that you can use as another tool to verify the BGP TCP connection between peers.
debug ip tcp transactions	This command, which should be used with caution on a production router, provides information about TCP session changes. It enables you to troubleshoot a session, displaying information about TCP retransmissions or state changes.
debug ip tcp packet [in out address IP-address port, port-number]	This command displays detailed information about TCP packets. It can be used with the in, out, address, or port arguments to specify particular traffic. This command must be used with extreme caution on a production router. With this command, you can monitor TCP packets sent and received by the local router. This information enables you to determine the cause of an unstable BGP TCP session and resolve route flapping or general connectivity issues.

If the show tcp command output for the peer IP address used for the BGP session is anything other than ESTAB, troubleshoot the TCP connection. The show tcp command, shown in [Example 8-14](#), displays information about the TCP session, and should, as a best practice, always be used as a TCP session troubleshooting tool.

troubleshooting command.

Example 8-14. show tcp Command

```
Alki#show tcp
```

```
Stand-alone TCP connection to host 192.168.32.2
```

```
Connection state is ESTAB, I/O status: 1, unread input bytes: 0
```

```
Local host: 192.168.32.1, Local port: 11009
```

```
Foreign host: 192.168.32.2, Foreign port: 179
```

```
Enqueued packets for retransmit: 0, input: 0 mis-ordered: 0 (0 bytes)
```

```
Event Timers (current time is 0x16681CC):
```

Timer	Starts	Wakeups	Next
Retrans	323	1	0x0
TimeWait	0	0	0x0
AckHold	320	164	0x0
SendWnd	0	0	0x0
KeepAlive	0	0	0x0
GiveUp	0	0	0x0
PmtuAger	0	0	0x0
DeadWait	0	0	0x0

```
iss: 3779523619 snduna: 3779529779 sndnxt: 3779529779 sndwnd: 16080
```

```
irs: 2902813429 rcvnxt: 2902819573 rcvwnd: 16099 delrcvwnd: 285
```

```
SRTT: 300 ms, RTTO: 303 ms, RTV: 3 ms, KRTT: 0 ms
```

```
minRTT: 20 ms, maxRTT: 300 ms, ACK hold: 200 ms
```

```
Flags: higher precedence, nagle
```

```
Datagrams (max data segment is 1460 bytes):
```

```
Rcvd: 556 (out of order: 0), with data: 320, total data bytes: 6143
```

```
Sent: 492 (retransmit: 1, fastretransmit: 0), with data: 321, total data bytes: 6159
```

Table 8-4 displays detailed information on the output of the show tcp command. You will probably all 20 lines of the command in day-to-day troubleshooting, but they might come in handy when you troubleshooting TCP connection problems, such as too many retransmissions.

Table 8-4. show tcp Command Output Explained

Command Output	Output Description
Stand-alone TCP connection to host 192.168.32.2	Identifies TCP connection from the local host to host 192.168.32.2.
Connection state is ESTAB	<p>Indicates an established TCP session.</p> <p>The Connection state is can be any of the following values:</p> <ul style="list-style-type: none"> LISTEN— Indicates that the router is waiting for a connection request SYNSENT— Indicates that the router is waiting for a connection request in response to a connection request that was sent (TCP-SYN message) SYNRCVD— Indicates that the router has received a connection request and is waiting for a connection acknowledgement (TCP-ACK message) ESTAB— Indicates an established TCP session after receiving both TCP-SYN and ACK messages FINWAIT1— Indicates that the router is either waiting for a termination request or has acknowledged a previously sent termination request (TCP-FIN ACK message) FINWAIT2— Indicates that the router is waiting for a termination request from the remote host (TCP-FIN message) CLOSEWAIT— Indicates that the router is waiting for a termination request from the remote host (TCP-FIN message) CLOSING— Indicates that the router is waiting for a termination request from the remote host (TCP-FIN message) LASTACK— Indicates that the router is waiting for a response to a termination request that was made to a remote host (TCP-FIN message)

	message)			
	TIMEWAIT— Indicates that the router is waiting for a connection termination request before closing the connection.			
	CLOSED— Indicates that there is no connection.			
	For a successful BGP session, the TCF must always be in the ESTAB state.			
I/O status: 1	Describes the status of the connection.			
unread input bytes: 0	Indicates the number of bytes that have been read and are awaiting processing.			
Local host: 192.168.32.1, Local port: 11009	Displays the local IP address and TCF number. You can use this number to determine if the local or remote router initiated the session. If the TCP port is in the 11,000 range, the router initiated the session to a remote router at port 179.			
Foreign host: 192.168.32.2, Foreign port: 179	Displays the remote IP address and TCF number for the connection. For BGP, you always look for values containing a port in the 11,000 range.			
Enqueued packets for retransmit: 0, input: 0 misordered: 0 (0 bytes)	Displays the number of packets waiting to be retransmitted. Any value greater than 0 indicates problems with retransmission and might point to TCP problems.			
Event Timers (current time is 0x16681CC):				
Timer	Starts	Wakeups	Next	This section displays TCP timer information in a counter form for the current TCP session. (The information can be cleared with the clear statistics command.)
Retrans	323	1	0x0	The <i>Event Timer</i> displays the amount of time that the system has been running in milliseconds.
TimeWait	0	0	0x0	The <i>Timer</i> column describes the timer for the rows beneath.
AckHold	320	164	0x0	The <i>Starts</i> column describes the number of times that the counter has been started during this session.
SendWnd	0	0	0x0	The <i>Wakeups</i> column describes the number of unacknowledged KEEPALIVES.
KeepAlive	0	0	0x0	The <i>Next</i> column shows the next time
GiveUp	0	0	0x0	
PmtuAger	0	0	0x0	

DeadWait	0	0	0x0	timer will go off.
Retrans	0	0	0x0	The <i>Retrans</i> timer displays the value of the timer used to time unacknowledged packets awaiting retransmission.
TimeWait	0	0	0x0	The <i>TimeWait</i> timer shows the amount of time the system will wait to allow a remote host to receive a connection termination request.
AckHold	0	0	0x0	The <i>AckHold</i> timer is used to delay the transmission of acknowledgements to prevent network congestion.
SendWnd	0	0	0x0	The <i>SendWnd</i> timer prevents TCP sessions from being lost due to missing acknowledgements.
KeepAlive	0	0	0x0	The <i>KeepAlive</i> timer is used to time the interval between KEEPALIVE messages.
Event Timers (current time is 0x16681CC):				The <i>GiveUp</i> timer is the minimum time before giving up on a pending resolution request.
Timer	Starts	Wakeups	Next	The <i>PmtuAger</i> timer is the timer that keeps track of the path MTU age-timer. It can be changed using the ip tcp path-mtu discovery [age-timer { minutes indefinite }] command.
Retrans	323	1	0x0	The <i>DeadWait</i> timer is the TCP DeadWait timer.
TimeWait	0	0	0x0	
AckHold	320	164	0x0	
SendWnd	0	0	0x0	
KeepAlive	0	0	0x0	
GiveUp	0	0	0x0	
PmtuAger	0	0	0x0	
DeadWait	0	0	0x0	
iss: 3779523619				Displays the initial send sequence number which is the initial sequence number during a new TCP session.
snduna: 3779529779				Displays the last unacknowledged sequence number that the router has sent.
sndnxt: 3779529779				Displays the next sequence number to be sent.
sndwnd: 16080				Displays the remote host's TCP window size.
irs: 2902813429				Displays the initial receive sequence number.

<code>rcvnxt: 2902819573</code>	Displays the last sequence number that has been received and acknowledged.
<code>rcvwnd: 16099</code>	Displays the local router's TCP window.
<code>delrcvwnd: 285</code>	Displays the delayed receive window or the uncomputed value of the receive window.
<code>SRTT: 300 ms</code>	The smooth round-trip timer is a measure of the average time that it takes a packet to be sent and acknowledged by the remote host.
<code>RTTO: 303 ms</code>	The round-trip timeout in milliseconds.
<code>RTV: 3 ms</code>	The variance of the round-trip time in milliseconds.
<code>KRTT: 0 ms</code>	The new round-trip (K stands for Karn) algorithm timeout. It measures the round-trip time, in milliseconds, for packets that have been retransmitted.
<code>minRTT: 20 ms</code>	The smallest round-trip timeout.
<code>maxRTT: 300 ms</code>	The largest round-trip timeout.
<code>ACK hold: 200 ms</code>	The acknowledgment delay timeout used to delay acknowledgements to allow time for the acknowledgement data to reach the packet.
<code>Flags: higher precedence</code>	Specifies IP precedence values that may be present in the packets.
<code>nagle</code>	Specifies that the Nagle flag is set.
<code>Datagrams (max data segment is 1460 bytes):</code>	The largest data segment in bytes.
<code>Rcvd: 556 (out of order: 0, total data bytes: 6143)</code>	<p>The number of datagrams received.</p> <p>The number of datagrams that were received out of order.</p> <p>The total bytes of data received.</p>
<code>Sent: 492 (retransmit: 1, fastretransmit: 0), with data: 321, total data bytes: 6159</code>	<p>The number of datagrams sent.</p> <p>The number of datagrams that had to be retransmitted.</p> <p>The number of fast retransmissions.</p> <p>The number of datagrams that were sent with contained data.</p> <p>The total bytes of data received.</p>

Two other frequently forgotten tools that enable you to troubleshoot a TCP connection are the debug transactions and debug tcp packet commands. Output from the debug tcp transactions command is shown in [Example 8-15](#).

Example 8-15. debug ip tcp transactions Command

```
Alki#debug ip tcp transactions

TCP special event debugging is on

Alki#clear ip bgp *

01:53:24: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Down User reset
Comment: BGP session reset at user request

01:53:24: TCP0: state was ESTAB -> FINWAIT1 [179 -> 192.168.32.2(11005)]
Comment: TCP session transitioned from ESTAB to FINWAIT1

01:53:24: TCP0: sending FIN

01:53:24: TCP0: state was FINWAIT1 -> FINWAIT2 [179 -> 192.168.32.2(11005)]

01:53:26: TCP0: FIN processed

01:53:26: TCP0: state was FINWAIT2 -> TIMEWAIT [179 -> 192.168.32.2(11005)]
Comment: TCP session was gracefully torn down and the router is waiting to close
the session between the two hosts on ports 179 and 110005

01:54:03: TCB8252932C created

01:54:03: TCP0: state was LISTEN -> SYNRCVD [179 -> 192.168.32.2(11006)]
Comment: BGP was listening for TCP connection request and received it on port
11006

01:54:03: TCP0: Connection to 192.168.32.2:11006, received MSS 1460, MSS is 516
01:54:03: TCP: sending SYN, seq 1620953691, ack 2271616142
01:54:03: TCP0: Connection to 192.168.32.2:11006, advertising MSS 1460
01:54:03: TCP0: state was SYNRCVD -> ESTAB [179 -> 192.168.32.2(11006)]
Comment: The TCP session between the two routers on port 179 and 11006 was
successfully established

01:54:03: TCB820E59F0 callback, connection queue = 1
01:54:03: TCB820E59F0 accepting 8252932C from 192.168.32.2.11006
01:54:03: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Up
```

Comment: BGP session is ESTABLISHED

01:54:26: TCP0: state was TIMEWAIT -> CLOSED [179 -> 192.168.32.2(11005)]

01:54:26: TCB 0x82528E90 destroyed

Comment: The old TCP session between ports 179 and 11005 was closed the TCB marker for the session was destroyed

After verifying that the TCP session between the routers is functioning properly, you can verify or troubleshoot the BGP session using the commands listed in [Table 8-5](#).

Table 8-5. BGP Neighbor Show and Debug Tools

Command	Description
show ip bgp [<i>ip-address</i> <i>prefix</i>]	Displays the BGP table, a summary, the table version, and the attributes associated with the paths listed in the table. The IP address or prefix can optionally be used to limit the information returned from the command.
show ip bgp neighbors [<i>ip-address</i>]	This command displays detailed information about each of the neighbors that the local router is configured to peer with, including the neighbor's BGP version, router ID, finite-state machine (FSM) state, the number of messages received, and detailed TCP connection information. The IP address or prefix can optionally be used to limit the information returned from the command.
show ip bgp summary	This command displays a summarized version of the information about each BGP neighbor, including the neighbor's BGP router ID, table version, information about paths received from the neighbor, and the attributes assigned to those paths. It also shows the number of messages that have been sent and have been received, the FSM state, and the amount of time that the neighbor has been in the Established state.
debug ip bgp [<i>ip-address</i>]	The debug ip bgp command displays real-time information about all BGP peer relationships, showing FSM states, messages sent and received, capability negotiation, and routes received.
debug ip bgp events	This command displays real-time information on BGP events, including BGP updates, changes to the local table for routes to be advertised, timers, and messages sent and received.

debug ip bgp [<i>ip-address</i>]updates [access-list] [in out]	The debug ip bgp updates command displays real-time information about that have been received in UPDATE messages from peering BGP neighbors. information includes paths received, installation of paths in the main IP route and updates sent out to neighboring routers. The / <i>P-address</i> parameter enables you to specify updates from a specific neighbor. The access-list command enables you to limit the output from the command to certain updates. The in and out parameters enable you to specify incoming or outgoing updates.
debug ip bgp in [<i>ip-address</i>]	This command displays real-time information about incoming messages sent by BGP session and paths that the local router has received from its neighbors.
debug ip bgp out [<i>ip-address</i>]	This command displays real-time information about outgoing messages sent by BGP session and paths that the local router sends to its neighbors.
debug ip bgp keepalives	This command displays real-time information on KEEPALIVE messages sent and received by the local BGP speaker.
debug ip routing	This command enables you to help diagnose problems when BGP routes are being added to the main IP routing table.

The show ip bgp Command

The show ip bgp command is a very handy tool that enables you to verify the local BGP configuration, path attributes, and troubleshoot problems with BGP route advertisement. This command lists a brief summary of the status of each path; the next hop used to reach the path; and the MED, LOCAL_PREF, WEIGHT, AS_PATH, and ORIGIN attributes for the route. [Example 8-16](#) shows an example of the show ip bgp command output, and [Table 8-6](#) describes the output from that command.

Example 8-16. show ip bgp Command Output Example

```
Alki#show ip bgp
```

```
BGP table version is 5, local router ID is 172.16.20.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          Next Hop            Metric LocPrf Weight Path
* > 10.1.1.0/24      192.168.32.2        0        0 600 i
* > 10.1.2.0/24      192.168.32.2        0        0 600 i
* > 172.16.14.0/24    0.0.0.0           0        32768 i
* > 172.16.20.0/24    0.0.0.0           0        32768 i
```

Table 8-6. show ip bgp Command Output Explained

Command Output	Output Description
BGP table version is 5	The current version of the BGP table. This number is increased each time the changes.
local router ID is 172.16.20.1	<p>The local BGP router ID. Unless explicitly configured, this number is generally highest loopback IP address. The BGP router ID is explicitly set using the <code>bgp id</code> command.</p> <p>Notice that the BGP local router ID does not match the interface that the router is using for the BGP session. As a best practice, you should always configure your router to use a specific router ID to avoid any future issues that might occur if you have multiple BGP peers or want to load share over multiple BGP paths.</p> <p>When troubleshooting a BGP connection, if one of the BGP peers is not configured to use the proper IP address (the BGP router ID) for its remote peer, the BGP session will not come up. This might never become an issue when you are working with a router that only has one E-BGP peer with one directly connected interface; if the router has more than one E-BGP peer that is not directly connected, however, you might need to add a route and use the <code>ebgp-multihop</code> command to specify that the peers are not directly connected. The <code>ebgp-multihop</code> command is covered later in this chapter.</p>
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal	<p>The status codes display the status for each path in the BGP table.</p> <p>suppressed(s)— Routes that have been suppressed by the local BGP configuration and are not advertised to remote peers but are still contained in the local BGP table.</p> <p>dampened(d)— Routes that are being dampened by a remote peer.</p> <p>history(h)— Shows that dampening is enabled for this route.</p> <p>valid(*)— Routes that have been verified as reachable; routes that are not marked with an asterisk sign are not used by BGP and will not be installed in the main routing table.</p> <p>best(>)— The best path to reach a destination. BGP stores all paths to each destination; however, it only uses the best path for the main routing table and advertises the best path to its neighbors.</p> <p>internal(i)— BGP learned the route by means of an IGP routing process.</p>

Origin codes: i - IGP e - EGP ? - incomplete	The origin codes are the ORIGIN attribute for the route. The origin code can be to the far-right side for each path in the output of this command. i - IGP— Learned through an I-BGP session. Most routes will have the i origin because they were initially learned by means of local configuration. e - EGP— Learned through an EGP session. These routes are not often seen, as the router is peering with an EGP peer. ? - INCOMPLETE— The route was learned by an unknown origination. This code is generally used if the route was learned by BGP through route redistribution via an IGP.
Network	The network that is being described by the command output in / <i>IPaddress/mask</i> format.
Next_Hop	The NEXT_HOP attribute for the network. This is the next hop that BGP will use to reach the network. If this next hop is unreachable, the route will not be marked valid. The NEXT_HOP attribute is also passed on by BGP to the main IP routing table; this might cause reachability problems when used with I-BGP if it is not reachable from downstream routers.
Metric	The MED attribute, which is used when there are multiple exit points to a network. By default, this metric is set to 0 and must be explicitly configured.
LocPrf	The LOCAL_PREF attribute for the path, used when there are locally preferred routes to a network. The default LOCAL_PREF for I-BGP peers is 100.
Weight	The locally configured WEIGHT attribute for a path. The default weight for a locally originated route is 0, and the default weight for a route learned by means of BGP is 32,768. Remember, the WEIGHT attribute is Cisco proprietary and is not passed on to the peer; it is only locally significant.
Path	The AS_PATH attribute for the path; this attribute lists the path of E-BGP autonomous systems that the route has passed through. The rightmost entries for the AS are the originating AS. Locally originated routes—that is, paths that originated from the local AS—do not contain an autonomous system path entry until they leave the AS.

The `show ip bgp regexp` command can also be used with a regular expression to create AS path access lists, or just to find all routes originating from a particular autonomous system. AS access lists and regular expressions are covered in [Chapter 9](#).

show ip bgp neighbors Command

The `show ip bgp neighbors` command is one of the commands that you will commonly use to troubleshoot and verify BGP peer sessions. This command displays a wealth of detailed information about each BGP session and the TCP parameters for each session. A number of lines in this command prove invaluable for troubleshooting BGP problems, and it should be one of your best tools to use for BGP. [Example 8-1](#) shows the `show ip bgp neighbors` command output for the Alki router.

Example 8-17. show ip bgp neighbors Command Output

```
Alki#show ip bgp neighbors

BGP neighbor is 192.168.32.2,  remote AS 600, external link
  BGP version 4, remote router ID 192.168.32.2
  BGP state = Established, up for 01:15:35
  Last read 00:00:34, hold time is 180, keepalive interval is 60 seconds

  Neighbor capabilities:
    Route refresh: advertised and received(old & new)
    Address family IPv4 Unicast: advertised and received

  Received 168 messages, 0 notifications, 0 in queue
  Sent 174 messages, 0 notifications, 0 in queue
  Route refresh request: received 0, sent 0
  Default minimum time between advertisement runs is 30 seconds

  For address family: IPv4 Unicast
    BGP table version 5, neighbor version 5
    Index 1, Offset 0, Mask 0x2
    2 accepted prefixes consume 72 bytes
    Prefix advertised 12, suppressed 0, withdrawn 0
    Number of NLRI's in the update sent: max 2, min 0
    Connections established 6; dropped 5
    Last reset 01:16:14, due to User reset

  Connection state is ESTAB, I/O status: 1, unread input bytes: 0
  Local host: 192.168.32.1, Local port: 179
  Foreign host: 192.168.32.2, Foreign port: 11006
  Enqueued packets for retransmit: 0, input: 0 mis-ordered: 0 (0 bytes)

  Event Timers (current time is 0xADA668):
    Timer          Starts        Wakeups        Next
```

```

Retrans          81           0           0x0
TimeWait         0            0           0x0
AckHold          79           40          0x0
SendWnd          0            0           0x0
KeepAlive        0            0           0x0
GiveUp           0            0           0x0
PmtuAger         0            0           0x0
DeadWait         0            0           0x0

iss: 1620953691  snduna: 1620955275  sndnxt: 1620955275      sndwnd: 16270
irs: 2271616141  rcvnxt: 2271617706  rcvwnd:       16289  delrcvwnd:      95
SRTT: 300 ms, RTTO: 303 ms, RTV: 3 ms, KRTT: 0 ms
minRTT: 20 ms, maxRTT: 300 ms, ACK hold: 200 ms
Flags: passive open, nagle, gen tcbs

```

Datagrams (max data segment is 1460 bytes):

```

Rcvd: 126 (out of order: 0), with data: 79, total data bytes: 1564
Sent: 122 (retransmit: 0, fastretransmit: 0), with data: 80, total data bytes:
1583

```

This command enables you to troubleshoot a host of problems, fine-tune BGP performance, and view configurations. For instance, the current BGP state and the time that the neighbor relationship has established can be viewed by entering `show ip bgp neighbors | includeBGPstate`. The number of prefixes received and the amount of memory they consume can be referenced using `show ip bgp | include accepted`. The number of connections that have been established and dropped by the peer can be viewed using `show ip bgp neighbors | include Connections`. And you can quickly display the time for the last connection reset by using `show ip bgp neighbors | include Last reset`. The output of the `show ip bgp neighbors` command is explained in detail in [Table 8-7](#).

Table 8-7. `show ip bgp neighbors` Command Output Explained

Command Output	Output Description
<code>BGP neighbor is 192.168.32.2</code>	The IP address for the remote

<code>remote AS 600</code>	The remote BGP AS number.
<code>external link</code>	The BGP session type.
<code>BGP version 4</code>	The BGP version number (that agreed on by both peers) for the session with the remote peer.
<code>remote router ID 192.168.32.2</code>	The remote peer's BGP router ID. Remember that this is not always the IP address of the directly connected interface.
<code>BGP state = Established</code>	<p>The current BGP FSM state.</p> <p>Possible states are the following:</p> <ul style="list-style-type: none"> Idle Connect Active OpenSent OpenConfirm Established <p>You will probably only ever see Active, and Established states.</p>
<code>up for 01:15:35</code>	The amount of time that the current BGP session has been up (in an established state in a format: <i>hours, minutes, and seconds</i> format).
<code>Last read 00:00:34</code>	The last time a message from the remote peer was received and processed.
<code>hold time is 180</code>	<p>The current hold-timer value, or the amount of time between messages from its peer.</p> <p>The default hold time is 180 seconds, which is 3 times the KeepAlive interval.</p>
<code>keepalive interval is 60 seconds</code>	The KeepAlive timer interval for the session. The KeepAlive timer specifies the amount of time that a BGP speaker waits before sending a KEEPALIVE message. If a KEEPALIVE is not received within 3 KEEPALIVE intervals, the timer expires, a NOTIFICATION message is sent, and the session terminates.

<p>Neighbor capabilities:</p> <p>Route refresh: advertised and received (old & new)</p> <p>Address family IPv4 Unicast: advertised and received</p>	<p>The negotiated capabilities for session between the local and peers:</p> <p>For a list of BGP capabilities, refer to the "BGP Capabilities Advertisements" section in Chapter 7, "BGP-4 Transport Protocol".</p> <p>The route refresh capability allows the request of dynamic inbound and outbound updates, without clearing the BGP session.</p> <p>There are different IPv4 address families that might appear in this field, depending on the configuration:</p> <ul style="list-style-type: none"> • IPv4 unicast • IPv4 multicast • VPNv4 unicast <p>The address family for IPv4 unicast capability allows the propagation and reception of IPv4 unicast paths.</p> <p>The address family for IPv4 multicast capability allows the propagation and reception of IPv4 multicast paths, which is a multiprotocol BGP function.</p> <p>The address family for IPv4 VPN unicast capability allows the propagation and reception of IPv4 VPN unicast paths.</p>
<p>Received 168 messages</p>	<p>The total number of BGP messages received by this peer, including the following:</p> <ul style="list-style-type: none"> • OPEN • UPDATE • KEEPALIVE • NOTIFICATION
<p>0 notifications</p>	<p>The number of NOTIFICATION messages that have been received by this peer.</p> <p>NOTIFICATION messages are error conditions and should be examined and monitored, and noted upon arrival.</p>

0 in queue	The number of messages waiting to be processed.
	A high number of messages in queue could indicate congested memory, CPU time, or a high number of BGP peers sending messages consistently on a regular basis.
	The queue normally contains messages when a production router is currently exchanging updates with multiple BGP peers. If this situation persists, it might be time to examine the router for performance improvements.
Sent 174 messages	The total number of messages sent from the local router to the remote peer, including the following:
	<ul style="list-style-type: none"> • OPEN • UPDATE • NOTIFICATION • KEEPALIVE
0 notifications	The number of NOTIFICATION messages sent from the local router to the remote peer.
0 in queue	The number of messages in the queue waiting to be transmitted.
Route refresh request: received 0, sent 0	The number of ROUTE-REFRESH messages that have been sent or received from, the remote peer.
Default minimum time between advertisement runs is 30 seconds.	The default minimum time between UPDATE messages.
For address family: IPv4 Unicast	The address family for the BGP table mentioned in the next field.
BGP table version 5	<p>The current local BGP table version.</p> <p>This number increments each time a table change occurs.</p> <p>Mismatched table numbers could indicate a problem between the local and remote peers.</p>
neighbor version 5	The current remote BGP table version.
Index 1, Offset 0, Mask 0x2	Internal BGP table information.

2 accepted prefixes consume 72 bytes	The number of prefixes accepted by the local peer and the amount of memory bytes that those prefixes consume.
Prefix advertised 12	The number of prefixes advertised to the local peer.
suppressed 0	The number of prefixes suppressed by the local peer.
withdrawn 0	The number of prefixes that have been withdrawn by the local peer. A high number of withdrawn routes could indicate route instability. This can be corrected by fixing the instability or adding a static route with high administrative distance to a neighboring interface.
Number of NLRI s in the update sent: max 2, min 0	The number of network layer reachability information (NLRI) sent in UPDATE messages. max— Indicates the maximum number of NLRI s that were sent in a single UPDATE message. min— Indicates the minimum number of NLRI s that were sent in a single UPDATE message.
Connections established 6; dropped 5	The number of sessions established between the local and remote peers since the last time the router booted. A high number of dropped sessions indicates a route-flapping condition. This should be corrected to prevent route dampening.
Last reset 01:16:14, due to User reset	The time of the last BGP session reset (in hours: minutes: seconds format) and the reason for the reset.
Connection state is ESTAB, I/O status: 1, unread input bytes: 0 Local host: 192.168.32.1, Local port: 179 Foreign host: 192.168.32.2, Foreign port: 11006 Enqueued packets for retransmit: 0, input: 0 mis-ordered: 0 (0 bytes)	The remaining part of the show neighbors command output is the same as the show tcp command output. For details on these items, refer to Table 8-3 .

```

Event Timers (current time is 0xADA668):

Timer          Starts      Wakeups      Next
Retrans        81          0            0x0
TimeWait       0           0            0x0
AckHold        79          40           0x0
SendWnd        0           0            0x0
KeepAlive      0           0            0x0
GiveUp         0           0            0x0
PmtuAger       0           0            0x0
DeadWait       0           0            0x0

iss: 1620953691  snduna: 1620955275  sndnxt:
→ 1620955275

sndwnd: 16270

irs: 2271616141  rcvnxt: 2271617706  rcvwnd:
→ 16289

delrcvwnd: 95

SRTT: 300 ms, RTTO: 303 ms, RTV: 3 ms, KRTT: 0 ms
minRTT: 20 ms, maxRTT: 300 ms, ACK hold: 200 ms
Flags: passive open, nagle, gen tcbs

Datagrams (max data segment is 1460 bytes):

Rcvd: 126 (out of order: 0), with data: 79,
      total data bytes: 1564

Sent: 122 (retransmit: 0, fastretransmit: 0),
      with data: 80, total data bytes: 1583

```

Essential parts of the show ip bgp neighbors command can be parsed using output modifiers (or command aliases, if configured) to view specific parts of the command output when troubleshootin

also use this command with the `/ip-address``advertised-networks` and `/ip-address``routes` keywords information on routes sent to or received from a specific neighbor, as shown in [Example 8-18](#).

Example 8-18. Displaying BGP Route Advertisements with the show ip bgp neighbors Command

```
Madison#show ip bgp neighbors 192.168.32.1 advertised-routes

BGP table version is 3, local router ID is 10.1.1.10

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
               r RIB-failure

Origin codes: i - IGP, e - EGP, ? - incomplete

Network          Next Hop          Metric LocPrf Weight Path
*> 6.0.0.0        0.0.0.0          0          32768 i

Madison#show ip bgp neighbors 192.168.32.1 routes

BGP table version is 3, local router ID is 10.1.1.10

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
               r RIB-failure

Origin codes: i - IGP, e - EGP, ? - incomplete

Network          Next Hop          Metric LocPrf Weight Path
*> 5.0.0.0        192.168.32.1      0          0 5300 i

Total number of prefixes 1
```

The first part of the preceding example shows how the `show ip bgp neighbors 192.168.32.1` `ad` routes command is used to display routes advertised to peer 192.168.32.1. The second part of the shows how the `show ip bgp neighbors 192.168.32.1 routes` command is used to display routes from the 192.168.32.1 peer. These commands can prove very useful for troubleshooting BGP routin

show ip bgp summary Command

The `show ip bgp summary` command displays a summarized version of the output displayed by the `ip bgp neighbors` command, including information about each neighbor. This command enables you to obtain a brief snapshot of the state of each of the BGP peer sessions, to troubleshoot connection or performance issues, and to check the amount of memory that BGP is using to store path information. [Example 8-19](#) shows an example of the output from the `show ip bgp summary` command, and [Table 8-8](#) shows the descriptions for the output in detail.

Example 8-19. `show ip bgp summary` Command Output

```
Alki#show ip bgp summary

BGP router identifier 172.16.20.1, local AS number 5300

BGP table version is 5, main routing table version 5

4 network entries and 4 paths using 532 bytes of memory

2 BGP path attribute entries using 120 bytes of memory

1 BGP AS-PATH entries using 24 bytes of memory

0 BGP route-map cache entries using 0 bytes of memory

0 BGP filter-list cache entries using 0 bytes of memory

BGP activity 4/0 prefixes, 4/0 paths, scan interval 60 secs

Neighbor          V     AS MsgRcvd MsgSent    TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.32.2      4     600       20        21          5     0     0 00:16:47           2
```

Table 8-8. `show ip bgp summary` Command Output Explained

Command Output	Output Description
<code>BGP router identifier 172.16.20.1,</code>	The local BGP router ID.
<code>localAS number 5300</code>	The local AS number.
<code>BGP table version is 5,</code>	The local BGP table version.
<code>main routing table version 5</code>	The main IP routing table version.
<code>network entries and paths using 532 bytes of memory</code>	The number of network entries, number of paths, and amount of memory consumed by those entries.

2 BGP path attribute entries using 120 bytes of memory	The number of BGP path attribute entries and the amount of memory consumed by those entries.
1 BGP AS-PATH entries using 24 bytes of memory	The number of AS_PATH entries and the amount of memory used for entries.
0 BGP route-map cache entries using 0 bytes of memory	The number of route map cache entries and the amount of memory consumed.
0 BGP filter-list cache entries using 0 bytes of memory	The number of filter list cache entries and the amount of memory used those entries.
BGP activity 4/0 prefixes	The number of prefixes contained in the local BGP table.
4/0 paths	The number of paths contained in the local BGP table.
scan interval 60 secs	The interval at which the BGP Scanner scans the BGP tables for char reachability. The default BGP Scanner interval is 60 seconds, and can caution, be changed to a value between 5 and 60 seconds using the scan-time command.
Neighbor 192.168.32.2	The remote peer's IP address.
V 4	The remote peer's BGP version.
AS 600	The remote peer's AS number.

MsgRcvd	The number of messages received from the remote peer (including C UPDATE, NOTIFICATION, and KEEPALIVE). 20
MsgSent	The number of messages sent to the remote peer (including OPEN, L NOTIFICATION, and KEEPALIVE). 21
TblVer	The last version of the BGP table that was sent to the remote peer. 5
InQ	The number of incoming messages waiting to be processed. 0
OutQ	The number of outgoing messages waiting to be transmitted. 0
Up / Down	The amount of time that the BGP session between the two peers has been up or down. 00:16:47

State/PfxRcd 2	<p>The number of prefixes received from the remote peer once a BGP session has been established.</p> <p>The current BGP FSM state if the state is not established.</p> <ul style="list-style-type: none"> • Idle • Connect • Active • OpenSent • OpenConfirm
-------------------------------------	---

Now that you have added the BGP show and debug commands to your BGP troubleshooting toolkit, the next section, the use of BGP messages, another BGP troubleshooting tool, is introduced and explained.

Using BGP Messages as Symptoms

One of the best ways to troubleshoot a BGP problem is to use the BGP messages as diagnostic tools. Cisco IOS Software displays messages in a number of different ways, depending on configuration. As a general practice, you will probably disable console logging using the no logging console command, and use a virtual terminal line to perform all configuration and troubleshooting. Because the messages are not sent directly to the virtual terminal lines, unless you use the terminal monitor command each time you troubleshoot, you might not see the output from the BGP messages, unless you enable buffered logging using the logging buffered command to save the messages in memory.

Another Cisco IOS Software feature that is generally overlooked is the logging configuration. The default logging behavior is to log each event in the log according to the router's uptime. You might prefer this behavior, or you might want to have the router display messages in a date/time view. You can control this behavior by using the service timestamps debug datetime msec and service timestamps log datetime msec commands. Using these commands, you can have the router display events with an accompanying timestamp rather than router uptime, which comes in quite handy when troubleshooting an event that occurred hours or days in the past.

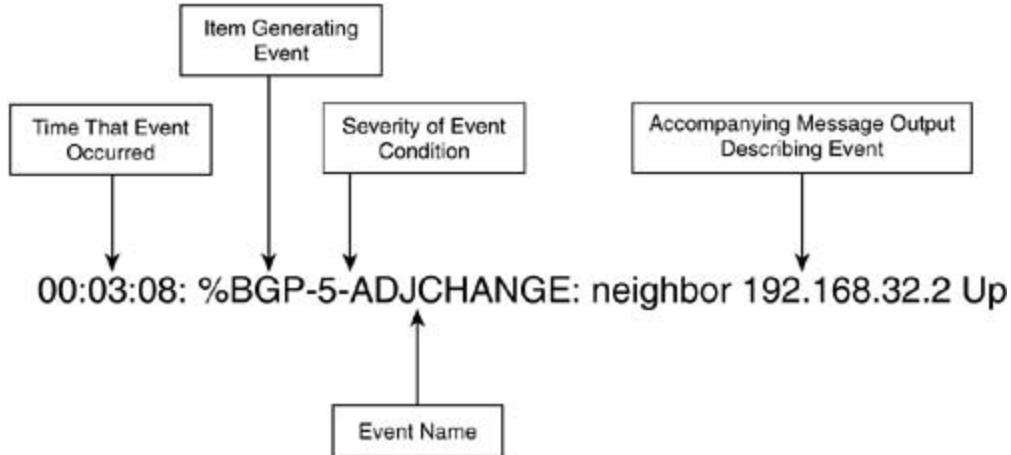
After configuring the router's logging style, you can use the messages generated by the software to troubleshoot problems. Cisco IOS Software has five major message-logging conditions, varying in severity, as shown in [Table 8-9](#).

Table 8-9. Cisco IOS Software Event Conditions

Event Condition Number	Event Condition	Condition Description
2	Critical	A critical condition requiring immediate action
3	Error	An error condition requiring immediate action
4	Warning	A warning condition showing an event that might cause i
5	Notification	A notification message displaying a message about an im but normal event
6	Informational	Informational messages about an issue that exists but is significant to router operation

BGP messages are displayed in the format shown in [Figure 8-2](#).

Figure 8-2. Cisco IOS Software Message Format



Based on the output displayed in the preceding figure, you can see that a BGP adjacency change event occurred with neighbor 192.168.32.2, and the BGP adjacency state changed to up. [Example 8-20](#) shows the output from the show logging command enables you to diagnose and troubleshoot a BGP route-flap problem in a matter of seconds.

Example 8-20. Messages from the show logging Command

```

00:00:51: %LINK-3-UPDOWN: Interface Serial0/0, changed state to down
00:00:52: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0, changed
                                state to down
00:02:23: %LINK-3-UPDOWN: Interface Serial0/0, changed state to up
  
```

```

00:02:24: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0, changed
state to up

00:03:08: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Up

00:44:23: %LINK-3-UPDOWN: Interface Serial0/0, changed state to down

00:44:23: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Down Interface flap

00:44:24: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0, changed
state to down

00:46:49: %LINK-3-UPDOWN: Interface Serial0/0, changed state to up

00:46:50: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0, changed
state to up

00:47:22: %BGP-5-ADJCHANGE: neighbor 192.168.32.2 Up

```

In this example, you can see that interface Serial 0/0 repeatedly transitioned from an up to down state, causing the BGP peer relationship with neighbor 192.168.32.2 to flap as well. The BGP messages displayed inline with the LINK-3-UPDOWN messages, making the symptoms of the BGP route-flapping issue easier to diagnose. In this case, it is fairly easy to isolate the BGP route-flapping problem to an issue with configuration on the Serial 0/0 interface. [Table 8-10](#) displays a list of BGP messages and their descriptions.

Table 8-10. BGP Messages

BGPMessage	Message Description
%BGP-2-INSUFMEM	This is a critical BGP message indicating that the router does not have sufficient memory to continue with the specified operation. This error frequently occurs on routers with insufficient memory to handle certain operations. (You might see this error right before a reload when debugging a 2500 series lab router.) To remedy the situation, you might need to upgrade the router. If it cannot exceed the current memory configuration, upgrade the software for the router, if possible, or use the show memory commands to find unnecessary processes and shut them down. If a lab router (not a production router—please note that the production router does not have the capacity to run BGP), you might need to save the configuration before debugging so that configurations are not lost during a reload.
%BGP-3-ADROUTE	This error message indicates an error condition where the router cannot add a route.
%BGP-3-BADMASK	This error message indicates that the router was unable to install a route in the local routing table because of an error with the subnet mask for the prefix listed in the message accompanying the error.

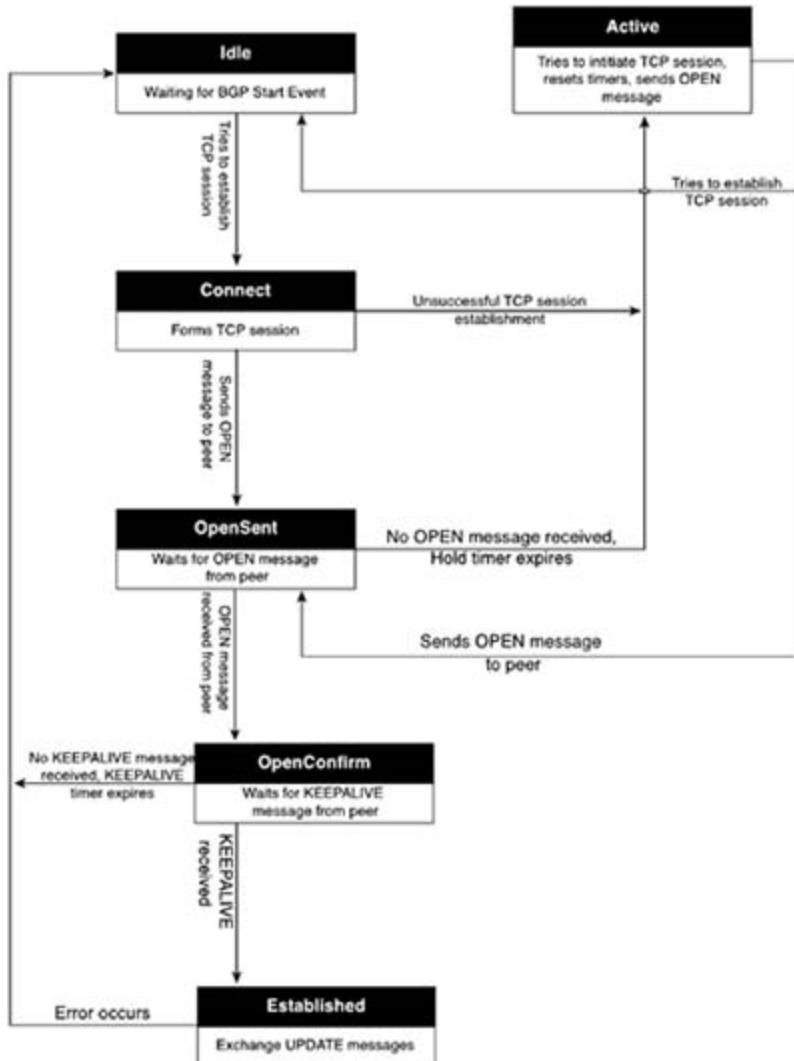
%BGP-3-BADROUTEMAP	This error message indicates that one of the route maps (specified in the <code>route-map</code> command accompanying the error) is not appropriate for its intended use.
%BGP-3-BGP_INCONSISTENT	This error indicates a BGP data structure inconsistency; this is an internal BGP error.
%BGP-3-DELPATH	This error indicates that an error occurred while trying to delete a path.
%BGP-3-DELROUTE	This error indicates that an error occurred while trying to delete a route from the router's internal BGP data structure, called a Radix Trie. This is an internal BGP error.
%BGP-3-INSUFCHUNKS	This error indicates an insufficient chunk definition; Cisco IOS Software allocates chunks to processes, similarly to memory allocation.
%BGP-3-MARTIAN_IP	This error message indicates that the local BGP speaker received a route with an invalid IP address or prefix on a remote router.
%BGP-3-MAXPATHS	<p>This error message indicates that there are too many equal cost paths to a destination network.</p> <p>The output from this error includes the IP prefix and mask, what the error is about, and the current maximum number of allowed paths. You can fix this by using the <code>maximum-paths</code> command under the BGP router configuration and specifying a higher number of paths (from 1 to 6).</p>
%BGP-3-MAXPFXEXCEEDED and %BGP-4-MAXPFX:	<p>These messages indicate that the neighboring BGP speaker sent more prefixes than the local speaker is configured to receive. The IP address of the remote BGP speaker sending the updates, and the maximum prefix limitation number, in decimal, are displayed as output with these messages.</p> <p>The %BGP-3 message is an error message that specifies that the maximum number of prefixes has been reached, and the connection is being terminated. The message is just a warning indicating that the number of prefixes was exceeded; the type of message received depends on the local BGP configuration.</p> <p>This is the command used to configure a maximum prefix limitation; its usage is covered in Chapter 9.</p>
%BGP-3-NEGOUNTER	This is a BGP internal error that occurs when the number of prefixes received by the peer counter is a value less than 0.
%BGP-3-NOBITFIELD	<p>This error message indicates that the router was unable to create an index for the peer displayed in the message output.</p> <p>This message occurs when the router does not have sufficient memory to complete a BGP session with the remote peer; to correct this situation, either add more memory or close other unnecessary processes.</p>
%BGP-3-NOTIFICATION	This error message indicates that the router received or sent a notification message to the remote peer specified in the message output. The notification message type is displayed in the message output, and the session with the remote peer is terminated.
%BGP-3-RADIXINIT	This error message indicates that the local router was unable to create the Radix Trie because it was unable to allocate sufficient memory. To correct this condition, either add more memory or disable other unnecessary processes.

%BGP-5-ADJCHANGE	This notification message indicates that an adjacency change has occurred peer specified in the message output. The output from this message also specifies whether the BGP adjacency transitioned to either an up (Established) or down state.
%BGP-5-VERSION_WRAP	This notification message indicates that the local BGP table exceeded the maximum allowed size and was wrapped.
%BGP-6-AS-PATH	This informational message indicates that the local router received an UPDATE message containing an invalid AS_PATH attribute. The message output includes the incorrect AS_PATH attribute and the sender's IP address.
%BGP-6-NEXTHOP	<p>This informational message appears when the local speaker receives an update message containing an illegal NEXT_HOP attribute. When this event occurs, the route is ignored, and BGP operation continues.</p> <p>The output of this message includes the IP address of the prefix received in the UPDATE message and the neighbor that sent the message.</p>

The BGP Idle/Active Scenario

If you remember from the previous chapter, the BGP Finite-State Machine (FSM) transitions through other states before reaching the Established state where BGP neighbors actually begin sending and receiving updates. As a brief review, [Figure 8-3](#) shows how the BGP FSM transitions from the Idle to Established states.

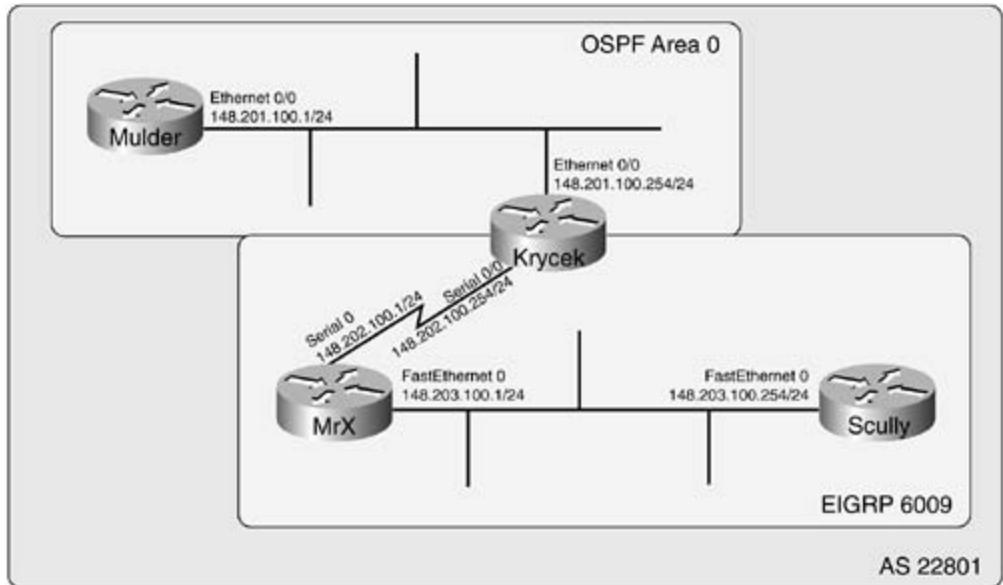
Figure 8-3. BGP Finite-State Machine Review



Notice that if an error occurs between the **Connect** and **OpenSent** states, the FSM transitions to the **Idle** state. If the FSM is still unable to transition from the **Active** state to the **Connect** or **OpenSent** state to the **Idle** state. Because the router actually stays only in **Connect** and **OpenSent** states for a brief time while waiting to move on to the next state, one troubleshooting symptom to note is the constant transition between the **Idle** and **Active** states. If you take careful note when peers are alternating between the **Active** and **Idle** states, you will notice that the peer also transitions between the **Connect** state. Once a TCP session is formed, the peer transitions between the **OpenSent** state as well. This problem generally occurs when there is an issue with the TCP session. If you used your layered troubleshooting methodology to this point, and the peers are constantly transitioning from the **Idle** to **Active** states, you will verify that steps 1 through 3 are up and operating properly before troubleshooting BGP specifically.

Take the Alien network, shown in [Figure 8-4](#), for example. In this example, the Mulder and Scully routers have been configured to peer with each other in AS 22801. Because both routers belong to AS 22801, they are I-BGP peers and do not have to be directly connected. Therefore, the Mulder router connects to the Krycek router over network 148.201.100.0/24, which connects to the MrX router over the 148.202.100.0/24 network. Finally, the 148.202.100.0/24 network connects to the Scully router on the 148.203.100.0/24 network.

Figure 8-4. The Alien Network



After configuring BGP, however, when the `show ip bgp summary` command is entered, you see the routers are stuck in the Idle and Active states. [Example 8-21](#) shows the configuration for the Mulder router.

The Mulder router connects to the Krycek router over interface FastEthernet 0, and that interface is in OSPF area 0.

Example 8-21. Mulder Router Configuration

```

hostname Mulder
<text omitted>
!
interface Ethernet0
    ip address 148.201.100.1 255.255.255.0
!
router ospf 1
    network 148.201.100.0 0.0.0.255 area 0
!
router bgp 22801
    bgp log-neighbor-changes

```

```
network 10.1.1.0 mask 255.255.255.0  
network 10.2.2.0 mask 255.255.255.0  
neighbor 148.203.100.254 remote-as 22801
```

The Krycek router is connected to the Mulder router on its Ethernet 0/0 interface, which runs in OS The Krycek router also connects to the MrX router across a serial interface, which is running EIGRP 6009.[Example 8-22](#) shows the configuration for the Krycek router and the output of the show ip route command showing connectivity to and from the Mulder and Scully networks.

Example 8-22. Krycek Router Configuration

```
hostname Krycek  
  
<text omitted>  
!  
interface Ethernet0/0  
ip address 148.201.100.254 255.255.255.0  
!  
interface Serial0/0  
ip address 148.202.100.254 255.255.255.0  
!  
router eigrp 6009  
passive-interface Ethernet0/0  
network 148.202.0.0  
auto-summary  
!  
router ospf 1  
passive-interface Serial0/0  
network 148.201.100.0 0.0.0.255 area 0  
!
```

```
Krycek#show ip route

 148.201.0.0/24 is subnetted, 1 subnets
C      148.201.100.0 is directly connected, Ethernet0/0

 148.202.0.0/24 is subnetted, 1 subnets
C      148.202.100.0 is directly connected, Serial0/0

D  148.203.0.0/16 [90/2172416] via 148.202.100.1, 00:45:21, Serial0/0
```

[Example 8-23](#) shows the configuration for the MrX router, which connects to the Krycek router on interface Serial 0 and the Scully router on interface FastEthernet 0.

Example 8-23. MrX Router Configuration

```
hostname MrX
<text omitted>
!
interface Serial0
  ip address 148.202.100.1 255.255.255.0
!
interface FastEthernet0
  ip address 148.203.100.1 255.255.255.0
!
router eigrp 6009
  network 148.202.0.0
  network 148.203.0.0
  auto-summary
```

Finally, [Example 8-24](#) shows the configuration for the Scully router.

Example 8-24. Scully Router Configuration

```
hostname Scully
<text omitted>
!
interface FastEthernet0
 ip address 148.203.100.254 255.255.255.0
!
router eigrp 6009
 network 148.203.0.0
 auto-summary
!
router bgp 22801
 bgp log-neighbor-changes
 network 192.168.8.0
 network 192.168.9.0
 neighbor 148.201.100.1 remote-as 22801
```

[Example 8-25](#) shows the output of the show ip bgp summary and show ip bgp neighbors commands which give several hints as to the cause of the problem.

Example 8-25. Troubleshooting Command Details

```
Scully#show ip bgp summary
BGP router identifier 192.168.1.1, local AS number 22801
BGP table version is 1, main routing table version 1
Neighbor          V     AS MsgRcvd MsgSent    TblVer  InQ OutQ Up/Down  State/PfxRcd
148.201.100.1    4  22801          0          0        0      0 never     Active
```

```

Scully#show ip bgp neighbor

BGP neighbor is 148.201.100.1, remote AS 22801, internal link

BGP version 4, remote router ID 0.0.0.0

BGP state = Active

Last read 00:23:24, hold time is 180, keepalive interval is 60 seconds

Received 0 messages, 0 notifications, 0 in queue

Sent 0 messages, 0 notifications, 0 in queue

Route refresh request: received 0, sent 0

Default minimum time between advertisement runs is 5 seconds

For address family: IPv4 Unicast

BGP table version 1, neighbor version 0

Index 1, Offset 0, Mask 0x2

0 accepted prefixes consume 0 bytes

Prefix advertised 0, suppressed 0, withdrawn 0

Connections established 0; dropped 0

Last reset never

No active TCP connection

```

Notice that the show ip bgp summary command shows that the remote peer 148.201.200.1 is in state and no messages have been sent or received on this connection. This would indicate that a BGP session has never been established between these peers. Next, notice that the show ip bgp neighbor command does not include the BGP router ID for the remote host, which means that the local host has never sent a message to the remote host to learn the router ID. Also notice that zero connections have been established (0 dropped), there have never been reset connections, and there are currently no active TCP connections. To follow the troubleshooting methodology mentioned earlier in the chapter, you will probably use the steps to investigate the cause of the missing TCP session.

Step 1. Verify Layer 1 connectivity.

- Use show commands to verify that the Ethernet interfaces are up on the Mulder and Scully routers.

- Verify that each router along the path between Mulder and Scully is up and operational.

Step 2. Verify Layer 2 connectivity.

- Check to make sure that there are no Layer 2 problems on any of the routers along the path between the two routers.

between the Mulder and Scully routers.

Step 3. Verify Layer 3 connectivity.

- Verify Layer 3 connectivity between the Mulder and Scully routers.
- Ping from the Mulder router to the Scully router, and check the local routing table for the remote peer's network.

```
Mulder#ping 148.203.100.254
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 148.203.100.254, timeout is 2 seconds:
```

```
.....
```

```
Success rate is 0 percent (0/5)
```

```
Mulder#show ip route 148.203.100.0
```

```
% Network not in table
```

Now it can be established that there is a Layer 3 routing problem between the Mulder and Scully routers. Because I-BGP requires an IGP to provide the underlying network connectivity between peers, it is necessary for the Mulder and Scully routers to form the TCP session required to become fully established BGP neighbors. By testing the IP connectivity between the two peers, you can immediately establish that the Mulder and Scully routers cannot reach each other, and you can move on to the Krycek router, its routing table, and try some ping tests.

```
Krycek#show ip route | begin Gateway
```

```
Gateway of last resort is not set
```

```
    148.201.0.0/24 is subnetted, 1 subnets
```

```
C          148.201.100.0 is directly connected, Ethernet0/0
```

```
148.202.0.0/24 is subnetted, 1 subnets
C      148.202.100.0 is directly connected, Serial0/0
D      148.203.0.0/16 [90/2172416] via 148.202.100.1, 01:00:08, Serial0/0
Krycek#ping 148.201.100.1
Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 148.201.100.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/4 ms
Krycek#ping 148.203.100.1
Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 148.203.100.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/4 ms
```

Now that you have verified that the Krycek router can reach both the Mulder and Scully routers, you can move on to the MrX router and verify IP connectivity again.

```
MrX#show ip route | begin Gateway
Gateway of last resort is not set

148.202.0.0/16 is variably subnetted, 2 subnets, 2 masks
C      148.202.100.0/24 is directly connected, Serial0
D      148.202.0.0/16 is a summary, 01:17:13, Null0
148.203.0.0/16 is variably subnetted, 2 subnets, 2 masks
C      148.203.100.0/24 is directly connected, FastEthernet0
D      148.203.0.0/16 is a summary, 01:17:13, Null0
```

```
MrX#show ip route 148.201.100.0
```

```
% Network not in table
```

By using the show ip route | begin Gateway command on the MrX router, you find that it does not have a route to the 148.201.100.0/ network either. After revisiting the Krycek router and finding that the redistribution between OSPF and EIGRP had not been configured, and you take the action to fix that problem, the connection between the MrX and Scully routers should be up.

```
Mulder#show ip route
```

```
10.0.0.0/24 is subnetted, 2 subnets
```

```
C       10.2.2.0 is directly connected, Loopback20
```

```
C       10.1.1.0 is directly connected, Loopback10
```

```
148.201.0.0/24 is subnetted, 1 subnets
```

```
C       148.201.100.0 is directly connected, Ethernet0
```

```
148.202.0.0/24 is subnetted, 1 subnets
```

```
O E1     148.202.100.0 [110/30] via 148.201.100.254, 00:02:26, Ethernet0
```

```
O E1 148.203.0.0/16 [110/30] via 148.201.100.254, 00:02:26, Ethernet0
```

```
Scully#show ip route
```

```
148.201.0.0/24 is subnetted, 1 subnets
```

```
D EX     148.201.100.0 [170/2223616] via 148.203.100.1, 00:00:53, FastEthernet0
```

```
D       148.202.0.0/16 [90/2172416] via 148.203.100.1, 01:19:24, FastEthernet0
```

```
148.203.0.0/24 is subnetted, 1 subnets
```

```
C       148.203.100.0 is directly connected, FastEthernet0
```

```
Scully#ping 148.201.100.1
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 148.201.100.1, timeout is 2 seconds:
```

!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 36/37/40 ms

Scully#**show ip bgp summary**

BGP router identifier 192.168.1.1, local AS number 22801

BGP table version is 1, main routing table version 1

2 network entries and 2 paths using 266 bytes of memory

1 BGP path attribute entries using 60 bytes of memory

0 BGP route-map cache entries using 0 bytes of memory

0 BGP filter-list cache entries using 0 bytes of memory

BGP activity 2/0 prefixes, 4/2 paths, scan interval 15 secs

Neighbor	V	AS	MsgRcvd	MsgSent	TblVer	InQ	OutQ	Up/Down	State/PfxRcd
148.201.100.1	4	22801	8	6	1	0	0	00:00:11	2

BGP Neighbor Configuration

Before configuring BGP, it is important to understand some basic rules of configuration between I-BGP and E-BGP configuration. In the next section, both BGP types are covered, with examples that show how BGP can be configured to support different network topologies:

- Directly connected I-BGP configurations
- I-BGP connections configured across an IGP backbone
- E-BGP direct connections
- E-BGP multihop configurations
- E-BGP transit autonomous system configurations
- Configuring BGP peers to interact with IGPs

IBGP Peer Relationships

As mentioned in [Chapter 9](#), I-BGP peer relationships rely on a full mesh of I-BGP speakers and the routing tables provided by IGP routing protocols to provide basic routing between each of the BGP peers. Because I-BGP peers do not need to be directly connected, there can be any number of IGP routers that do not participate in BGP routing between two I-BGP speakers, and as long as the two speakers have routes to each other, they can form a BGP peering relationship and exchange BGP routes.

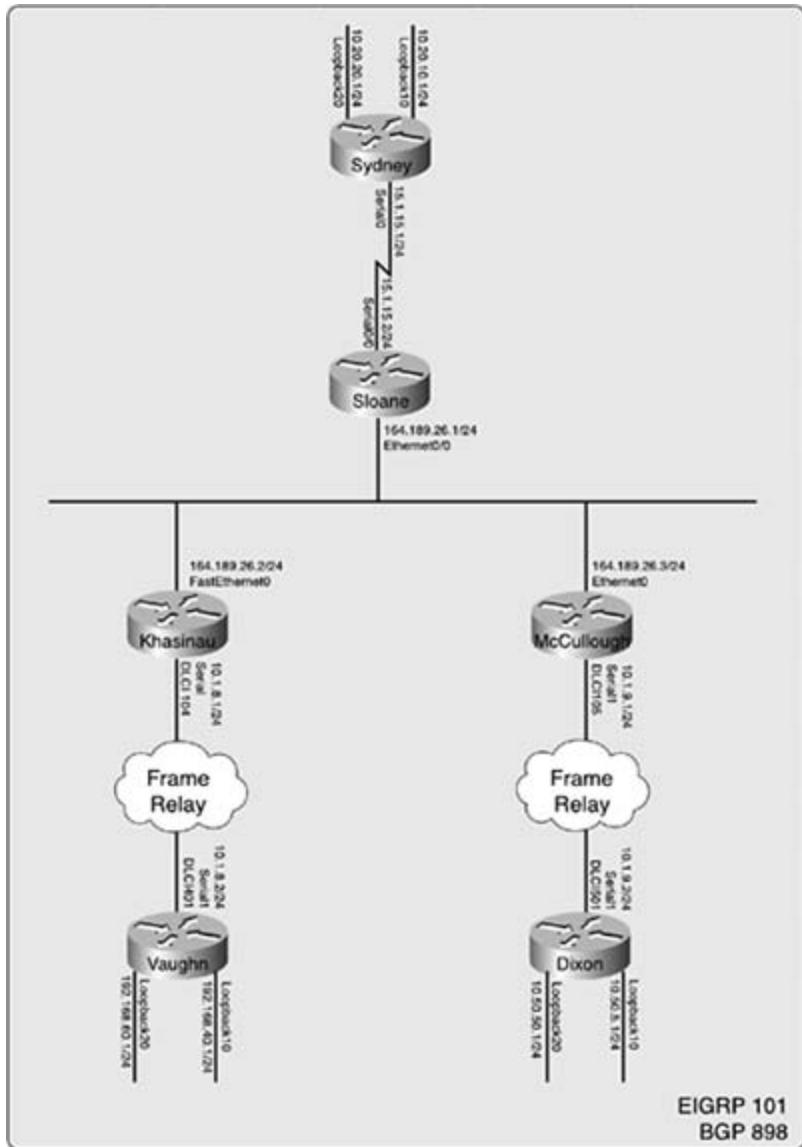
BGP Synchronization

As a rule, I-BGP speakers must have their BGP routes synchronized with the routes from their IGP routing table before those routes will be considered usable. If an I-BGP peer is not synchronized with its IGP or does not have an IGP process running, that peer will not advertise networks or install BGP routes in the main IP routing table. There are two ways to correct a synchronization issue: First, when an IGP is running and you do not want to use it for synchronization, you use the `no synchronization` command. Second, if you are not running an IGP, use the `no synchronization` command to disable BGP/IGP synchronization.

Practical Example: I-BGP Synchronization Experiment

In this example, I-BGP is used to advertise remote BGP networks, symbolized by loopback IP addresses. This example demonstrates how IGP synchronization affects BGP routing and how I-BGPs operate in a fully meshed environment. [Figure 8-5](#) shows the network used in this example.

Figure 8-5. The SD-6 Network



In this example, you use the IP addresses and DLCIs in [Table 8-11](#).

Table 8-11. Interface and IP Addresses for This Practical Example

Router	Interface	Serial Encapsulation and/or DCLI	IPAddress
Sydney	Serial0	56 kbps PPP with Compression	15.1.15.1/24
Sydney	Loopback10	None	10.20.10.1/24
Sydney	Loopback20	None	10.20.20.1/24
Sloane	Serial0/0	56 kbps PPP with Compression	15.1.15.2/24
Sloane	Ethernet0/0	None	164.189.26.1/24
Khasinau	FastEthernet0	None	164.189.26.2/24
Khasinau	Serial1	Frame Relay DLCI 104	10.1.8.1/24
McCullough	Ethernet0	None	164.189.26.3/24
McCullough	Serial0	Frame Relay DLCI 105	10.1.9.1/24
Vaughn	Serial1	Frame Relay DLCI 401	10.1.8.2/24
Vaughn	Loopback10	None	192.168.40.1/24
Vaughn	Loopback20	None	192.168.60.1/24
Dixon	Serial1	Frame Relay DLCI 501	10.1.9.2/24
Dixon	Loopback10	None	10.50.5.1/24
Dixon	Loopback20	None	10.50.50.1/24

Step 1. Configure the Frame Relay switch as shown in [Table 8-12](#). For help configuring Frame Relay switching, refer to [Chapter 1](#) in *CCIE Practical Studies, Volume I*.

Table 8-12. Frame Relay Switch Configuration

Interface	DLCI	Interface	DLCI
Serial4	104	Serial2	401
Serial2	401	Serial4	104
Serial1	105	Serial3	501
Serial3	501	Serial1	105

[Example 8-26](#) shows the configuration for the Frame Relay switch and the Frame Relay routes present after configuring the switch.

Example 8-26. Configuration for the Frame Relay Switch

```
hostname Frame-Relay-Switch
```

```
!
```

```
frame-relay switching

!

interface Serial1

no ip address

encapsulation frame-relay IETF

frame-relay lmi-type ansi

frame-relay intf-type dce

frame-relay route 105 interface Serial3 501

!

interface Serial2

no ip address

encapsulation frame-relay IETF

frame-relay lmi-type ansi

frame-relay intf-type dce

frame-relay route 401 interface Serial4 104

!

interface Serial3

no ip address

encapsulation frame-relay IETF

frame-relay lmi-type ansi

frame-relay intf-type dce

frame-relay route 501 interface Serial1 105

!

interface Serial4

no ip address

encapsulation frame-relay IETF

frame-relay lmi-type ansi

frame-relay intf-type dce
```

```
frame-relay route 104 interface Serial2 401
```

```
Frame-Relay-Switch#show frame-relay route
```

Input Intf	Input Dlci	Output Intf	Output Dlci	Status
Serial1	105	Serial3	501	active
Serial2	401	Serial4	104	active
Serial3	501	Serial1	105	active
Serial4	104	Serial2	401	active

Step 2. Configure Frame Relay between Khasinau and Vaughn using IP addresses and DLCIs from [Table 8-11](#). Also, configure the loopback IP addresses on the Vaughn router. At this time, you should be able to verify that the Vaughn and Khasinau routers can reach each other using the IP addresses on their serial interfaces. [Example 8-27](#) shows the Frame Relay configurations for the Khasinau and Vaughn routers.

Example 8-27. Khasinau and Vaughn Router Configurations

```
hostname Khasinau
!
interface Serial0
  ip address 10.1.8.1 255.255.255.0
  encapsulation frame-relay IETF
  clockrate 1300000
  frame-relay map ip 10.1.8.2 104 broadcast
  frame-relay lmi-type ansi
```

```
hostname Vaughn
!
interface Loopback10
  ip address 192.168.40.1 255.255.255.0
```

```
!  
  
interface Loopback20  
  ip address 192.168.60.1 255.255.255.0  
!  
  
interface Serial1  
  ip address 10.1.8.2 255.255.255.0  
  encapsulation frame-relay IETF  
  clockrate 1300000  
  frame-relay map ip 10.1.8.1 401 broadcast  
  frame-relay lmi-type ansi
```

Step 3. Configure Frame Relay between McCullough and Dixon using IP addresses and DLCIs from [Table 8-11](#). At this point, you should also configure the loopback IP addresses on the Dixon router and verify that the McCullough and Dixon routers can reach each other using the IP addresses on their serial interfaces. [Example 8-28](#) shows the Frame Relay configuration for the McCullough and Dixon routers.

Example 8-28. McCullough and Dixon Router Configurations

```
hostname McCullough  
!  
  
interface Serial1  
  ip address 10.1.9.1 255.255.255.0  
  encapsulation frame-relay  
  
  clockrate 1300000  
  frame-relay map ip 10.1.9.2 105 broadcast  
  frame-relay lmi-type ansi  
  


---

  
hostname Dixon  
!
```

```

interface Loopback10
  ip address 10.50.5.1 255.255.255.0
!
interface Loopback20
  ip address 10.50.50.1 255.255.255.0
!
interface Serial1
  ip address 10.1.9.2 255.255.255.0
  encapsulation frame-relay IETF
  clockrate 1300000
  frame-relay map ip 10.1.9.1 501 broadcast
  frame-relay lmi-type ansi

```

Step 4. Configure an Ethernet network between the Sloane, Khasinau, and McCullough routers using IP addresses from [Table 8-11](#). Then enable EIGRP on the Sloane, Khasinau, Vaughn, and McCullough routers and assign them to EIGRP AS 101. Do not configure EIGRP to include the loopback addresses on the Vaughn and Dixon routers. Verify that all routers can reach all interfaces on all other routers (except the loopback addresses) before proceeding to Step 5. [Example 8-29](#) shows the configuration for the Ethernet and EIGRP configuration for the Sloane, Khasinau, Vaughn, McCullough, and Dixon routers, and their routing tables.

Example 8-29. Ethernet and EIGRP Configurations for the Sloane, Khasinau, Vaughn, McCullough, and Dixon Routers

```

hostname Sloane
!
interface Ethernet0/0
  ip address 164.189.26.1 255.255.255.0
!
router eigrp 101
  network 167.189.26.0 0.0.0.255

```

```
no auto-summary
```

```
Sloane#show ip route
```

```
10.0.0.0/24 is subnetted, 2 subnets
```

```
D      10.1.9.0 [90/2195456] via 164.189.26.3, 00:08:06, Ethernet0/0
```

```
D      10.1.8.0 [90/2195456] via 164.189.26.2, 00:01:50, Ethernet0/0
```

```
164.189.0.0/24 is subnetted, 1 subnets
```

```
C      164.189.26.0 is directly connected, Ethernet0/0
```

```
hostname Khasinau
```

```
!
```

```
interface FastEthernet0
```

```
ip address 164.189.26.2 255.255.255.0
```

```
!
```

```
router eigrp 101
```

```
network 10.1.8.0 0.0.0.255
```

```
network 164.189.26.0 0.0.0.255
```

```
no auto-summary
```

```
Khasinau#show ip route
```

```
10.0.0.0/24 is subnetted, 2 subnets
```

```
D      10.1.9.0 [90/2172416] via 164.189.26.3, 00:02:21, FastEthernet0
```

```
C      10.1.8.0 is directly connected, Serial0
```

```
164.189.0.0/24 is subnetted, 1 subnets
```

```
C      164.189.26.0 is directly connected, FastEthernet0
```

```
hostname Vaughn
```

```
!
```

```
router eigrp 101
```

```
network 10.1.8.0 0.0.0.255  
no auto-summary
```

```
Vaughn#show ip route  
C    192.168.60.0/24 is directly connected, Loopback20  
C    192.168.40.0/24 is directly connected, Loopback10  
      10.0.0.0/24 is subnetted, 2 subnets  
D      10.1.9.0 [90/2684416] via 10.1.8.1, 00:04:03, Serial1  
C      10.1.8.0 is directly connected, Serial1  
      164.189.0.0/24 is subnetted, 1 subnets  
D      164.189.26.0 [90/2172416] via 10.1.8.1, 00:04:03, Serial1
```

```
hostname McCullough  
!  
interface Ethernet0  
  ip address 164.189.26.3 255.255.255.0  
!  
router eigrp 101  
  network 10.1.9.0 0.0.0.255  
  network 164.189.26.0 0.0.0.255  
  no auto-summary
```

```
McCullough # show ip route  
      10.0.0.0/24 is subnetted, 2 subnets  
C      10.1.9.0 is directly connected, Serial1  
D      10.1.8.0 [90/2195456] via 164.189.26.2, 00:06:50, Ethernet0  
      164.189.0.0/24 is subnetted, 1 subnets  
C      164.189.26.0 is directly connected, Ethernet0
```

```
hostname Dixon

!
router eigrp 101

network 10.1.9.0 0.0.0.255

no auto-summary
```

```
Dixon#show ip route

10.0.0.0/24 is subnetted, 4 subnets

C      10.1.9.0 is directly connected, Serial1
D      10.1.8.0 [90/2707456] via 10.1.9.1, 00:07:41, Serial1
C      10.50.50.0 is directly connected, Loopback20
C      10.50.5.0 is directly connected, Loopback10

164.189.0.0/24 is subnetted, 1 subnets

D      164.189.26.0 [90/2195456] via 10.1.9.1, 00:10:35, Serial1
```

Step 5. Configure the serial link between the Sydney and Sloane routers and the loopback interfaces on the Sydney router. Then enable EIGRP routing process 101 to allow the Sydney router to ping all interfaces except the loopback interfaces on the Vaughn and Dixon routers. Do not allow the Sydney router to advertise its loopback interfaces using EIGRP. [Example 8-30](#) shows the configuration and routing table from the Sydney and Sloane routers.

Example 8-30. Configuration and Routing Table for the Sydney Router

```
hostname Sydney

!
interface Loopback10

ip address 10.20.10.1 255.255.255.0

!
```

```
interface Loopback20
  ip address 10.20.20.1 255.255.255.0
!
interface Serial0
  ip address 15.1.15.1 255.255.255.0
!
router eigrp 101
  network 15.1.15.0 0.0.0.255
  no auto-summary
!
Sydney#show ip route
  10.0.0.0/24 is subnetted, 4 subnets
D      10.1.9.0 [90/2707456] via 15.1.15.2, 00:02:23, Serial0
D      10.1.8.0 [90/2707456] via 15.1.15.2, 00:02:23, Serial0
C      10.20.20.0 is directly connected, Loopback20
C      10.20.10.0 is directly connected, Loopback10
  164.189.0.0/24 is subnetted, 1 subnets
D      164.189.26.0 [90/2195456] via 15.1.15.2, 00:02:23, Serial0
  15.0.0.0/24 is subnetted, 1 subnets
C      15.1.15.0 is directly connected, Serial0


---


hostname Sloane
!
interface Ethernet0/0
  ip address 164.189.26.1 255.255.255.0
!
interface Serial0/0
  ip address 15.1.15.2 255.255.255.0
```

```
!
router eigrp 101
network 15.1.15.0 0.0.0.255
network 164.189.26.0 0.0.0.255
no auto-summary

Sloane#show ip route | begin Gateway
Gateway of last resort is not set

10.0.0.0/24 is subnetted, 2 subnets
D      10.1.9.0 [90/2195456] via 164.189.26.3, 00:07:09, Ethernet0/0
D      10.1.8.0 [90/2195456] via 164.189.26.2, 00:07:50, Ethernet0/0
164.189.0.0/24 is subnetted, 1 subnets
C      164.189.26.0 is directly connected, Ethernet0/0
15.0.0.0/24 is subnetted, 1 subnets
C      15.1.15.0 is directly connected, Serial0/0
```

Step 6. Configure BGP between the Sydney, Vaughn, and Dixon routers to advertise the loopback interfaces between BGP peers. Assign each of these routers to BGP AS 898. Do not allow the BGP peers to automatically summarize network addresses. Use the show ip bgp command to verify that the routes for each of the peering routers appear in the BGP routing tables. [Example 8-31](#) shows the BGP configuration for each of the routers and their BGP routing tables.

Example 8-31. BGP Configurations and BGP Tables for the Sydney, Vaughn, and Dixon Routers

```
Sydney#show run | begin bgp
router bgp 898
bgp log-neighbor-changes
network 10.20.10.0 mask 255.255.255.0
```

```
network 10.20.20.0 mask 255.255.255.0  
neighbor 10.1.8.2 remote-as 898  
neighbor 10.1.9.2 remote-as 898  
no auto-summary
```

```
Sydney#show ip bgp  
BGP table version is 3, local router ID is 10.20.20.1  
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal  
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.20.10.0/24	0.0.0.0	0		32768	i
*> 10.20.20.0/24	0.0.0.0	0		32768	I
* i10.50.5.0/24	10.1.9.2	0	100	0	i
* i10.50.50.0/24	10.1.9.2	0	100	0	i
* i192.168.40.0	10.1.8.2	0	100	0	i
* i192.168.60.0	10.1.8.2	0	100	0	i

```
Vaughn#show run | begin bgp  
router bgp 898  
bgp log-neighbor-changes  
network 192.168.40.0  
network 192.168.60.0  
neighbor 10.1.9.2 remote-as 898  
neighbor 15.1.15.1 remote-as 898  
no auto-summary
```

```
Vaughn#show ip bgp  
BGP table version is 3, local router ID is 196.168.60.1
```

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
* i10.20.10.0/24	15.1.15.1	0	100	0	i
* i10.20.20.0/24	15.1.15.1	0	100	0	i
* i10.50.5.0/24	10.1.9.2	0	100	0	i
* i10.50.50.0/24	10.1.9.2	0	100	0	i
*> 192.168.40.0	0.0.0.0	0		32768	i
*> 192.168.60.0	0.0.0.0	0		32768	i

Dixon#**show run | begin bgp**

```
router bgp 898
bgp log-neighbor-changes
network 10.50.5.0 mask 255.255.255.0
network 10.50.50.0 mask 255.255.255.0
neighbor 10.1.8.2 remote-as 898
neighbor 15.1.15.1 remote-as 898
no auto-summary
```

Dixon#**show ip bgp**

BGP table version is 3, local router ID is 10.50.50.1

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
* i10.20.10.0/24	15.1.15.1	0	100	0	i
* i10.20.20.0/24	15.1.15.1	0	100	0	i
*> 10.50.5.0/24	0.0.0.0	0		32768	i

```

*> 10.50.50.0/24      0.0.0.0          0          32768  I
* i192.168.40.0      10.1.8.2        0          100      0 i
* i192.168.60.0      10.1.8.2        0          100      0 i

```

If you configured each of the BGP peers in a full mesh, you would notice that each of the routers received the routes to the loopback interfaces on their peers. However, none of the routers store the routes to the loopback interfaces as the best (>) routes. This is because the loopback interface routes are not synchronized with routes in the main IP routing table. To determine whether a route synchronized is an issue, use the show ip bgp command and look for routes that show up as best (>). BGP only stores valid routes in the main routing table, and only the valid (*), best (>) routes are sent to peering BGP speakers.

Step 7. Now that you can see the effect that synchronization has on I-BGP peers, disable BGP synchronization, reset the BGP sessions between the peers, and check the BGP table again. [Example 8-32](#) shows the effect of the no synchronization command on the Sydney router.

Example 8-32. Disabling BGP Synchronization on the Sydney Router

```

Sydney(config)#router bgp 898
Sydney(config-router)#no synchronization
Sydney#show ip bgp

BGP table version is 7, local router ID is 10.20.20.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.20.10.0/24	0.0.0.0	0		32768	i
*> 10.20.20.0/24	0.0.0.0	0		32768	I
*>i10.50.5.0/24	10.1.9.2	0	100	0	i
*>i10.50.50.0/24	10.1.9.2	0	100	0	i
*>i192.168.40.0	10.1.8.2	0	100	0	i
*>i192.168.60.0	10.1.8.2	0	100	0	i

Step 8. To allow the BGP routers to ping their peers' loopback interfaces, you need to configure redistribution between BGP and EIGRP. To do so, you need to enter BGP configuration mode and enable BGP to IGP redistribution first, using the `bgp redistribute-internal` command, and then enable BGP redistribution on the EIGRP process as well. After EIGRP has reconverged, you will see the routes to the loopback networks in the main routing table on all routers, and you should be able to ping all addresses on all routers. The external EIGRP routes should also have replaced the BGP routes in the Sydney, Vaughn, and Dixon routers because external EIGRP has a lower administrative distance than BGP (external EIGRP 170, I-BGP 200). [Example 8-33](#) shows the final configuration and routing table from the Sydney router.

Example 8-33. Final Configuration and Routing Table for the Sydney Router

```
hostname Sydney

!
interface Loopback10
    ip address 10.20.10.1 255.255.255.0
!
interface Loopback20
    ip address 10.20.20.1 255.255.255.0
!
interface Serial0
    ip address 15.1.15.1 255.255.255.0
!
router eigrp 101
    redistribute bgp 898 metric 56 200 255 1 1500
    network 15.1.15.0 0.0.0.255
    no auto-summary
!
router bgp 898
    no synchronization
    bgp redistribute-internal
```

```
bgp log-neighbor-changes

network 10.20.10.0 mask 255.255.255.0

network 10.20.20.0 mask 255.255.255.0

neighbor 10.1.8.2 remote-as 898

neighbor 10.1.9.2 remote-as 898

no auto-summary
```

```
Sydney#show ip route | begin Gateway
```

```
Gateway of last resort is not set
```

```
D EX 192.168.60.0/24 [170/2758656] via 15.1.15.2, 00:00:25, Serial0
```

```
D EX 192.168.40.0/24 [170/2758656] via 15.1.15.2, 00:00:25, Serial0
```

```
    10.0.0.0/24 is subnetted, 6 subnets
```

```
D      10.1.9.0 [90/2707456] via 15.1.15.2, 00:37:45, Serial0
```

```
D      10.1.8.0 [90/2707456] via 15.1.15.2, 00:38:26, Serial0
```

```
D EX     10.50.50.0 [170/2758656] via 15.1.15.2, 00:08:21, Serial0
```

```
C      10.20.20.0 is directly connected, Loopback20
```

```
C      10.20.10.0 is directly connected, Loopback10
```

```
D EX     10.50.5.0 [170/2758656] via 15.1.15.2, 00:08:21, Serial0
```

```
    164.189.0.0/24 is subnetted, 1 subnets
```

```
D      164.189.26.0 [90/2195456] via 15.1.15.2, 00:39:36, Serial0
```

```
    15.0.0.0/24 is subnetted, 1 subnets
```

```
C      15.1.15.0 is directly connected, Serial0
```

```
Sydney#ping 10.50.5.1
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 10.50.5.1, timeout is 2 seconds:
```

```
!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 56/58/60 ms
```

```

Sydney#ping 192.168.40.1
Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 192.168.40.1, timeout is 2 seconds:
!!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 40/41/44 ms

```

[Example 8-34](#) shows the complete configuration and routing table for the Sloane router.
[Example 8-35](#) shows the complete configuration and routing table for the Khasinau router.
[Example 8-36](#) shows the same type of information for the McCullough router.

Example 8-34. Final Configuration and Routing Table for the Sloane Router

```

hostname Sloane
!
interface Ethernet0/0
  ip address 164.189.26.1 255.255.255.0
!
interface Serial0/0
  ip address 15.1.15.2 255.255.255.0
!
router eigrp 101
  network 15.1.15.0 0.0.0.255
  network 164.189.26.0 0.0.0.255
  no auto-summary
!

Sloane#show ip route | include via|is
Gateway of last resort is not set

D EX 192.168.60.0/24 [170/2246656] via 164.189.26.3, 00:16:58, Ethernet0/0

```

```

D EX 192.168.40.0/24 [170/2246656] via 164.189.26.3, 00:16:58, Ethernet0/0
    10.0.0.0/24 is subnetted, 6 subnets
      D      10.1.9.0 [90/2195456] via 164.189.26.3, 00:54:18, Ethernet0/0
      D      10.1.8.0 [90/2195456] via 164.189.26.2, 00:54:59, Ethernet0/0
D EX     10.50.50.0 [170/2246656] via 164.189.26.3, 00:24:54, Ethernet0/0
D EX     10.20.20.0 [170/46277376] via 15.1.15.1, 00:26:04, Serial0/0
D EX     10.20.10.0 [170/46277376] via 15.1.15.1, 00:26:04, Serial0/0
D EX     10.50.5.0 [170/2246656] via 164.189.26.3, 00:24:54, Ethernet0/0

164.189.0.0/24 is subnetted, 1 subnets
C       164.189.26.0 is directly connected, Ethernet0/0

15.0.0.0/24 is subnetted, 1 subnets
C       15.1.15.0 is directly connected, Serial0/0

```

Example 8-35. Final Configuration and Routing Table for the Khasinau Router

```

hostname Khasinau
!
interface FastEthernet0
  ip address 164.189.26.2 255.255.255.0
!
interface Serial1
  ip address 10.1.8.1 255.255.255.0
  encapsulation frame-relay IETF
  clockrate 1300000
  frame-relay map ip 10.1.8.2 104 broadcast
  frame-relay lmi-type ansi
!
```

```
!
router eigrp 101
  network 10.1.8.0 0.0.0.255

  network 164.189.26.0 0.0.0.255
  no auto-summary

Khasinau#show ip route | include via|is
Gateway of last resort is not set

D EX 192.168.60.0/24 [170/2223616] via 164.189.26.3, 00:21:11, FastEthernet0
D EX 192.168.40.0/24 [170/2223616] via 164.189.26.3, 00:21:11, FastEthernet0
  10.0.0.0/24 is subnetted, 6 subnets
D      10.1.9.0 [90/2172416] via 164.189.26.3, 00:58:31, FastEthernet0
C      10.1.8.0 is directly connected, Serial1
D EX    10.50.50.0 [170/2223616] via 164.189.26.3, 00:29:07, FastEthernet0
D EX    10.20.20.0 [170/46279936] via 164.189.26.1, 00:30:17, FastEthernet0
D EX    10.20.10.0 [170/46279936] via 164.189.26.1, 00:30:17, FastEthernet0
D EX    10.50.5.0 [170/2223616] via 164.189.26.3, 00:29:07, FastEthernet0
  164.189.0.0/24 is subnetted, 1 subnets
C      164.189.26.0 is directly connected, FastEthernet0
  15.0.0.0/24 is subnetted, 1 subnets
D      15.1.15.0 [90/2172416] via 164.189.26.1, 00:59:15, FastEthernet0
```

Example 8-36. Final Configuration and Routing Table for the McCullough Router

```
hostname McCullough
```

```
!
```

```
interface Ethernet0
    ip address 164.189.26.3 255.255.255.0
!
interface Serial1
    ip address 10.1.9.1 255.255.255.0
    encapsulation frame-relay IETF
    clockrate 1300000
    frame-relay map ip 10.1.9.2 105 broadcast
    frame-relay lmi-type ansi
!
router eigrp 101
    network 10.1.9.0 0.0.0.255
    network 164.189.26.0 0.0.0.255
    no auto-summary
```

```
McCullough#show ip route | include via|is
Gateway of last resort is not set

D EX 192.168.60.0/24 [170/2221056] via 10.1.9.2, 00:23:34, Serial1
D EX 192.168.40.0/24 [170/2221056] via 10.1.9.2, 00:23:34, Serial1

    10.0.0.0/24 is subnetted, 6 subnets
C        10.1.9.0 is directly connected, Serial1
D        10.1.8.0 [90/2172416] via 164.189.26.2, 01:00:59, Ethernet0
D EX     10.50.50.0 [170/2221056] via 10.1.9.2, 00:31:30, Serial1
D EX     10.20.20.0 [170/46279936] via 164.189.26.1, 00:32:40, Ethernet0
D EX     10.20.10.0 [170/46279936] via 164.189.26.1, 00:32:40, Ethernet0
D EX     10.50.5.0 [170/2221056] via 10.1.9.2, 00:31:30, Serial1

    164.189.0.0/24 is subnetted, 1 subnets
C        164.189.26.0 is directly connected, Ethernet0
```

```
15.0.0.0/24 is subnetted, 1 subnets  
D      15.1.15.0 [90/2172416] via 164.189.26.1, 01:00:59, Ethernet0
```

[Example 8-37](#) displays the final configuration, BGP table, and routing table for the Vaughn router, and [Example 8-38](#) shows the same type of data for the Dixon router.

Example 8-37. Final Configuration and Routing Tables for the Vaughn Router

```
hostname Vaughn  
!  
interface Loopback10  
ip address 192.168.40.1 255.255.255.0  
!  
interface Loopback20  
ip address 192.168.60.1 255.255.255.0  
!  
interface Serial1  
ip address 10.1.8.2 255.255.255.0  
encapsulation frame-relay IETF  
clockrate 1300000  
frame-relay map ip 10.1.8.1 401 broadcast  
frame-relay lmi-type ansi  
!  
router eigrp 101  
redistribute bgp 898 metric 1544 200 255 1 1500  
network 10.1.8.0 0.0.0.25  
no auto-summary  
!
```

```

router bgp 898

no synchronization

bgp redistribute-internal

network 192.168.40.0

network 192.168.60.0

neighbor 10.1.9.2 remote-as 898

neighbor 15.1.15.1 remote-as 898

```

Vaughn#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.20.10.0/24	15.1.15.1	0	100	0	i
*>i10.20.20.0/24	15.1.15.1	0	100	0	i
*>i10.50.5.0/24	10.1.9.2	0	100	0	i
*>i10.50.50.0/24	10.1.9.2	0	100	0	i
*> 192.168.40.0	0.0.0.0	0		32768	i
*> 192.168.60.0	0.0.0.0	0		32768	i

Vaughn#**show ip route | include via|is**

```

Gateway of last resort is not set

C      192.168.60.0/24 is directly connected, Loopback20
C      192.168.40.0/24 is directly connected, Loopback10

      10.0.0.0/24 is subnetted, 6 subnets

D      10.1.9.0 [90/2684416] via 10.1.8.1, 01:05:52, Serial1
C      10.1.8.0 is directly connected, Serial1
D EX    10.20.20.0 [170/46791936] via 10.1.8.1, 00:39:46, Serial1
D EX    10.50.50.0 [170/2735616] via 10.1.8.1, 00:38:36, Serial1
D EX    10.20.10.0 [170/46791936] via 10.1.8.1, 00:39:46, Serial1
D EX    10.50.5.0 [170/2735616] via 10.1.8.1, 00:38:36, Serial1

```

```
164.189.0.0/24 is subnetted, 1 subnets
D      164.189.26.0 [90/2172416] via 10.1.8.1, 01:05:52, Serial1
      15.0.0.0/24 is subnetted, 1 subnets
D      15.1.15.0 [90/2684416] via 10.1.8.1, 01:05:53, Serial1
```

Example 8-38. Final Configuration and Routing Tables for the Dixon Router

```
hostname Dixon
!
interface Loopback10
  ip address 10.50.5.1 255.255.255.0
!
interface Loopback20
  ip address 10.50.50.1 255.255.255.0
!
interface Serial1
  ip address 10.1.9.2 255.255.255.0
  encapsulation frame-relay IETF
  frame-relay map ip 10.1.9.1 501 broadcast
  frame-relay lmi-type ansi
!
router eigrp 101
  redistribute bgp 898 metric 1544 200 255 1 1500
  network 10.1.9.0 0.0.0.255
  no auto-summary
!
router bgp 898
```

```

no synchronization

bgp redistribute-internal

bgp log-neighbor-changes

network 10.50.5.0 mask 255.255.255.0

network 10.50.50.0 mask 255.255.255.0

neighbor 10.1.8.2 remote-as 898

neighbor 15.1.15.1 remote-as 898

```

Dixon#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.20.10.0/24	15.1.15.1	0	100	0	i
*>i10.20.20.0/24	15.1.15.1	0	100	0	i
*> 10.50.5.0/24	0.0.0.0	0		32768	i
*> 10.50.50.0/24	0.0.0.0	0		32768	i
*>i192.168.40.0	10.1.8.2	0	100	0	i
*>i192.168.60.0	10.1.8.2	0	100	0	i

Dixon#**show ip route | include via|is**

Gateway of last resort is not set

```

B    192.168.60.0/24 [200/0] via 10.1.8.2, 00:33:41
B    192.168.40.0/24 [200/0] via 10.1.8.2, 00:33:41

    10.0.0.0/24 is subnetted, 6 subnets

C      10.1.9.0 is directly connected, Serial1
D      10.1.8.0 [90/2684416] via 10.1.9.1, 01:08:24, Serial1
D EX    10.20.20.0 [170/46791936] via 10.1.9.1, 00:42:47, Serial1
C      10.50.50.0 is directly connected, Loopback20
D EX    10.20.10.0 [170/46791936] via 10.1.9.1, 00:42:47, Serial1
C      10.50.5.0 is directly connected, Loopback10

```

```
164.189.0.0/24 is subnetted, 1 subnets
D      164.189.26.0 [90/2172416] via 10.1.9.1, 01:08:24, Serial1
15.0.0.0/24 is subnetted, 1 subnets
D      15.1.15.0 [90/2684416] via 10.1.9.1, 01:08:24, Serial1
```

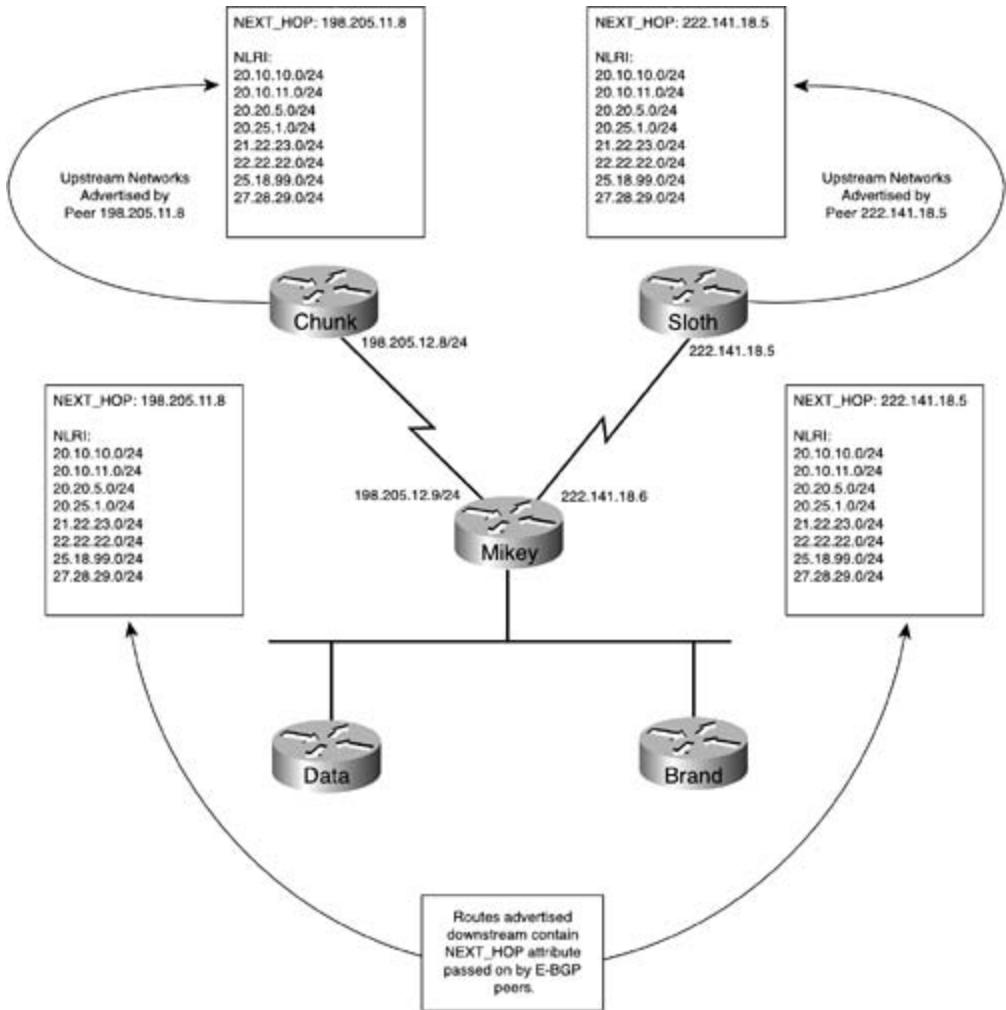
NOTE

Redistribution between BGP and IGPs, and vice versa, can have serious effects on routing performance. Use BGP/IGP redistribution with caution on production networks.

I-BGPnext-hop self Command

One problem that frequently creeps up when multihoming BGP networks is unreachable BGP routes. This generally occurs when E-BGP to I-BGP relationships have just been configured and downstream I-BGP speakers cannot reach the next hop advertised by the router that peers directly with the routers sending E-BGP updates. Although the router peering with the upstream E-BGP peers can reach the addresses of its E-BGP peers, other routers that are downstream from this router do not have routes to the E-BGP peers, so those routers cannot reach the next hop advertised in the BGP updates. This action is by design, and this happens because I-BGP-speaking routers do not alter the NEXT_HOP attribute as they forward routes to other I-BGP peers. [Figure 8-6](#) shows how routes sent from upstream routers, Chunk and Sloth, have NEXT_HOP attributes that are unchanged as they pass through the Mikey router onto Data and Brand.

Figure 8-6. I-BGP NEXT_HOP Behavior



To change the NEXT_HOP attribute on an I-BGP peer to that of the local router, you just need to complete three steps.

Step 1. Enable BGP routing.

```
Mikey(config)#router bgp 10101
```

Step 2. Configure BGP neighbor relationships.

```

Mikey(config-router)#neighbor 198.205.12.8 remote-as 811      ← E-BGP peer
Mikey(config-router)#neighbor 222.141.18.5 remote-as 945      ← E-BGP peer
Mikey(config-router)#neighbor 192.168.1.2 remote-as 10101     ← I-BGP peer
Mikey(config-router)#neighbor 192.168.1.3 remote-as 10101     ← I-BGP peer

```

Step 3. Modify the NEXT_HOP attribute using the neighbor *ip-address* next-hop-self command.

```

Mikey(config-router)#neighbor 192.168.1.2 next-hop-self      ← Change attribute
Mikey(config-router)#neighbor 192.168.1.3 next-hop-self      ← Change attribute

```

Changes to the NEXT_HOP attribute can be seen when the show ip bgp command is issued. [Example 8-39](#) shows how the NEXT_HOP attribute appears on the Data router before the next-hop-self command is used on the Mikey router, and [Example 8-40](#) shows the same command on the same router after the next-hop-self command is added to the configuration on the Mikey router.

Example 8-39. Before Changing the NEXT_HOP Attribute

```
Data#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 2.0.0.0	157.68.90.1	0	100	0	3456 i
*> 3.0.0.0	157.68.90.1	0	100	0	3456 i

Example 8-40. After the next-hop-self Command

```
Data#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i2.0.0.0	192.168.1.1	0	100	0	3456 i
*>i3.0.0.0	192.168.1.1	0	100	0	3456 i

Practical Example: I-BGP Next-Hop Manipulation

This example shows the effects that the next-hop-self command has on I-BGP routing within an autonomous system. This example requires five Cisco routers with the interfaces shown in [Table 8-13](#).

Table 8-13. Router Interface Requirements

Router	Ethernet, Fast Ethernet, or Token Ring Interfaces	Serial Interfaces
Skinner	0	1
Kritchgau	0	1
Langle	1	2
Byers	1	0
Frohike	1	0

Before configuring any routers, make sure the routers are cabled, as shown in [Figure 8-7](#). This example requires two back-to-back serial cables and three Ethernet cables connected to a hub, switch, or MSAU. If you are using a switch, all interfaces should be placed in the same VLAN.

Step 1. Configure all IP addresses as specified in [Figure 8-7](#). Verify that all interfaces are up before proceeding to Step 2. Configure OSPF on all I-BGP-speaking routers in AS 123, putting all interfaces on these routers in area 0. Do not configure OSPF on the Skinner or Kritchgau routers. [Example 8-41](#) shows the IP addressing and OSPF configuration for the Skinner, Langle, Byers, and Frohike routers.

Example 8-41. Configuration for Step 1 on Skinner, Langle, and Byers Routers

```
Skinner#show run | begin Loopback
```

```
interface Loopback10
  ip address 152.86.75.1 255.255.255.0
!
interface Loopback20
  ip address 148.98.72.1 255.255.255.0
!
interface Serial0
  ip address 175.40.20.1 255.255.255.0
```

```
Kritchgau#show run | begin Loopback
interface Loopback10
  ip address 42.21.92.1 255.255.255.0
!
interface Loopback20
  ip address 197.201.128.1 255.255.255.0
!
interface Serial0
  ip address 208.42.18.1 255.255.255.0
```

```
Langle#show run | begin Ethernet
interface Ethernet0/0
  ip address 10.1.1.1 255.255.255.0
!
interface Serial0/0
  ip address 175.40.20.2 255.255.255.0
!
interface Serial0/1
  ip address 208.42.18.2 255.255.255.0
```

```
clock rate 1300000

!
router ospf 1

network 10.1.1.0 0.0.0.255 area 0
```

```
Byers#show run | begin Ethernet

interface Ethernet0

ip address 10.1.1.2 255.255.255.0

!

router ospf 1

network 10.1.1.0 0.0.0.255 area 0
```

```
Frohike#show run | begin Ethernet

interface Ethernet0

ip address 10.1.1.3 255.255.255.0

!

router ospf 1

network 10.1.1.0 0.0.0.255 area 0
```

Step 2. Configure the E-BGP sessions between the Skinner and Langle routers and the Kritchgau and Langle routers. Configure the Skinner and Kritchgau routers to advertise the networks belonging to their loopback interfaces via BGP. Have the Langle router advertise the 10.1.1.0/24 network to both of its E-BGP peers. Before moving on to Step 3, make sure that the Langle router can ping all IP addresses on the loopback interfaces of the Skinner and Kritchgau routers. [Example 8-42](#) shows the BGP configurations for each of the BGP routers and the routing table from the Langle router.

Example 8-42. BGP Configurations for the Skinner, Kritchgau, and Langle Routers

```
Skinner#show run | begin bgp

router bgp 405
```

```
bgp log-neighbor-changes

network 148.98.72.0 mask 255.255.255.0

network 152.86.75.0 mask 255.255.255.0

neighbor 175.40.20.2 remote-as 123

no auto-summary
```

```
Kritchgau#show run | begin bgp

router bgp 912

bgp log-neighbor-changes

network 42.21.92.0 mask 255.255.255.0

network 197.201.128.0

neighbor 208.42.18.2 remote-as 123

no auto-summary
```

```
Langle#show run | begin bgp

router bgp 123

bgp log-neighbor-changes

network 10.1.1.0 mask 255.255.255.0

neighbor 175.40.20.1 remote-as 405

neighbor 208.42.18.1 remote-as 912

no auto-summary

Langle#show ip route | begin Gateway

Gateway of last resort is not set

1.0.0.0/32 is subnetted, 1 subnets

C      1.1.1.1 is directly connected, Loopback0

B      197.201.128.0/24 [20/0] via 208.42.18.1, 00:01:54

152.86.0.0/24 is subnetted, 1 subnets

B      152.86.75.0 [20/0] via 175.40.20.1, 00:05:21
```

```

175.40.0.0/24 is subnetted, 1 subnets
C      175.40.20.0 is directly connected, Serial0/0
42.0.0.0/24 is subnetted, 1 subnets
B      42.21.92.0 [20/0] via 208.42.18.1, 00:01:54
10.0.0.0/24 is subnetted, 1 subnets
C      10.1.1.0 is directly connected, Ethernet0/0
148.98.0.0/24 is subnetted, 1 subnets
B      148.98.72.0 [20/0] via 175.40.20.1, 00:05:22
C      208.42.18.0/24 is directly connected, Serial0/1

```

Step 3. Configure I-BGP connections between the Langle, Byers, and Frohike routers. Before moving on to the next step, verify that Byers and Frohike received the E-BGP routes from the Skinner and Kritchgau routers. [Example 8-43](#) shows the BGP configuration and BGP table for the Langle router, [Example 8-44](#) shows the same data for the Byers router, and [Example 8-45](#) shows the configuration and BGP data for the Frohike router.

Example 8-43. BGP Configuration and BGP Table for the Langle Router

```

Langle#show run | begin bgp
router bgp 123
bgp log-neighbor-changes
network 10.1.1.0 mask 255.255.255.0
neighbor 10.1.1.2 remote-as 123
neighbor 10.1.1.3 remote-as 123
neighbor 175.40.20.1 remote-as 405
neighbor 208.42.18.1 remote-as 912

```

```
Langle#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.1.1.0/24	0.0.0.0	0		32768	i

```

*> 42.21.92.0/24      208.42.18.1          0          0 912 i
*> 148.98.72.0/24    175.40.20.1          0          0 405 i
*> 152.86.75.0/24    175.40.20.1          0          0 405 i
*> 197.201.128.0     208.42.18.1          0          0 912 i

```

Example 8-44. BGP Configuration and BGP Table for the Byers Router

```

Byers#show run | begin bgp

router bgp 123

bgp log-neighbor-changes

neighbor 10.1.1.1 remote-as 123

neighbor 10.1.1.3 remote-as 123

```

```
Byers#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.1.1.0/24	10.1.1.1	0	100	0	i
* i42.21.92.0/24	208.42.18.1	0	100	0	912 i
* i148.98.72.0/24	175.40.20.1	0	100	0	405 i
* i152.86.75.0/24	175.40.20.1	0	100	0	405 i
* i197.201.128.0	208.42.18.1	0	100	0	912 i

Example 8-45. BGP Configuration and BGP Table for the Frohike Router

```

Frohike#show run | begin bgp

router bgp 123

bgp log-neighbor-changes

neighbor 10.1.1.1 remote-as 123

neighbor 10.1.1.3 remote-as 123

```

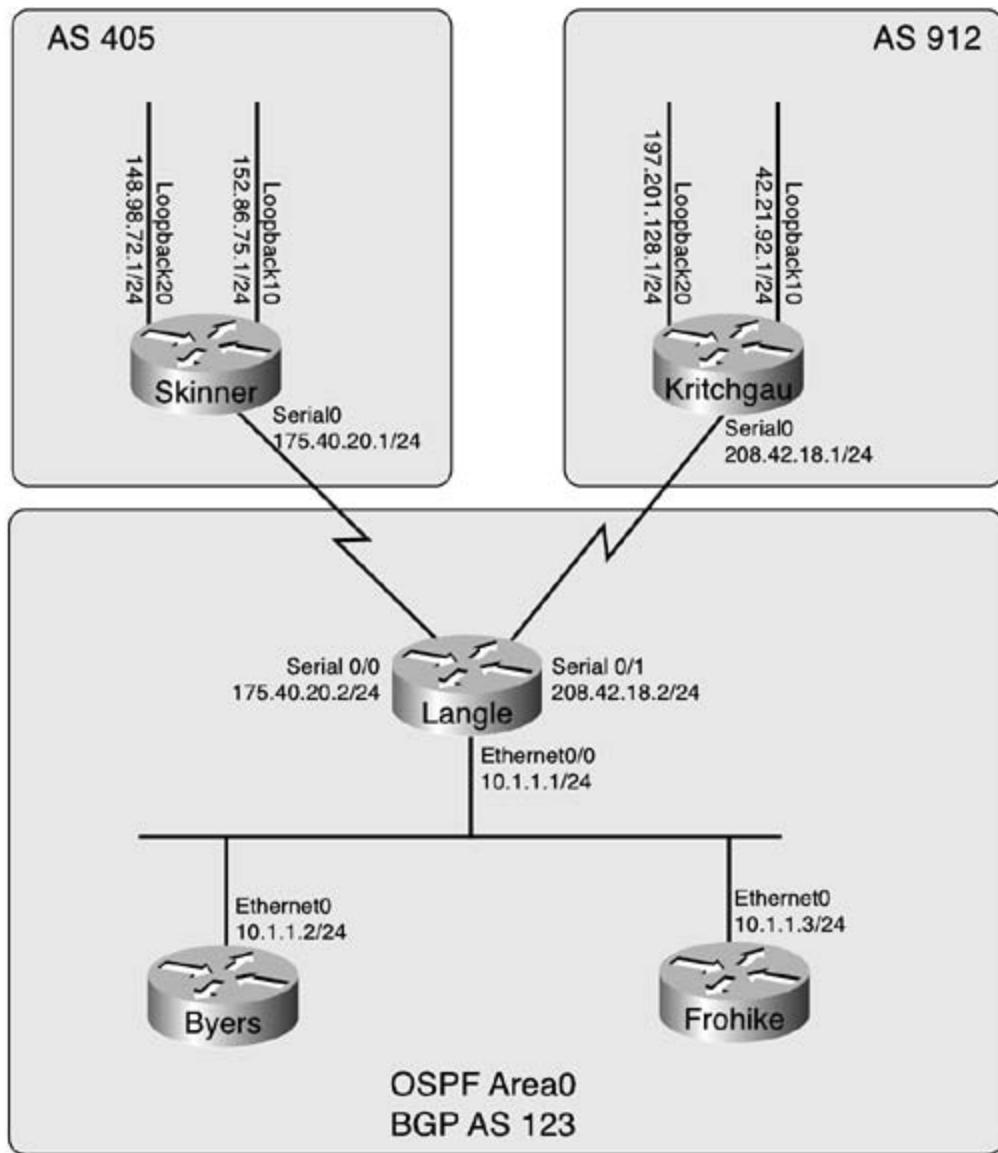
```
Frohike#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.1.1.0/24	10.1.1.1	0	100	0	i
* i42.21.92.0/24	208.42.18.1	0	100	0	912 i
* i148.98.72.0/24	175.40.20.1	0	100	0	405 i
* i152.86.75.0/24	175.40.20.1	0	100	0	405 i
* i197.201.128.0	208.42.18.1	0	100	0	912 i

Step 4. After configuring BGP between the Langle, Byers, and Frohike routers, you might have noticed that the Byers and Frohike routers received the routes from the upstream E-BGP peers of the Langle router but did not install them in the routing table. The reason why the routes were not installed in the table is because they are not reachable using the IP address of the next hop that was advertised by the Langle router. To correct this problem, use the next-hop-self command on each of the I-BGP sessions on the Langle router, and then reset the BGP sessions using the clear ip bgp * command. After the BGP sessions have come back up and the Langle router advertises its routes from the upstream router, it will modify the NEXT_HOP attribute on all routes sent to Byers and Frohike.

[Example 8-46](#) shows the configuration for the Langle router after the addition of the next-hop-self command, and [Example 8-47](#) shows the resulting BGP and IP routing tables for the Byers and Frohike routers.

Figure 8-7. The Conspiracy Network Diagram



Example 8-46. Langle Router's BGP Configuration

```
Langle#show run | begin bgp

router bgp 123

no synchronization

bgp router-id 177.164.8.5

bgp log-neighbor-changes

network 10.1.1.0 mask 255.255.255.0

neighbor 10.1.1.2 remote-as 123
```

```

neighbor 10.1.1.2 next-hop-self
neighbor 10.1.1.3 remote-as 123
neighbor 10.1.1.3 next-hop-self
neighbor 175.40.20.1 remote-as 405
neighbor 208.42.18.1 remote-as 912
no auto-summary

```

Example 8-47. Resulting BGP and IP Routing Tables

Byers#**show ip bgp**

```

BGP table version is 6, local router ID is 10.1.1.2
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          Next Hop            Metric LocPrf Weight Path
*->i10.1.1.0/24      10.1.1.1                  0    100     0  I
*->i42.21.92.0/24    10.1.1.1                  0    100     0  912 i
*->i148.98.72.0/24   10.1.1.1                  0    100     0  405 i
*->i152.86.75.0/24   10.1.1.1                  0    100     0  405 i
*->i197.201.128.0    10.1.1.1                  0    100     0  912 i

```

Byers#**show ip route | begin Gateway**

```

Gateway of last resort is not set

B      197.201.128.0/24 [200/0] via 10.1.1.1, 00:01:09
      152.86.0.0/24 is subnetted, 1 subnets
B          152.86.75.0 [200/0] via 10.1.1.1, 00:01:09
      42.0.0.0/24 is subnetted, 1 subnets
B          42.21.92.0 [200/0] via 10.1.1.1, 00:01:09

```

```

10.0.0.0/24 is subnetted, 1 subnets

C      10.1.1.0 is directly connected, Ethernet0

148.98.0.0/24 is subnetted, 1 subnets

B      148.98.72.0 [200/0] via 10.1.1.1, 00:01:09

Byers#ping 197.201.128.1

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 197.201.128.1, timeout is 2 seconds:
!!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/8 ms

Byers#ping 152.86.75.1

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 152.86.75.1, timeout is 2 seconds:
!!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 36/36/40 ms

```

```

Frohike#show ip bgp | begin Network

      Network          Next Hop            Metric LocPrf Weight Path
*->i10.1.1.0/24    10.1.1.1                  0     100      0 i
*->i42.21.92.0/24  10.1.1.1                  0     100      0 912 i
*->i148.98.72.0/24 10.1.1.1                  0     100      0 405 i
*->i152.86.75.0/24 10.1.1.1                  0     100      0 405 i
*->i197.201.128.0   10.1.1.1                  0     100      0 912 i

```

```

Frohike#show ip route | begin Gateway

Gateway of last resort is not set

B    197.201.128.0/24 [200/0] via 10.1.1.1, 00:02:24

152.86.0.0/24 is subnetted, 1 subnets

B      152.86.75.0 [200/0] via 10.1.1.1, 00:02:24

42.0.0.0/24 is subnetted, 1 subnets

```

```
B      42.21.92.0 [200/0] via 10.1.1.1, 00:02:24  
  
10.0.0.0/24 is subnetted, 1 subnets  
  
C      10.1.1.0 is directly connected, Ethernet0  
  
148.98.0.0/24 is subnetted, 1 subnets  
  
B      148.98.72.0 [200/0] via 10.1.1.1, 00:02:24
```

```
Frohike#ping 42.21.92.1
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 42.21.92.1, timeout is 2 seconds:
```

```
!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/8 ms
```

```
Frohike#ping 152.86.75.1
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 152.86.75.1, timeout is 2 seconds:
```

```
!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 36/36/40 ms
```

Now that you can see the effects that the use of I-BGP full-mesh configurations, BGP synchronization, and next-hop-self commands have, it's time to move on to E-BGP peer configurations and look at some of the issues that you will encounter when working with E-BGP configurations.

E-BGP Peer Relationships

E-BGP peer relationships are, undoubtedly, the most common type of BGP peering relationship that most enterprise network professionals will encounter. Regardless of how many peers one BGP speaker has, only a few types of connections can occur between E-BGP peers.

- Directly connected peers— Peers that are directly connected; usually over a WAN connection between the customer and the service providers, or between transit peers.
- Indirectly connected peers— E-BGP peers that must cross one or more non-BGP-speaking routers to reach each other.

Configuring direct E-BGP connections is an extremely straightforward process involving only three steps.

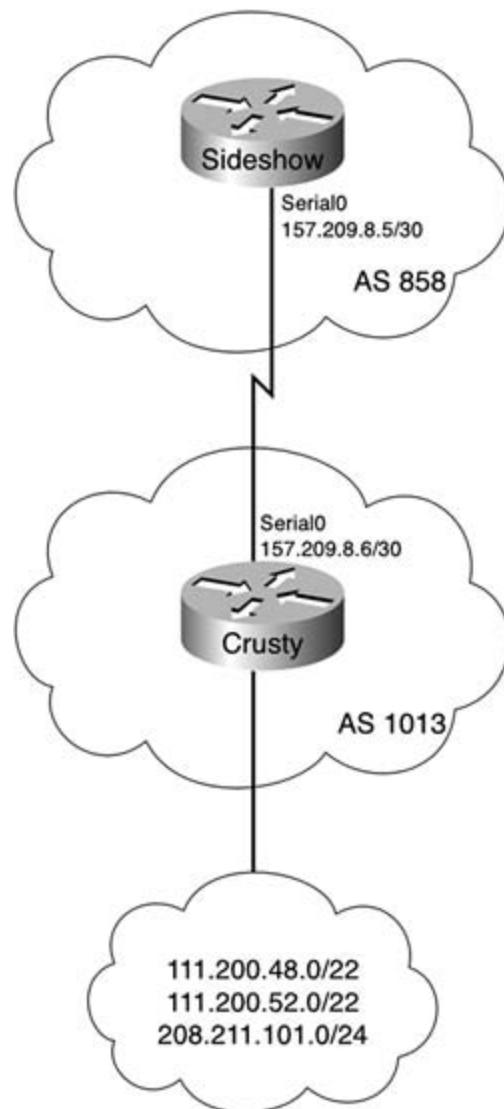
Step 1. Enable BGP routing using the router `bgp as-number` command.

Step 2. Configure BGP peers using the neighbor `ip-address remote-as remote-as-number` command. E-BGP peer relationships are formed if the AS number entered during the configuration of the neighbor command is not the same as locally configured AS number.

Step 3. (Optional) Specify the networks that the local peer is to advertise using the `network network [mask subnet-mask]` command. Similar to the EIGRP network command, the BGP network command specifies networks that the local peer will advertise; if those networks do not fall exactly between the classful boundaries, the subnet masks define those networks.

[Figure 8-8](#) shows an example of the direct E-BGP configuration between the Sideshow and Crusty routers.

Figure 8-8. Directly Connected E-BGP Peers



In this example, the Sideshow and Crusty routers form an E-BGP peer connection over a serial connection on the 157.209.8.4/30 network. The Sideshow router is in AS 858 and does not advertise BGP networks; the Crusty router belongs to AS 1013 and advertises networks 111.200.48.0/22, 111.200.52.0/22, and 208.211.101.0/24. [Example 8-48](#) shows the Sideshow router configuration and the routes as seen by the Sideshow router, and [Example 8-49](#) shows the configuration for the Crusty router.

Example 8-48. Sideshow Router Configuration

```
Sideshow#show run | begin bgp

router bgp 858

bgp log-neighbor-changes
```

```
neighbor 157.209.8.6 remote-as 1013  
no auto-summary
```

```
Sideshow#show ip bgp
```

```
BGP table version is 8, local router ID is 157.209.8.5
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 111.200.48.0/22	157.209.8.6	0		0	1013 i
*> 111.200.52.0/22	157.209.8.6	0		0	1013 i
*> 208.211.101.0	157.209.8.6	0		0	1013 i

Example 8-49. Crusty Router Configuration

```
Crusty#show run | begin bgp  
  
router bgp 1013  
  
bgp log-neighbor-changes  
  
network 111.200.48.0 mask 255.255.252.0  
  
network 111.200.52.0 mask 255.255.252.0  
  
network 208.211.101.0  
  
neighbor 157.209.8.5 remote-as 858  
  
no auto-summary
```

Exceeding BGP Limitations with E-BGP Multihop

Because the BGP-4 specification does not allow E-BGP speakers to form peer relationships unless they are directly connected, you must plan for indirect external BGP configurations. You need to know whether special design considerations are required for BGP to operate properly when the

peers must pass through other routers to form peer relationships and exchange update messages.

The `neighbor ip-address bgp multihop` command specifies that the remote peer specified by the `neighbor` statement is not directly connected. This command is used to connect E-BGP speakers that must traverse one or more hops to form a successful E-BGP session. The `neighbor ip-address bgp multihop` command uses the following syntax:

```
neighbor ip-address bgp multihop [number-of-hops]
```

To specify the number of hops that must be crossed to reach a neighbor (ranging from 1 to 255), or, if you are unsure of the number of hops required, you can accept the default value of 255, although the default is not always recommended because it might allow for suboptimal routing across long paths.

You must complete five steps to create successful E-BGP peering relationships between peers.

Step 1. Verify that the local and remote routers have routes to reach each other before configuring BGP using the `show ip route neighbor-ip-address` command.

Step 2. Enable the local BGP process using the `router bgp as-number` command.

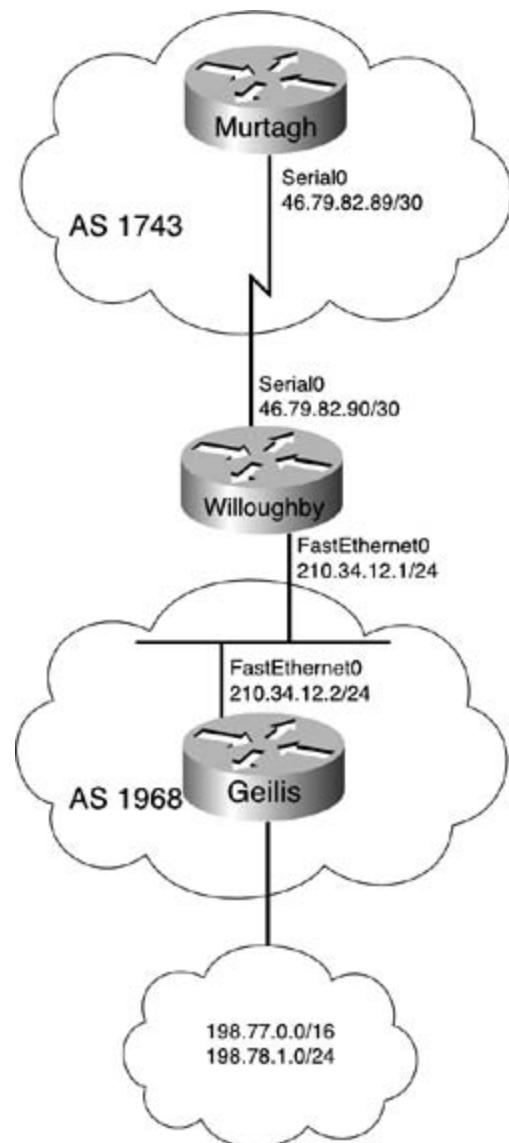
Step 3. Configure the remote peer's IP address and AS number using the `neighbor ip-address remote-as remote-as-number` command.

Step 4. Configure the networks that are to be advertised by the local peer using the `network` command.

Step 5. Enable E-BGP multihop using the `neighbor ip-address bgp multihop number-of-hops` command.

In the network shown in [Figure 8-9](#), for example, notice that the Murtagh and Geilis routers are indirectly connected by means of the Willoughby router. The Murtagh router belongs to AS 1743, and the Geilis router belongs to AS 1968, so they must be able to form an E-BGP peer relationship by sending BGP messages through the Willoughby router, which does not participate in BGP.

Figure 8-9. Running E-BGP Across Multiple Hops



This shows how the `ebgp-multihop` keyword was used to enable BGP routing between the Murtagh and Geilis routers. Notice how the `neighbor 210.34.12.2 ebgp-multihop 2` command is used in [Example 8-50](#) to specify that the Geilis router can be up to two hops away, and that a static route is used to tell the Murtagh router how to reach the 210.32.12.0/24 network, the route to the Geilis router.

Example 8-50. Murtagh Router Configuration

```
Murtagh#show run | begin bgp
router bgp 1743
  bgp log-neighbor-changes
```

```
neighbor 210.34.12.2 remote-as 1968
neighbor 210.34.12.2 ebgp-multipath 2
!
ip classless
ip route 210.34.12.0 255.255.255.0 46.79.82.90
```

To verify that the E-BGP multihop configuration is working, use the show ip bgp neighbor command (or show ip bgp neighbors | i external|state|hops for an abbreviated summary of E-BGP neighbors), and look for an established connection. [Example 8-51](#) shows the output of the show ip bgp neighbors and show ip bgp neighbors | i external|state|hops commands for the Murtagh router.

Example 8-51. show ip bgp neighbors Command Output

```
Murtagh#show ip bgp neighbors
BGP neighbor is 210.34.12.2,  remote AS 1968,  external link
  BGP version 4,  remote router ID 198.78.1.1
  BGP state = Established, up for 00:16:08
  Last read 00:00:08, hold time is 180, keepalive interval is 60 seconds
  Neighbor capabilities:
    Route refresh: advertised and received(old & new)
    Address family IPv4 Unicast: advertised and received
  Received 25 messages, 0 notifications, 0 in queue
  Sent 25 messages, 0 notifications, 0 in queue
  Route refresh request: received 0, sent 0
  Default minimum time between advertisement runs is 30 seconds
  For address family: IPv4 Unicast
    BGP table version 5, neighbor version 5
    Index 1, Offset 0, Mask 0x2
    2 accepted prefixes consume 72 bytes
```

```
Prefix advertised 0, suppressed 0, withdrawn 0

Number of NLRI's in the update sent: max 0, min 0

Connections established 2; dropped 1

Last reset 00:16:53, due to Peer closed the session

External BGP neighbor might be up to 2 hops away.

Connection state is ESTAB, I/O status: 1, unread input bytes: 0

Local host: 46.79.82.89, Local port: 179

Foreign host: 210.34.12.2, Foreign port: 11020

Byers#show ip bgp neighbors | i external|state|hops

BGP neighbor 210.34.12.2, remote AS 1968, external link

BGP state = Established, up for 00:16:08

External BGP neighbor might be up to 2 hops away.
```

If the `ebgp-meshgroup` keyword had not been used for each indirect E-BGP session, the `show ip bgp neighbors` command will show you several hints about the problem, as shown in [Example 8-52](#).

Example 8-52. Diagnosing Indirect E-BGP Peering Problems

```
Murtagh#show ip bgp neighbors

BGP neighbor is 210.34.12.2, remote AS 1968, external link

BGP version 4, remote router ID 0.0.0.0

BGP state = Idle

Last read 00:00:09, hold time is 180, keepalive interval is 60 seconds

Received 0 messages, 0 notifications, 0 in queue

Sent 0 messages, 0 notifications, 0 in queue

Route refresh request: received 0, sent 0

Default minimum time between advertisement runs is 30 seconds

For address family: IPv4 Unicast
```

```

BGP table version 1, neighbor version 0

Index 1, Offset 0, Mask 0x2

0 accepted prefixes consume 0 bytes

Prefix advertised 0, suppressed 0, withdrawn 0

Number of NLRI's in the update sent: max 0, min 0

Connections established 0; dropped 0

Last reset never

External BGP neighbor not directly connected.

No active TCP connection

```

For instance, the first highlighted line shows that the local BGP speaker is unaware of the remote peer's BGP router ID, indicating that the local router has never seen the remote peer's BGP router ID. Also, notice that the BGP session is in the Idle state, which generally indicates that there was a problem establishing a TCP session between the peers. No BGP messages have been sent or received from the remote peer, as indicated by the zero sent and received BGP messages, and no connections have been established or dropped. The reason for the problem is clearly displayed in the line "External BGP neighbor not directly connected." In addition, the final line of the command output clearly shows that there is no active TCP connection between the peers. If you are having problems connecting E-BGP-speaking routers, you should always use the show ip bgp neighbors command for help diagnosing error conditions. [Example 8-53](#) shows the configurations for the Willoughby and Geilis routers.

Example 8-53. Willoughby and Geilis Router Configurations

```

hostname Willoughby

!

interface Serial0
    ip address 46.79.82.90 255.255.255.252
    !
    interface FastEthernet0
        ip address 210.34.12.1 255.255.255.0
        !
        router ospf 1

```

```
network 46.79.82.88 0.0.0.3 area 0  
network 210.34.12.0 0.0.0.255 area 0
```

```
hostname Geilis  
!  
interface Loopback10  
ip address 198.77.1.1 255.255.0.0  
!  
interface Loopback20  
ip address 198.78.1.1 255.255.255.0  
!  
interface FastEthernet0  
ip address 210.34.12.2 255.255.255.0  
!  
router ospf 1  
network 210.34.12.0 0.0.0.255 area 0  
!  
router bgp 1968  
bgp log-neighbor-changes  
network 198.77.0.0 mask 255.255.0.0  
network 198.78.1.0  
neighbor 46.79.82.89 remote-as 1743  
neighbor 46.79.82.89 ebgp-multipath 2  
no auto-summary
```

Now that you have a practical view about how BGP is configured and how to troubleshoot BGP connection problems, it is time to examine how BGP interacts with other routing protocols, how it stores routes in the table, and how it can be configured to advertise local networks.

BGP and IGP Interaction

One thing that you must always remember when using BGP as your AS routing protocol is that, unlike distance-vector and link-state protocols such as OSPF and EIGRP, BGP is a path-vector routing protocol. It does not route packets based on hops, costs, or other metrics like IGP protocols; it routes based on AS paths. Keeping this in mind will save hours of troubleshooting when you notice BGP behaving differently than IGP protocols.

Keep in mind these rules when using BGP with other IGP protocols:

- BGP will not put routes that it cannot verify reachability for in the main IP routing table.
- For routers to successfully use BGP routes, they must always have a route to the next-hop IP address in the main IP routing table.
- Unless otherwise configured, BGP stores only the best path to a destination network in the main IP routing table. However, you can use the BGP maximum-paths command, discussed in [Chapter 9](#), to configure more than one path.
- BGP advertises only the best path to a destination network. You can control BGP path selection using BGP attributes, and you can control the best path selection process using certain Cisco IOS Software BGP configuration commands, which are discussed in [Chapter 9](#).
- BGP follows its own best path decision process to find the most efficient path; this path is stored in the main routing table.
- BGP forms peer relationships only with explicitly configured peers, and only advertises networks that it was explicitly configured to advertise.
- BGP does not redistribute its routes into IGPs unless explicitly configured to do so.
- BGP is an extremely customizable protocol; it can be as dynamic or static as it is configured to be. You can advertise and control route policies in a number of different ways.

Using BGP as a Routing Protocol

You can use BGP to complement your existing IGP protocols in several ways. The easiest way to design a BGP network is first to analyze your IP addressing, verifying that you have created a network design that allows for route aggregation and route table conservation. Suppose, for instance, that you are responsible for designing a national enterprise network, and that you have been assigned a /22 block of public IP addresses to use across that network. In this case, you have to decide where to put your primary data-center locations, how to allocate IP addresses to take advantage of your routing protocols. During this process, you must create policies that specify which router to filter, how route aggregation and summarization will be accomplished, and how these routes will be advertised (to internal peers, to external partners, and the Internet).

Assume that your company has decided to build four major data centers that will peer with two service providers for Internet routing, and that you will use OSPF for your internal IGP routing protocol. Also assume that you were assigned the 109.248.4.0/22 block of IP addresses and AS number 444. You can break that IP allocation into four /24 networks and spread those across the nation, with one /24 per data center. [Table 8-13](#) shows how you can break the /22 network into

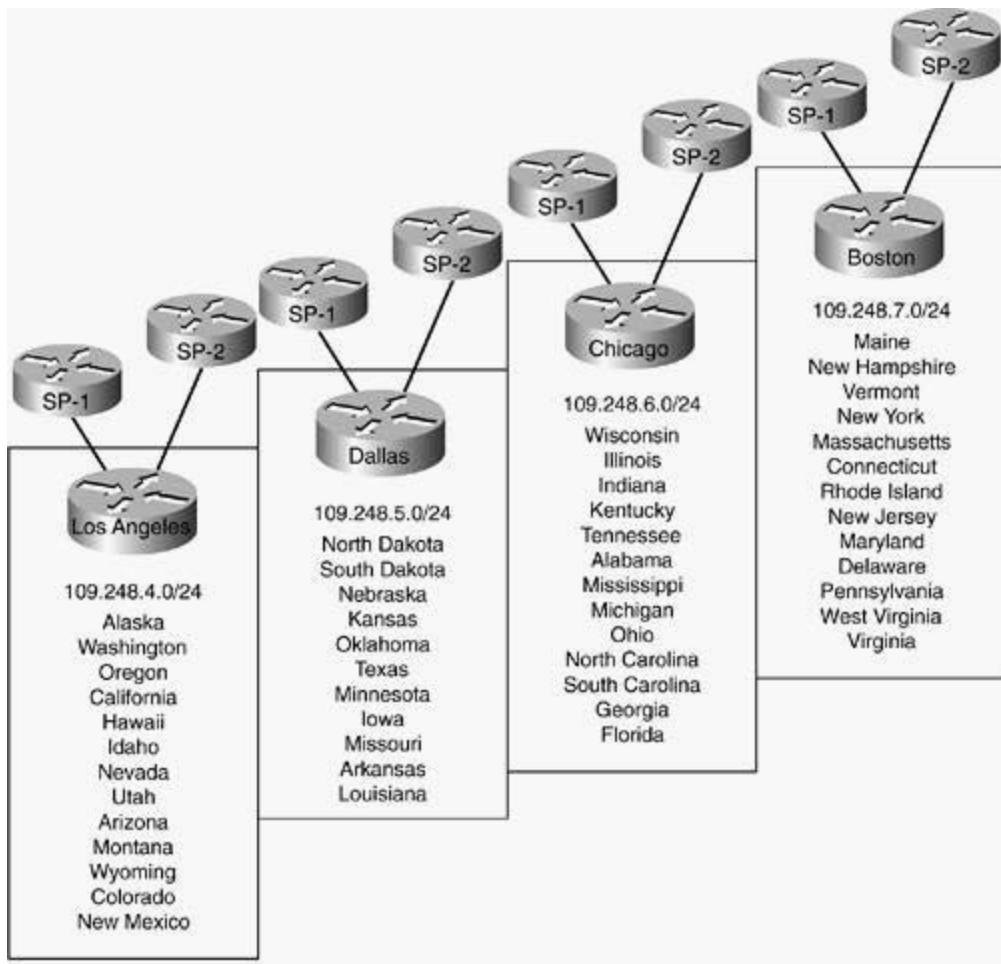
four /24 networks and spread them across the nation to sites in Los Angeles, Dallas, Chicago, and Boston.

Table 8-14. IP Addressing for a Nationwide Enterprise Network

Los Angeles	Dallas	Chicago	Boston
109.248.4.0/24	109.248.5.0/24	109.248.6.0/24	109.248.7.0/24

To provide hierarchical routing for your new network, you need to aggregate those addresses at each Internet border router and advertise the aggregate networks to each of the service providers at each data center. To provide carrier redundancy, each data center will require at least two E-BGP connections, and, to create a full I-BGP mesh, there will need to be an I-BGP connection between each of the Internet border routers inside of your autonomous system. To provide a successful design to your company, you have to make sure that the OSPF design sends its updates to the BGP routers, and that each of the Internet border routers has information about the routes it learned from the OSPF routing process. You need to do this so that, in the event that one of the border routers becomes unavailable, the other three routers can successfully advertise your network to the Internet. [Figure 8-10](#) shows a high-level example of how the autonomous system border routers in this example can be arranged to handle routes for each state for which the data center provides routing.

Figure 8-10. Autonomous System Border Router Arrangement for National Network with Four Data Centers



In this example, OSPF enables you to advertise and summarize the /27 or /28 networks that are used for smaller sites, using the OSPF ASBR routers to aggregate those smaller networks into /24 blocks that can be sent, through a firewall, to the Internet border routers, where they will be advertised to the Internet.

Now that you have an idea of how you can use BGP in a practical real-world example, let's look at how BGP uses the main IP routing table to store and advertise its routes, how IGPs learn BGP routes, and how to configure BGP to advertise different network types.

BGP and IP Routing Tables

In [Chapter 7](#), you saw a brief overview of how BGP used its tables to store and advertise routes, and you learned the process that BGP uses to update the main IP routing table so that the routes can be used to forward traffic. Now you will see how you need to configure BGP to perform these functions, and what you can do to control the routing policies.

How BGP Stores Routes

Before BGP advertises a route to a peer, it always checks the validity of the route. Therefore, if the route originated locally, BGP checks to see whether the route exists in the main IP routing table, or whether the route was received from a peering router. It verifies that it can reach the next hop for that route. If either of these cases is not true, the router only stores the route in its BGP routing table, as you can see using the `show ip bgp` command, and the router does not advertise the route to any of its peers or store it in the main IP routing table.

NOTE

Always check your typing before troubleshooting BGP. Cisco IOS Software enables you to type any valid IP address as a network using the `network` command. If you accidentally mistype a network address (for instance `10.1.1.1 mask 255.255.255.0`, rather than `10.1.1.0 mask 255.255.255.0`), the router will accept the network configuration, and you might spend time trying to figure out why BGP is not advertising the `10.1.1.0/24` network, when you really configured it to advertise the `10.1.1.1/24` network.

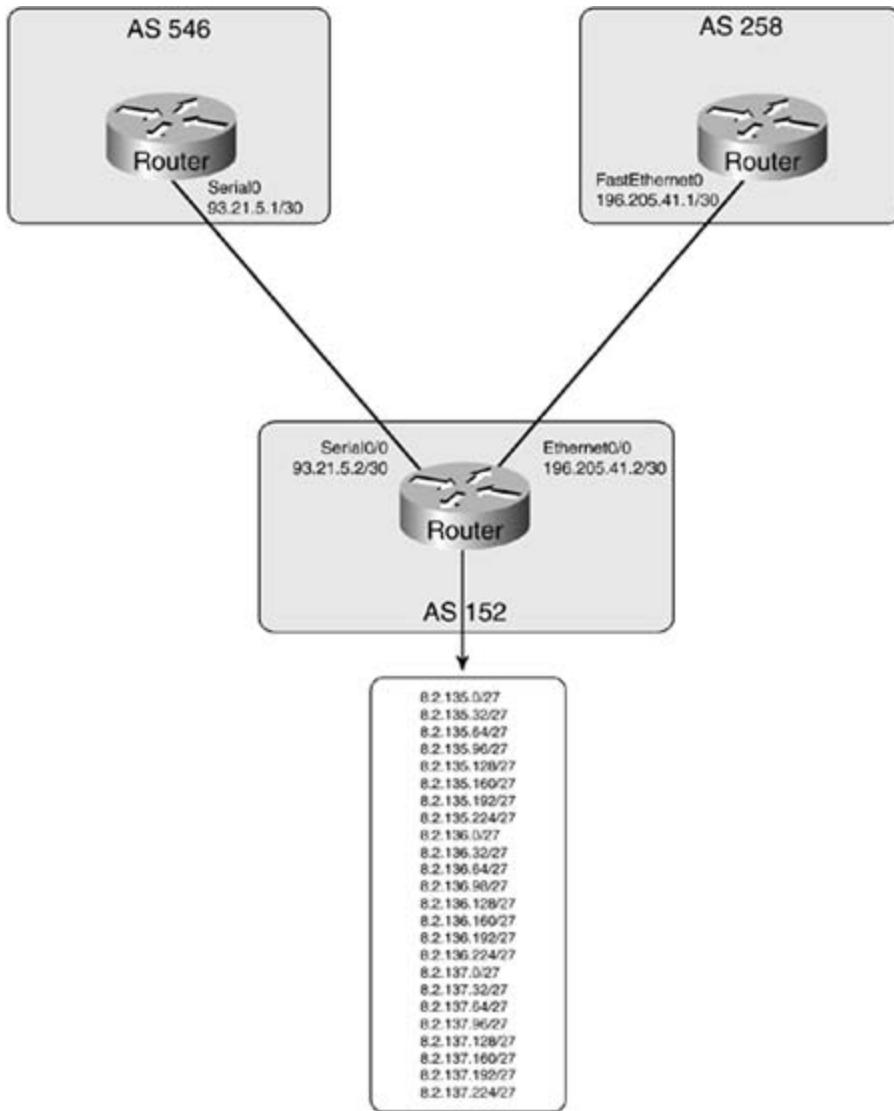
Advertising Local Networks

There are quite a few ways to advertise networks to BGP peers; the command that you use to advertise the networks depends on a few variables. For example, you might want BGP to control exactly which networks BGP advertises to its remote peers. You might want to advertise any network that the router is directly connected to, or you might want to advertise static routes to networks, to "nail them down" so that when the path to that network changes, the route that BGP advertises to its upstream peers stays the same. Or, under certain circumstances, you might want to advertise an entire IGP routing process to the remote peers. BGP enables you to control how you advertise networks, by giving you different options on route origination. These options include the following:

- Using the `network` command
- Redistributing connected networks
- Redistributing static routes
- Redistributing IGP routes

This section shows you how to use the commands listed here to advertise networks to BGP peers. The network shown in [Figure 8-11](#) is used for the following examples.

Figure 8-11. Reservoir Network



Advertising Connected Networks

As previously mentioned, if you have a need to dynamically advertise directly connected networks, you might choose to redistribute connected networks into the local BGP process, which will limit the amount of static configuration. Take a look at the router in [Example 8-54](#), for instance; more than 20 loopback interfaces need to be advertised using BGP.

Example 8-54. Advertising Many Directly Connected Networks

```
Black#show ip interface brief
```

Interface	IP-Address	OK?	Method	Status	Protocol
Ethernet0/0	196.205.41.2	YES	manual	up	

Serial0/0	93.21.5.2	YES manual up	up
Loopback2	8.2.135.1	YES manual up	up
Loopback3	8.2.135.33	YES manual up	up
Loopback4	8.2.135.65	YES manual up	up
Loopback5	8.2.135.97	YES manual up	up
Loopback6	8.2.135.129	YES manual up	up
Loopback7	8.2.135.161	YES manual up	up
Loopback8	8.2.135.193	YES manual up	up
Loopback9	8.2.135.225	YES manual up	up
Loopback10	8.2.136.1	YES manual up	up
Loopback11	8.2.136.33	YES manual up	up
Loopback12	8.2.136.65	YES manual up	up
Loopback13	8.2.136.97	YES manual up	up
Loopback14	8.2.136.129	YES manual up	up
Loopback15	8.2.136.161	YES manual up	up
Loopback16	8.2.136.193	YES manual up	up
Loopback17	8.2.136.225	YES manual up	up
Loopback18	8.2.137.1	YES manual up	up
Loopback19	8.2.137.33	YES manual up	up
Loopback20	8.2.137.65	YES manual up	up
Loopback21	8.2.137.97	YES manual up	up
Loopback22	8.2.137.129	YES manual up	up
Loopback23	8.2.137.161	YES manual up	up
Loopback24	8.2.137.193	YES manual up	up
Loopback25	8.2.137.225	YES manual up	up

You could advertise all these networks using the BGP network command, which would require quite a bit of configuration and no dynamic route additions or subtractions, and allow for plenty of room for typos, as shown in [Example 8-55](#).

Example 8-55. Using the network Command to Advertise Networks

```
Black#show run | begin bgp

router bgp 152

bgp log-neighbor-changes

network 8.2.135.0 mask 255.255.255.224

network 8.2.135.32 mask 255.255.255.224

network 8.2.135.64 mask 255.255.255.224

network 8.2.135.96 mask 255.255.255.224

network 8.2.135.128 mask 255.255.255.224

network 8.2.135.160 mask 255.255.255.224

network 8.2.135.192 mask 255.255.255.224

network 8.2.135.224 mask 255.255.255.224

network 8.2.136.0 mask 255.255.255.224

network 8.2.136.32 mask 255.255.255.224

network 8.2.136.64 mask 255.255.255.224

network 8.2.136.98 mask 255.255.255.224

network 8.2.136.128 mask 255.255.255.224

network 8.2.136.160 mask 255.255.255.224

network 8.2.136.192 mask 255.255.255.224

network 8.2.136.224 mask 255.255.255.224

network 8.2.137.0 mask 255.255.255.224

network 8.2.137.32 mask 255.255.255.224

network 8.2.137.64 mask 255.255.255.224

network 8.2.137.96 mask 255.255.255.224

network 8.2.137.128 mask 255.255.255.224

network 8.2.137.160 mask 255.255.255.224
```

```

network 8.2.137.192 mask 255.255.255.224
network 8.2.137.224 mask 255.255.255.224
neighbor 93.21.5.1 remote-as 546
neighbor 196.205.41.1 remote-as 258

```

Black#**show ip bgp**

```

BGP table version is 32, local router ID is 8.2.137.225
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 8.2.135.0/27	0.0.0.0	0		32768	i
*> 8.2.135.32/27	0.0.0.0	0		32768	i
*> 8.2.135.64/27	0.0.0.0	0		32768	i
*> 8.2.135.96/27	0.0.0.0	0		32768	i
*> 8.2.135.128/27	0.0.0.0	0		32768	i
*> 8.2.135.160/27	0.0.0.0	0		32768	i
*> 8.2.135.192/27	0.0.0.0	0		32768	i
*> 8.2.135.224/27	0.0.0.0	0		32768	i
*> 8.2.136.0/27	0.0.0.0	0		32768	i
*> 8.2.136.32/27	0.0.0.0	0		32768	i
*> 8.2.136.64/27	0.0.0.0	0		32768	i
*> 8.2.136.128/27	0.0.0.0	0		32768	i
*> 8.2.136.160/27	0.0.0.0	0		32768	i
*> 8.2.136.192/27	0.0.0.0	0		32768	i
*> 8.2.136.224/27	0.0.0.0	0		32768	i
*> 8.2.137.0/27	0.0.0.0	0		32768	i
*> 8.2.137.32/27	0.0.0.0	0		32768	i
*> 8.2.137.64/27	0.0.0.0	0		32768	i

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 8.2.137.96/27	0.0.0.0	0		32768	i
*> 8.2.137.128/27	0.0.0.0	0		32768	i
*> 8.2.137.160/27	0.0.0.0	0		32768	i
*> 8.2.137.192/27	0.0.0.0	0		32768	i
*> 8.2.137.224/27	0.0.0.0	0		32768	i

Alternatively, you could use the redistribute connected command to tell BGP to automatically redistribute all directly connected networks, as shown in [Example 8-56](#).

Example 8-56. Using the redistribute connected Command

```
Black#show run | begin bgp

router bgp 152

no synchronization

bgp log-neighbor-changes

redistribute connected

neighbor 93.21.5.1 remote-as 546

neighbor 196.205.41.1 remote-as 258
```

```
Black#show ip bgp
```

BGP table version is 5, local router ID is 8.2.137.225

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 8.0.0.0	0.0.0.0	0		32768	?
*> 93.0.0.0	0.0.0.0	0		32768	?
*> 196.205.41.0	0.0.0.0	0		32768	?

Notice that when you use the redistribute connected command, as in the preceding example, BGP automatically summarizes networks at their classful boundaries. It is fairly unusual to have networks that can be summarized on their classful network boundaries; to overcome the default BGP behavior, you can use the no auto-summary command to tell BGP not to summarize networks, as shown in [Example 8-57](#).

Example 8-57. Using the BGP no auto-summary Command

```
Black#show run | begin bgp

router bgp 152

bgp log-neighbor-changes

redistribute connected

neighbor 93.21.5.1 remote-as 546

neighbor 196.205.41.1 remote-as 258

no auto-summary
```

```
Black#show ip bgp

BGP table version is 28, local router ID is 8.2.137.225

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          Next Hop            Metric LocPrf Weight Path
* > 1.1.1.1/32        0.0.0.0                  0        32768  ?
* > 8.2.135.0/27      0.0.0.0                  0        32768  ?
* > 8.2.135.32/27     0.0.0.0                  0        32768  ?
* > 8.2.135.64/27     0.0.0.0                  0        32768  ?
* > 8.2.135.96/27     0.0.0.0                  0        32768  ?
* > 8.2.135.128/27    0.0.0.0                  0        32768  ?
* > 8.2.135.160/27    0.0.0.0                  0        32768  ?
* > 8.2.135.192/27    0.0.0.0                  0        32768  ?
* > 8.2.135.224/27    0.0.0.0                  0        32768  ?
```

*> 8.2.136.0/27	0.0.0.0	0	32768 ?		
*> 8.2.136.32/27	0.0.0.0	0	32768 ?		
*> 8.2.136.64/27	0.0.0.0	0	32768 ?		
*> 8.2.136.96/27	0.0.0.0	0	32768 ?		
*> 8.2.136.128/27	0.0.0.0	0	32768 ?		
*> 8.2.136.160/27	0.0.0.0	0	32768 ?		
*> 8.2.136.192/27	0.0.0.0	0	32768 ?		
*> 8.2.136.224/27	0.0.0.0	0	32768 ?		
*> 8.2.137.0/27	0.0.0.0	0	32768 ?		
Network	Next Hop	Metric	LocPrf	Weight	Path
*> 8.2.137.32/27	0.0.0.0	0	32768 ?		
*> 8.2.137.64/27	0.0.0.0	0	32768 ?		
*> 8.2.137.96/27	0.0.0.0	0	32768 ?		
*> 8.2.137.128/27	0.0.0.0	0	32768 ?		
*> 8.2.137.160/27	0.0.0.0	0	32768 ?		
*> 8.2.137.192/27	0.0.0.0	0	32768 ?		
*> 8.2.137.224/27	0.0.0.0	0	32768 ?		
*> 93.21.5.0/30	0.0.0.0	0	32768 ?		
*> 196.205.41.0/30	0.0.0.0	0	32768 ?		

Advertising Static Routes

One way to make BGP announce very stable routes to the Internet is to "nail the routes down" using static routes to null0 with a high administrative distance. This causes the router to advertise the network specified by the static route to its neighbors. Because the static route to null0 has a high administrative distance (such as 253), any routes received from other routing protocols are preferred for use in the main IP routing table. Dynamic routes, learned from IGP neighbors, can change or even disappear. BGP will still advertise the "nailed-down" networks, without interruption, because of the static routes. [Example 8-58](#) shows how you use the redistribute static command, static routes to null0, and the no auto-summary command to create stable Internet-facing routes.

Example 8-58. Redistributing Static Routes

```
Black#show run | begin bgp

router bgp 152
  no synchronization
  bgp log-neighbor-changes
  redistribute static
    neighbor 93.21.5.1 remote-as 546
    neighbor 196.205.41.1 remote-as 258
  no auto-summary
!
ip classless
  ip route 8.2.135.0 255.255.255.224 Null0 254
  ip route 8.2.135.32 255.255.255.224 Null0 254
  ip route 8.2.135.64 255.255.255.224 Null0 254
  ip route 8.2.135.96 255.255.255.224 Null0 254
  ip route 8.2.135.128 255.255.255.224 Null0 254
  ip route 8.2.135.160 255.255.255.224 Null0 254
  ip route 8.2.135.192 255.255.255.224 Null0 254
  ip route 8.2.135.224 255.255.255.224 Null0 254
  ip route 8.2.136.0 255.255.255.224 Null0 254
  ip route 8.2.136.32 255.255.255.224 Null0 254
  ip route 8.2.136.64 255.255.255.224 Null0 254
  ip route 8.2.136.96 255.255.255.224 Null0 254
  ip route 8.2.136.128 255.255.255.224 Null0 254
  ip route 8.2.136.160 255.255.255.224 Null0 254
  ip route 8.2.136.192 255.255.255.224 Null0 254
  ip route 8.2.136.224 255.255.255.224 Null0 254
```

```
ip route 8.2.137.0 255.255.255.224 Null0 254
ip route 8.2.137.32 255.255.255.224 Null0 254
ip route 8.2.137.64 255.255.255.224 Null0 254
ip route 8.2.137.96 255.255.255.224 Null0 254
ip route 8.2.137.128 255.255.255.224 Null0 254
ip route 8.2.137.160 255.255.255.224 Null0 254
ip route 8.2.137.192 255.255.255.224 Null0 254
ip route 8.2.137.224 255.255.255.224 Null0 254
```

Black#**show ip bgp**

BGP table version is 25, local router ID is 1.1.1.1

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 8.2.135.0/27	0.0.0.0	0		32768	?
*> 8.2.135.32/27	0.0.0.0	0		32768	?
*> 8.2.135.64/27	0.0.0.0	0		32768	?
*> 8.2.135.96/27	0.0.0.0	0		32768	?
*> 8.2.135.128/27	0.0.0.0	0		32768	?
*> 8.2.135.160/27	0.0.0.0	0		32768	?
*> 8.2.135.192/27	0.0.0.0	0		32768	?
*> 8.2.135.224/27	0.0.0.0	0		32768	?
*> 8.2.136.0/27	0.0.0.0	0		32768	?
*> 8.2.136.32/27	0.0.0.0	0		32768	?
*> 8.2.136.64/27	0.0.0.0	0		32768	?
*> 8.2.136.96/27	0.0.0.0	0		32768	?
*> 8.2.136.128/27	0.0.0.0	0		32768	?
*> 8.2.136.160/27	0.0.0.0	0		32768	?

*> 8.2.136.192/27	0.0.0.0	0	32768 ?
*> 8.2.136.224/27	0.0.0.0	0	32768 ?
*> 8.2.137.0/27	0.0.0.0	0	32768 ?
*> 8.2.137.32/27	0.0.0.0	0	32768 ?
Network	Next Hop	Metric	LocPrf
*> 8.2.137.64/27	0.0.0.0	0	32768 ?
*> 8.2.137.96/27	0.0.0.0	0	32768 ?
*> 8.2.137.128/27	0.0.0.0	0	32768 ?
*> 8.2.137.160/27	0.0.0.0	0	32768 ?
*> 8.2.137.192/27	0.0.0.0	0	32768 ?
*> 8.2.137.224/27	0.0.0.0	0	32768 ?

Notice that each of the routes is stored in the BGP table ready to be advertised to any remote peers; if an IGP route exists, the router forwards all traffic for the networks specified by the redistribute static command on to the correct destination, allowing IGP routes to change or disappear with no BGP service interruption. Just keep in mind that if you use a static route to null0, you still have to have a route to the destination network with a lower administrative distance; otherwise, the router actually forwards the routes to interface null0—the bit bucket.

Advertising Routes Learned via IGPs

The last, and least desirable, way to locally originate routes into BGP is to redistribute IGP routes into BGP dynamically. This is not a recommended practice because IGP routes tend to change rather often, and you (and anyone that you peer with) will not want BGP to constantly add, change, or remove IGP redistributed routes on a regular basis. However, you can configure BGP to have IGP routes redistributed directly into BGP by using the `redistribute protocol` command. [Example 8-59](#) shows how routes advertised by an OSPF process are dynamically redistributed into BGP. This example shows the routes received by OSPF, the OSPF/BGP configuration, and the final BGP table.

Example 8-59. Redistributing IGP Routes into BGP

```
Black#show run | begin ospf
router ospf 1
  log adjacency-changes
```

```
network 8.2.138.0 0.0.0.3 area 0
```

```
Black#show ip route
```

```
196.205.41.0/30 is subnetted, 1 subnets
C      196.205.41.0 is directly connected, Ethernet0/0
          8.0.0.0/8 is variably subnetted, 25 subnets, 2 masks
O        8.2.137.129/32 [110/65] via 8.2.138.2, 00:02:29, Serial0/1
O        8.2.136.129/32 [110/65] via 8.2.138.2, 00:02:29, Serial0/1
O        8.2.135.129/32 [110/65] via 8.2.138.2, 00:02:29, Serial0/1
O        8.2.137.161/32 [110/65] via 8.2.138.2, 00:02:29, Serial0/1
O        8.2.136.161/32 [110/65] via 8.2.138.2, 00:02:30, Serial0/1
O        8.2.135.161/32 [110/65] via 8.2.138.2, 00:02:30, Serial0/1
O        8.2.137.193/32 [110/65] via 8.2.138.2, 00:02:30, Serial0/1
O        8.2.136.193/32 [110/65] via 8.2.138.2, 00:02:30, Serial0/1
O        8.2.135.193/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.137.225/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.136.225/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.135.225/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
C      8.2.138.0/30 is directly connected, Serial0/1
O        8.2.137.1/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.136.1/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.135.1/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.137.33/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.136.33/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.135.33/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.137.65/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.136.65/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.135.65/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
O        8.2.137.97/32 [110/65] via 8.2.138.2, 00:02:31, Serial0/1
```

```

O      8.2.136.97/32 [110/65] via 8.2.138.2, 00:02:32, Serial0/1
O      8.2.135.97/32 [110/65] via 8.2.138.2, 00:02:32, Serial0/1
      93.0.0.0/30 is subnetted, 1 subnets
C      93.21.5.0 is directly connected, Serial0/0

Black#show run | begin bgp

router bgp 152
  no synchronization
  bgp log-neighbor-changes
  redistribute ospf 1 match internal external 1 external 2
  neighbor 93.21.5.1 remote-as 546
  neighbor 196.205.41.1 remote-as 258
  no auto-summary

Black#show ip bgp

BGP table version is 26, local router ID is 1.1.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

      Network          Next Hop           Metric LocPrf Weight Path
* > 8.2.135.1/32    8.2.138.2        65      32768  ?
* > 8.2.135.33/32   8.2.138.2        65      32768  ?
* > 8.2.135.65/32   8.2.138.2        65      32768  ?
* > 8.2.135.97/32   8.2.138.2        65      32768  ?
* > 8.2.135.129/32  8.2.138.2        65      32768  ?
* > 8.2.135.161/32  8.2.138.2        65      32768  ?
* > 8.2.135.193/32  8.2.138.2        65      32768  ?
* > 8.2.135.225/32  8.2.138.2        65      32768  ?
* > 8.2.136.1/32    8.2.138.2        65      32768  ?
* > 8.2.136.33/32   8.2.138.2        65      32768  ?
* > 8.2.136.65/32   8.2.138.2        65      32768  ?

```

```

*> 8.2.136.97/32      8.2.138.2          65        32768 ?
*> 8.2.136.129/32    8.2.138.2          65        32768 ?
*> 8.2.136.161/32    8.2.138.2          65        32768 ?
*> 8.2.136.193/32    8.2.138.2          65        32768 ?
*> 8.2.136.225/32    8.2.138.2          65        32768 ?
*> 8.2.137.1/32       8.2.138.2          65        32768 ?
*> 8.2.137.33/32     8.2.138.2          65        32768 ?

      Network           Next Hop          Metric LocPrf Weight Path
*> 8.2.137.65/32     8.2.138.2          65        32768 ?
*> 8.2.137.97/32     8.2.138.2          65        32768 ?
*> 8.2.137.129/32    8.2.138.2          65        32768 ?
*> 8.2.137.161/32    8.2.138.2          65        32768 ?
*> 8.2.137.193/32    8.2.138.2          65        32768 ?
*> 8.2.137.225/32    8.2.138.2          65        32768 ?
*> 8.2.138.0/30       0.0.0.0            0         32768 ?

```

Notice in the preceding example that redistribution between IGP and BGP is a fairly straightforward process, only requiring one or two commands (depending on your auto-summary requirements). However, the amount of routes redistributed into BGP could be rather large, and the routes will only be as stable as the networks that the IGPs are advertising. It is best to save this command for when absolutely necessary.

Lab 14: BGP Routing

As you have learned in this chapter, there are many ways to use BGP in a production network; the most common use is to use BGP to multihome a network to two or more service providers for Internet access. The following lab concentrates on the different BGP connection types and provides an application for BGP route testing using Voice over IP (VoIP).

Lab Exercise

In this lab, you configure BGP peering relationships between the "I-Scream for Coffee" 32-flavor network and use the BGP routing as a backbone for routing between the external networks hosted by the Mint and Chocolate routers in autonomous systems 203 and 507, and the internal networks hosted by the Vanilla, Strawberry, Latte, and Americano routers in AS 409. To test your skill in BGP routing, you have to send test calls between the phones on the Chocolate and Latte routers.

Lab Objectives

- Use E-BGP and I-BGP with associated commands to perform routing between autonomous systems.
- Allow BGP routes to pass through access lists.
- Configure BGP around IGP routers, without enabling BGP on all routers.
- Use the routes provided by BGP to make test calls over phones connected between routers in different autonomous systems.

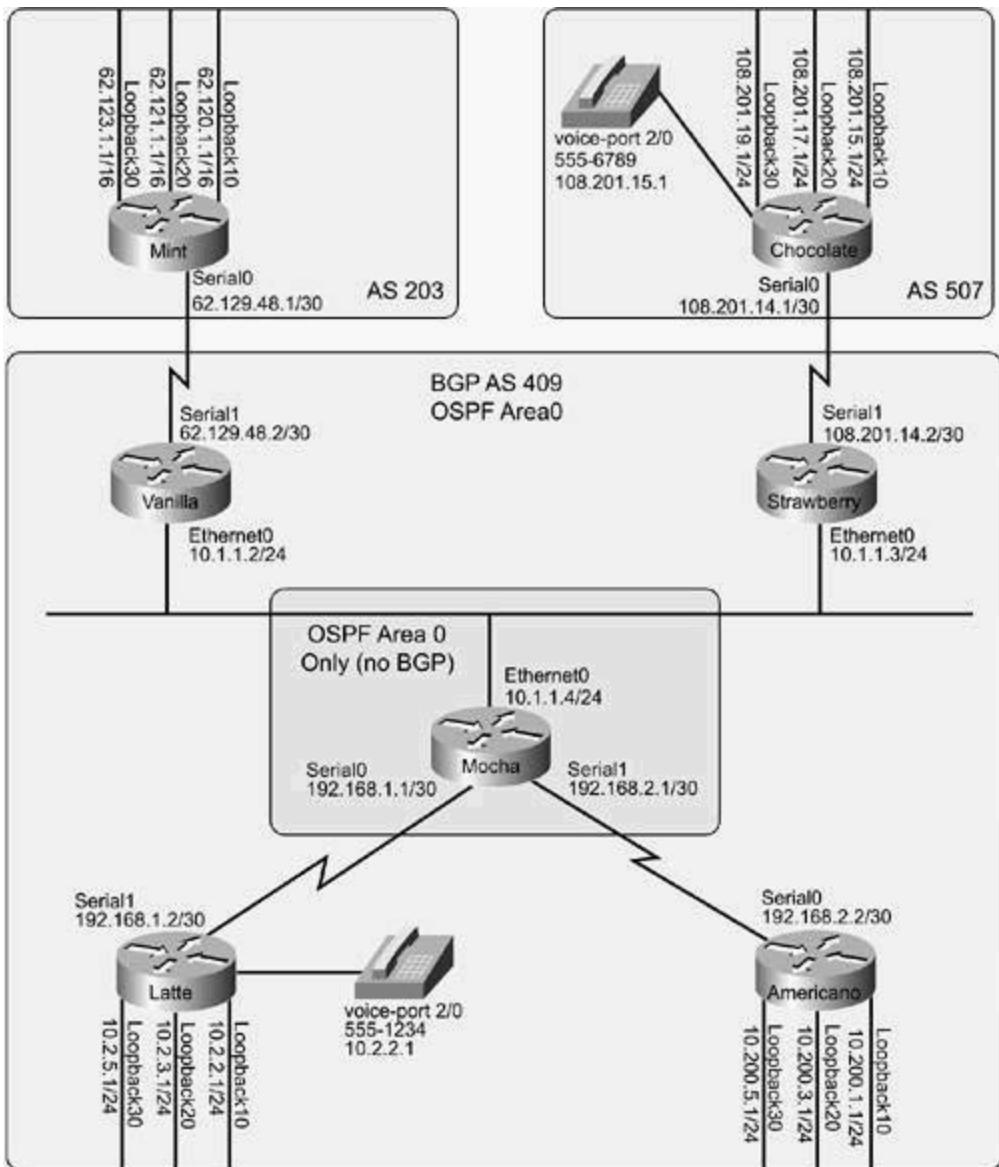
Equipment Needed

- Seven Cisco routers (two with voice modules to allow for VoIP testing).
- Six routers will require only one or two serial interfaces, and three routers will require serial and Ethernet or Token Ring interfaces.
- One hub, switch, or MSAU, which is required to connect the three multiaccess routers.

Physical Layout and Prestaging

- Cable the routers as shown in [Figure 8-12](#). The Mint, Chocolate, Vanilla, and Strawberry routers can be connected using back-to-back serial cables.

Figure 8-12. The I-Scream for Coffee Network



- The Vanilla, Strawberry, and Mocha routers require back-to-back serial and Ethernet (or Token Ring) connections.
- The Mocha, Latte, and Americano routers also require back-to-back serial connections.
- Configure all IP addresses on the loopback, serial, and Ethernet interfaces, as shown in [Figure 8-12](#).
- Enable OSPF routing on all routers except for Mint and Chocolate; with the exception of the loopback interfaces, all interfaces on these routers should belong to OSPF area 0. Make sure OSPF advertisements are not sent out non-OSPF interfaces.

To successfully complete this lab, follow these steps:

Step 1. Configure E-BGP peering sessions between the Mint and Vanilla routers; assign the Mint router to AS 203 and the Vanilla router to AS 409. After configuring BGP on the Mint and Vanilla routers, configure BGP on the Chocolate and Strawberry routers. Put the

Chocolate router in AS 507 and the Strawberry router in AS 409. Advertise all external loopback interfaces from AS 203 and AS 507, using BGP without using the network command. Do not allow BGP routers to perform auto summarization. Test the BGP router configurations using the show ip bgp and show ip bgp summary commands. To verify TCP reachability for the sessions, use the show ip bgp neighbors and show tcp brief all commands.

Step 2. Configure an I-BGP connection between the Strawberry and Vanilla routers, and verify that the Mint, Vanilla, Chocolate, and Strawberry routers can all reach each other's BGP routes.

Step 3. Configure I-BGP between the Vanilla, Latte, and Americano routers and the Strawberry, Latte, and Americano routers. Configure the Latte and Americano routers to advertise their loopback and serial IP addresses into BGP. Verify that all BGP routers can reach all other routers.

Step 4. Test the configuration using an application. To do this, make voice calls between the Chocolate and Latte routers. To configure VoIP on the Chocolate and Latte routers, create dial peers, add destination patterns and an IP address or physical port, and then dial from the phones. (For more information on VoIP configuration, refer to *CCIE Practical Studies*, Volume I.)

Lab Walkthrough

After cabling all the routers, verify connectivity using the show cdp neighbors and show ip interface brief commands; this will save a lot of time troubleshooting cabling and clock rate problems. After verifying Layer 2 connectivity, assign IP addresses to each of the routers using the information from [Figure 8-12](#). After assigning all IP addresses, verify Layer 3 connectivity between directly connected networks using the ping command. Now that you have verified that all routers can reach each other, enable OSPF routing on all routers and put all of their interfaces in area 0. Each router should use the nonloopback interface with the highest IP address as the OSPF router ID. After enabling OSPF, verify that all routers have routes to all other OSPF routers using the show ip route, show ip ospf neighbors, and show ip ospf interfaces commands, and verify that they can ping each other before proceeding to Step 1.

Step 1. Configure E-BGP peering sessions between the Mint and Vanilla routers; assign the Mint router to AS 203 and the Vanilla router to AS 409. After configuring BGP on the Mint and Vanilla routers, configure BGP on the Chocolate and Strawberry routers. Put the Chocolate router in AS 507 and the Strawberry router in AS 409. Advertise all external loopback interfaces from AS 203 and AS 507, using BGP without using the network command. Do not allow BGP routers to perform auto summarization. Test the BGP router configurations using the show ip bgp and show ip bgp summary commands. To verify TCP reachability for the sessions, use the show ip bgp neighbors and show tcp brief all commands. [Example 8-60](#) shows the configuration for the Mint and Vanilla routers, and [Example 8-61](#) shows the configuration for the Chocolate and Strawberry routers.

Example 8-60. BGP Configuration for the Mint and Vanilla Routers

```
Mint#show run | begin bgp  
  
router bgp 203
```

```
no synchronization

bgp log-neighbor-changes

redistribute connected

neighbor 62.129.48.2 remote-as 409

no auto-summary
```

```
Vanilla#show run | begin bgp
```

```
router bgp 409

no synchronization

bgp log-neighbor-changes

neighbor 62.129.48.1 remote-as 203

no auto-summary
```

```
Vanilla#show ip bgp
```

```
BGP table version is 17, local router ID is 62.129.48.6
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 62.120.0.0/16	62.129.48.1	0		0	203 ?
*> 62.121.0.0/16	62.129.48.1	0		0	203 ?
*> 62.123.0.0/16	62.129.48.1	0		0	203 ?
*> 62.129.48.0/30	62.129.48.1	0		0	203 ?

Example 8-61. BGP Configuration for the Chocolate and Strawberry Routers

```
Chocolate#show run | begin bgp
```

```
router bgp 507

no synchronization
```

```

bgp log-neighbor-changes

redistribute connected

neighbor 108.201.14.2 remote-as 409

no auto-summary

```

```

Strawberry#show run | begin bgp

router bgp 409

no synchronization

bgp log-neighbor-changes

neighbor 108.201.14.1 remote-as 507

no auto-summary

```

```

Strawberry#show ip bgp

BGP table version is 11, local router ID is 108.201.14.10

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
Origin codes: i - IGP, e - EGP, ? - incomplete

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 108.201.14.0/30	108.201.14.1	0		0	507 ?
*> 108.201.15.0/24	108.201.14.1	0		0	507 ?
*> 108.201.17.0/24	108.201.14.1	0		0	507 ?
*> 108.201.19.0/24	108.201.14.1	0		0	507 ?

Step 2. Configure an I-BGP connection between the Strawberry and Vanilla routers, and verify that the Mint, Vanilla, Chocolate, and Strawberry routers can all reach each other's BGP routes. [Example 8-62](#) shows how I-BGP was configured on the Vanilla and Strawberry routers, and the routes that are exchanged between those routers.

Example 8-62. I-BGP Configuration for the Strawberry and Vanilla Routers

```

Strawberry(config)#router bgp 409
Strawberry(config-router)#neighbor 10.1.1.2 remote-as 409
Strawberry(config-router)#neighbor 10.1.1.2 next-hop-self
Strawberry#show ip bgp | begin Network

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i62.120.0.0/16	10.1.1.2	0	100	0	203 ?
*>i62.121.0.0/16	10.1.1.2	0	100	0	203 ?
*>i62.123.0.0/16	10.1.1.2	0	100	0	203 ?
*>i62.129.48.0/30	10.1.1.2	0	100	0	203 ?
*> 108.201.14.0/30	108.201.14.1	0		0	507 ?
*> 108.201.15.0/24	108.201.14.1	0		0	507 ?
*> 108.201.17.0/24	108.201.14.1	0		0	507 ?
*> 108.201.19.0/24	108.201.14.1	0		0	507 ?

```

Vanilla(config)#router bgp 409
Vanilla(config-router)#neighbor 10.1.1.3 remote-as 409
Vanilla(config-router)#neighbor 10.1.1.3 next-hop-self
Vanilla#show ip bgp | begin Network

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 62.120.0.0/16	62.129.48.1	0		0	203 ?
*> 62.121.0.0/16	62.129.48.1	0		0	203 ?
*> 62.123.0.0/16	62.129.48.1	0		0	203 ?
*> 62.129.48.0/30	62.129.48.1	0		0	203 ?
*>i108.201.14.0/30	10.1.1.3	0	100	0	507 ?
*>i108.201.15.0/24	10.1.1.3	0	100	0	507 ?
*>i108.201.17.0/24	10.1.1.3	0	100	0	507 ?
*>i108.201.19.0/24	10.1.1.3	0	100	0	507 ?

The preceding example also demonstrated how the neighbor *ip-address* next-hop-self command was used to alter the NEXT_HOP attribute for routes passed between the I-BGP peers. Also, notice that after configuring BGP routing between the Vanilla and Strawberry routers, even though the routers have valid routes in their BGP tables, the Vanilla router cannot ping the Chocolate router's networks, and the Strawberry router cannot ping the Mint router's networks, as shown here:

```
Vanilla#ping 108.201.14.1
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 108.201.14.1, timeout is 2 seconds:
```

```
.....
```

```
Success rate is 0 percent (0/5)
```

```
Strawberry#ping 62.129.48.1
```

```
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 62.129.48.1, timeout is 2 seconds:
```

```
.....
```

```
Success rate is 0 percent (0/5)
```

```
Strawberry#
```

After verifying that the Mint router could ping the Vanilla router and that the Strawberry router could ping the Chocolate router, the problem is identified on the Chocolate (or Mint, whichever you look at first) router, namely that the Chocolate router does not know how to reach anything on the 10.0.0.0/8 network (the Vanilla and Strawberry router's ping source IP address). To fix this problem, add a network statement to the Strawberry and Vanilla routers to advertise the 10.1.1.0/24 network to both the Mint and Chocolate routers and try again. [Example 8-63](#) shows the Strawberry BGP network configuration addition and the subsequent changes that result in the Chocolate router's IP routing table. This example also shows that, after the Chocolate router receives the route to the 10.1.1.0/24 network, all four BGP routers can now ping all the BGP networks.

Example 8-63. Adding a Route to the 10.1.1.0/24 Network

```

Strawberry(config)#router bgp 409

Strawberry(config-router)#network 10.1.1.0 mask 255.255.255.0

Chocolate#show ip route | begin Gateway

Gateway of last resort is not set

    10.0.0.0/24 is subnetted, 1 subnets

B      10.1.1.0 [20/0] via 108.201.14.10, 00:00:32

    108.0.0.0/8 is variably subnetted, 5 subnets, 3 masks

S      108.201.14.10/32 [1/0] via 108.201.14.2

C      108.201.15.0/24 is directly connected, Loopback10

C      108.201.14.0/30 is directly connected, Serial0

C      108.201.17.0/24 is directly connected, Loopback20

C      108.201.19.0/24 is directly connected, Loopback30

Chocolate#ping 10.1.1.2

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 10.1.1.2, timeout is 2 seconds:

!!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 40/42/44 ms

Vanilla#ping 108.201.14.1

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 108.201.14.1, timeout is 2 seconds:

!!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/8 ms

```

Step 3. Configure I-BGP between the Vanilla, Latte, and Americano routers and the Strawberry, Latte, and Americano routers. Configure the Latte and Americano routers to advertise their loopback and serial IP addresses into BGP. Verify that all BGP routers can reach all other routers. [Example 8-64](#) shows the configuration and BGP table for the Vanilla router.

Example 8-64. Configuration and BGP Table for the Vanilla Router

```
Vanilla#show run | begin bgp
```

```
router bgp 409
no synchronization
bgp log-neighbor-changes
network 10.1.1.0 mask 255.255.255.0
neighbor 10.1.1.3 remote-as 409
neighbor 10.1.1.3 next-hop-self
neighbor 62.129.48.1 remote-as 203
neighbor 192.168.1.2 remote-as 409
neighbor 192.168.2.2 remote-as 409
no auto-summary
```

```
Vanilla#show ip bgp
```

```
BGP table version is 435, local router ID is 62.129.48.6
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* i10.1.1.0/24	10.1.1.3	0	100	0	i
*>	0.0.0.0	0		32768	i
*>i10.2.2.0/24	192.168.1.2	0	100	0	?
*>i10.2.3.0/24	192.168.1.2	0	100	0	?
*>i10.2.5.0/24	192.168.1.2	0	100	0	?
*>i10.200.1.0/24	192.168.2.2	0	100	0	?
*>i10.200.3.0/24	192.168.2.2	0	100	0	?
*>i10.200.5.0/24	192.168.2.2	0	100	0	?
*> 62.120.0.0/16	62.129.48.1	0		0	203 ?
*> 62.121.0.0/16	62.129.48.1	0		0	203 ?

```

*> 62.123.0.0/16      62.129.48.1          0          0 203 ?
*> 62.129.48.0/30    62.129.48.1          0          0 203 ?
*>i108.201.14.0/30   10.1.1.3           0 100      0 507 ?
*>i108.201.15.0/24   10.1.1.3           0 100      0 507 ?
*>i108.201.17.0/24   10.1.1.3           0 100      0 507 ?
*>i108.201.19.0/24   10.1.1.3           0 100      0 507 ?
*>i192.168.1.0/30    192.168.1.2          0 100      0 ?
*>i192.168.2.0/30    192.168.2.2          0 100      0 ?

```

Now, take a look at the Latte router. Notice that the Latte router is not storing the external BGP routes as reachable; they have *, but no >, meaning they are valid, but not reachable, as shown in [Example 8-65](#).

Example 8-65. Latte Router's BGP Table

```
Latte#show ip bgp
```

```

BGP table version is 6, local router ID is 10.2.5.1

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.1.1.0/24	10.1.1.3	0	100	0	i
* i	10.1.1.2	0	100	0	i
*> 10.2.2.0/24	0.0.0.0	0		32768	?
*> 10.2.3.0/24	0.0.0.0	0		32768	?
*> 10.2.5.0/24	0.0.0.0	0		32768	?
* i62.120.0.0/16	62.129.48.1	0	100	0	203 ?
* i62.121.0.0/16	62.129.48.1	0	100	0	203 ?
* i62.123.0.0/16	62.129.48.1	0	100	0	203 ?
* i62.129.48.0/30	62.129.48.1	0	100	0	203 ?
* i108.201.14.0/30	108.201.14.1	0	100	0	507 ?

```

* i108.201.15.0/24 108.201.14.1          0    100      0 507 ?
* i108.201.17.0/24 108.201.14.1          0    100      0 507 ?
* i108.201.19.0/24 108.201.14.1          0    100      0 507 ?
*> 192.168.1.0/30  0.0.0.0               0            32768 ?

      Network          Next Hop           Metric LocPrf Weight Path
*>i192.168.2.0/30  192.168.2.2          0    100      0 i

```

The routes are not reachable because the upstream BGP neighbors are advertising them with the original E-BGP next hop of 62.129.48.1 and 108.201.14.1 rather than local, reachable networks that the Latte and Americano are aware of (by means of OSPF). The answer to this problem is very simple and requires only a few steps—add the next-hop-self statement to all the I-BGP-speaking routers; clear the BGP process; add two routes to the Mocha router, telling it how to get to the 62.0.0.0/8 and 108.201.0.0/16 networks; and disable synchronization on all the I-BGP speaking routers so that they will not wait for OSPF routes to those networks. After making those configuration changes, check the routes again. [Example 8-66](#) shows the steps taken to correct the I-BGP routing problem and the solution.

Example 8-66. Steps to Correct the I-BGP Routing Problem

```

Vanilla#show run | begin bgp

router bgp 409

no synchronization

bgp log-neighbor-changes

network 10.1.1.0 mask 255.255.255.0

neighbor 10.1.1.3 remote-as 409

neighbor 10.1.1.3 next-hop-self

neighbor 62.129.48.1 remote-as 203

neighbor 192.168.1.2 remote-as 409

neighbor 192.168.1.2 next-hop-self

neighbor 192.168.2.2 remote-as 409

neighbor 192.168.2.2 next-hop-self

```

```
Strawberry#show run | begin bgp

router bgp 409

no synchronization

bgp log-neighbor-changes

network 10.1.1.0 mask 255.255.255.0

neighbor 10.1.1.2 remote-as 409

neighbor 10.1.1.2 next-hop-self

neighbor 108.201.14.1 remote-as 507

neighbor 192.168.1.2 remote-as 409

neighbor 192.168.1.2 next-hop-self

neighbor 192.168.2.2 remote-as 409

neighbor 192.168.2.2 next-hop-self

no auto-summary
```

```
Mocha#show run | begin ip route

ip route 62.0.0.0 255.0.0.0 10.1.1.2

ip route 108.201.0.0 255.255.0.0 10.1.1.3
```

```
Latte#show run | begin bgp

router bgp 409

no synchronization

bgp log-neighbor-changes

network 10.2.2.0 mask 255.255.255.0

network 10.2.3.0 mask 255.255.255.0

network 10.2.5.0 mask 255.255.255.0

network 192.168.1.0 mask 255.255.255.252

neighbor 10.1.1.2 remote-as 409

neighbor 10.1.1.2 next-hop-self
```

```
neighbor 10.1.1.3 remote-as 409
neighbor 10.1.1.3 next-hop-self
neighbor 192.168.2.2 remote-as 409
neighbor 192.168.2.2 next-hop-self
no auto-summary
```

```
Americano#show run | begin bgp
router bgp 409
no synchronization
network 10.200.1.0 mask 255.255.255.0
network 10.200.3.0 mask 255.255.255.0
network 10.200.5.0 mask 255.255.255.0
network 192.168.2.0 mask 255.255.255.252
neighbor 10.1.1.2 remote-as 409
neighbor 10.1.1.2 next-hop-self
neighbor 10.1.1.3 remote-as 409
neighbor 10.1.1.3 next-hop-self
neighbor 192.168.1.2 remote-as 409
neighbor 192.168.1.2 next-hop-self
no auto-summary
```

[Example 8-67](#) shows the Latte BGP table before the changes, and [Example 8-68](#) shows the BGP table after the changes. In the first example, notice that the 62.120.0.0/16, 62.121.0.0/16, 62.122.0.0/16, 62.129.48.0/30, 108.201.14.0/30, 108.201.15.0/24, 108.201.17.0/24, and 108.201.19.0/24 networks are not reachable, and in the second example, after you add the next-hop-self statement and fix the bad next-hop routing problem, they are all reachable.

Example 8-67. Latte BGP Table Before next-hop-self

```
Latte#show ip bgp
BGP table version is 6, local router ID is 10.2.5.1
```

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i10.1.1.0/24	10.1.1.3	0	100	0	i
* i	10.1.1.2	0	100	0	i
*> 10.2.2.0/24	0.0.0.0	0		32768	?
*> 10.2.3.0/24	0.0.0.0	0		32768	?
*> 10.2.5.0/24	0.0.0.0	0		32768	?
* i62.120.0.0/16	62.129.48.1	0	100	0	203 ?
* i62.121.0.0/16	62.129.48.1	0	100	0	203 ?
* i62.123.0.0/16	62.129.48.1	0	100	0	203 ?
* i62.129.48.0/30	62.129.48.1	0	100	0	203 ?
* i108.201.14.0/30	108.201.14.1	0	100	0	507 ?
* i108.201.15.0/24	108.201.14.1	0	100	0	507 ?
* i108.201.17.0/24	108.201.14.1	0	100	0	507 ?
* i108.201.19.0/24	108.201.14.1	0	100	0	507 ?
*> 192.168.1.0/30	0.0.0.0	0		32768	?
Network	Next Hop	Metric	LocPrf	Weight	Path
*>i192.168.2.0/30	192.168.2.2	0	100	0	I

Example 8-68. Latte BGP Table After next-hop-self

Latte#show ip bgp

BGP table version is 15, local router ID is 10.2.5.1

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path

```

*>i10.1.1.0/24      10.1.1.2          0     100      0 i
* i                  10.1.1.3          0     100      0 i
*> 10.2.2.0/24      0.0.0.0          0           32768 ?
*> 10.2.3.0/24      0.0.0.0          0           32768 ?
*> 10.2.5.0/24      0.0.0.0          0           32768 ?
*>i62.120.0.0/16    10.1.1.2          0     100      0 203 ?
*>i62.121.0.0/16    10.1.1.2          0     100      0 203 ?
*>i62.123.0.0/16    10.1.1.2          0     100      0 203 ?
*>i62.129.48.0/30   10.1.1.2          0     100      0 203 ?
*>i108.201.14.0/30  10.1.1.3          0     100      0 507 ?
*>i108.201.15.0/24  10.1.1.3          0     100      0 507 ?
*>i108.201.17.0/24  10.1.1.3          0     100      0 507 ?
*>i108.201.19.0/24  10.1.1.3          0     100      0 507 ?
*> 192.168.1.0/30   0.0.0.0          0           32768 ?

      Network          Next Hop          Metric LocPrf Weight Path
*>i192.168.2.0/30   192.168.2.2        0     100      0 I

```

Latte#**ping 108.201.14.1**

Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 108.201.14.1, timeout is 2 seconds:

!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 40/42/44 ms

Step 4. Test the configuration using an application. To do this, make voice calls between the Chocolate and Latte routers. To configure VoIP on the Chocolate and Latte routers, create dial peers, add destination patterns and an IP address or physical port, and then dial from the phones. (For more information on VoIP configuration, refer to *CCIE Practical Studies, Volume 1*.) [Example 8-69](#) shows the voice configuration for the Chocolate router, and [Example 8-70](#) shows the voice configuration for the Latte router.

Example 8-69. Chocolate Router's Voice Configuration

```
Chocolate#show run | begin dial

dial-peer voice 5551234 voip
destination-pattern 5551234
session target ipv4:10.2.2.1

!
dial-peer voice 5556789 pots
destination-pattern 5556789
port 2/0
```

Example 8-70. Latte Router's Voice Configuration

```
Latte#show run | begin dial

dial-peer voice 5556789 voip
destination-pattern 5556789
session target ipv4:108.201.15.1

!
dial-peer voice 5551234 pots
destination-pattern 5551234
port 2/0
```

Now that the introductory BGP configuration and troubleshooting commands have been covered, it is time to look into the features that make BGP the most powerful protocol available for IP routing. [Chapter 9](#) covers advanced BGP features, such as the use of the BGP attribute, route filtering and policy, route aggregation, manipulating the best path selection process, and tuning BGP. [Example 8-71](#) shows the final configurations for all routers in this lab.

Example 8-71. Final Router Configurations for Lab 11

```
hostname Mint

!
interface Loopback10
  ip address 62.120.1.1 255.255.0.0
!
interface Loopback20
  ip address 62.121.1.1 255.255.0.0
!
interface Loopback30
  ip address 62.123.1.1 255.255.0.0
!
interface Serial0
  ip address 62.129.48.1 255.255.255.252
  clockrate 1300000
!
router bgp 203
  no synchronization
  bgp log-neighbor-changes
  redistribute connected
  neighbor 62.129.48.2 remote-as 409
  no auto-summary
```

```
hostname Vanilla

!
interface Ethernet0
  ip address 10.1.1.2 255.255.255.0
!
interface Serial1
```

```
ip address 62.129.48.2 255.255.255.252

!

router ospf 1

router-id 10.1.1.2

log-adjacency-changes

passive-interface Serial1

network 10.1.1.0 0.0.0.255 area 0

network 62.129.48.0 0.0.0.3 area 0

!

router bgp 409

no synchronization

bgp log-neighbor-changes

network 10.1.1.0 mask 255.255.255.0

neighbor 10.1.1.3 remote-as 409

neighbor 10.1.1.3 next-hop-self

neighbor 62.129.48.1 remote-as 203

neighbor 192.168.1.2 remote-as 409

neighbor 192.168.1.2 next-hop-self

neighbor 192.168.2.2 remote-as 409

neighbor 192.168.2.2 next-hop-self

no auto-summary
```

```
hostname Chocolate
```

```
!

voice-port 2/0

!

voice-port 2/1

!
```

```
dial-peer voice 5551234 voip
destination-pattern 5551234
session target ipv4:10.2.2.1

!
dial-peer voice 5556789 pots
destination-pattern 5556789
port 2/0

!
interface Loopback10
ip address 108.201.15.1 255.255.255.0

!
interface Loopback20
ip address 108.201.17.1 255.255.255.0

!
interface Loopback30
ip address 108.201.19.1 255.255.255.0

!
interface Serial0
ip address 108.201.14.1 255.255.255.252

!
router bgp 507
no synchronization
bgp log-neighbor-changes
redistribute connected
neighbor 108.201.14.2 remote-as 409
no auto-summary

!
```

```
hostname Strawberry

!
interface Ethernet0
    ip address 10.1.1.3 255.255.255.0

!
interface Serial1
    ip address 108.201.14.2 255.255.255.252
    clockrate 1300000

!
router ospf 1
    router-id 10.1.1.3
    log adjacency-changes
    passive-interface Serial1
    network 10.1.1.0 0.0.0.255 area 0
    network 108.201.14.0 0.0.0.3 area 0

!
router bgp 409
    no synchronization
    bgp log-neighbor-changes
    network 10.1.1.0 mask 255.255.255.0
    neighbor 10.1.1.2 remote-as 409
    neighbor 10.1.1.2 next-hop-self
    neighbor 108.201.14.1 remote-as 507
    neighbor 192.168.1.2 remote-as 409
    neighbor 192.168.1.2 next-hop-self
    neighbor 192.168.2.2 remote-as 409
    neighbor 192.168.2.2 next-hop-self
    no auto-summary
```

```
hostname Mocha

!
interface Ethernet0
 ip address 10.1.1.4 255.255.255.0

!
interface Serial0
 ip address 192.168.1.1 255.255.255.252
 clock rate 1300000

!
interface Serial1
 ip address 192.168.2.1 255.255.255.252

!
router ospf 1
 log-adjacency-changes
 network 10.1.1.0 0.0.0.255 area 0
 network 192.168.1.0 0.0.0.3 area 0
 network 192.168.2.0 0.0.0.3 area 0

!
ip classless
ip route 62.0.0.0 255.0.0.0 10.1.1.2
ip route 108.201.0.0 255.255.0.0 10.1.1.3
```

```
hostname Latte

!
voice-port 2/0
!
voice-port 2/1
```

```
!  
  
dial-peer voice 5556789 voip  
destination-pattern 5556789  
session target ipv4:108.201.15.1  
!  
  
dial-peer voice 5551234 pots  
destination-pattern 5551234  
port 2/0  
!  
  
interface Loopback10  
ip address 10.2.2.1 255.255.255.0  
!  
  
interface Loopback20  
ip address 10.2.3.1 255.255.255.0  
!  
  
interface Loopback30  
ip address 10.2.5.1 255.255.255.0  
!  
  
interface Serial0  
ip address 192.168.1.2 255.255.255.252  
!  
  
router ospf 1  
log-adjacency-changes  
network 10.2.2.0 0.0.0.255 area 0  
network 10.2.3.0 0.0.0.255 area 0  
network 10.2.5.0 0.0.0.255 area 0  
network 192.168.1.0 0.0.0.3 area 0  
!
```

```
router bgp 409
no synchronization
bgp log-neighbor-changes
redistribute connected
network 10.200.1.0 mask 255.255.255.0
network 10.200.3.0 mask 255.255.255.0
network 10.200.5.0 mask 255.255.255.0
network 192.168.1.0 mask 255.255.255.252
neighbor 10.1.1.2 remote-as 409
neighbor 10.1.1.2 next-hop-self
neighbor 10.1.1.3 remote-as 409
neighbor 10.1.1.3 next-hop-self
neighbor 192.168.2.2 remote-as 409
neighbor 192.168.2.2 next-hop-self
no auto-summary
```

```
hostname Americano
!
interface Loopback10
ip address 10.200.1.1 255.255.255.0
!
interface Loopback20
ip address 10.200.3.1 255.255.255.0
!
interface Loopback30
ip address 10.200.5.1 255.255.255.0
!
interface Serial0
```

```
ip address 192.168.2.2 255.255.255.252
clockrate 1300000
!
router ospf 1
log-adjacency-changes
network 10.200.1.0 0.0.0.255 area 0
network 10.200.3.0 0.0.0.255 area 0
network 10.200.5.0 0.0.0.255 area 0
network 192.168.2.0 0.0.0.3 area 0
!
router bgp 409
no synchronization
network 10.200.1.0 mask 255.255.255.0
network 10.200.3.0 mask 255.255.255.0
network 10.200.5.0 mask 255.255.255.0
network 192.168.2.0 mask 255.255.255.252
neighbor 10.1.1.2 remote-as 409
neighbor 10.1.1.2 next-hop-self
neighbor 10.1.1.3 remote-as 409
neighbor 10.1.1.3 next-hop-self
neighbor 192.168.1.2 remote-as 409
neighbor 192.168.1.2 next-hop-self
no auto-summary
```

Further Reading

Cisco IOS Configuration Fundamentals, by Cisco Systems Inc., Riva Technologies

TCP/IP Principles, Protocols, and Architectures, by Douglas E. Comer

Internet Routing Architectures, Second Edition, by Sam Halabi with Danny McPherson

Routing TCP/IP, Volume II, by Jeff Doyle and Jennifer DeHaven Carroll

Cisco BGP-4 Command and Configuration Handbook, by William R. Parkhurst

Chapter 9. Advanced BGP Configuration

The preceding chapter discussed several BGP troubleshooting concepts, examined simple BGP designs, and showed how to advertise various types of BGP networks. Together, the last two chapters provided the foundation, or a review of BGP concepts, that allow for a more technical discussion of the advanced topics covered in this chapter. This chapter demonstrates ways to use BGP to support larger, more stable networks and explains how to implement advanced routing policies. This chapter covers the following topics:

- BGP router authentication
- How to simplify large network implementations with route reflectors and confederations
- The effective use of BGP peer groups
- Advanced BGP redistribution methods
- BGP route filtering, suppression, and conditional advertisements
- Route dampening
- Route aggregation and policies
- The use of BGP backdoors
- How to configure BGP to support different route table sizes and maintaining symmetric routes
- Tuning BGP performance

BGP Neighbor Authentication

One of the easiest ways to reduce security risks on a BGP network is to use BGP peer authentication. The Cisco implementation of BGP uses the TCP MD-5 signature as specified in RFC 2385. This algorithm takes a key, the password entered during configuration, and performs an MD-5 hash on the key, and sends the resulting hash to the remote peer. The password itself is never sent over the connection.

Only one configuration step is required to use BGP MD-5 password authentication; that step is enabling password authentication on a peer-by-peer basis using the neighbor *ip-address* *password* command, shown here:

```
neighbor {ip-address|peer-group} password [0-7]password-string
```

This command also has an optional parameter, which enables you to use a previously encrypted password by specifying the password level of 7, as follows:

```
SlyDog(config-router)#neighbor 8.8.9.1 password 7 1511021F0725
```

Both sides of an authenticated BGP peer session must use the same password. If a router receives a BGP OPEN message with an invalid password, it sends a NOTIFICATION message with the OPEN message error stating that there has been an authentication failure. [Example 9-1](#) shows how password authentication is used to protect a session between two E-BGP peers.

Example 9-1. BGP MD-5 Password Authentication

```
Mariner#show run | begin bgp
```

```
router bgp 5151  
bgp log-neighbor-changes  
neighbor 217.204.187.8 remote-as 1578  
neighbor 217.204.187.8 password cisco
```

```
OtherGuys#show run | begin bgp  
router bgp 1578  
bgp log-neighbor-changes  
neighbor 217.204.187.7 remote-as 5151  
neighbor 217.204.187.7 password cisco
```

Although the use of MD-5 authentication does not completely guarantee the safety of a BGP session, it does reduce the risk of a BGP session attack.

Simplifying Large BGP Networks

One issue that eventually appears in almost any large BGP network is that of design complexity. When you have a large number of BGP-speaking routers that have a large number of BGP peers, either internally or externally, you eventually need to reassess the network design to determine ways to create a simpler, more scalable network. Proactive network professionals plan their network so that each of the routers has the capacity to hold a large BGP Routing Information Base (RIB) and plan for future network growth while considering the many factors that affect the network design and implementation, some of which are listed here:

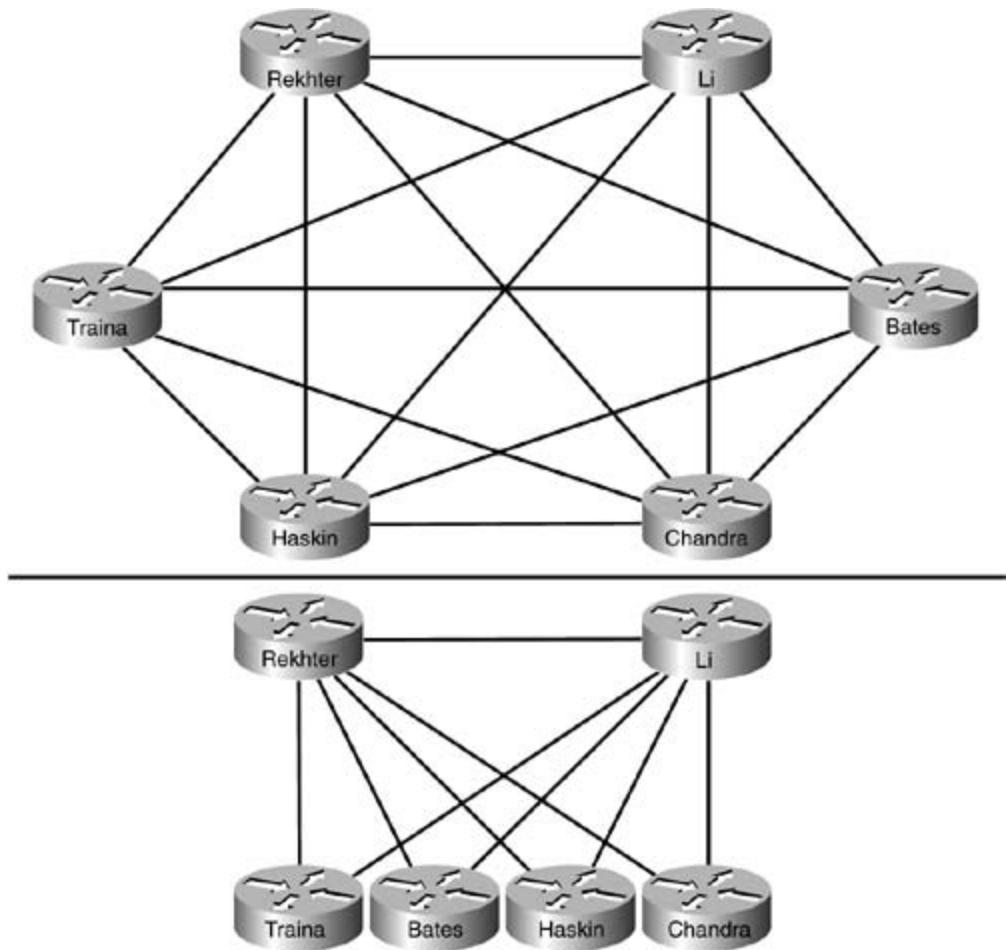
- The number of routers participating in E-BGP peering sessions and the number of peers that must be configured
- The number, size, and frequency of the BGP updates sent between the peering routers
- Asymmetric routes caused by multiple paths
- The number of paths that must be sent between peers prior to network convergence, and the delay that the convergence time has upon network applications
- The possibility of route dampening due to route instability
- The full-mesh requirement for I-BGP peers
- Long, complicated router configurations, with the possibility for human error during router configuration

You can deal with each of these issues in several ways. This section examines how the use of route reflectors and confederations help solve the I-BGP full-mesh problem, and how peer groups and route aggregation can help control the size and complexity of large BGP implementations.

Route Reflectors

BGP *route reflectors*, defined in RFC 1966, provide a simple solution to the I-BGP full-mesh problem for large I-BGP implementations. As a quick review, there are two entities in a route reflector scenario: the server and the clients. Each route reflector server requires an I-BGP peer connection to each of its clients. However, the clients require only a connection to the route reflector server. The server sends updates to each of the client routers through the I-BGP connection, eliminating the need for a fully meshed topology. [Figure 9-1](#) shows a before and after look at an I-BGP network in need of help.

Figure 9-1. Before and After Route Reflectors



In the first part of the figure, each of the 6 routers has an I-BGP peer connection to each of its peers, creating 15 I-BGP connections. The second part of the figure shows how route reflectors simplify the I-BGP configuration for each of the six routers—with Routers Rekhter and Li acting as route reflector servers; and Routers Traina, Haskin, Bates, and Chandra acting as route reflector clients to the Rekhter and Li routers. When route reflector clients are homed to two or more route reflector servers, path redundancy is still maintained, and the configurations are greatly simplified.

You must complete two steps to create a route reflector server, sometimes referred to as a *route server*. This process is demonstrated here using the network in [Figure 9-2](#).

Step 1. Configure I-BGP peer connections for each of the BGP peers with which the route reflector server will peer. [Example 9-2](#) shows the initial BGP configuration for the Holmes router.

Example 9-2. Configuring the Holmes Router as a Route Reflector Server

```
Holmes#show run | begin bgp
```

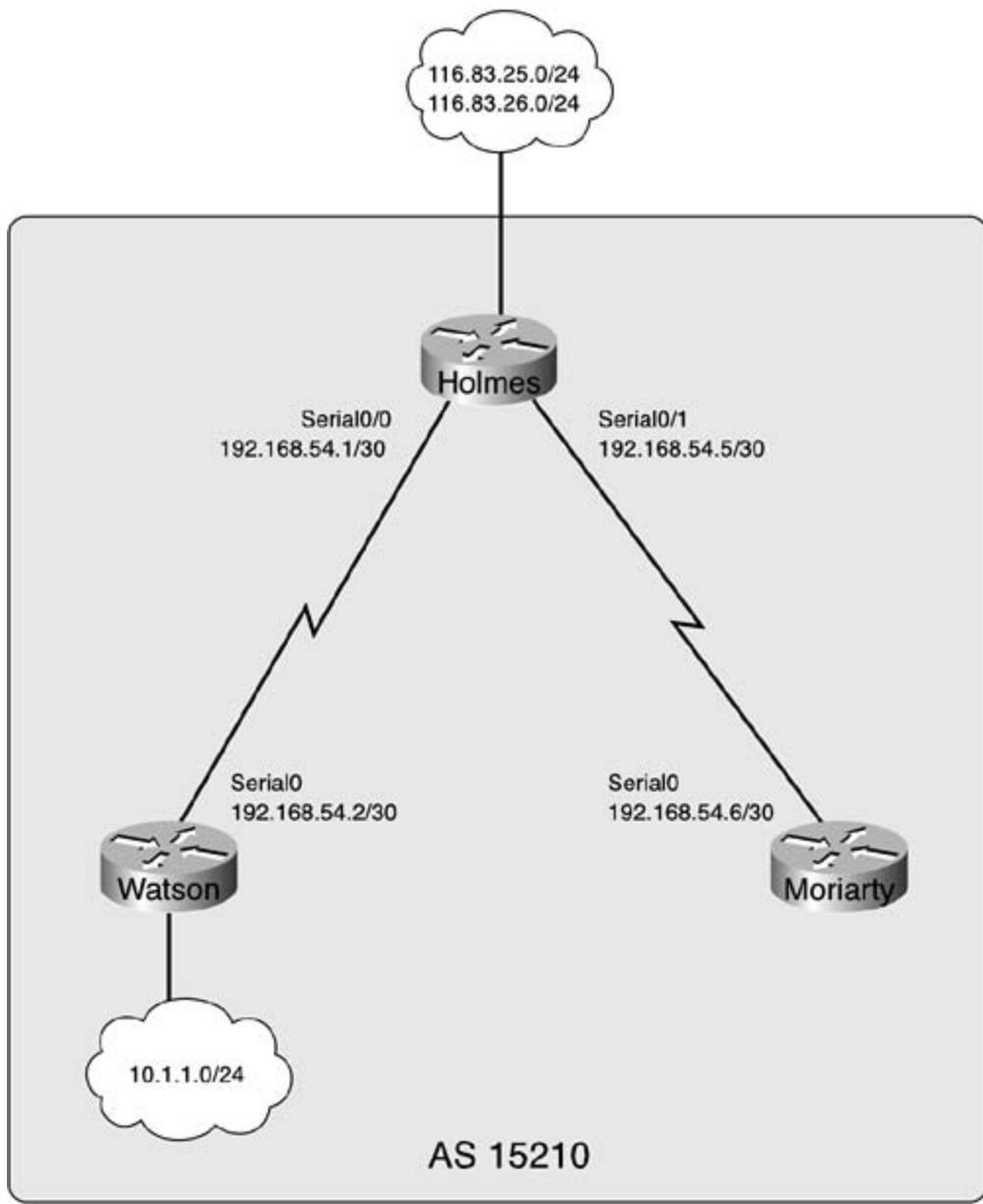
```
router bgp 15210
no synchronization
neighbor 192.168.54.2 remote-as 15210
neighbor 192.168.54.6 remote-as 15210
```

Step 2. On the route reflector server, configure each of the neighbors that are to act as route reflector clients using the `neighbor /ip-address route-reflector-client` command. [Example 9-3](#) shows the route reflector server configuration from the Holmes router.

Example 9-3. Holmes Router's Route Reflector Configuration

```
neighbor 192.168.54.2 route-reflector-client
neighbor 192.168.54.6 route-reflector-client
```

Figure 9-2. Route Reflection



No special configuration steps need to occur to make a router act as a route reflector client. All you need to do is configure the client to peer with the route reflector server. [Example 9-4](#) shows the BGP configuration for the Watson and Moriarty route reflector clients.

Example 9-4. BGP Configuration for the Route Reflector Clients

```
Watson#show run | begin bgp
router bgp 15210
no synchronization
```

```
neighbor 192.168.54.1 remote-as 15210
```

```
Moriarty#show run | begin bgp
router bgp 15210
no synchronization
neighbor 192.168.54.5 remote-as 15210
```

The `show ip bgp neighbors | include BGP neighbor|Route-Reflector` command displays a brief summary of the routers that the route reflector server is providing routes to, as shown in [Example 9-5](#).

Example 9-5. Displaying Route Reflector Client Summary

```
Holmes#show ip bgp neighbors | include BGP neighbor|Route-Reflector
BGP neighbor is 192.168.54.2,  remote AS 15210, internal link
    Route-Reflector Client
BGP neighbor is 192.168.54.6,  remote AS 15210, internal link
    Route-Reflector Client
```

To verify a route learned from a route reflector server, use the `show ip bgp /p-prefix` command, as shown in [Example 9-6](#).

Example 9-6. Displaying Route Reflector Server Information

```
Moriarty#show ip bgp 10.1.1.0/24
BGP routing table entry for 10.1.1.0/24, version 8
Paths: (1 available, best #1, table Default-IP-Routing-Table)
Flag: 0x208
Not advertised to any peer
```

Local

```
192.168.54.2 from 192.168.54.5 (10.1.1.1)

Origin IGP, metric 0, localpref 100, valid, internal, best

Originator: 10.1.1.1, Cluster list: 116.83.26.1
```

In the preceding example, the Moriarty router shows that the route to 10.1.1.0/24 contains two new BGP attributes: the ORIGINATOR attribute, which specifies the BGP router ID for the router that originated the route; and the CLUSTER_LIST attribute, which specifies the BGP cluster ID for the route. The BGP cluster ID is the BGP router ID of the route reflector server that originated the route. The *cluster list* is a loop-avoidance mechanism designed to prevent routers belonging to a route reflector cluster from accepting routes that originated within the local cluster from routers that belong to a different cluster. If a route reflector receives a route that contains its own cluster ID in the cluster list, it ignores that route.

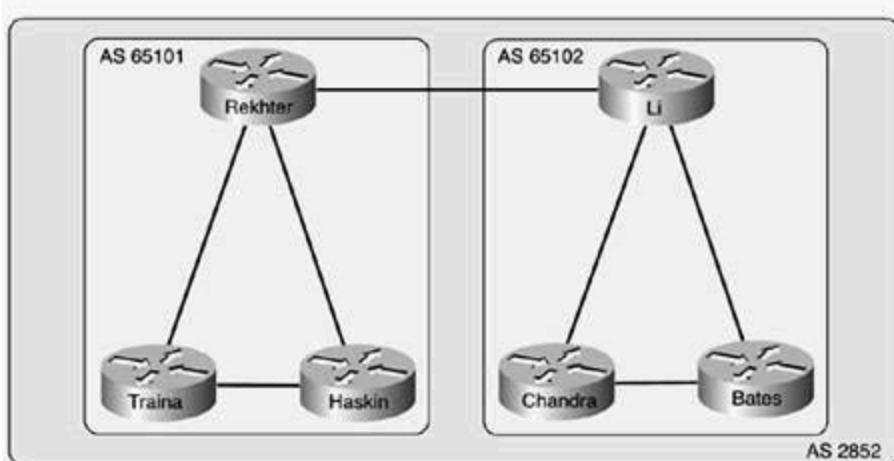
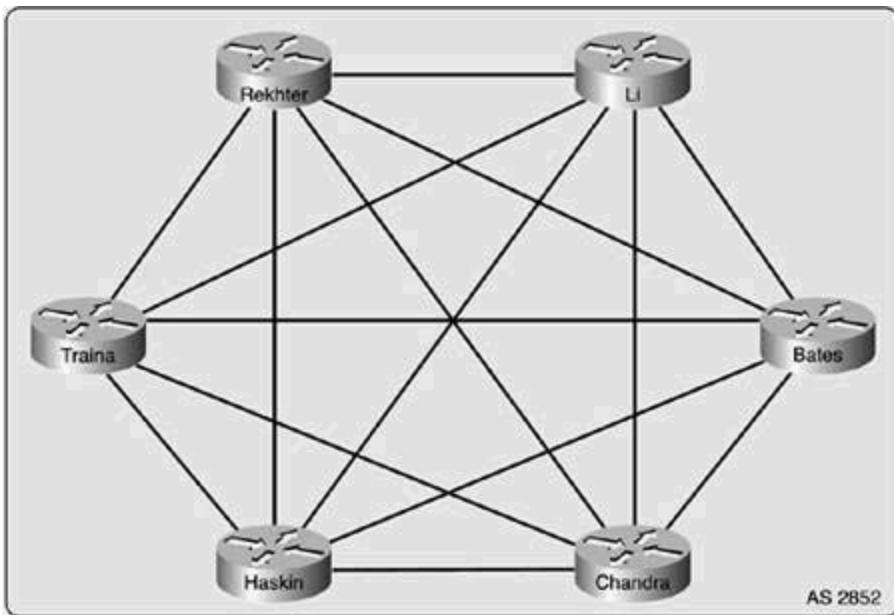
NOTE

If a route has passed through more than one route reflector cluster, there is more than one cluster ID in the route's cluster list. Each route reflector that forwards a route on to its clients prepends its own local cluster ID to the cluster list. For more information on these BGP attributes, refer to the "[Route Reflectors](#)" section in [Chapter 7](#), "BGP-4 Theory."

Confederations

Another way to manage the full-mesh requirement for I-BGP peers is to configure BGP confederations. As a quick review, *BGP confederations* break large I-BGP autonomous systems into smaller, more manageable sub-autonomous systems known as *member autonomous systems*. Comparing the example shown earlier in [Figure 9-1](#) to the confederation solution shown in [Figure 9-3](#), you can see how the same network could be reconfigured using BGP confederations.

Figure 9-3. Before and After BGP Confederations



Notice in this example that confederations break Routers Rekhter, Traina, and Haskin into member autonomous systems 65,101 and routers Li, Chandra, and Bates into sub-AS 65,102. All routers in both AS 65,101 and AS 65,102 still belong to AS 2852, decreasing the number of I-BGP peer connections that have to be configured. Also, notice that each of the I-BGP routers within a sub-AS is still fully meshed with the other I-BGP peers in the same sub-AS. This brings attention to a key point about confederation use: Although confederations are a simpler solution to the I-BGP full-mesh problem, they still require full-mesh peer relationships within each sub-AS, so they still must be designed carefully to allow for growth.

You must complete five steps to configure confederations in a BGP AS. This process is described here using the network shown in [Figure 9-4](#).

Step 1. Enable BGP routing using the member AS number as the BGP AS number, as shown here on the Calvin router:

```
Calvin(config)#router bgp 65111
```

In this example, the Calvin Router belongs to BGP sub-AS (member AS) 65,111, so the local BGP routing process is started using AS number 65,111.

Step 2. Configure the *confederation identifier*, this is the AS number that the parent AS uses when peering with other external BGP neighbors.

```
Calvin(config-router)#bgp confederation identifier 2610
```

The BGP confederation ID defines the parent AS that the two sub-autonomous systems, AS 65,111 and AS 65,112, both belong to.

Step 3. Configure fully meshed I-BGP sub-AS neighbor relationships using the sub-AS number as the remote ASN for all internal I-BGP peers. In the following example, the Calvin router peers with its I-BGP neighbors, the Bart and Zim routers, in BGP sub-AS 65,111:

```
Calvin(config-router)#neighbor 10.1.1.2 remote-as 65111
```

```
Calvin(config-router)#neighbor 10.1.1.3 remote-as 65111
```

Step 4. Configure other BGP neighbors within the same parent AS, but not the same confederation sub-AS as external neighbors, by specifying their sub-AS number as the BGP remote AS number. Other confederation peers from different sub-autonomous systems must also be identified as external confederation peers using the `bgp confederation peers sub-AS number` command, as shown here on the Calvin router:

```
Calvin(config-router)#neighbor 10.10.1.2 remote-as 65112
```

```
Calvin(config-router)#bgp confederation peers 65112
```

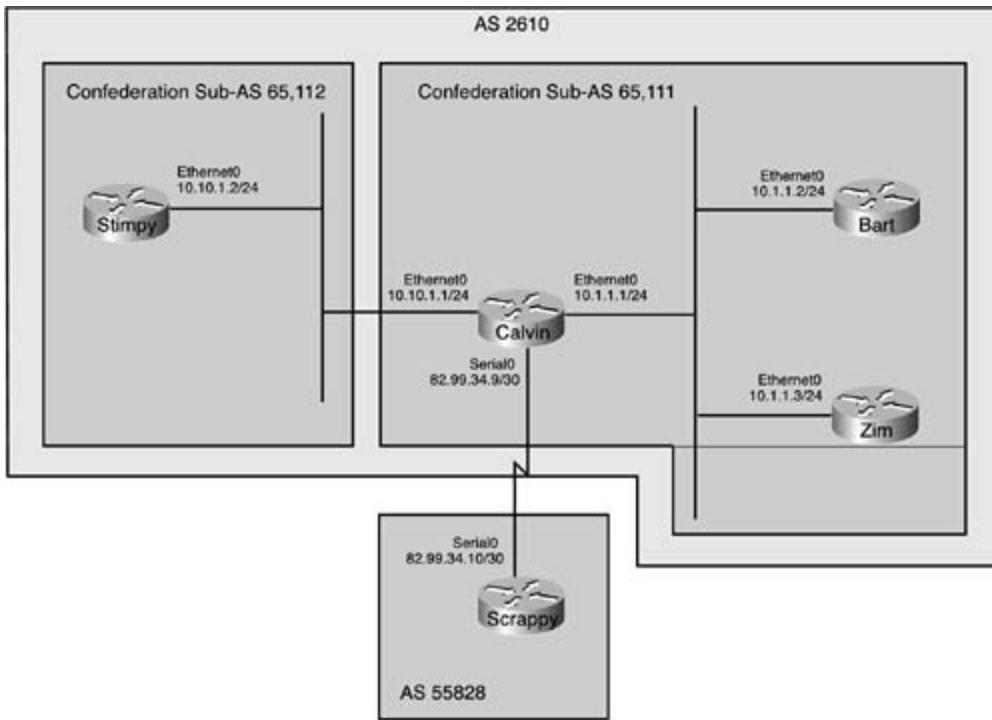
You can use the bgp confederation peers command to define multiple confederation peer autonomous systems. When defining multiple confederation peer autonomous systems, you can use this command in two ways, and each method will have the same result:

- Enter the bgp confederation peers command followed by each of the confederation peer AS numbers, separated by spaces.
- Enter one instance of the bgp confederation peers *member-AS number* command for each confederation peer ID.

Step 5. Configure any E-BGP neighbors (peers that do not belong to the parent or sub-autonomous systems) as you normally would configure any other E-BGP peer. Each external peer will peer with each internal confederation peer using the parent ASN. The external BGP neighbors are unaware of the I-BGP confederation information from peers in other autonomous systems because all confederation information is stripped from the AS_PATH before updates are sent to neighboring external peers:

```
Calvin(config-router)#neighbor 82.99.34.10 remote-as 55828
```

Figure 9-4. The Good-Old-Boy Network



The Calvin router forms an E-BGP peering session with the Scrappy router using its local confederation ID because the Calvin router belongs to parent AS 2610. In turn, the Scrappy router must peer with the Calvin router using its parent AS number (the confederation ID) because that is the only AS number of which it is aware.

NOTE

When configuring routers that belong to AS federations, always pay close attention to the type of AS to which each peer belongs. When working with federations, remember these three simple rules:

- Member AS peers (peers belonging to the same sub-AS) only require a normal I-BGP neighbor definition using the `neighbor ip-address remote-as remote-AS-number` command.
- External federation peers (peers that belong to the same I-BGP parent AS, but different member AS numbers) require two steps: defining a peer with the `neighbor ip-address remote-as remote-AS-number` command and the `bgp confederation peers remote-AS-number` command.
- External BGP peers are configured using the standard E-BGP commands; however, the remote E-BGP peer will not be aware of any BGP federation information. So, you must always make sure to use the `bgp confederation identifier parent-AS-number` command to define the parent AS.

To verify the configuration for each of the BGP federation peers, use the `show ip bgp`

neighbors command. This command shows each neighbor from a sub-AS as *under common administration*, as follows:

```
Calvin#show ip bgp neighbors 10.1.1.2

BGP neighbor is 10.1.1.2, remote AS 65111, internal link

BGP version 4, remote router ID 10.1.1.2

Neighbor under common administration

BGP state = Established, up for 00:00:45

Last read 00:00:45, hold time is 180, keepalive interval is 60 seconds

Neighbor capabilities:

Route refresh: advertised and received(old & new)

Address family IPv4 Unicast: advertised and received

Received 3 messages, 0 notifications, 0 in queue

Sent 4 messages, 0 notifications, 0 in queue

Route refresh request: received 0, sent 0

Default minimum time between advertisement runs is 5 seconds
```

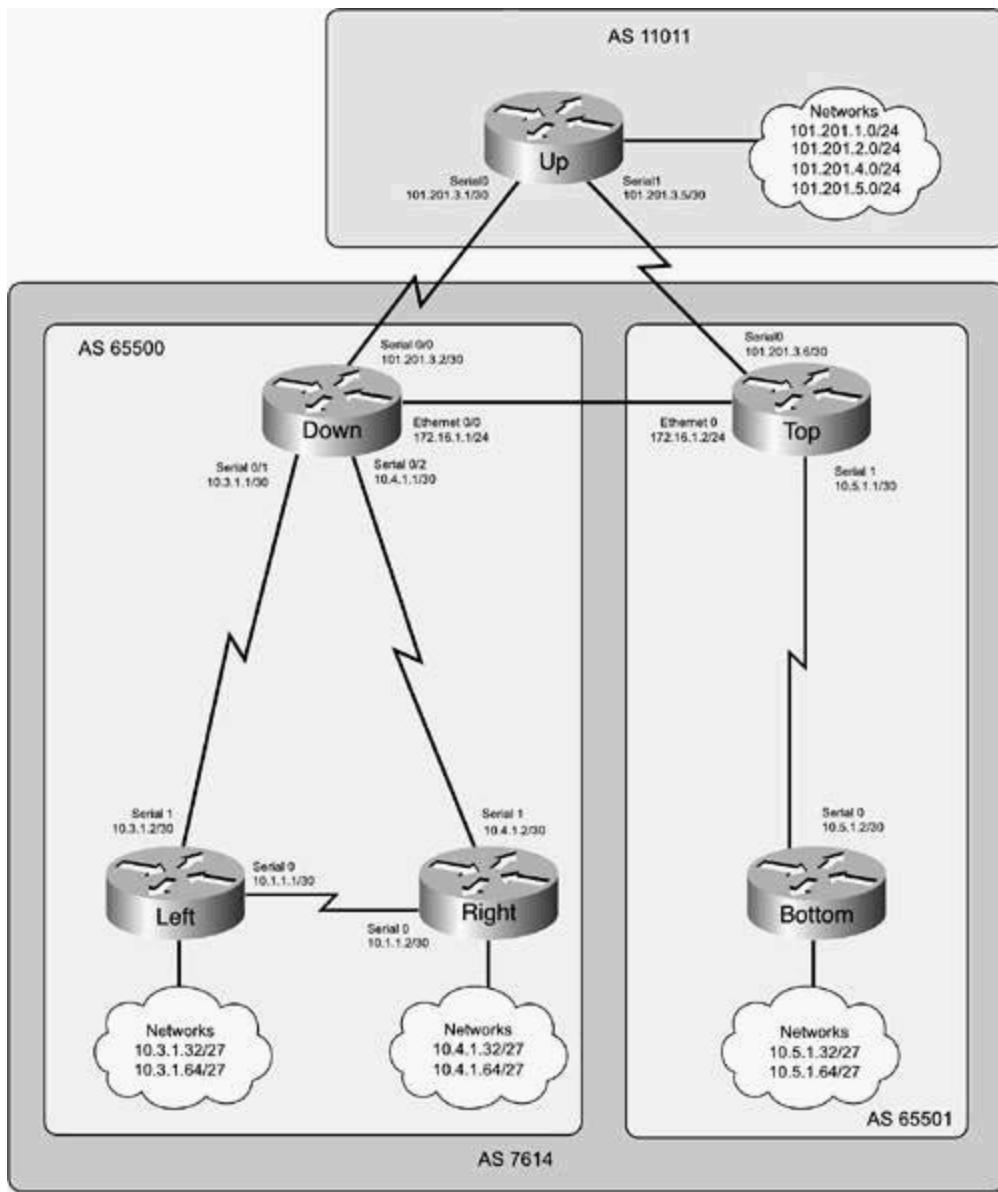
Now that you have seen how BGP confederations can create sub-AS that simplify internal BGP configurations, examine a practical BGP confederation example.

Practical Example: BGP Confederations

In this example, using the network shown in [Figure 9-5](#), BGP confederations split AS 7614 into two member autonomous systems, AS 65,500 and AS 65,501. This example explores a number of facets of BGP confederation configuration. It shows you how to perform the following:

- Configure peers within a member AS
- Configure special E-BGP-style peers that are within the same parent AS, but belong to a different member AS
- Configure confederation peers to interact with standard E-BGP peers

Figure 9-5. Using Confederations to Simplify an AS



This example requires five Cisco routers with the interfaces shown in [Table 9-1](#).

Table 9-1. Router Interface Requirements

Router Name	Ethernet, FastEthernet or Token Ring Interfaces	Serial Interfaces
Up	0	2
Down	1	3
Top	1	2
Right	0	2
Left	0	2
Bottom	0	1

Before configuring any routers, make sure that they are physically connected, as shown in [Figure 9-5](#). This example, requires six back-to-back serial cables, and two Ethernet or Token Ring cables connected to a hub, switch, or multistation access unit (MSAU). If you are using a switch, all interfaces should be placed in the same VLAN:

Step 1. Configure all IP addresses as specified in the preceding figure. Place all members of AS 7614 in EIGRP process 1709. Do not send EIGRP updates out to the Up router. Verify that all interfaces are up and all routers in EIGRP 1709 can ping each other before proceeding to Step 2. [Example 9-7](#) shows how the routing table from the Bottom router should look after completing this step.

Example 9-7. Bottom Router's Routing Table

```
Bottom#show ip route | include is|via

101.0.0.0/30 is subnetted, 2 subnets
D      101.201.3.4 [90/2681856] via 10.5.1.1, 00:09:45, Serial0
D      101.201.3.0 [90/2707456] via 10.5.1.1, 00:09:45, Serial0

172.16.0.0/24 is subnetted, 1 subnets
D      172.16.1.0 [90/2195456] via 10.5.1.1, 00:09:45, Serial0

10.0.0.0/30 is subnetted, 4 subnets
D      10.3.1.0 [90/2707456] via 10.5.1.1, 00:09:45, Serial0
D      10.1.1.0 [90/3219456] via 10.5.1.1, 00:08:53, Serial0
C      10.5.1.0 is directly connected, Serial0
D      10.4.1.0 [90/2707456] via 10.5.1.1, 00:09:46, Serial0
```

Step 2. Configure BGP routing between the Down, Right, and Left routers. Put all routers in member AS 65,500 and parent AS 7614; BGP routes should not be summarized on

classful boundaries. [Example 9-8](#) shows the resulting BGP configuration for the Down router.

Example 9-8. BGP Configuration for the Down Router

```
Down#show run | begin bgp

router bgp 65500
  no synchronization
  bgp log-neighbor-changes
  bgp confederation identifier 7614
  neighbor 10.3.1.2 remote-as 65500
  neighbor 10.3.1.2 route-reflector-client
  neighbor 10.3.1.2 next-hop-self
  neighbor 10.4.1.2 remote-as 65500
  neighbor 10.4.1.2 route-reflector-client
  neighbor 10.4.1.2 next-hop-self
  no auto-summary
```

The highlighted portions of the preceding example show that the member AS number is defined using the router bgp 65500 command, and the parent AS is defined using the bgp confederation identifier 7614 statement. If those statements had not been used, the router would have participated only in the private AS 65,500 and not been part of the parent AS. The next-hop-self command alters the BGP NEXT_HOP attribute for outgoing routes to the peer and changes it to the IP address for the local BGP speaker. The route-reflector-client command forwards routes learned by means of I-BGP peering sessions so that each of the I-BGP routers in member AS 65,500 has two routes to each network. [Example 9-9](#) shows the BGP configurations for the Right and Left routers at the end of Step 2.

Example 9-9. Left and Right Router Configurations

```
Left#show run | begin bgp

router bgp 65500
  no synchronization
```

```
bgp log-neighbor-changes

bgp confederation identifier 7614

network 10.3.1.32 mask 255.255.255.224

network 10.3.1.64 mask 255.255.255.224

neighbor 10.1.1.2 remote-as 65500

neighbor 10.1.1.2 route-reflector-client

neighbor 10.1.1.2 next-hop-self

neighbor 10.3.1.1 remote-as 65500

neighbor 10.3.1.1 route-reflector-client

neighbor 10.3.1.1 next-hop-self

no auto-summary
```

```
Right#show run | begin bgp

router bgp 65500

no synchronization

bgp log-neighbor-changes

bgp confederation identifier 7614

network 10.4.1.32 mask 255.255.255.224

network 10.4.1.64 mask 255.255.255.224

neighbor 10.1.1.1 remote-as 65500

neighbor 10.1.1.1 route-reflector-client

neighbor 10.1.1.1 next-hop-self

neighbor 10.4.1.1 remote-as 65500

neighbor 10.4.1.1 route-reflector-client

neighbor 10.4.1.1 next-hop-self
```

Step 3. Configure BGP routing on the Top and Bottom routers, place each router in member AS 65,501, and parent AS 7,614. Neither of these routers should auto-summarize any routes. [Example 9-10](#) shows the resulting configuration for the Top and Bottom routers.

Example 9-10. BGP Configuration for the Top and Bottom Routers

```
Top#show run | begin bgp

router bgp 65501
  no synchronization
  bgp log-neighbor-changes
  bgp confederation identifier 7614
  neighbor 10.5.1.2 remote-as 65501
  neighbor 10.5.1.2 next-hop-self
  no auto-summary



---


Bottom#show run | begin bgp

router bgp 65501
  no synchronization
  bgp log-neighbor-changes
  bgp confederation identifier 7614
  network 10.5.1.32 mask 255.255.255.224
  network 10.5.1.65 mask 255.255.255.224
  neighbor 10.5.1.1 remote-as 65501
  no auto-summary
```

Step 4. Configure BGP routing between the Up, Down, and Top routers. Verify that the Up router receives the correct ASN from the Down and Top routers, and that the Right, Left, and Bottom routers can reach the routes advertised by the Up router. [Example 9-11](#) shows the BGP configuration and BGP RIB for the Up router.

Example 9-11. BGP Configuration and BGP RI B for the Up Router

```
Up#show run | begin bgp
```

```

router bgp 11011

no synchronization

bgp log-neighbor-changes

network 101.201.1.0 mask 255.255.255.0

network 101.201.2.0 mask 255.255.255.0

network 101.201.4.0 mask 255.255.255.0

network 101.201.5.0 mask 255.255.255.0

neighbor 101.201.3.2 remote-as 7614

neighbor 101.201.3.6 remote-as 7614

no auto-summary

```

Up#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
* 10.3.1.32/27	101.201.3.6			0	7614 i
*>	101.201.3.2			0	7614 i
* 10.3.1.64/27	101.201.3.6			0	7614 i
*>	101.201.3.2			0	7614 i
* 10.4.1.32/27	101.201.3.6			0	7614 i
*>	101.201.3.2			0	7614 i
* 10.4.1.64/27	101.201.3.6			0	7614 i
*>	101.201.3.2			0	7614 i
* 10.5.1.32/27	101.201.3.2			0	7614 i
*>	101.201.3.6			0	7614 i
* 10.5.1.64/27	101.201.3.2			0	7614 i
*>	101.201.3.6			0	7614 i
*> 101.201.1.0/24	0.0.0.0	0		32768	i
*> 101.201.2.0/24	0.0.0.0	0		32768	i
*> 101.201.4.0/24	0.0.0.0	0		32768	i
*> 101.201.5.0/24	0.0.0.0	0		32768	i

When configuring E-BGP peer relationships with confederation members, always remember to use the parent AS number for the remote AS. [Example 9-12](#) shows the resulting configuration for the Down router.

Example 9-12. BGP Configuration and BGP Routing Table for the Down Router

```
Down#show run | begin bgp
```

```
router bgp 65500
no synchronization
bgp log-neighbor-changes
bgp confederation identifier 7614
bgp confederation peers 65501
neighbor 10.3.1.2 remote-as 65500
neighbor 10.3.1.2 route-reflector-client
neighbor 10.3.1.2 next-hop-self
neighbor 10.4.1.2 remote-as 65500
neighbor 10.4.1.2 route-reflector-client
neighbor 10.4.1.2 next-hop-self
neighbor 101.201.3.1 remote-as 11011
neighbor 172.16.1.2 remote-as 65501
neighbor 172.16.1.2 next-hop-self
no auto-summary
```

```
Down#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* i10.3.1.32/27	10.1.1.1	0	100	0	i
*>i	10.3.1.2	0	100	0	i
* i10.3.1.64/27	10.1.1.1	0	100	0	i
*>i	10.3.1.2	0	100	0	i

```

*>i10.4.1.32/27      10.4.1.2          0    100    0 i
* i                  10.1.1.2          0    100    0 i
*>i10.4.1.64/27      10.4.1.2          0    100    0 i
* i                  10.1.1.2          0    100    0 i
*> 10.5.1.32/27      172.16.1.2        0    100    0 (65501) i
*> 10.5.1.64/27      172.16.1.2        0    100    0 (65501) i
* 101.201.1.0/24     172.16.1.2        0    100    0 (65501) 11011 i
*>                   101.201.3.1        0          0 11011 i
* 101.201.2.0/24     172.16.1.2        0    100    0 (65501) 11011 i
*>                   101.201.3.1        0          0 11011 i
* 101.201.4.0/24     172.16.1.2        0    100    0 (65501) 11011 i
*>                   101.201.3.1        0          0 11011 i
* 101.201.5.0/24     172.16.1.2        0    100    0 (65501) 11011 i
*>                   101.201.3.1        0          0 11011 i

```

In order for the Down router to form a special E-BGP type confederation peer relationship with the Top router, the `bgp confederation peer 65501` statement is required. This statement tells the router that AS 65501 is also a peer member AS in the 7614 parent AS. [Example 9-13](#) shows the BGP configuration and show ip bgpRI B information for the Top router.

Example 9-13. BGP Configuration and the Resulting BGP RIB for the Top Router

```

Top#show run | begin bgp
router bgp 65501
  no synchronization
  bgp log-neighbor-changes
  bgp confederation identifier 7614
  bgp confederation peers 65500
  neighbor 10.5.1.2 remote-as 65501

```

```

neighbor 10.5.1.2 next-hop-self
neighbor 101.201.3.5 remote-as 11011
neighbor 172.16.1.1 remote-as 65500
neighbor 172.16.1.1 next-hop-self
no auto-summary

```

Top#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.3.1.32/27	172.16.1.1	0	100	0	(65500) i
*> 10.3.1.64/27	172.16.1.1	0	100	0	(65500) i
*> 10.4.1.32/27	172.16.1.1	0	100	0	(65500) i
*> 10.4.1.64/27	172.16.1.1	0	100	0	(65500) i
*>i10.5.1.32/27	10.5.1.2	0	100	0	i
*>i10.5.1.64/27	10.5.1.2	0	100	0	i
*> 101.201.1.0/24	101.201.3.5	0		0	11011 i
*	172.16.1.1	0	100	0	(65500) 11011 i
*> 101.201.2.0/24	101.201.3.5	0		0	11011 i
*	172.16.1.1	0	100	0	(65500) 11011 i
*> 101.201.4.0/24	101.201.3.5	0		0	11011 i
*	172.16.1.1	0	100	0	(65500) 11011 i
*> 101.201.5.0/24	101.201.3.5	0		0	11011 i
*	172.16.1.1	0	100	0	(65500) 11011 i

At this point, you can ping all interfaces on all routers. If each I-BGP speaker has two routes to all the networks that originate in sub-AS 65,500, and you can successfully ping each interface on each router, you have completed this example. [Example 9-14](#) shows the complete configurations for each of the routers from this experiment.

Example 9-14. Complete Router Configurations

Up#**show run | begin int**

```
interface Loopback100
    ip address 101.201.1.1 255.255.255.0
!
interface Loopback101
    ip address 101.201.2.1 255.255.255.0
!
interface Loopback102
    ip address 101.201.4.1 255.255.255.0
!
interface Loopback103
    ip address 101.201.5.1 255.255.255.0
!
interface Serial0
    ip address 101.201.3.1 255.255.255.252
!
interface Serial1
    ip address 101.201.3.5 255.255.255.252
!
router bgp 11011
    no synchronization
    bgp log-neighbor-changes
    network 101.201.1.0 mask 255.255.255.0
    network 101.201.2.0 mask 255.255.255.0
    network 101.201.4.0 mask 255.255.255.0
    network 101.201.5.0 mask 255.255.255.0
    neighbor 101.201.3.2 remote-as 7614
    neighbor 101.201.3.6 remote-as 7614
    no auto-summary
```

```
Down#show run | begin int

interface Ethernet0/0
    ip address 172.16.1.1 255.255.255.0
!
interface Serial0/0
    ip address 101.201.3.2 255.255.255.252
!
interface Serial0/1
    ip address 10.3.1.1 255.255.255.252
    clock rate 1300000
!
interface Serial0/2
    ip address 10.4.1.1 255.255.255.252
    clock rate 1300000
!
router eigrp 1709
    passive-interface Serial0/0
    network 10.3.1.0 0.0.0.3
    network 10.4.1.0 0.0.0.3
    network 101.201.3.0 0.0.0.3
    network 172.16.1.0 0.0.0.255
    no auto-summary
!
router bgp 65500
    no synchronization
    bgp log-neighbor-changes
    bgp confederation identifier 7614
```

```
bgp confederation peers 65501  
neighbor 10.3.1.2 remote-as 65500  
neighbor 10.3.1.2 route-reflector-client  
neighbor 10.3.1.2 next-hop-self  
neighbor 10.4.1.2 remote-as 65500  
neighbor 10.4.1.2 route-reflector-client  
neighbor 10.4.1.2 next-hop-self  
neighbor 101.201.3.1 remote-as 11011  
neighbor 172.16.1.2 remote-as 65501  
neighbor 172.16.1.2 next-hop-self  
no auto-summary
```

```
Top#show run | begin int  
  
interface Ethernet0  
  ip address 172.16.1.2 255.255.255.0  
  
!  
  
interface Serial0  
  ip address 101.201.3.6 255.255.255.252  
  clockrate 1300000  
  
!  
  
interface Serial1  
  ip address 10.5.1.1 255.255.255.252  
  
!  
  
router eigrp 1709  
  passive-interface Serial0  
  network 10.5.1.0 0.0.0.3  
  network 101.201.3.4 0.0.0.3  
  network 172.16.1.0 0.0.0.255
```

```
no auto-summary

!
router bgp 65501
no synchronization
bgp log-neighbor-changes
bgp confederation identifier 7614
bgp confederation peers 65500
neighbor 10.5.1.2 remote-as 65501
neighbor 10.5.1.2 next-hop-self
neighbor 101.201.3.5 remote-as 11011
neighbor 172.16.1.1 remote-as 65500
neighbor 172.16.1.1 next-hop-self
no auto-summary
```

```
Left#show run | begin int

interface Loopback100
ip address 10.3.1.33 255.255.255.224
!

interface Loopback200
ip address 10.3.1.65 255.255.255.224
!

interface Serial0
ip address 10.1.1.1 255.255.255.252
clockrate 1300000
!

interface Serial1
ip address 10.3.1.2 255.255.255.252
!
```

```
router eigrp 1709

network 10.1.1.0 0.0.0.3

network 10.3.1.0 0.0.0.3

no auto-summary

!

router bgp 65500

no synchronization

bgp log-neighbor-changes

bgp confederation identifier 7614

network 10.3.1.32 mask 255.255.255.224

network 10.3.1.64 mask 255.255.255.224

neighbor 10.1.1.2 remote-as 65500

neighbor 10.1.1.2 route-reflector-client

neighbor 10.1.1.2 next-hop-self

neighbor 10.4.1.1 remote-as 65500

neighbor 10.3.1.1 route-reflector-client

neighbor 10.3.1.1 next-hop-self

no auto-summary
```

```
Right#show run | begin int

interface Loopback100

ip address 10.4.1.33 255.255.255.224

!

interface Loopback200

ip address 10.4.1.65 255.255.255.224

!

interface Serial0

ip address 10.1.1.2 255.255.255.252
```

```
!  
  
interface Serial1  
  ip address 10.4.1.2 255.255.255.252  
!  
router eigrp 1709  
  network 10.1.1.0 0.0.0.3  
  network 10.4.1.0 0.0.0.3  
  no auto-summary  
!  
router bgp 65500  
  no synchronization  
  bgp log-neighbor-changes  
  bgp confederation identifier 7614  
  network 10.4.1.32 mask 255.255.255.224  
  network 10.4.1.64 mask 255.255.255.224  
  neighbor 10.1.1.1 remote-as 65500  
  neighbor 10.1.1.1 route-reflector-client  
  neighbor 10.1.1.1 next-hop-self  
  neighbor 10.4.1.1 remote-as 65500  
  neighbor 10.4.1.1 route-reflector-client  
  neighbor 10.4.1.1 next-hop-self  
  no auto-summary
```

```
Bottom#show run | begin int  
  
interface Loopback100  
  ip address 10.5.1.33 255.255.255.224  
!  
interface Loopback200
```

```

ip address 10.5.1.65 255.255.255.224

!
interface Serial0
  ip address 10.5.1.2 255.255.255.252
  clockrate 1300000
!
router eigrp 1709
  network 10.5.1.0 0.0.0.3
  no auto-summary
!
router bgp 65501
  no synchronization
  bgp log-neighbor-changes
  bgp confederation identifier 7614
  network 10.5.1.32 mask 255.255.255.224
  network 10.5.1.65 mask 255.255.255.224
  neighbor 10.5.1.1 remote-as 65501
  no auto-summary

```

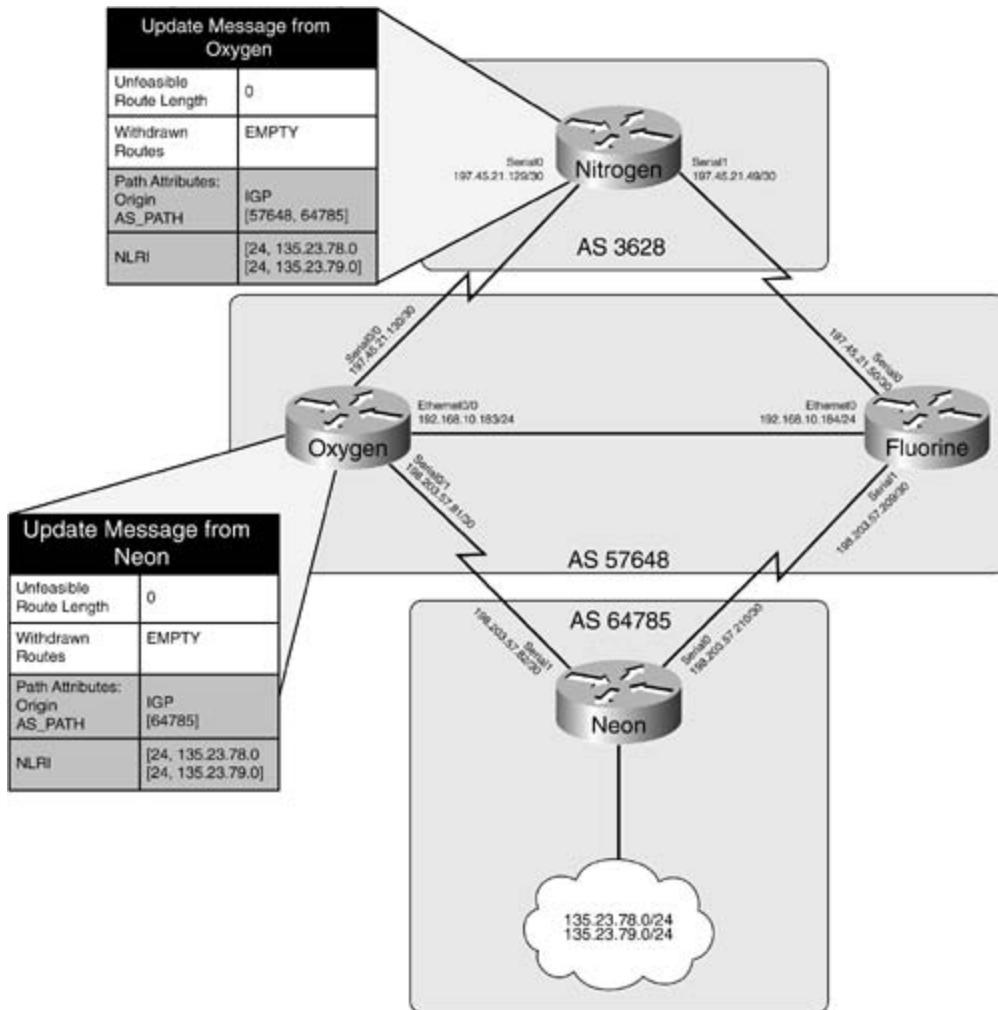
Private Autonomous Systems

Like private RFC 1918 IP addresses, a range of private AS numbers is reserved for networks that do not require a public AS number. Private ASNs (ranging from 64,512 to 65,535) are commonly used in two ways: They can be used between two private BGP networks, or as member AS numbers in BGP confederations. If you recall back to [Chapter 7](#), you will remember that the default behavior for BGP confederations states that the member AS number must be removed from the AS path as the path is advertised to E-BGP neighbors. Although you manually do not have to remove the private AS number from confederation members before exiting an AS (the router will do this for you), you do need to remove private AS numbers from private BGP networks before advertising them to the public Internet.

You can remove private AS numbers from the AS path at an AS egress point before the path is advertised to an external peer. To remove private AS numbers from an AS path, use the `neighbor ip-address remove-private-as` command for each E-BGP peer that you configured. For example, looking at the network shown in [Figure 9-6](#), notice that the Neon router sends the

advertisement for networks 135.23.78.0/24 and 135.23.79.0/24 to the routers in AS 57,648 with an AS path of 64,785.

Figure 9-6. Elements Network with Private Autonomous System Numbers



The upstream Nitrogen router receives the update for these networks that have the AS path value of [57648, 64785]. To remove the 64,785 AS from the path, you add the remove-private-as command to the E-BGP neighbor configuration on the Oxygen and Fluorine routers. You also need to clear the BGP session on these routers to apply the changes. Before you remove the private AS numbers, the BGP RIB on the Nitrogen router would look like the table shown in [Example 9-15](#).

Example 9-15. Nitrogen BGP RIB

```
Nitrogen#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* 135.23.78.0/24	197.45.21.130			0	57648 64785 i
*>	197.45.21.50			0	57648 64785 i
* 135.23.79.0/24	197.45.21.130			0	57648 64785 i
*>	197.45.21.50			0	57648 64785 i

[Example 9-16](#) shows the BGP configuration for the Oxygen router after the remove-private-as command was used.

Example 9-16. Using the remove-private-as Command on the Oxygen Router

```
Oxygen#show run | begin bgp

router bgp 57648
  no synchronization
  bgp log-neighbor-changes
  neighbor 192.168.10.184 remote-as 57648
  neighbor 192.168.10.184 next-hop-self
  neighbor 197.45.21.129 remote-as 3628
  neighbor 197.45.21.129 remove-private-as
  neighbor 198.203.57.82 remote-as 64785
  no auto-summary
```

After adding the remove-private-as command and clearing the BGP session on the Oxygen router, the private AS number, 64,785, is removed from the AS path, as shown in [Example 9-17](#).

Example 9-17. BGP RI B from the Nitrogen Router

```
Nitrogen#show ip bgp | begin Network
```

Network	Next Hop	Metric LocPrf Weight Path
*> 135.23.78.0/24	197.45.21.130	0 57648 i
*	197.45.21.50	0 57648 64785 I
*> 135.23.79.0/24	197.45.21.130	0 57648 i
*	197.45.21.50	0 57648 64785 I

Now that the remove-private-as command has been issued, you can also see that the Nitrogen router now prefers the new route with the shorter AS path as well. To correct that problem, issue the remove-private-as command on the Fluorine router, clear the BGP session, and the Nitrogen router will once again prefer the path to networks 135.23.78.0/24 and 135.23.79.0/24 through the Fluorine router, as shown in [Example 9-18](#).

Example 9-18. Final Nitrogen BGP RIB

```
Nitrogen#show ip bgp | begin Network
```

Network	Next Hop	Metric LocPrf Weight Path
* 135.23.78.0/24	197.45.21.130	0 57648 i
*>	197.45.21.50	0 57648 i
* 135.23.79.0/24	197.45.21.130	0 57648 i
*>	197.45.21.50	0 57648 i

Simplifying Configurations with Peer Groups

Large, complex configurations tend to appear in more advanced BGP implementations. For each individual peer that you configure, you might require a neighbor statement, next-hop-self statements, route filtering, route aggregation, attribute modification, and so on, making the configurations complicated and difficult to read. The solution to this problem is to use BGP peer groups.

In Cisco IOS Software, BGP peer groups are used with BGP to simplify configuration tasks by incorporating repetitive statements into one or more peer groups. Each neighbor is assigned to a peer group, and the router determines that peer's configuration based on that of the peer group.

Three steps are required to create a peer group:

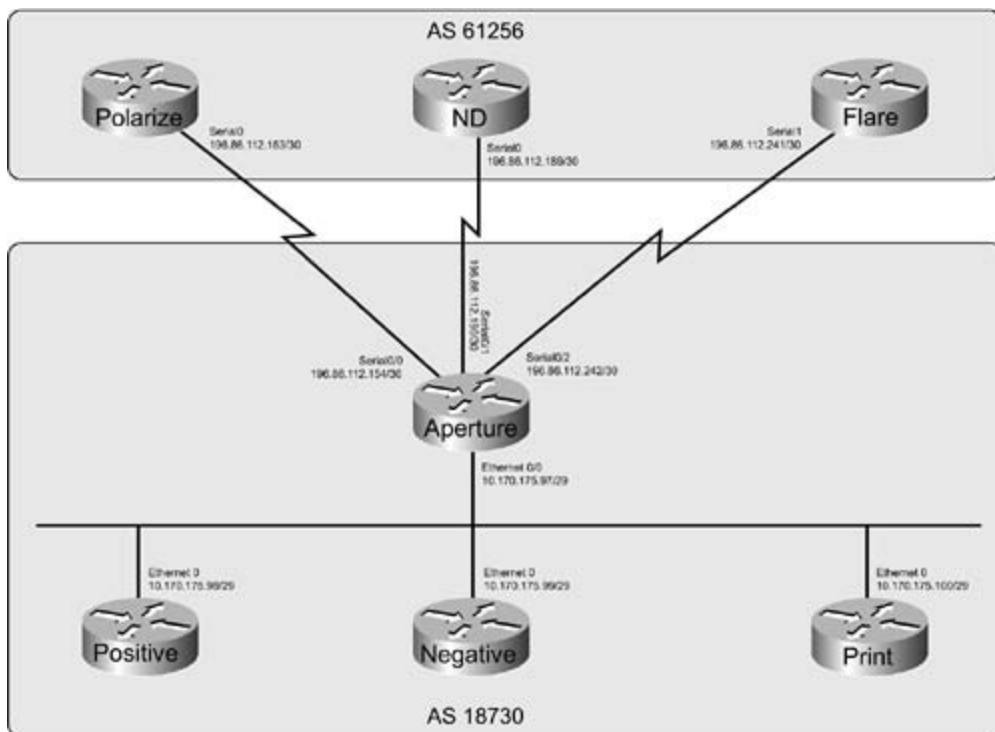
- Step 1. Create the peer group using the neighbor *peer-group-name* peer-group command.

Step 2. Add groupwide configuration elements to the peer group as you would any other BGP neighbor, using the `neighbor peer-group-name` statement command for each item.

Step 3. Assign BGP peers with common group traits to the peer group using the `neighbor ip-address peer-group` command.

For example, the network shown in [Figure 9-7](#) is a great candidate for peer group use.

Figure 9-7. Shadow-Box Network



In this example, the Aperture router has three external BGP connections to routers in AS 61,256, and three internal BGP connections to its peers in AS 18,730. Each of these BGP peering sessions has the same basic configuration, as shown in [Example 9-19](#).

Example 9-19. BGP Configuration for the Aperture Router

```
Aperture#show run | begin bgp

router bgp 18730

no synchronization

bgp log-neighbor-changes
```

```

neighbor 10.170.175.98 remote-as 18730
neighbor 10.170.175.98 password tough-password
neighbor 10.170.175.98 route-reflector-client
neighbor 10.170.175.98 next-hop-self
neighbor 10.170.175.99 remote-as 18730
neighbor 10.170.175.99 password tough-password
neighbor 10.170.175.99 route-reflector-client
neighbor 10.170.175.99 next-hop-self
neighbor 10.170.175.100 remote-as 18730
neighbor 10.170.175.100 password tough-password
neighbor 10.170.175.100 route-reflector-client
neighbor 10.170.175.100 next-hop-self
neighbor 196.86.112.153 remote-as 61256
neighbor 196.86.112.153 password secret
neighbor 196.86.112.189 remote-as 61256
neighbor 196.86.112.189 password secret
neighbor 196.86.112.241 remote-as 61256
neighbor 196.86.112.241 password secret
no auto-summary

```

The preceding configuration shows that the Aperture router contains 18 statements for six BGP sessions. Each external session has a remote AS and password configuration, and each internal session has a remote-as, password, next-hop-self statement, and route reflector configuration. If any new statements are to be added to the configuration, they must be added on a peer-by-peer basis. The addition of any new peers also requires at least two more lines of configuration. The combination of peers and new configuration statements would create quite a long and tedious configuration. To solve this problem, two peer groups can be created, one for external peers in AS 61,256, and one for internal peers in AS 18,730. Each of the configuration statements for each peer group is added into the peer group configuration, and after the groups have been configured, each of the external and internal neighbors requires only one line of configuration, as shown in [Example 9-20](#).

Example 9-20. Aperture Router Configuration with Peer Groups

```
Aperture#show run | begin bgp

router bgp 18730

no synchronization

bgp log-neighbor-changes

neighbor External peer-group

neighbor External remote-as 61256

neighbor External password secret

neighbor Internal peer-group

neighbor Internal remote-as 18730

neighbor Internal password tough-password

neighbor Internal route-reflector-client

neighbor Internal next-hop-self

neighbor 10.170.175.98 peer-group Internal

neighbor 10.170.175.99 peer-group Internal

neighbor 10.170.175.100 peer-group Internal

neighbor 196.86.112.153 peer-group External

neighbor 196.86.112.189 peer-group External

neighbor 196.86.112.241 peer-group External

no auto-summary
```

Now that you have seen how to simplify large network implementations using route reflectors, confederations, and peer groups, it is time to learn how to simplify routing tables using BGP route aggregation techniques.

Route Aggregation

Another way to simplify large BGP implementations, is to decrease the size of the BGP RIBs by aggregating BGP routes. Route aggregation is a simple process that can help keep Internet routing tables down in size, lowering the number of routes that must be passed between neighboring BGP routers during updates. The following route aggregation schemes are covered in this section:

- General route aggregation;
- Route aggregation with filtering
- Route suppression
- Conditional route advertisement

By default, BGP advertises only aggregated routes if a more specific route exists in the main IP routing table. If you specify an aggregate for a collection of routes that the BGP scanner is not aware of, the aggregate is not advertised. By default, aggregated routes lose the attribute values that applied to the individual, more specific routes; however, you can change this behavior by using route maps that contain lists of routes and attributes to apply to those routes or the aggregate. Controlling BGP update traffic with route aggregation is a simple, easily configured process requiring only three steps:

Step 1. Specify networks that are to be aggregated using the network command.

Step 2. Use the aggregate-address command to specify the way the networks should be summarized. The syntax for the aggregate-address command in Cisco IOS Software Release 12.2(12)T is as follows:

```
aggregate-address ip-address aggregate-mask [advertise-map route-map-name ]  
[as-set] [attribute-map route-map-name] [route-map route-map-name] [summary-  
only] [suppress-map route-map-name]
```

Step 3. (Optional) Specify any additional aggregation schemes that are to be used.

You can use a number of optional commands with BGP route aggregates by using the aggregate-address command. [Table 9-2](#) shows these optional command values and their descriptions.

Table 9-2. Optional aggregate-address Commands

Command Name	Description
advertise-map	Specifies a route map containing a list of routes that an AS_SET attribute will apply to. This command can also be used to specify routes the routes that will be aggregated.
as-set	Creates an AS_SET attribute for the aggregated route. The AS_SET stores the aggregated subset of AS paths within a larger aggregated AS path for situations when the path contains different AS path values.
attribute-map	Allows for the custom specification of BGP attributes based on user-defined information.
route-map	Similar to the attribute-map command, this command allows for the manipulation of aggregate attributes.
summary-only	Limits the output of BGP advertisements to the aggregate address—filtering all the individual routes that create the aggregate.
suppress-map	Specifies more specific routes that are to be suppressed based on user-defined information contained in a route map.

When an aggregate route is created, both the new aggregate route and all other more specific routes are advertised to each BGP peer. If this is not the desired effect you had in mind, you can control this behavior by using the summary-only command. The new route, by default, contains the ATOMIC_AGGREGATE and AGGREGATOR attributes. The ATOMIC_AGGREGATE attribute specifies that the route has been aggregated, and path information for the specific routes that were aggregated has been lost. The AGGREGATOR attribute gives information about the router that originally aggregated the route.

It is possible to retain the AS path information for the paths being aggregated at the aggregation point using the as-set command, which creates an AS_SET path segment type within the AS_PATH field of the UPDATE message containing the information about the aggregated routes.

[Example 9-21](#) shows how route aggregation summarizes the 156.202.148.x networks into one aggregated network, 156.202.148.0/24, between the Day and Night routers shown in [Figure 9-8](#).

Example 9-21. Aggregating Routes and Filtering Specific Routes

```
Day#show run | begin bgp

router bgp 8

bgp log-neighbor-changes

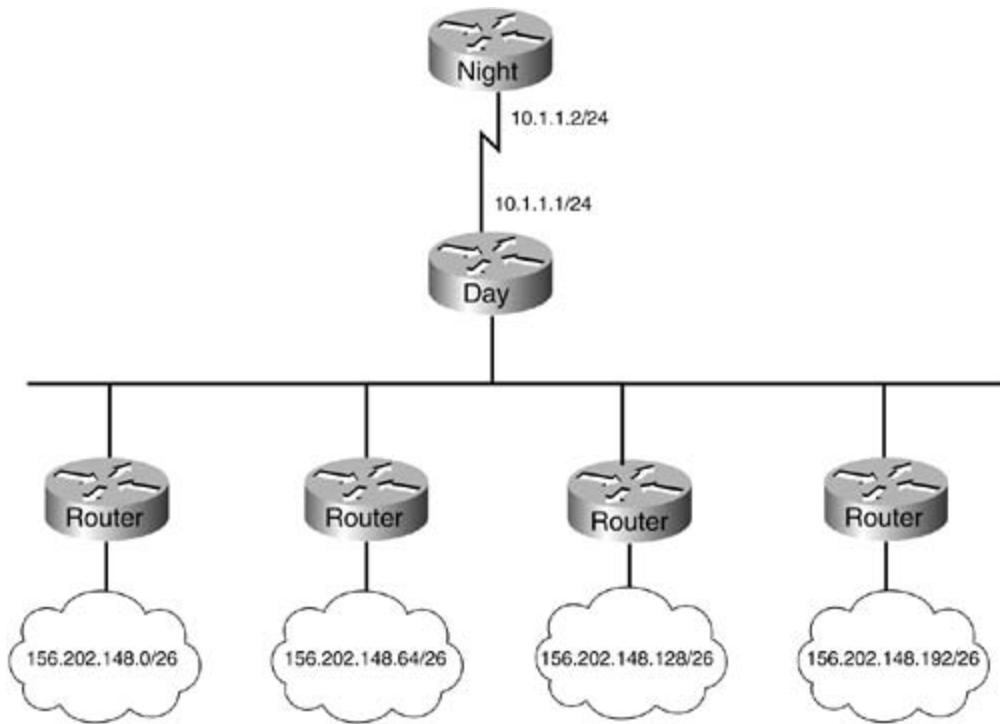
network 10.1.1.0 mask 255.255.255.0
```

```

network 156.202.148.0 mask 255.255.255.192
network 156.202.148.64 mask 255.255.255.192
network 156.202.148.128 mask 255.255.255.192
network 156.202.148.192 mask 255.255.255.192
aggregate-address 156.202.148.0 255.255.255.0 summary-only
neighbor 10.1.1.2 remote-as 9

```

Figure 9-8. Day and Night Network



In this example, the aggregate-address command aggregates the four 156.202.148.0/26 networks into one 156.202.148.0/24 summary route. The summary-only statement tells the router to suppress the individual routes that created the summary, advertising only the 156.202.148.0/24 network to remote peers. To verify that the command is working properly, you can use the show ip bgp and show ip bgp neighbors 10.1.1.2 advertised-routes commands on the Day router, as shown in [Example 9-22](#).

Example 9-22. show ip bgp Command Output from the Day Router

```
Day#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
s> 156.202.148.0/26 0.0.0.0		0		32768	i
*> 156.202.148.0/24 0.0.0.0				32768	i
s> 156.202.148.64/26	0.0.0.0	0		32768	i
s> 156.202.148.128/26	0.0.0.0	0		32768	i
s> 156.202.148.192/26	0.0.0.0	0		32768	i

```
Day#show ip bgp neighbors 10.1.1.2 advertised-routes | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.1.1.0/24	0.0.0.0	0		32768	I
*> 156.202.148.0/24 0.0.0.0				32768	i

Notice how the specific routes for the 156.202.148.0/24 aggregate network, highlighted in the preceding example, with the /26 mask are displayed with the s> characters, indicating a suppressed route; and the aggregate route, 156.202.148.0/24, is displayed with the *> characters, indicating that it is the best valid route to that network. Also, notice that when the show ip bgp neighbors 10.1.1.2 advertised-routes command is issued, you can see that the router is advertising only the 156.202.148.0/24 summary network. [Example 9-23](#) shows the BGP-specific information for the 156.202.148.0/24 network.

Example 9-23. show ip bgp 156.202.148.0/24 Command Output from the Day Router

```
Day#show ip bgp 156.202.148.0/24
```

```
BGP routing table entry for 156.202.148.0/24, version 7
```

```
Paths: (1 available, best #1, table Default-IP-Routing-Table)
```

```
Advertised to non peer-group peers:
```

```
10.1.1.2
```

```
Local, (aggregated by 8 10.1.1.1)
```

```
0.0.0.0 from 0.0.0.0 (10.1.1.1)

    Origin IGP, localpref 100, weight 32768, valid, aggregated, local,
    atomic-aggregate, best
```

Notice that the route for the 156.202.148.0/24 network contains the AGGREGATE and ATOMIC_AGGREGATE attributes, specifying that the Day router (10.1.1.1 in AS 8) aggregated the route, and that the path information for that route might have been lost during the aggregation. The as-set argument can also be used with the aggregate-address command to store the AS_SET path information for the route. In [Figure 9-9](#), for example, the Day router is aggregating the 156.202.148.0/26 networks into a larger 156.202.148.0/24 aggregate network advertisement, which it then forwards to the Night router. In this example, the 156.202.148.0/26 networks each originate from a different AS. The as-set keyword can be used with the aggregate-address command to add the list of individual AS numbers, which were removed during the aggregation process, back to the AS_PATH attribute for the aggregate route. [Example 9-24](#) shows the Night router's BGP RIB entry for the 156.202.148.0/24 network before the as-set keyword is used, and [Example 9-25](#) shows the configuration change for the Day router, and the resulting BGP route change on the Night router.

Example 9-24. Night Router's BGP Entry for the 156.202.148.0/24 Network (Before)

```
Night#show ip bgp 156.202.148.0/24

BGP routing table entry for 156.202.148.0/24, version 13
Paths: (1 available, best #1, table Default-IP-Routing-Table)
Not advertised to any peer
8, (aggregated by 8 10.1.1.1)
    10.1.1.1 from 10.1.1.1 (10.1.1.1)
        Origin IGP, localpref 100, valid, external, atomic-aggregate, best
```

Example 9-25. Using the AS_SET Value to Preserve Individual AS_PATH Values

```
Day#show run | begin bgp

router bgp 8
```

```
no synchronization

bgp log-neighbor-changes

aggregate-address 156.202.148.0 255.255.255.0 summary-only

neighbor 10.1.1.2 remote-as 9

neighbor 192.168.1.2 remote-as 141

neighbor 192.168.1.3 remote-as 142

neighbor 192.168.1.4 remote-as 143
```

```
Night#show ip bgp 156.202.148.0/24

BGP routing table entry for 156.202.148.0/24, version 18

Paths: (1 available, best #1, table Default-IP-Routing-Table)

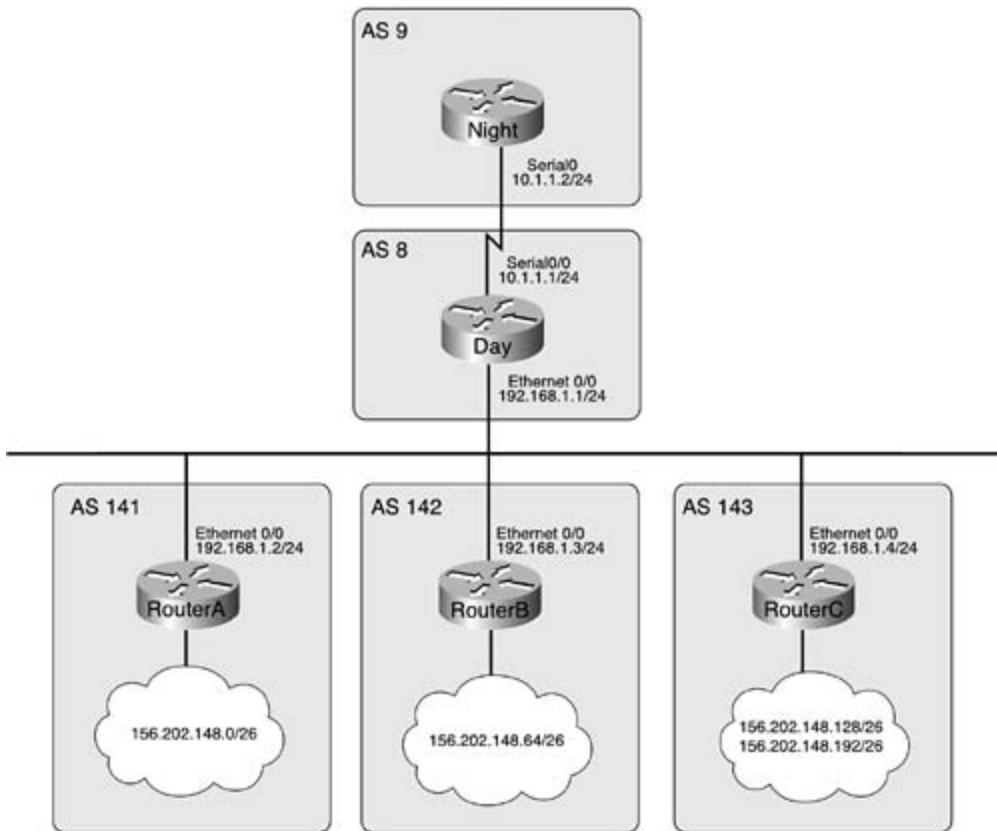
Not advertised to any peer

8 {141,142,143}, (aggregated by 8 10.1.1.1)

10.1.1.1 from 10.1.1.1 (10.1.1.1)

    Origin IGP, localpref 100, valid, external, best
```

Figure 9-9. Detailed Day and Night Network



After the `as-set` statement has been added to the `aggregate-address` command, and the BGP session has been cleared, the Night router now shows a more detailed AS_PATH entry for the 156.202.148.0/24 route. That route now lists the 141, 142, and 143 ASNs in the AS_PATH attribute, and that list is referred to as an AS_SET.

You can use static routes to a null interface with a high administrative distance to prevent route flapping caused by network instabilities related to individual networks that have been aggregated. Remember, for BGP to advertise a route, it must first learn the route from its main IP routing table. If you use a static route with high administrative distance to a null interface, you allow the router to prefer routes learned by IGP protocols, while BGP can rely on the stability of the static route. In the event that the IGP protocol stops advertising the route, the router will begin sending all packets for that network to the null interface—the bit bucket; however, the BGP routes that the router advertises to upstream routers will not flap. [Example 9-26](#) shows how you can use a static route to help aggregate the 189.28.145.0/24 network.

Example 9-26. Using Static Routes to the Null Interface for Route Stability

```
Doh#show run | begin bgp
router bgp 104
no synchronization
```

```

bgp router-id 10.1.1.1

bgp log-neighbor-changes

network 189.28.145.0 mask 255.255.255.128

network 189.28.145.128 mask 255.255.255.128

aggregate-address 189.28.145.0 255.255.255.0 summary-only

neighbor 10.1.1.2 remote-as 9

no auto-summary

!

ip route 189.28.145.0 255.255.255.128 Null0 253 permanent

ip route 189.28.145.128 255.255.255.128 Null0 253 permanent

```

Doh#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
s> 189.28.145.0/25	0.0.0.0	0		32768	i
*> 189.28.145.0/24	0.0.0.0			32768	i
s> 189.28.145.128/25		0		32768	i
	0.0.0.0				

Now that you have seen how BGP route aggregation is performed, it is time to move on to more advanced BGP route aggregation and advertisement schemes, such as route suppression and conditional route advertisement.

Aggregation and Route Suppression

Another way to control routing advertisements for aggregated routes is to use route suppression to suppress the advertisement of certain networks; suppressed routes can also be unsuppressed on a neighbor-by-neighbor basis. You can use the optional `summary-only` command with the `aggregate-address` command to suppress all the more specific routes; and you can use `suppress maps` and `unsuppress maps` to specify exactly which routes should or should not be suppressed. By using route aggregation with route suppression, you can filter specific longer prefixes from the aggregated routing advertisements.

Four steps are required to use route aggregation with route suppression:

Step 1. Start BGP routing and configure neighbor relationships and networks that are to be advertised. If necessary, use the `no auto-summary` command to disable classful route

summarization.

Step 2. Use an access or prefix list to specify the networks that are to be suppressed.

Step 3. Create the route map that will be used as a suppress map for the aggregated network. This route map should specify the access or prefix list that tells the router which prefixes to suppress.

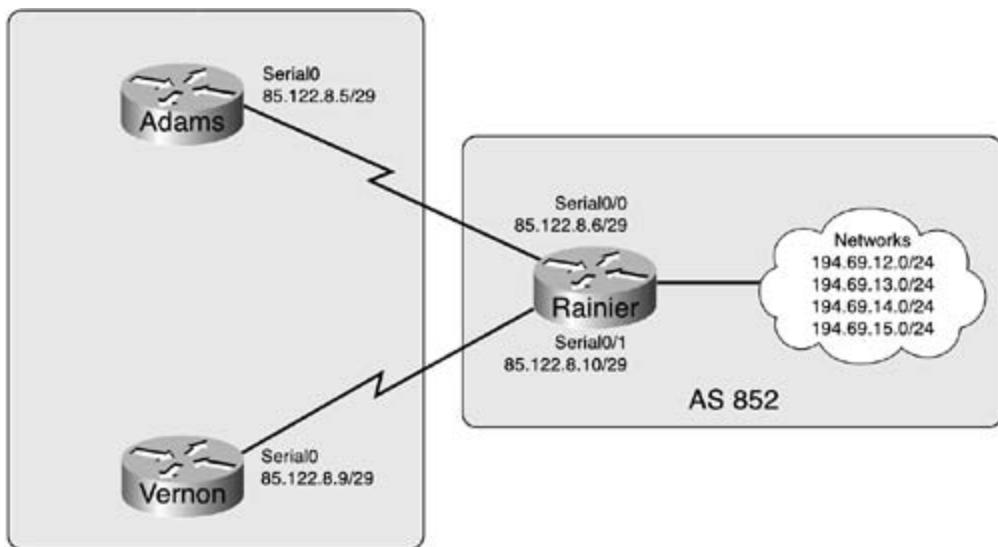
Step 4. Configure route aggregation using the aggregate-address command with the suppress-map statement to specify the aggregate and the suppressed routes. The command structure used to specify route aggregation with suppression is as follows:

```
aggregate-address ip-prefix mask [suppress-map route-map-name]
```

To verify that the longer prefixes belonging to the aggregated routes are correctly suppressed, use the show ip bgp command or the show ip bgp neighbors *neighbor-address* advertised-routes command. The show ip bgp command displays the suppressed routes with the s> characters in the status field, and the show ip bgp neighbors *ip-address* advertised-routes command displays only the routes that are actually advertised to the specified neighbor.

Consider, for instance, the network shown in [Figure 9-10](#). The Rainier router is connected to the Adams and Vernon routers and is sending two prefixes in each of its advertisements, the aggregate for the 194.69.12.0/22 network and the more specific route to the 194.69.14.0/24 network.

Figure 9-10. Route Suppression and the Volcano Network



[Example 9-27](#) shows how the aggregate-address command specifies the 194.69.12.0/22 prefix. The hide-me suppress map specifies that any network contained in IP prefix list 10 will be suppressed, whereas the Rainier router still advertises the more specific route to the 194.69.14.0/24 network. You can use the suppress-map command when you want to advertise a summary route, and only particular specific routes.

Example 9-27. Using a Suppress Map with the Summary Only Statement

```
Rainier#show run | begin bgp

router bgp 852
  no synchronization
  bgp log-neighbor-changes
  network 194.69.12.0
  network 194.69.13.0
  network 194.69.14.0
  network 194.69.15.0
  aggregate-address 194.69.12.0 255.255.252.0 suppress-map hide-me
  neighbor 85.122.8.5 remote-as 7518
  neighbor 85.122.8.5 description Adams Peer
  neighbor 85.122.8.9 remote-as 7518
```

```

neighbor 85.122.8.9 description Vernon Peer
no auto-summary
!
ip prefix-list 10 seq 5 permit 194.69.12.0/24
ip prefix-list 10 seq 10 permit 194.69.13.0/24
ip prefix-list 10 seq 15 permit 194.69.15.0/24
!
route-map hide-me permit 10
match ip address prefix-list 10

```

In [Example 9-28](#), notice that the BGP RIB for the Rainier router contains three suppressed routes and two valid, best routes. These results are achieved using route aggregation with the suppress-map statement, as shown previously in [Example 9-27](#).

Example 9-28. BGP RIB from the Rainier Router

```
Rainier#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
s> 194.69.12.0	0.0.0.0	0		32768	i
*> 194.69.12.0/22	0.0.0.0			32768	i
s> 194.69.13.0	0.0.0.0	0		32768	i
*> 194.69.14.0	0.0.0.0	0		32768	i
s> 194.69.15.0	0.0.0.0	0		32768	i

To make a router suppress routes for certain peers and advertise them to others, use the neighbor *ip-address* unsuppress-map *route-map-name* command. [Example 9-29](#) shows how that command advertises all the specific 194.69.x.0 routes to the Vernon router, while still using route suppression with the Adams router.

Example 9-29. Using unsuppress-map to Unsuppress Previously Suppressed Routes

```

Rainier#show run | begin bgp

router bgp 852

no synchronization

bgp log-neighbor-changes

network 194.69.12.0

network 194.69.13.0

network 194.69.14.0

network 194.69.15.0

aggregate-address 194.69.12.0 255.255.252.0 suppress-map hide-me

neighbor 85.122.8.5 remote-as 7518

neighbor 85.122.8.5 description Adams Peer

neighbor 85.122.8.9 remote-as 7518

neighbor 85.122.8.9 description Vernon Peer

neighbor 85.122.8.9 unsuppress-map hide-me

no auto-summary

!

ip prefix-list 10 seq 5 permit 194.69.12.0/24

ip prefix-list 10 seq 10 permit 194.69.13.0/24

ip prefix-list 10 seq 15 permit 194.69.15.0/24

!

route-map hide-me permit 10

match ip address prefix-list 10

```

In the preceding example, the hide-me unsuppress map, which is also used as the hide-me suppress map, states that the routes specified in IP prefix list 10 will not be suppressed for neighbor 85.122.8.9, the Vernon router. You can verify this by issuing the `show ip bgp` command on the Vernon router. [Example 9-30](#) shows the resulting BGP tables from the Vernon and Adams routers.

Example 9-30. Routes Advertised by the Rainier Router to the Vernon and Adams Routers

```
Vernon#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 194.69.12.0	85.122.8.10	0		0	852 i
*> 194.69.12.0/22	85.122.8.10			0	852 i
*> 194.69.13.0	85.122.8.10	0		0	852 i
*> 194.69.14.0	85.122.8.10	0		0	852 i
*> 194.69.15.0	85.122.8.10	0		0	852 i

```
Adams#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 194.69.12.0/22	85.122.8.6			0	852 i
*> 194.69.14.0	85.122.8.6	0		0	852 i

Now that you have seen how you can use route suppression to suppress or unsuppress routes on a neighbor-by-neighbor basis, the next section examines how you can use conditional route advertisement to conditionally advertise routes to BGP neighbors.

Conditional Route Advertisement

Conditional route advertisements provide a method of user-defined route advertisement that allows for more control over the way routes are advertised. Conditional route advertisements enable you to specify a set of conditions to track the state of a route using a route map called a non-exist-map, and if that route does not exist, advertise another route specified by another route map called an advertise-map. Advertise maps can be used by themselves to provide conditional route advertisements, with the aggregate-address command to specify routes that should contain the AS_SET AS_PATH attribute during route aggregation, or as a condition to advertise an aggregated route.

The non-exist-map specifies the network that will be tracked in the BGP RIB. While the routes in non-exist-map exist, the routes specified by the advertise-map statement will not be advertised. If the route specified by the non-exist-map is withdrawn, however, the route specified by the advertise-map will be advertised until the non-exist-map routes reappear. Conditional route advertisement can be used with multihomed networks to prevent asymmetric routes or alone to provide additional routing functionality.

Four steps are required to configure conditional route advertisement:

Step 1. Configure BGP peering with the other routers that are to be involved in the route advertisements.

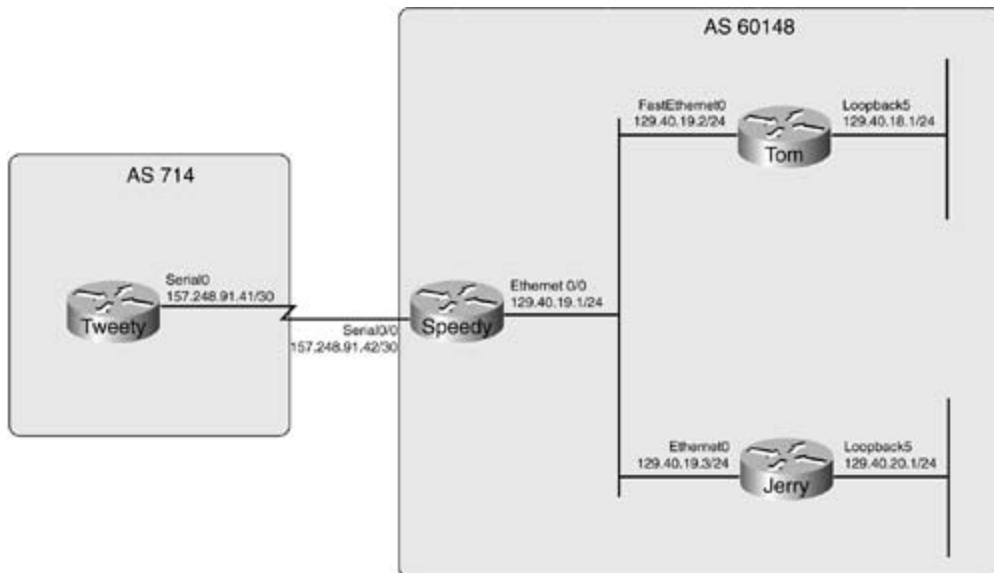
Step 2. Create a non-exist-map using a standard route map statement. This route map should specify an access or prefix list that identifies the network prefix that is to be tracked. Make sure to configure the access or prefix list specified in the route map.

Step 3. Create an advertise-map using a standard route map statement that specifies the access or prefix list describing the network prefixes that should be advertised when the networks specified by the non-exist-map are withdrawn from the BGP RIB. Also, create an access or prefix list that specifies the prefixes that should be advertised.

Step 4. Apply the route maps to the BGP neighbor using the neighbor *ip-address* advertise-map *route-map-name* no-exist-map *route-map-name* command.

In [Figure 9-11](#), for example, the Speedy router is connected to the Tom and Jerry routers via an Ethernet connection. The Tom router is advertising the 129.40.18.0/24 network, and the Jerry router is advertising the 129.40.20.0/24 network. The Speedy router advertises both of these networks to the Tweety router in AS 714.

Figure 9-11. Conditional Route Advertisement on the Cartoon Network



[Example 9-31](#) shows the BGP RIB entries for the Tweety router. In this example, the Tweety router is receiving all routes (129.40.18.0/24, 129.40.19.0/24, and 129.40.20.0/24) from the Speedy router.

Example 9-31. Tweety Router's BGP RIB

```
Tweety#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 129.40.18.0/24	157.248.91.42		0	60148	i
*> 129.40.19.0/24	157.248.91.42	0	0	60148	i
*> 129.40.20.0/24	157.248.91.42		0	60148	I

Example 9-32 shows how a conditional route advertisement manipulates the routes advertised by the Speedy router.

Example 9-32. Conditional Advertisement on the Speedy Router

```
Speedy#show ip bgp | begin bgp

router bgp 60148

no synchronization

network 129.40.19.0 mask 255.255.255.0

neighbor 129.40.19.2 remote-as 60148

neighbor 129.40.19.2 description Tom Router

neighbor 129.40.19.3 remote-as 60148

neighbor 129.40.19.2 description Jerry Router

neighbor 157.248.91.41 remote-as 714

neighbor 129.40.19.2 description Tweety Router

neighbor 157.248.91.41 advertise-map advertise-me non-exist-map not-in-table

no auto-summary

!

ip prefix-list 1000 seq 5 permit 129.40.18.0/24

!

ip prefix-list 1001 seq 5 permit 129.40.20.0/24

!
```

```

route-map not-in-table permit 10
match ip address prefix-list 1001
!
route-map advertise-me permit 10
match ip address prefix-list 1000

```

The not-in-table route map is used as the non-exist-map to specify the 129.40.20.0/24 network, and the advertise-me route map is used to specify the network that is to be conditionally advertised. As long as the 129.40.20.0/24 route exists in the Speedy router's routing table, the 129.40.18.0/24 route will not be advertised. If the 129.40.20.0/24 route is withdrawn, however, the 129.40.18.0/24 route is advertised in its place. [Example 9-33](#) shows the Tweety router's routing table after the conditional route advertisement was added.

Example 9-33. Tweety Routing Table After Conditional Routing

```

Tweety#show ip bgp | begin Network

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 129.40.19.0/24	157.248.91.42	0		60148	i
*> 129.40.20.0/24	157.248.91.42	0		60148	i

As you can see in the preceding example, after the Speedy router was configured to conditionally advertise the 129.40.18.0/24 network it began to suppress the advertisement of the 149.40.18.0/24 network. If the Jerry router stops advertising the 129.40.20.0/24 network, however, the Speedy router withdraws the advertisement for the 129.40.20.0/24 network, and starts advertising the 129.40.18.0/24 network in its place. [Example 9-34](#) shows the Speedy router conditionally routing the 129.40.18.0/24 network after the Loopback5 interface is disabled on the Jerry router.

Example 9-34. Conditionally Advertising the 129.40.18.0/24 Network

```

Jerry(config)#interface loopback 5
Jerry(config-if)#shutdown

```

```
Speedy#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i129.40.18.0/24	129.40.19.2	0	100	0	i
*> 129.40.19.0/24	0.0.0.0	0		32768	i

```
Tweety#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 129.40.18.0/24	157.248.91.42	0	60148	i	
*> 129.40.19.0/24	157.248.91.42	0	60148	i	

You can monitor conditional route advertisement using the `show ip bgp neighbors/p-address [| begin Condition]` command, as shown in [Example 9-35](#).

Example 9-35. Using the show ip bgp neighbors Command to Monitor Conditional Route Advertisement

```
Speedy#show ip bgp neighbors 157.248.91.41 | begin Condition
```

```
Condition-map not-in-table, Advertise-map advertise-me, status: Withdraw
```

When the condition map, specified with the non-exist-map, is not available, the status of the conditional advertisement is *Advertise*, and the route specified by the Advertise map is advertised to the peer.

Now that you are armed with an understanding of BGP route suppression and aggregation, it is important to understand how you can use BGP route filtering to help define network policy. The next section introduces route filtering, and the following sections show how to use route filtering along with BGP attributes to filter routes and modify path selection.

Filtering BGP Routes

You can filter BGP routes in a number of ways; filtering incoming or outgoing routes from neighbors using distribute lists, route maps, prefix lists, filter lists, by BGP attribute, or by BGP COMMUNITY attributes. This section introduces basic BGP route filtering using route maps, distribution lists, and prefix lists.

Basic BGP route filtering is similar to the configuration of route filtering used with IGP protocols. A list of network prefixes is created, using access lists, or prefix lists, and that information is applied either to a specific neighbor or neighbors, a peer group, or as a blanket application to all BGP peers. The major difference between BGP and IGP route filtering is the number of options that BGP provides for filter selection criteria.

Using Distribute Lists to Filter Network Prefixes

The simplest way to filter BGP routes is to use a distribute list, either as a blanket statement for all peers or applied to specific peers using the neighbor statement. To apply a distribute list to all peers for all incoming or outgoing routes, follow these steps:

Step 1. Create an access or prefix list that specifies the traffic that is to be filtered.

Step 2. From BGP router configuration mode, create the distribution list that will be used to filter all incoming or outgoing UPDATE messages. Distribute lists use the following syntax:

```
distribute-list {access-list-number|access-list-name| gatewayprefix-list-name| prefixprefix-list-name[gatewayprefix-list-name]} {in [interface-name interface-number] | out [interface-name interface-number| bgp | connected | egp | eigrp | igrp | ospf | rip | static]}
```

NOTE

The optional gateway statement in the distribute-list gatewayprefix-list-name command enables you to filter all routes from a particular peer; the peer for route filtration is specified by a prefix list.

You can apply only one distribution list to incoming and outgoing (either or both) updates at any time. Distribution lists can also be applied to UPDATE messages from a particular interface using the optional *interface-name* and *number* statement at the end of a list. For instance, the Willis router is currently receiving routes to all the networks shown in [Example 9-36](#).

Example 9-36. Willis BGP RIB

```
Willis#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 23.75.18.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.19.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.20.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.21.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.22.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.23.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.24.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.25.0/24	62.128.47.6			0	11151 5623 i
*> 23.75.26.0/24	62.128.47.6			0	11151 5623 i
*> 189.168.56.0/23	62.128.47.198	0		0	645 i
*> 189.168.58.0/23	62.128.47.198	0		0	645 i
*> 189.168.60.0/23	62.128.47.198	0		0	645 i
*> 189.168.62.0/23	62.128.47.198	0		0	645 i
*> 189.168.64.0/23	62.128.47.198	0		0	645 i
*> 189.168.66.0/23	62.128.47.198	0		0	645 i
*> 189.168.68.0/23	62.128.47.198	0		0	645 i
*> 189.168.70.0/23	62.128.47.198	0		0	645 i
Network	Next Hop	Metric	LocPrf	Weight	Path
*> 189.168.72.0/23	62.128.47.198	0		0	645 i
*> 189.168.74.0/23	62.128.47.198	0		0	645 i
*> 189.168.76.0/23	62.128.47.198	0		0	645 i

```

*> 189.168.78.0/23 62.128.47.198          0          0 645 i
*> 189.168.80.0/23 62.128.47.198          0          0 645 i
*> 189.168.82.0/23 62.128.47.198          0          0 645 i
*> 189.168.84.0/23 62.128.47.198          0          0 645 i
*> 189.168.86.0/23 62.128.47.198          0          0 645 i
*> 189.168.88.0/23 62.128.47.198          0          0 645 i

```

To filter all routes, except for routes to the prefix 23.75.0.0/16, you create an access list specifying the 23.75.0.0/16 network prefix and use that access list with a distribute list to filter all incoming routes. [Example 9-37](#) shows the Willis BGP configuration and the results of its application. In this case, the distribute list applies globally to all BGP neighbors.

Example 9-37. Willis Router Configuration and Postconfiguration BGP RIB

```

Willis#show run | begin bgp

router bgp 2001
  no synchronization
  bgp log-neighbor-changes
  neighbor 62.128.47.6 remote-as 11151
  neighbor 62.128.47.194 remote-as 645
  neighbor 62.128.47.198 remote-as 645
  distribute-list 1 in
  no auto-summary
!
access-list 1 permit 23.75.0.0 0.0.255.255

```

```
Willis#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 23.75.18.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.19.0/24	62.128.47.6	0	11151	5623	i

```

*> 23.75.20.0/24      62.128.47.6          0 11151 5623 i
*> 23.75.21.0/24      62.128.47.6          0 11151 5623 i
*> 23.75.22.0/24      62.128.47.6          0 11151 5623 i
*> 23.75.23.0/24      62.128.47.6          0 11151 5623 i
*> 23.75.24.0/24      62.128.47.6          0 11151 5623 i
*> 23.75.25.0/24      62.128.47.6          0 11151 5623 i
*> 23.75.26.0/24      62.128.47.6          0 11151 5623 i

```

As previously mentioned, you can also use the distribute-list command with a neighbor statement to filter traffic to or from a specific neighbor or peer group. You can accomplish this type of BGP route filtering using the following command:

```

neighbor {ip-address | peer-group}distribute-list {access-list-number |
access-list-name}{in | out}

```

For example, using the BGP configuration from the previous example, and a neighbor distribute list, you can filter all but two routes from peer 62.128.47.6. [Example 9-38](#) shows the required commands and the resulting BGP routes.

Example 9-38. Filtering Incoming Routes from a Specific Peer

```

Willis#show run | begin bgp

router bgp 2001

no synchronization

bgp log-neighbor-changes

neighbor 62.128.47.6 remote-as 11151

neighbor 62.128.47.6 distribute-list 50 in

```

```

neighbor 62.128.47.194 remote-as 645
neighbor 62.128.47.198 remote-as 645
no auto-summary
!
access-list 50 permit 23.75.18.0 0.0.0.255
access-list 50 permit 23.75.19.0 0.0.0.255
Willis#show ip bgp neighbors 62.128.47.6 routes | begin Network

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 23.75.18.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.19.0/24	62.128.47.6	0	11151	5623	i

Using Prefix Lists to Filter BGP Routes

For a simpler, more readable route filtration configuration, you can also apply prefix lists directly to BGP peers using the `neighbor {ip-address|peer-group} prefix-list prefix-list-name{in|out}` command.

IP prefix lists offer a simpler, more intuitive alternative to the access list. IP prefix lists enable you to use a list name or number that specifies a sequence of permit or deny statements. By specifying the prefix list sequence number, you can edit each statement in an IP prefix list individually, without removing and reapplying the entire list. Prefix lists also remove the burden of wildcard mask calculation. If you want to specify a particular host IP—for example, 110.80.8.118/32—type the following:

```
ip prefix-list bad-host seq 100 deny 110.80.8.118/32
```

If you were to add several 62.128.0.0/23 networks to the local BGP configuration on the Willis router, and then issue the `show ip bgp neighbor 62.128.47.6 advertised-routes` command, for instance, you would see the routes advertised in [Example 9-39](#).

Example 9-39. Networks Currently Advertised to Peer 62.128.47.6

```
Willis#show ip bgp neighbors 62.128.47.6 advertised-routes | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 62.128.60.0/23	0.0.0.0	0		32768	i
*> 62.128.64.0/23	0.0.0.0	0		32768	i
*> 62.128.68.0/23	0.0.0.0	0		32768	i
*> 62.128.72.0/23	0.0.0.0	0		32768	i
*> 62.128.76.0/23	0.0.0.0	0		32768	i
*> 189.168.56.0/23	62.128.47.198	0		0	645 i
*> 189.168.58.0/23	62.128.47.198	0		0	645 i
*> 189.168.60.0/23	62.128.47.198	0		0	645 i
*> 189.168.62.0/23	62.128.47.198	0		0	645 i
*> 189.168.64.0/23	62.128.47.198	0		0	645 i
*> 189.168.66.0/23	62.128.47.198	0		0	645 i
*> 189.168.68.0/23	62.128.47.198	0		0	645 i
*> 189.168.70.0/23	62.128.47.198	0		0	645 i
*> 189.168.72.0/23	62.128.47.198	0		0	645 i
*> 189.168.74.0/23	62.128.47.198	0		0	645 i
*> 189.168.76.0/23	62.128.47.198	0		0	645 i
*> 189.168.78.0/23	62.128.47.198	0		0	645 i
*> 189.168.80.0/23	62.128.47.198	0		0	645 i
*> 189.168.82.0/23	62.128.47.198	0		0	645 i
*> 189.168.84.0/23	62.128.47.198	0		0	645 i
*> 189.168.86.0/23	62.128.47.198	0		0	645 i
*> 189.168.88.0/23	62.128.47.198	0		0	645 i

Now, suppose you want to allow only local 62.128.x.0 networks to be advertised to neighbor

62.128.47.6. To accomplish this task, add an IP prefix list and call that list from the neighbor command, as shown in [Example 9-40](#).

Example 9-40. Using a Prefix List to Filter BGP Routes

```
Willis#show run | begin bgp

router bgp 2001

no synchronization

bgp log-neighbor-changes

network 62.128.60.0 mask 255.255.254.0

network 62.128.64.0 mask 255.255.254.0

network 62.128.68.0 mask 255.255.254.0

network 62.128.72.0 mask 255.255.254.0

network 62.128.76.0 mask 255.255.254.0

neighbor 62.128.47.6 remote-as 11151

neighbor 62.128.47.6 prefix-list route-filter out

neighbor 62.128.47.194 remote-as 645

neighbor 62.128.47.198 remote-as 645

no auto-summary

!

ip prefix-list route-filter seq 5 permit 62.128.0.0/16 le 23

Willis#show ip bgp neighbors 62.128.47.6 advertised-routes | begin Network

Network          Next Hop           Metric LocPrf Weight Path
*> 62.128.60.0/23    0.0.0.0                  0        32768  i
*> 62.128.64.0/23    0.0.0.0                  0        32768  i
*> 62.128.68.0/23    0.0.0.0                  0        32768  i
*> 62.128.72.0/23    0.0.0.0                  0        32768  i
*> 62.128.76.0/23    0.0.0.0                  0        32768  i
```

This IP prefix list provides the same type of functionality as an access list with a 0.0.1.255 wildcard mask. The 62.128.0.0/16 le 23 prefix list allows any network that begins with 62.128.x.x with a 23-bit subnet mask. If you decide to change from access lists and try IP prefix lists, be careful to check your syntax before applying the prefix list to a neighbor. Remember, that just like access lists, prefix lists end with an implicit deny; so, if you use a deny statement at the beginning of a list, you must include a permit statement at some point in the list to allow other traffic. The use of the ge and le commands might be a bit tricky at first; remember that the mask used for the prefix must match the exact prefix for all filtered routes. The ge/le statements match a range of subnet masks, like an inverse wildcard mask. For more help configuring IP prefix lists, refer to [Appendix D](#), "IP Prefix Lists."

Using Route Maps to Filter BGP Routes

Another more sophisticated approach to route filtering is to use a neighbor statement with an associated route map. There are a number of basic ways that route maps can be used to filter BGP routes: by attribute, network prefix, next-hop value, or route type. When filtering BGP routes, the match command specifies the item to match, and the route map itself is then applied to a neighbor or peer group. [Table 9-3](#) lists the route map match command types supported by BGP.

Table 9-3. BGP-Related Route Map match Commands

Match Command	Description
as-path <i>as-path-access-list-number</i>	Matches the AS_PATH attribute specified by an <i>as-path-access-list number</i> (ranging from 1 to 199). AS_PATH access lists and other AS_PATH functionality is covered later in this chapter.
community <i>community-list-number</i> [exact-match]	Matches the community value specified by the community list. There are two types of community lists: standard (ranging from 1 to 99) and extended (ranging from 100 to 199). The exact-match command can be used to specify an exact match. Community lists and other BGP COMMUNITY attribute functionality is covered later in this chapter.
ip address { <i>access-list-number</i> <i>access-list-name</i> prefix-list <i>prefix-list-name</i> }	Matches the IP prefix specified by the access or prefix list.
ip next-hop { <i>access-list-number</i> <i>access-list-name</i> prefix-list <i>prefix-list-name</i> }	Matches the NEXT_HOP attribute of a route. The NEXT_HOP value is specified by the trailing access list or prefix list. The NEXT_HOP attribute, and its uses, is covered later in this chapter.
ip route-source { <i>access-list-number</i> <i>access-list-name</i> prefix-list <i>prefix-list-name</i> }	Matches the source IP address of the peer that sent the route. The peer's IP address is specified by an access or prefix list. The match ip route-source command is supported only for outbound route maps.

<code>metric <i>metric-value</i></code>	Matches a MULTI_EXIT_DISC (MED) value; metric matches are not supported for in- or outbound route filtering. The MED attribute, and its uses, is covered later in this chapter.
<code>route-type { internal external local}</code>	Matches a locally generated route (sourced from 0.0.0.0 using show ip bgp). The match route-type command is supported only for outbound route filtering. Make sure to test the results obtained using the route-type local command; this command matches any locally originated routes, including routes that entered a BGP process by redistribution.
<code>tag <i>tag-value</i></code>	Matches a tag value. The use of BGP tags was covered earlier in Chapter 2 , "Configuring Route Maps and Policy-Based Routing."

Only two steps are required to configure BGP basic route filtering with route maps:

Step 1. Create a route map using the route-map command, and from route map configuration mode, use match commands to specify the attributes that are to be matched. (Route map configuration is covered in detail in [Chapter 2](#).)

Step 2. Apply the route map to a neighbor or peer group using the following command:

```
neighbor {ip-address | peer-group-name}route-maproute-map-name{in | out}
```

The following example shows how you can use a simple route map to limit route advertisements to locally generated routes. [Example 9-41](#) shows the routes that the Willis router is currently advertising to peer 62.128.47.6 before the application of route map filtering.

Example 9-41. Routes Advertised by Willis to Peer 62.128.47.6 Before Applying the Route Map

```
Willis#show ip bgp neighbors 62.128.47.6 advertised-routes | begin Network
```

Network	Next Hop	Metric LocPrf Weight Path
*> 23.75.18.0/24	62.128.47.6	0 11151 5623 i

*> 23.75.19.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.20.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.21.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.22.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.23.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.24.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.25.0/24	62.128.47.6	0	11151	5623	i
*> 23.75.26.0/24	62.128.47.6	0	11151	5623	i
*> 62.128.0.0/23	0.0.0.0	0		32768	i
*> 62.128.4.0/23	0.0.0.0	0		32768	i
*> 62.128.8.0/23	0.0.0.0	0		32768	i
*> 62.128.12.0/23	0.0.0.0	0		32768	i
*> 62.128.16.0/23	0.0.0.0	0		32768	i
*> 62.128.20.0/23	0.0.0.0	0		32768	i
*> 62.128.24.0/23	0.0.0.0	0		32768	i
*> 62.128.28.0/23	0.0.0.0	0		32768	i
*> 62.128.32.0/23	0.0.0.0	0		32768	i
*> 62.128.36.0/23	0.0.0.0	0		32768	i
*> 62.128.40.0/23	0.0.0.0	0		32768	i
*> 62.128.44.0/23	0.0.0.0	0		32768	i
*> 62.128.48.0/23	0.0.0.0	0		32768	i
Network	Next Hop	Metric	LocPrf	Weight	Path
*> 62.128.52.0/23	0.0.0.0	0		32768	i
*> 62.128.56.0/23	0.0.0.0	0		32768	i
*> 62.128.60.0/23	0.0.0.0	0		32768	i
*> 62.128.64.0/23	0.0.0.0	0		32768	i
*> 62.128.68.0/23	0.0.0.0	0		32768	i
*> 62.128.72.0/23	0.0.0.0	0		32768	i

```

*> 62.128.76.0/23    0.0.0.0                  0          32768 i
*> 189.168.56.0/23   62.128.47.198        0          0 645 i
*> 189.168.58.0/23   62.128.47.198        0          0 645 i
*> 189.168.60.0/23   62.128.47.198        0          0 645 i
*> 189.168.62.0/23   62.128.47.198        0          0 645 i
*> 189.168.64.0/23   62.128.47.198        0          0 645 i
*> 189.168.66.0/23   62.128.47.198        0          0 645 i
*> 189.168.68.0/23   62.128.47.198        0          0 645 i
*> 189.168.70.0/23   62.128.47.198        0          0 645 i
*> 189.168.72.0/23   62.128.47.198        0          0 645 i
*> 189.168.74.0/23   62.128.47.198        0          0 645 i
*> 189.168.76.0/23   62.128.47.198        0          0 645 i
*> 189.168.78.0/23   62.128.47.198        0          0 645 i
*> 189.168.80.0/23   62.128.47.198        0          0 645 i
*> 189.168.82.0/23   62.128.47.198        0          0 645 i
*> 189.168.84.0/23   62.128.47.198        0          0 645 i

      Network          Next Hop           Metric LocPrf Weight Path
*> 189.168.86.0/23   62.128.47.198        0          0 645 i
*> 189.168.88.0/23   62.128.47.198        0          0 645 i

```

[Example 9-42](#) shows how one simple little route map filters all routes from any source other than locally generated routes to the members of the all-peers peer group.

Example 9-42. Using the route-type local Command to Filter Routes

```

Willis#show run | begin bgp

router bgp 2001

no synchronization

bgp log-neighbor-changes

```

```

network 62.128.60.0 mask 255.255.254.0
network 62.128.64.0 mask 255.255.254.0
network 62.128.68.0 mask 255.255.254.0
network 62.128.72.0 mask 255.255.254.0
network 62.128.76.0 mask 255.255.254.0

neighbor all-peers peer-group

neighbor all-peers route-map route-filter out

neighbor 62.128.47.6 remote-as 11151

neighbor 62.128.47.6 peer-group all-peers

neighbor 62.128.47.194 remote-as 645

neighbor 62.128.47.194 peer-group all-peers

neighbor 62.128.47.198 remote-as 645

neighbor 62.128.47.198 peer-group all-peers

no auto-summary

!

route-map route-filter permit 10
match route-type local

```

After this configuration is applied, the Willis router will advertise only the routes shown in [Example 9-43](#) to any peer belonging to the all-peers peer group. This example uses the `show ip bgp neighbors <peer-group> advertised-routes` command to display the routes that are advertised to the all-peers peer group.

Example 9-43. `show ip bgp neighbors peer-group advertised-routes` Command

```
Willis#show ip bgp neighbors 62.128.47.6 advertised-routes | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 62.128.60.0/23	0.0.0.0	0		32768	i
*> 62.128.64.0/23	0.0.0.0	0		32768	i

```

*> 62.128.68.0/23    0.0.0.0          0      32768 i
*> 62.128.72.0/23    0.0.0.0          0      32768 i
*> 62.128.76.0/23    0.0.0.0          0      32768 i

```

You might have noticed that the route map set commands are not shown in [Table 9-3](#); this is because the route map set commands provide more advanced BGP functionality—BGP attribute manipulation. Another even more powerful use for BGP route maps involves the manipulation of BGP attributes and BGP route dampening. Each of these subjects is covered later in this chapter. BGP attribute values are usually manipulated using the set command under route map configuration mode and applying the route map to a neighbor or peer group using the neighbor {ip-address | peer-group}route-maproute-map-name {in | out} command. The following list shows a brief hint of the set commands that are covered in the next section:

- as-path prepend*as-path-number*
- as-path tag*as-path-string*
- comm-list*community-list-number*[delete]
- community [*community-value-decimal* | *aa:nn-format*]
- community additive
- community internet
- community local-as
- community no-advertise
- community no-export
- community none
- dampening*half-life-value reuse-penalty-value suppress-penalty-value*
- ip default next-hop*ip-address*
- ip default next-hop verify-availability
- local-preference*value*
- metric [+ | -] *metric-value*
- origin {egp*as-number* | igrp | incomplete}
- tag*tag-value*
- weight*weight-value*

Using BGP Attributes to Create Routing Policies

In the previous few chapters, this book covered BGP mechanics, neighbor configuration, MD-5 authentication, and route aggregation. This section shows how you can use BGP attributes to tie all previous technologies together and use BGP as the robust routing protocol that it is. This section covers the configuration of various attribute types, and the many ways that they might be used with BGP, including how to do the following:

- Filter inbound or outbound routes
- Customize route redistribution
- Special route aggregation
- Manipulate the BGP route selection process
- Specify preferred network ingress or egress points
- Next-hop modification
- Modify how upstream or downstream peers will propagate specific routes

You can use attributes in a number of ways to modify BGP routing on a Cisco router—using route maps, attribute maps, prefix lists, AS path access lists, regular expressions, and more. This section introduces each attribute's most common configuration uses and presents ways that you can use attributes to build stronger, more resilient BGP networks. Attributes mentioned in this chapter are described in more detail in [Chapter 7](#); therefore, each attribute is presented along with references to its accompanying explanation.

Modifying the ORIGIN Attribute to Affect Path Selection

The ORIGIN attribute, which describes the origin of a network prefix in BGP, is one of the key decision factors in the BGP path selection process. There are only three possible BGP ORIGIN types: IGP, EGP, and INCOMPLETE. BGP always prefers an IGP origin, then EGP, and finally, an INCOMPLETE origin. The ORIGIN attribute for each route can be displayed using the `show ip bgp` command; the ORIGIN attribute is the last column shown on the right side of the `show ip bgp` table in [Example 9-44](#).

Example 9-44. Displaying a Route's ORIGIN Attribute

```
Vernon#show ip bgp | begin Origin
```

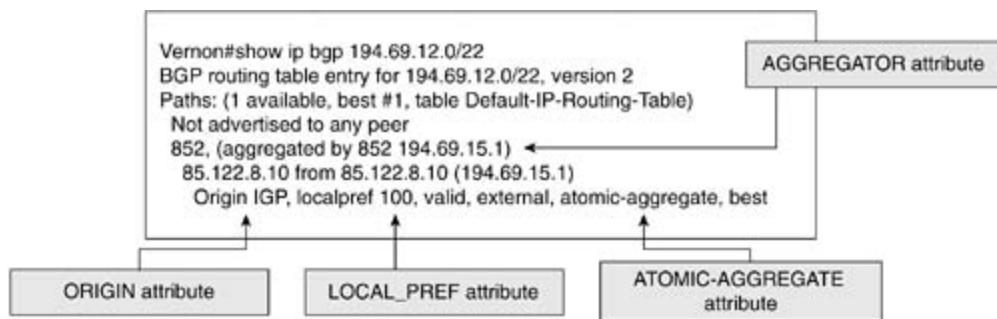
```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 194.69.12.0	85.122.8.10	0		0	852 i
*> 194.69.12.0/22	85.122.8.10			0	852 i

```
*> 194.69.13.0      85.122.8.10      0          0 852 i
*> 194.69.14.0      85.122.8.10      0          0 852 i
*> 194.69.15.0      85.122.8.10      0          0 852 i
```

You can also display the BGP attributes for each route using the `show ip bgp /ip-prefix` command. The ORIGIN is shown in the lower-left corner in [Figure 9-12](#).

Figure 9-12. Using the `show ip bgp` Command to Display BGP Attributes



Unless a route has entered BGP by means of redistribution, the ORIGIN attribute for each route will normally be IGP. The ORIGIN attribute is near the top of the BGP route selection process (number one in the decision process), so in certain instances, it might be useful to modify the ORIGIN for a route under some conditions. Three steps are required to change the origin for a route:

- Step 1. Configure BGP peers and specify the networks that are to be advertised.
- Step 2. Create a route map that changes the BGP ORIGIN attribute to the desired value (IGP or INCOMPLETE).
- Step 3. (Multiple choices) To apply the route map to a network statement, use the `network subnet-mask route-map route-map-name` command.

To apply the route map to an aggregate network, use the `aggregate-address /ip-prefix subnet mask route-map route-map-name [summary-only]` command.

To apply the route-map to all advertisements to or from a certain neighbor or peer group, use the `neighbor { /ip-address | peer-group-name} route-map route-map-name { in | out }` command.

TIP

When you make configuration changes, you might need to reset the BGP process to apply the changes. To clear a BGP process without resetting all sessions, use the `clear ip bgp * soft [in | out]` command.

To test the effect that changes to the ORIGIN attribute have on the BGP route selection process on router, shown in [Figure 9-13](#), change all outbound BGP updates using the neighbor *ip-address* route-map-name command. [Example 9-45](#) shows the BGP entries for the 189.168.x.0 networks before change.

Example 9-45. Willis Router's BGP Table for the 189.168.x.0 Networks

```
Willis#show ip bgp 189.168.0.0/16 longer-prefixes

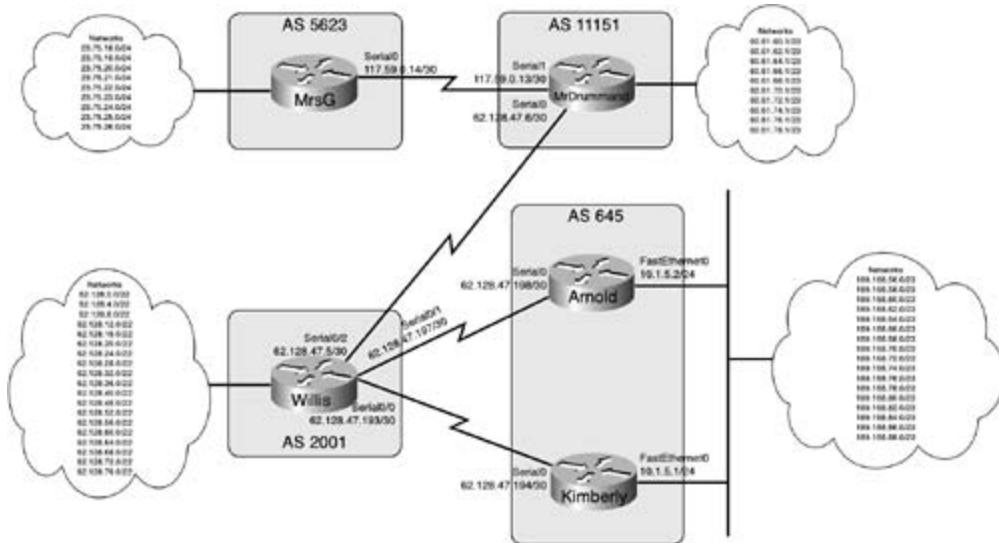
BGP table version is 119, local router ID is 62.128.47.5

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* 189.168.56.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.58.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.60.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.62.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.64.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.66.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.68.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i
* 189.168.70.0/23	62.128.47.198	0		0	645 i
*>	62.128.47.194	0		0	645 i

	Network	Next Hop	Metric	LocPrf	Weight	Path
* >	189.168.72.0/23	62.128.47.198	0	0	645	i
* >	189.168.74.0/23	62.128.47.198	0	0	645	i
* >	189.168.76.0/23	62.128.47.198	0	0	645	i
* >	189.168.78.0/23	62.128.47.198	0	0	645	i
* >	189.168.80.0/23	62.128.47.198	0	0	645	i
* >	189.168.82.0/23	62.128.47.198	0	0	645	i
* >	189.168.84.0/23	62.128.47.198	0	0	645	i
* >	189.168.86.0/23	62.128.47.198	0	0	645	i
* >	189.168.88.0/23	62.128.47.198	0	0	645	i

Figure 9-13. BGP Attributes Network



NOTE

For simplicity sake, the BGP Attributes network shown in [Figure 9-13](#) is used in all examples for this section.

[Example 9-46](#) shows the configuration for the Kimberly router. In this case, the Kimberly router has been configured to send all locally originated routes to neighbor 62.128.47.97, the Willis router, with the attribute changed to INCOMPLETE. The Willis router is shown in [Example 9-47](#).

Example 9-46. Kimberly Router's Beginning BGP Configuration

```
Kimberly#show run | begin bgp

router bgp 645

no synchronization

bgp router-id 10.1.5.1

bgp log-neighbor-changes

network 189.168.56.0 mask 255.255.254.0

network 189.168.58.0 mask 255.255.254.0

network 189.168.60.0 mask 255.255.254.0

network 189.168.62.0 mask 255.255.254.0
```

```

network 189.168.64.0 mask 255.255.254.0
network 189.168.66.0 mask 255.255.254.0
network 189.168.68.0 mask 255.255.254.0
network 189.168.70.0 mask 255.255.254.0
network 189.168.72.0 mask 255.255.254.0
network 189.168.74.0 mask 255.255.254.0
network 189.168.76.0 mask 255.255.254.0
network 189.168.78.0 mask 255.255.254.0
network 189.168.80.0 mask 255.255.254.0
network 189.168.82.0 mask 255.255.254.0
network 189.168.84.0 mask 255.255.254.0
network 189.168.86.0 mask 255.255.254.0
network 189.168.88.0 mask 255.255.254.0
neighbor 10.1.5.2 remote-as 645
neighbor 10.1.5.2 route-reflector-client
neighbor 10.1.5.2 next-hop-self
neighbor 62.128.47.193 remote-as 2001
neighbor 62.128.47.193 route-map change-origin out
no auto-summary
!
route-map change-origin permit 10
match route-type local
set origin incomplete

```

Example 9-47. Willis Router's BGP RIB After the ORIGIN Attribute Change

```
Willis#show ip bgp | include 645
```

*> 189.168.56.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.58.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.60.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.62.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.64.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.66.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.68.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.70.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.72.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.74.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.76.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.78.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.80.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?
*> 189.168.82.0/23	62.128.47.198	0	0 645 i
*	62.128.47.194	0	0 645 ?

```

*> 189.168.84.0/23  62.128.47.198      0          0 645 i
*
*                  62.128.47.194      0          0 645 ?
*
*> 189.168.86.0/23  62.128.47.198      0          0 645 i
*
*                  62.128.47.194      0          0 645 ?
*
*> 189.168.88.0/23  62.128.47.198      0          0 645 i
*
*                  62.128.47.194      0          0 645 ?

```

Also, notice that the Willis router now prefers all routes from the Arnold router, 62.128.47.198. [Ex: 48](#) shows the Willis router's IP routing table.

Example 9-48. Willis Router's IP Routing Table

```

Willis#show ip route | include 189

    189.168.0.0/23 is subnetted, 17 subnets

B        189.168.60.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.62.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.56.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.58.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.84.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.86.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.80.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.82.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.88.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.68.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.70.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.64.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.66.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.76.0 [20/0] via 62.128.47.198, 00:02:48
B        189.168.78.0 [20/0] via 62.128.47.198, 00:02:48

```

```
B      189.168.72.0 [20/0] via 62.128.47.198, 00:02:48  
B      189.168.74.0 [20/0] via 62.128.47.198, 00:02:48
```

As you can see, the ORIGIN attribute can be used to manipulate the BGP route selection process. Now you have seen an example of ORIGIN attribute modification, it is time to look at how you can use the AS_PATH attribute to affect path selection. Although the ORIGIN attribute can be modified to alter path decision, ORIGIN attribute modification is not the best choice for BGP path selection.

Using the AS_PATH Attribute to Affect Path Selection

Every time a routing update passes from one AS to another, the AS_PATH attribute is updated to show the path that the route has taken to reach its current location. As you might remember from [Chapter 7](#), the AS_PATH field in the BGP UPDATE message contains the AS path, in a right-to-left format, beginning with the originating AS, as shown in [Example 9-49](#).

Example 9-49. Displaying the AS_PATH Attribute for a BGP Route

```
MrsG#show ip bgp 189.168.88.0/23  
  
BGP routing table entry for 189.168.88.0/23, version 699  
  
Paths: (1 available, best #1, table Default-IP-Routing-Table)  
  
Not advertised to any peer  
  
Please add shading to next line  
  
11151 2001 645  
  
117.59.0.13 from 117.59.0.13 (117.59.0.13)  
  
Origin IGP, localpref 100, valid, external, best
```

In the preceding example, you can see that the route to the 189.168.88.0/23 network originated in AS 117.59.0.13 at the Arnold router, then passed to AS 2001, the Willis router, and then to AS 11,151, the MrDrun router, before reaching its current location, the MrsG router. The AS_PATH information is intended to be a BGP loop-prevention mechanism; if a router sees its own AS number in the path, the route is assumed to have looped and is ignored.

NOTE

The `neighbor ip-address allowas-in [number-of-occurrences]` command allows routers running Cisco IOS Software to accept up to 10 occurrences of the local AS number in the AS_F attribute of incoming BGP updates. Use this command with extreme caution, as it disables BGP prime loop-prevention method.

The AS path information is also used to provide several other features, including BGP AS_PATH filtering, BGP RIB lookups using regular expressions, and the AS_PATH information that also affects the BGP process. Remember, the BGP route selection process selects a route based on the following items:

1. Largest WEIGHT attribute.
2. Largest LOCAL_PREF attribute.
3. Locally originated routes (Next hop 0.0.0.0 in the BGP RIB).
4. Shortest AS_PATH attribute.
5. Best route ORIGIN attribute: IGP, EGP, INCOMPLETE.
6. Lowest MED attribute.
7. E-BGP routes are preferred over I-BGP routes (and also have lower administrative distance).
8. The oldest route first. (Older routes are more stable.)
9. The path that originated from the router with the lowest BGP router ID.
10. If the router is a route reflector, the lowest CLUSTER_ID attribute length.
11. Routes received from the peer with the lowest IP address.

It is a common, though not recommended, practice to use the AS path as a decision factor in Internet selection. As an experiment, go to an Internet looking-glass website and find routes containing AS with the same AS number repeated several times; this is referred to as *AS path prepending*. AS path prepending adds the local AS number to the current location (the leftmost AS path position) in the path as many times as the user specifies. It is not generally recommended because Internet routes travel through many autonomous systems, and as each route leaves each AS, the AS border routers also add their local AS number to the path, so there is no guarantee that the AS numbers that you originally prepended to the path will always have the desired effect. While exploring the Internet routing tab, you might even notice some routes that have up to 20 entries in the AS_PATH. This is most likely because two or more entities prepended their AS number to the AS_PATH, and at the time you are viewing the route, it might have passed through several autonomous systems. There are several other more efficient route attribute manipulation techniques.

To manipulate the AS path on a Cisco router, use the `set as-path prepend as-number` command in a route map and specify the AS values that you want to add to the route. Only two steps are required to prepend an AS number to an AS path:

Step 1. Create a route map and access or prefix list specifying the networks that are to be prepended and identify the AS that is to be added to the path. To change the AS path for all locally originated routes, use the `match route-type local` command, which matches all routes originating from the local router. (This might not be a good idea on a large public network.)

Step 2. Apply the route map to the desired neighbors or peer groups.

NOTE

Although it is possible to prepend any AS value to the AS_PATH by adding a random AS number to increase the size of the AS path, this is not a good practice to follow in the field. Prepending your local AS will not hurt anything on your local network or your direct peers' networks, but the routes with the randomly prepended ASNs might actually flow through the AS that owns the AS number that you randomly selected, causing serious (and very embarrassing) problems. Most service providers have a policy on AS prepending. Always consult your service provider's policies before configuring BGP attributes. If you plan to use AS prepending in your network, be a good Internet neighbor and prepend only the number of AS numbers required for the situation.

Because Cisco's implementation of BGP compares the AS_PATH length (as the fourth best path decision factor), when one AS has more than one entrance point, you can use AS_PATH prepending to make its path longer than the other. This causes the upstream BGP peers to prefer the route with the smaller AS_PATH attribute. If the Kimberly router prepends its own AS number (AS 645) to all locally originated routes sent to the Willis router, for example, this causes the Willis router to prefer routes from the Kimberly router. If the connection between the Willis and Arnold routers is lost, the Willis router removes the Kimberly router's routes and uses the routes from the Kimberly router. When the connection between the Willis and Arnold routers is repaired, and BGP routes are exchanged, the Willis router will, once again, prefer routes from the Arnold router. [Example 9-50](#) shows how autonomous system prepending is used in the Atm network. In this example, autonomous system 645 has two exit points: the Arnold router, and the Kimberly router.

Remove the change-origin route map, used in the preceding example, before trying the next example.

Example 9-50. Prepending ASNs to the AS_PATH

```
Kimberly#show run | begin bgp

router bgp 645

no synchronization

bgp router-id 10.1.5.1

bgp log-neighbor-changes

network 189.168.56.0 mask 255.255.254.0

network 189.168.58.0 mask 255.255.254.0

network 189.168.60.0 mask 255.255.254.0

network 189.168.62.0 mask 255.255.254.0

network 189.168.64.0 mask 255.255.254.0
```

```

network 189.168.66.0 mask 255.255.254.0
network 189.168.68.0 mask 255.255.254.0
network 189.168.70.0 mask 255.255.254.0
network 189.168.72.0 mask 255.255.254.0
network 189.168.74.0 mask 255.255.254.0
network 189.168.76.0 mask 255.255.254.0
network 189.168.78.0 mask 255.255.254.0
network 189.168.80.0 mask 255.255.254.0
network 189.168.82.0 mask 255.255.254.0
network 189.168.84.0 mask 255.255.254.0
network 189.168.86.0 mask 255.255.254.0
network 189.168.88.0 mask 255.255.254.0
neighbor 10.1.5.2 remote-as 645
neighbor 62.128.47.193 remote-as 2001
neighbor 62.128.47.193 route-map prepend out
no auto-summary
!
route-map prepend permit 10
match route-type local
set as-path prepend 645

```

After the Willis router receives the updates from the Kimberly router, it no longer prefers the route to the Kimberly router, which had the lowest BGP router ID and IP address. This is because the AS_Path length for the Kimberly router's routes is now longer than the AS_PATH length of the routes that originated from the Arnold router. [Example 9-51](#) shows a sample BGP route from the Willis router.

Example 9-51. BGP Route Information for a Prepended Route

```

Willis#show ip bgp 189.168.56.0/23
BGP routing table entry for 189.168.56.0/23, version 276

```

```
Paths: (2 available, best #1, table Default-IP-Routing-Table)
Flag: 0x820

Advertised to non peer-group peers:

 62.128.47.6 62.128.47.194

 645

 62.128.47.198 from 62.128.47.198 (10.1.5.2)

    Origin IGP, metric 0, localpref 100, valid, external, best

 645 645

 62.128.47.194 from 62.128.47.194 (10.1.5.1)

    Origin IGP, metric 0, localpref 100, valid, external
```

Filtering BGP Routes Using the AS_PATH Attribute

One of the easiest ways to filter large numbers of routes is to filter by AS number using an AS path list. If you are not familiar with regular expressions, the first time you use AS path access lists you find the AS_PATH filtering process to be rather confusing, causing unexpected results. Creating AS path access lists requires you to become familiar with the use of regular expressions. But, relax, breathe deeply, and read on, because you are now going to learn regular expressions the easy way.

NOTE

Cisco IOS Software uses many of the same regular expressions that you might have seen in the UNIX/Linux world. If you are not familiar with regular expressions, you can find an appendix dealing directly with that subject in the *Cisco IOS Dial Solutions* book, or on the documentation website under "dial solutions."

How to Use Regular Expressions

One of the first things that scares people about regular expressions is the strange-looking structures they use. If you are like most of the non-math majors out there, you might have found that expressions such as `^400$` look more like abbreviations for foreign currency than AS_PATH values; however, the regular expression simply means the following:

`^` = "beginning with"

`$` = "ends with"

or begins and ends with ASN 400

So, this statement simply means beginning and ending with the number 400; this regular expression matches only one instance of the AS number 400. Right about now you might be asking, why can't type "400" and be done with it? The reason is that the number 400 matches any string beginning, or containing the number 400. There are a number of ways that the special characters used in regular expressions can be applied to represent different character strings. The best way to find the AS path sequence that you need is to use the `show ip bgp regexp regular-expression` command. When you run this command, you can test to find all the possible matches that the router finds for each regular expression before using the best expression in a route filter. [Example 9-52](#) shows how the `show ip bgp regexp` command finds any instances of the AS path 645.

Example 9-52. `show ip bgp regexp` Command

```
Willis#show ip bgp regexp _645_
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* 10.1.1.0/24	62.128.47.198			0	645 800 234 6768 i
*>	62.128.47.194	0		0	645 400 i
* 10.2.2.0/24	62.128.47.198			0	645 800 234 6768 i
*>	62.128.47.194	0		0	645 100 400 i
* 10.3.3.0/24	62.128.47.198			0	645 800 234 6768 i
*>	62.128.47.194	0		0	645 400 400 100 i
*> 189.168.56.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.58.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.60.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.62.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.64.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.66.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.68.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.70.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.72.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.74.0/23	62.128.47.194	0		0	645 645 645 645 i
*> 189.168.76.0/23	62.128.47.194	0		0	645 645 645 645 i
Network	Next Hop	Metric	LocPrf	Weight	Path

```

*> 189.168.78.0/23 62.128.47.194      0      0 645 645 645 645 i
* 189.168.80.0/23 62.128.47.198      0      0 645 800 234 6768 i
*>                      62.128.47.194      0      0 645 645 645 645 i
* 189.168.82.0/23 62.128.47.198      0      0 645 800 234 6768 i
*>                      62.128.47.194      0      0 645 645 645 645 i
* 189.168.84.0/23 62.128.47.198      0      0 645 800 234 6768 i
*>                      62.128.47.194      0      0 645 645 645 645 i
* 189.168.86.0/23 62.128.47.198      0      0 645 800 234 6768 i
*>                      62.128.47.194      0      0 645 645 645 645 i
* 189.168.88.0/23 62.128.47.198      0      0 645 800 234 6768 i
*>                      62.128.47.194      0      0 645 645 645 645 i

```

TIP

If you experiment with the show ip bgp regexp command and find that a particular regular expression is not working, even though you absolutely know it should, check again! You might have accidentally hit the Spacebar at the end of the regular expression; doing so changes the meaning of the regular expression and prevents it from making the appropriate match. That is also why it is a good idea to give any regular expressions a test run before application in production environments.

[Table 9-4](#) shows the special characters that you can use with regular expressions, the character de and examples of their use.

Table 9-4. Special Characters Used for Regular Expressions

Character	Meaning	Examples
-----------	---------	----------

^ caret Used at beginning of expression.	Begins with <i>item</i>	1 = begins with 1. This means that any other characters will also match this string. For example: 1 400 500 or 123 456 7891
\$ dollar Used at end of expression.	Ends with <i>item</i>	400\$ = ends with 400. This means that any other characters before the string will also match this regular expression. For example: 645 400 or 645 100 400 400 However, the regular expression 400$ means begins and ends with 400. ^\$ matches an empty AS
* asterisk Used at the end of an expression.	0 or more of item.	40* = contains 0 or more instances of the string 4. This could match: 645 645 400 645 100 4 645 400 400 100 44 645 775 801 212 $^645^*$ matches any string that begins with 645. For example: 645 100 400 645 645 645

<p>. period</p> <p>Used anywhere in an expression.</p>	<p>Any character (including space).</p>	<p>.645 matches any instance of character-645, but only 645.</p> <p>For example:</p> <p>1645 645 645</p> <p>777 645</p> <p>645 645</p> <p>645. matches any string containing 645-character.</p> <p>For example:</p> <p>645 645 645</p> <p>100 645 400</p> <p>189 201 13645</p> <p>.* matches any as path, including a blank path.</p>
<p>+ plus</p> <p>Cannot be used at the beginning of an expression.</p>	<p>1 or more of /item preceding + character.</p>	<p>645+ matches 1 or more instances of the 645 string.</p> <p>For example:</p> <p>6451</p> <p>65 400 100</p> <p>400 100 645</p> <p>645 645 645</p>
<p>- hyphen</p> <p>Used between brackets to specify a range.</p>	<p>Used between starting and ending points of a range.</p>	<p>Used in a range specified in brackets [x-x].</p> <p>*See brackets [].</p>
<p>? question mark</p> <p>Used at the end of an expression.</p> <p>Requires the use of the CTRL-v characters before the ? character can be used as a character.</p>	<p>0 or 1 instances of /item.</p>	<p>645? matches anything that contains any 645 string.</p> <p>For example:</p> <p>645</p> <p>645 645 645</p> <p>645 645 400</p> <p>123 400 400 645</p> <p>^645? begins with 645 and ends with anything.</p>

__ underscore	<p>Matches special characters such as the following:</p> <ul style="list-style-type: none"> , comma () parenthesis { } braces beginning of string end or string blank space 	<p>Used when creating complex expressions with special characters.</p> <p>For example: __645__ matches path containing 645:</p> <p>645</p> <p>645 645 645</p> <p>645 800 234 645</p>
() parenthesis	<p>Matches confederation identifiers in AS_PATH and can also be used to create number patterns.</p>	<p>(65501)\$ matches any path ending with the string (65501).</p> <p>For example:</p> <p>101 (65501)</p>
[] brackets	<p>Range of characters.</p>	<p>[0-9] matches any string of numbers, but does not match empty AS_PATHs.</p> <p>For example:</p> <p>645</p> <p>645 400 100</p> <p>11151 2001</p> <p>5623 11151 2001</p> <p>[058]\$ matches any path containing a last character or 8.</p> <p>For example:</p> <p>645 645</p> <p>645 800 234 6768</p> <p>645 400 400 100</p> <p>^356_[0-9] matches any path that begins with 356 and has more than one trailing ASN.</p> <p>For example:</p> <p>356 789 012</p> <p>356 012</p> <p>356 356</p>

TIP

Do not forget to use the CTRL-V key sequence when entering the ? character; otherwise, you constantly be asking Cisco IOS Software for help.

After you are comfortable creating regular expressions, you can use those expressions to create AS access lists.

AS Path Access Lists and Regular Expressions

Similar to regular numbered access lists used for IP traffic, AS path access lists are numbered access lists that match traffic based on an AS path value. This AS value is specified using a regular expression. Similar to IP access lists, each AS path access list ends with an explicit deny any. AS path access lists are created using the following command:

```
ip as-path access-list list-number {permit | deny} regular-expression
```

Suppose, for instance, that the Willis router has a new requirement to block all network prefixes containing the AS_PATH value of 645. This can easily be accomplished using an AS_PATH access list that denies any instance of 645 in the AS_PATH, as shown in [Example 9-53](#).

Example 9-53. Using AS Path Access Lists to Filter BGP Routes Containing 645

```
Willis#show run | include as-path
ip as-path access-list 1 deny _645_
ip as-path access-list 1 permit .*
```

In the preceding example, AS path access list 1 is used to deny any AS path containing the string _645_, whereas all other traffic is permitted. The regular expression _645_ describes any string containing the string _645_.

value 645, and the `.*` regular expression allows any other path values.

Like most parameters in BGP, there are two ways to apply an AS path access list: using a route map or applying a filter list. Both ways are examined in this section. Consider the route map configuration:

Three steps are required to configure AS path prefix filtering using route maps:

Step 1. Create the AS path access list that will be used to specify the AS path regular expression.

Step 2. Create a route map to tell the router how to use the AS path access list.

Step 3. Apply the route map to a BGP neighbor or peer using the `neighbor { ip-address|peer-group} route-map route-map-name{ in | out}` command.

If you are going to apply the access list using a route map, you must define a route map that tells the router how to use the AS path access list. As mentioned earlier in [Table 9-3](#), the `match as-path as-access-list-number` command specifies the AS path that is to be matched. For example, `route-map as`, shown in [Example 9-54](#), is used to match AS path access list 1.

Example 9-54. Using a Route Map with an AS Path Access List

```
Willis#show run | begin route-map  
  
route-map filter-as permit 10  
  
match as-path 1
```

After you create the route map, you can then apply it to a neighbor or peer group. [Example 9-55](#) shows a completed AS path access list filtering configuration for the Willis router.

Example 9-55. Applying a Route Map to a BGP Peer

```
Willis#show run | begin bgp  
  
router bgp 2001  
  
no synchronization  
  
bgp router-id 62.128.47.5  
  
bgp log-neighbor-changes  
  
network 62.128.0.0 mask 255.255.252.0  
  
network 62.128.4.0 mask 255.255.252.0
```

```
network 62.128.8.0 mask 255.255.252.0
network 62.128.12.0 mask 255.255.252.0
network 62.128.16.0 mask 255.255.252.0
network 62.128.20.0 mask 255.255.252.0
network 62.128.24.0 mask 255.255.252.0
network 62.128.28.0 mask 255.255.252.0
network 62.128.32.0 mask 255.255.252.0
network 62.128.36.0 mask 255.255.252.0
network 62.128.40.0 mask 255.255.252.0
network 62.128.48.0 mask 255.255.252.0
network 62.128.52.0 mask 255.255.252.0
network 62.128.56.0 mask 255.255.252.0
network 62.128.60.0 mask 255.255.252.0
network 62.128.64.0 mask 255.255.252.0
network 62.128.68.0 mask 255.255.252.0
network 62.128.72.0 mask 255.255.252.0
network 62.128.76.0 mask 255.255.252.0
aggregate-address 62.128.44.0 255.255.255.252
neighbor 62.128.47.6 remote-as 11151
neighbor 62.128.47.6 route-map filter-as out
neighbor 62.128.47.194 remote-as 645
neighbor 62.128.47.198 remote-as 645
no auto-summary
!
ip as-path access-list 1 deny _645_
ip as-path access-list 1 permit .*
!
route-map filter-as permit 10
```

```
match as-path 1
```

In the preceding example, route map filter-as is used to deny any instance of ASN 645 for all outgoing updates to the MrDrummond router. The permit `.*` regular expression is used to allow all other AS numbers.

BGP filter lists provide a simpler, less granular approach to AS path access list filtering. Filter lists can only be applied to filter BGP routes by AS path.

Only two steps are required to configure BGP route filter routes based on the AS path:

Step 1. Create an AS path access list that specifies the AS path that is to be matched.

Step 2. Apply the route map to a BGP neighbor or peer using the following command:

```
neighbor {ip-address|peer-group} filter-listas-path-access-list-number  
{in | out}
```

[Example 9-56](#) shows how the filter list command accomplishes the same effect as the route map shown earlier in [Example 9-55](#).

Example 9-56. Using a Filter List to Filter BGP Traffic by AS Path

```
Willis#show run | begin bgp  
  
router bgp 2001  
  
no synchronization  
  
bgp router-id 62.128.47.5  
  
bgp log-neighbor-changes  
  
network 62.128.0.0 mask 255.255.252.0  
  
network 62.128.4.0 mask 255.255.252.0  
  
network 62.128.8.0 mask 255.255.252.0
```

```
network 62.128.12.0 mask 255.255.252.0
network 62.128.16.0 mask 255.255.252.0
network 62.128.20.0 mask 255.255.252.0
network 62.128.24.0 mask 255.255.252.0
network 62.128.28.0 mask 255.255.252.0
network 62.128.32.0 mask 255.255.252.0
network 62.128.36.0 mask 255.255.252.0
network 62.128.40.0 mask 255.255.252.0
network 62.128.48.0 mask 255.255.252.0
network 62.128.52.0 mask 255.255.252.0
network 62.128.56.0 mask 255.255.252.0
network 62.128.60.0 mask 255.255.252.0
network 62.128.64.0 mask 255.255.252.0
network 62.128.68.0 mask 255.255.252.0
network 62.128.72.0 mask 255.255.252.0
network 62.128.76.0 mask 255.255.252.0
aggregate-address 62.128.44.0 255.255.255.252
neighbor 62.128.47.6 remote-as 11151
neighbor 62.128.47.6 filter-list 1 out
neighbor 62.128.47.194 remote-as 645
neighbor 62.128.47.198 remote-as 645
no auto-summary
!
ip as-path access-list 1 deny _645_
ip as-path access-list 1 permit .*
```

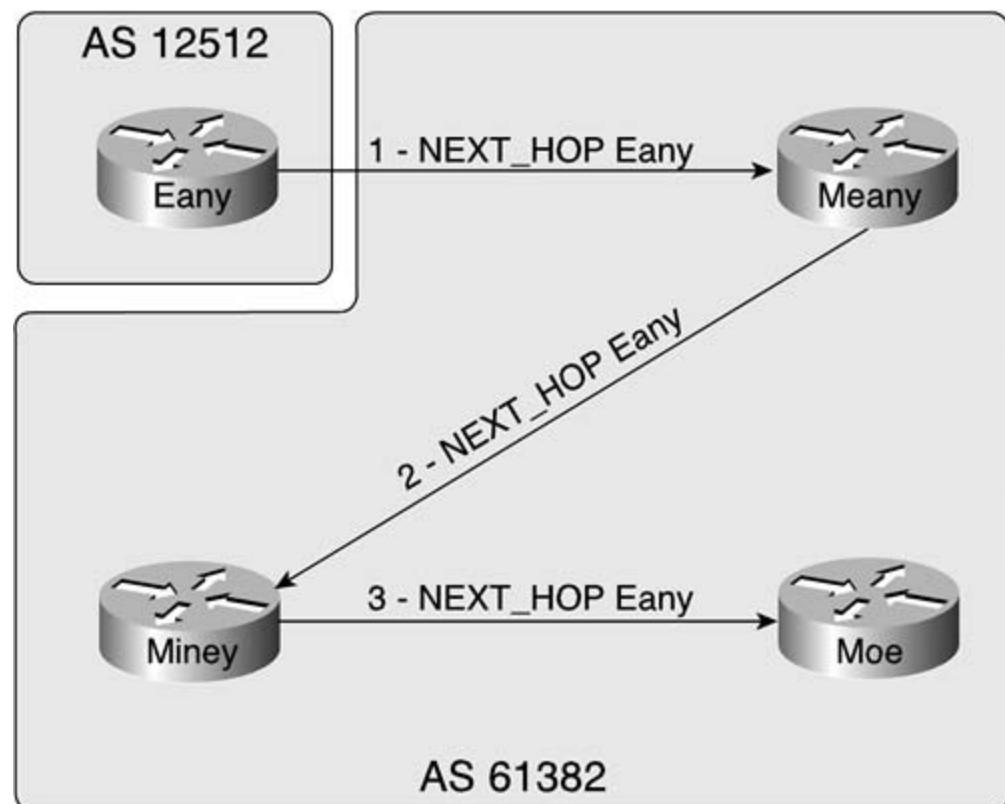
You can use AS path access lists to filter network prefixes in a number of ways:

- In multihomed environments, the `^$` regular expression can be used to prevent local autonumber systems from providing transit services between two upstream service providers, allowing outgoing route advertisements that have an empty AS_PATH attribute.
- Provide only partial BGP RIB updates to downstream neighbors by using the `^AS$` regular expression.
- Use an AS path access list to allow only locally sourced updates to exit to an upstream neighbor using the `_AS_` regular expression.
- Filter certain AS paths from incoming or outgoing updates, by using a combination of complex expressions and AS path access lists.

Modifying the NEXT_HOP Attribute for Path Manipulation

You can manipulate routing by using BGP attributes in several ways. One of the simplest modifications you can make is to change the next hop for a route. As you learned in the preceding chapter, the NEXT_HOP attribute is changed each time a route crosses an AS border, but not when a route is advertised within an AS. In [Figure 9-14](#), for example, there are four routers: Eany in AS 12,512; and Meany, Miney, and Moe in AS 61,382.

Figure 9-14. How BGP Modifies the NEXT_HOP Attribute



This figure shows a logical representation of how the `NEXT_HOP` attribute changes as a route passes through routers in different autonomous systems. First, the route passes between two autonomous systems (AS 12512 and AS 61382), changing the `NEXT_HOP` to the address of the router in the adjacent AS (Meany). Then, as the route continues within AS 61382, it passes through Miney and Moe, both of which have their `NEXT_HOP` set to the address of the previous router in the sequence (Eany).

as it is forwarded between the Eany and Meany routers. In this case, the NEXT_HOP attribute of the route is modified at the egress interface by the Eany router. The Eany router modifies the NEXT_HOP attribute before it passes the route to the Meany router. By default, the Meany router does not alter the NEXT_HOP value before it passes the route to the Miney router because the route originated from an external AS. When the Miney router advertises the route to the Moe router, it does not change the NEXT_HOP attribute because unless specified to do otherwise, I-BGP speakers do not modify the NEXT_HOP attribute.

NOTE

The NEXT_HOP attribute is covered in detail in the "The NEXT_HOP Attribute" section of [Chapter 10](#).

It is usually necessary to change the NEXT_HOP attribute for routes forwarded between I-BGP speakers when an I-BGP speaker is forwarding a route learned by means of an update from an E-BGP peer. If the I-BGP neighbor has been configured with a gateway of last resort pointing to its upstream I-BGP neighbor, the I-BGP will be unable to reach the E-BGP router's IP address. You can correct this situation in three ways:

- Originate a default route using the `neighbor { ip-address | peer-group} default-originator` command.
- Redistribute BGP routes in an IGP (if an IGP is in use).
- Use the `next-hop-self` command to alter the NEXT_HOP attribute for I-BGP routes.

NEXT_HOP attribute modification is accomplished using the `neighbor { ip-address | peer-group} next-hop-self` command. Sometimes, you might not want to modify the outgoing NEXT_HOP attribute for a particular route; in which case, you can use the `neighbor { ip-address | peer-group} next-hop-unchanged` command. So, you might ask, what do you do when you want to modify a NEXT_HOP attribute in certain cases? Simple, the NEXT_HOP attribute can also be modified by using a route map.

NOTE

Be careful changing the NEXT_HOP attributes for a route. If that path fails, traffic might not be able to reroute correctly.

Three steps are required to manually change the NEXT_HOP attribute for a route:

Step 1. Create an access or prefix list that specifies the networks that the attribute changes apply to. If all routes to a particular neighbor or peer group are to be changed, you can skip this step.

Step 2. Create a route map that references the access or prefix list created in Step 1 and use the `set next-hop { ip-address | peer-address | verify-availability}` command.

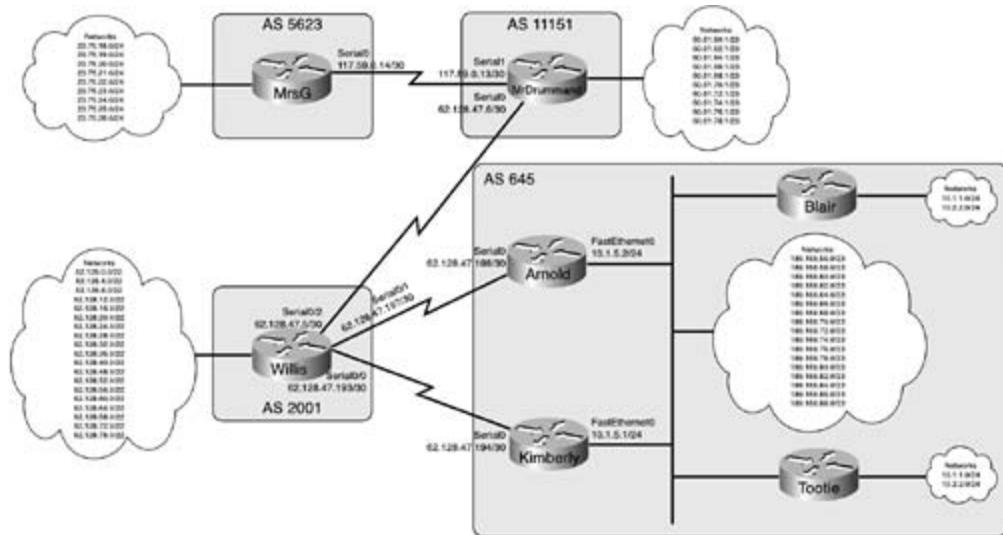
NOTE

The `verify-availability` command can be used only for incoming routes.

Step 3. Apply the route map to a neighbor or peer group using the neighbor { ip-address | , group}route-map route-map-name { in | out} command.

If two more routers are added into AS 645, as shown in [Figure 9-15](#), for instance, the Arnold and K routers need to be configured to peer with the new routers, provide reflected routes, and modify the outgoing NEXT_HOP attribute for all externally originated routes.

Figure 9-15. Adding Two New Routers to the Mix



In this example, it would be easy to use the next-hop-self command to allow the Blair and Tootie to reach the external networks. For the sake of this example, however, a route map is used instead. Although the next-hop-self is simpler in most cases, sometimes you might need to modify the next hop and not want to use the NEXT_HOP value generated using the next-hop-self command. For example, you might want to point the next hop to an external firewall that is not advertised to I-BGP peers; in this case, you might want to use a route map to manually set the next hop. [Example 9-57](#) shows how you can use a simple route map to change the NEXT_HOP attribute for all routes bound to a particular neighbor.

Example 9-57. Using Route Maps to Modify the NEXT_HOP Attribute

```
Arnold#show run | begin bgp

router bgp 645

no synchronization

bgp router-id 10.1.5.2

bgp log-neighbor-changes

network 189.168.56.0 mask 255.255.254.0
```

```
network 189.168.58.0 mask 255.255.254.0
network 189.168.60.0 mask 255.255.254.0
network 189.168.62.0 mask 255.255.254.0
network 189.168.64.0 mask 255.255.254.0
network 189.168.66.0 mask 255.255.254.0
network 189.168.68.0 mask 255.255.254.0
network 189.168.70.0 mask 255.255.254.0
network 189.168.72.0 mask 255.255.254.0
network 189.168.74.0 mask 255.255.254.0
network 189.168.76.0 mask 255.255.254.0
network 189.168.78.0 mask 255.255.254.0
network 189.168.80.0 mask 255.255.254.0
network 189.168.82.0 mask 255.255.254.0
network 189.168.84.0 mask 255.255.254.0
network 189.168.86.0 mask 255.255.254.0
network 189.168.88.0 mask 255.255.254.0
neighbor 10.1.5.3 remote-as 645
neighbor 10.1.5.1 route-reflector-client
neighbor 10.1.5.1 next-hop-self
neighbor 10.1.5.3 route-reflector-client
neighbor 10.1.5.3 route-map next-hop out
neighbor 10.1.5.4 remote-as 645
neighbor 10.1.5.4 route-reflector-client
neighbor 10.1.5.4 route-map next-hop out
neighbor 62.128.47.197 remote-as 2001
no auto-summary
!
route-map next-hop permit 10
```

```
set ip next-hop 10.1.5.2
```

In the preceding example, the next-hop route map is used to change the NEXT_HOP attribute of the FastEthernet interface of the Arnold router. This same effect could have been achieved using the `neighbor <ip> next-hop self` command.

Using the MED Attribute to Specify the Best Path

When you have a multihomed network, you can use the *Multi Exit Discriminator* (MED) attribute to specify the preferred entry point for an AS. The MED attribute is a BGP metric that makes E-BGP neighbors prefer the preferred entry point to a network. As a nontransitive BGP attribute, the MED is not advertised beyond the directly connected AS border, and is applied only on a peer-by-peer basis.

NOTE

The technical specifications for the MED attribute are covered in the "The MED Attribute" section of [Chapter 7](#).

Only three steps are required to set the MED attribute for an AS. You might optionally apply a different MED value for each AS bordering router, or modify how the BGP decision process will use the MED attribute.

Step 1. (Optional) Create an access list that specifies to which traffic the MED value is to be applied.

Step 2. Create a route map specifying the MED value for the entry point. The default MED value is 0, and this can be changed to any value ranging from 1 to 4,294,967,295, with the lowest value being most preferred. The metric is applied using the `set metric [+ / - metric-value]` command within a route map configuration mode. The optional + and - parameters change a preexisting metric.

Step 3. Apply the route map to a neighbor using the `neighbor { ip-address | peer-group} route-map route-map-name { in | out }` command.

Step 4. (Optional) Use the `bgp always-compare-med`, `bgp bestpath med confed`, `bgp local-preference`, `bgp missing-as-worst`, or `bgp deterministic-med` commands to modify how BGP uses the MED attribute during the best path selection process. [Table 9-5](#) shows how each of these commands works and when they are used.

Table 9-5. Best Path MED Modifications

MEDCommand	Command Definition
bgp always-compare-med	Allows the BGP best path selection process to compare BGP MED attribute received from E-BGP peers that belong to different autonomous systems.
bgp bestpath med confed	Allows BGP to compare MED attributes received from confederation peers.
bgp bestpath med missing-as-worst	Specifies that BGP should consider a path to be the worst option if the MED attribute is not present.
bgp deterministic-med	Allows BGP to compare MED values from different E-BGP peers in the same AS.

NOTE

Although the MED attribute can be applied to incoming or outgoing paths, you should always use the MED to specify the preferred network entry point to E-BGP peers, and the LOCAL_PREF attribute to specify the preferred network exit point for I-BGP peers.

After you apply the new metric to a neighbor, you can verify its use by using the show ip bgp command on the remote peer. The MED attribute displays as the Metric value, as shown in [Example 9-58](#).

Example 9-58. Using the show ip bgp Command to Verify the MED Attribute

```
Willis#show ip bgp regexp ^645$
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* 10.1.1.0/24	62.128.47.194	100		0	645 i
*>	62.128.47.198	50		0	645 i
* 10.2.2.0/24	62.128.47.194	100		0	645 i
*>	62.128.47.198	50		0	645 i
* 189.168.56.0/23	62.128.47.194	100		0	645 i
*>	62.128.47.198	50		0	645 i
* 189.168.58.0/23	62.128.47.194	100		0	645 i
*>	62.128.47.198	50		0	645 i
* 189.168.60.0/23	62.128.47.194	100		0	645 i
*>	62.128.47.198	50		0	645 i

```

* 189.168.62.0/23 62.128.47.194      100      0 645 i
*>          62.128.47.198      50      0 645 i
* 189.168.64.0/23 62.128.47.194      100      0 645 i
*>          62.128.47.198      50      0 645 i
* 189.168.66.0/23 62.128.47.194      100      0 645 i
*>          62.128.47.198      50      0 645 i
* 189.168.68.0/23 62.128.47.194      100      0 645 i

```

To illustrate the use of the MED attribute, it can be applied to the Arnold and Kimberly routers in A. Before a MED attribute was applied to the paths advertised by the two AS 645 border routers, the ' router preferred the paths advertised by the Kimberly router because it had a lower IP address. By applying the MED attribute, an attribute that is ranked higher in the BGP decision process, on the Arnold router, with a value lower than that of the Kimberly router, the preferred path to AS 645 will be changed. [Example 9-59](#) shows how the MED attribute is changed on the Arnold and Kimberly routers.

Example 9-59. Changing the MED Attribute for AS 645 on the Arnold and Kimberly Routers

```

Arnold#show run | begin bgp

router bgp 645
  no synchronization
  bgp router-id 10.1.5.2
  bgp log-neighbor-changes
  network 189.168.56.0 mask 255.255.254.0
  network 189.168.58.0 mask 255.255.254.0
  network 189.168.60.0 mask 255.255.254.0
  network 189.168.62.0 mask 255.255.254.0
  network 189.168.64.0 mask 255.255.254.0
  network 189.168.66.0 mask 255.255.254.0
  network 189.168.68.0 mask 255.255.254.0
  network 189.168.70.0 mask 255.255.254.0

```

```
network 189.168.72.0 mask 255.255.254.0
network 189.168.74.0 mask 255.255.254.0
network 189.168.76.0 mask 255.255.254.0
network 189.168.78.0 mask 255.255.254.0
network 189.168.80.0 mask 255.255.254.0
network 189.168.82.0 mask 255.255.254.0
network 189.168.84.0 mask 255.255.254.0
network 189.168.86.0 mask 255.255.254.0
network 189.168.88.0 mask 255.255.254.0
neighbor 10.1.5.1 remote-as 645
neighbor 10.1.5.1 route-reflector-client
neighbor 10.1.5.1 next-hop-self
neighbor 10.1.5.3 remote-as 645
neighbor 10.1.5.3 route-reflector-client
neighbor 10.1.5.3 next-hop-self
neighbor 10.1.5.4 remote-as 645
neighbor 10.1.5.4 route-reflector-client
neighbor 10.1.5.4 next-hop-self
neighbor 62.128.47.197 remote-as 2001
neighbor 62.128.47.197 route-map MED out
no auto-summary
!
route-map MED permit 10
set metric 50
```

```
Kimberly#show run | begin bgp
```

```
router bgp 645
no synchronization
```

```
bgp router-id 10.1.5.1

bgp log-neighbor-changes

network 189.168.56.0 mask 255.255.254.0

network 189.168.58.0 mask 255.255.254.0

network 189.168.60.0 mask 255.255.254.0

network 189.168.62.0 mask 255.255.254.0

network 189.168.64.0 mask 255.255.254.0

network 189.168.66.0 mask 255.255.254.0

network 189.168.68.0 mask 255.255.254.0

network 189.168.70.0 mask 255.255.254.0

network 189.168.72.0 mask 255.255.254.0

network 189.168.74.0 mask 255.255.254.0

network 189.168.76.0 mask 255.255.254.0

network 189.168.78.0 mask 255.255.254.0

network 189.168.80.0 mask 255.255.254.0

network 189.168.82.0 mask 255.255.254.0

network 189.168.84.0 mask 255.255.254.0

network 189.168.86.0 mask 255.255.254.0

network 189.168.88.0 mask 255.255.254.0

neighbor 10.1.5.2 remote-as 645

neighbor 10.1.5.2 route-reflector-client

neighbor 10.1.5.2 next-hop-self

neighbor 10.1.5.3 remote-as 645

neighbor 10.1.5.3 route-reflector-client

neighbor 10.1.5.3 next-hop-self

neighbor 10.1.5.4 remote-as 645

neighbor 10.1.5.4 route-reflector-client

neighbor 10.1.5.4 next-hop-self
```

```
neighbor 62.128.47.193 remote-as 2001

neighbor 62.128.47.193 route-map MED out

no auto-summary

!

route-map MED permit 10

set metric 100
```

Using the LOCAL_PREF Attribute to Specify Network Exit Points

The local preference (LOCAL_PREF) attribute is used with an AS to modify the desirability for route more than one possible path that can be used to exit the local AS. As its name implies, the LOCAL_PREF attribute is passed only between I-BGP peers; the LOCAL_PREF attribute is not forwarded to external peers.

NOTE

It is sometimes hard to remember the difference between the LOCAL_PREF and the MED attributes. One easy way to remember which attribute does which task is to look at the name—LOCAL_PREF applies only to local peers, and the Multi Exit Discriminator (MED) tells external peers the preferred entry point into your AS. The MED attribute is not compared for routes from I-BGP peers, and the LOCAL_PREF attribute is not compared for routes from E-BGP peers.

Like the MED, the LOCAL_PREF attribute is applied on a peer-by-peer basis using a route map. The value of the LOCAL_PREF attribute is 100, and it can be changed to any value from 1 to 4,294,967. The largest LOCAL_PREF value is always preferred. Three steps are required to modify the LOCAL_PREF path:

Step 1. (Optional) Create an access or prefix list that specifies the networks to which the LOCAL_PREF will apply.

Step 2. Create a route map to assign the LOCAL_PREF using the `set local-preference value` command in route map configuration mode.

Step 3. Apply the route map to a neighbor or peer group using the `neighbor { ip-address | group } route-map route-map-name { in | out }` command.

NOTE

Remember that the LOCAL_PREF attribute is not passed to external peers; so, if you want to modify LOCAL_PREF that will be used for external networks, you must apply the route map to

incoming traffic.

To demonstrate the use of the LOCAL_PREF attribute, it is applied on the Arnold and Kimberly routers. The Arnold router tells the Blair router to prefer its routes, and the Kimberly router tells the Tootie router to prefer its own routes. Both the Arnold and Kimberly routers still send routes to the other routers using default LOCAL_PREF values. [Example 9-60](#) shows the configuration on the Arnold and Kimberly routers.

Example 9-60. Setting the LOCAL_PREF Configuration on the Arnold and Kimberly Routers

```
Arnold#show run | begin bgp

router bgp 645

no synchronization

bgp router-id 10.1.5.2

<networks excluded>

bgp log-neighbor-changes

neighbor 10.1.5.1 remote-as 645

neighbor 10.1.5.1 route-reflector-client

neighbor 10.1.5.1 next-hop-self

neighbor 10.1.5.3 remote-as 645

neighbor 10.1.5.3 route-reflector-client

neighbor 10.1.5.3 next-hop-self

neighbor 10.1.5.3 route-map local-pref out

neighbor 10.1.5.4 remote-as 645

neighbor 10.1.5.4 route-reflector-client

neighbor 10.1.5.4 next-hop-self

neighbor 62.128.47.197 remote-as 2001

no auto-summary

!
```

```

route-map local-pref permit 10
set local-preference 500



---


Kimberly#show run | begin bgp
router bgp 645
no synchronization
bgp router-id 10.1.5.1
bgp cluster-id 3181926401
bgp log-neighbor-changes
neighbor 10.1.5.2 remote-as 645
neighbor 10.1.5.2 route-reflector-client
neighbor 10.1.5.2 next-hop-self
neighbor 10.1.5.3 remote-as 645
neighbor 10.1.5.3 route-reflector-client
neighbor 10.1.5.3 next-hop-self
neighbor 10.1.5.4 remote-as 645
neighbor 10.1.5.4 route-reflector-client
neighbor 10.1.5.4 next-hop-self
neighbor 10.1.5.4 route-map local-pref out
neighbor 62.128.47.193 remote-as 2001
no auto-summary
!
route-map local-pref permit 10
set local-preference 500

```

In the preceding example, route map local-pref sets the LOCAL_PREF for all routes from Arnold to the Blair router to 500, and likewise, for the Kimberly and Tootie routers. [Example 9-61](#) shows excerpts from the BGP RIB from the Blair and Tootie routers.

Example 9-61. BGP RIBs from the Blair and Tootie Routers After Changing LOCAL_PREF Attribute

```
Blair#show ip bgp regexp _11151_
```

BGP table version is 95, local router ID is 10.2.2.1

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
r RIB-failure

Origin codes: i - IGP, e - EGP, ? - incomplete

Network	Next Hop	Metric	LocPrf	Weight	Path
* i23.75.18.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.19.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.20.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.21.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.22.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.23.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.24.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.25.0/24	10.1.5.1		100	0	2001 11151 5623 i
*>i	10.1.5.2		500	0	2001 11151 5623 i
* i23.75.26.0/24	10.1.5.1		100	0	2001 11151 5623 i
Network	Next Hop	Metric	LocPrf	Weight	Path
*>i	10.1.5.2		500	0	2001 11151 5623 I

```
Tootie#show ip bgp regexp _11151_
```

```
BGP table version is 307, local router ID is 10.2.2.2
```

```
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i23.75.18.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.19.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.20.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.21.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.22.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.23.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.24.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.25.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.26.0/24	10.1.5.1	500	0	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i

Notice in both examples that the routers prefer the routes with the larger LOCAL_PREF attribute. T router prefers routes from the Arnold router, and the Tootie router prefers routes from the Kimberl

Using the WEIGHT Attribute to Influence Path Selection

Unlike the MED and LOCAL_PREF attributes, the Cisco proprietary WEIGHT attribute, which specifies locally preferred path, is only locally significant; this attribute is not forwarded to *any* peer. The WEIGHT attribute is a value ranging from 0 to 65,535. The default WEIGHT attribute for a locally originated route is 32,768, and the default weight for all other routes is 0.

Three steps are required to set the WEIGHT for a path:

Step 1. (Optional) Create an access or prefix list that specifies the paths that should be matched during WEIGHT manipulation.

Step 2. Create a route map to apply the access or prefix list and the WEIGHT attribute value to the set weight *value* command.

Step 3. Apply the route map to a neighbor or peer group using the neighbor { *ip-address* | *group*} route-map *route-map-name* in command.

NOTE

Even though Cisco IOS Software enables you to apply a route map that modifies the WEIGHT attribute for outbound routes, this command will have no effect because the WEIGHT attribute is not passed to any peers.

Suppose, for example, that the Tootie router should always prefer routes from the Kimberly router (10.1.5.1), unless that router is not available. One easy way to accomplish this task is to set the WEIGHT attribute for all incoming routes from the Kimberly router to a high value. [Example 9-62](#) shows how this might be accomplished using the WEIGHT attribute.

Example 9-62. Using the WEIGHT Attribute to Set Route Preference

```
Tootie#show run | begin bgp

router bgp 645

no synchronization

bgp log-neighbor-changes

network 10.1.1.0 mask 255.255.255.0

network 10.2.2.0 mask 255.255.255.0

neighbor 10.1.5.1 remote-as 645

neighbor 10.1.5.1 next-hop-self

neighbor 10.1.5.1 route-map Heavy-Routes in

neighbor 10.1.5.2 remote-as 645
```

```

neighbor 10.1.5.2 next-hop-self
neighbor 10.1.5.3 remote-as 645
neighbor 10.1.5.3 next-hop-self
no auto-summary
!
route-map Heavy-Routes permit 10
set weight 150

```

In the preceding example, route map Heavy-Routes sets the WEIGHT value to 150. This route map applied to incoming routes from the Arnold router, making those routes more desirable, and produced results shown in [Example 9-63](#).

NOTE

Before configuring this example, the local-pref route map was removed from the Kimberly and Arnold routers; however, the WEIGHT attribute would still have precedence over LOCAL_PREF (even though the LOCAL_PREF and WEIGHT attributes accomplished the same thing) because WEIGHT is higher on the BGP path selection process.

Example 9-63. Tootie BGP RIB After WEIGHT Attribute Modification

```

Tootie#show ip bgp regexp _5623_
BGP table version is 111, local router ID is 10.1.5.4
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
               r RIB-failure
Origin codes: i - IGP, e - EGP, ? - incomplete

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i23.75.18.0/25	10.1.5.1	100	150	2001	11151 5623 i
* i	10.1.5.2	100	0	2001	11151 5623 i
*>i23.75.19.0/24	10.1.5.1	100	150	2001	11151 5623 i

			Metric	LocPrf	Weight	Path
	Network	Next Hop				
* i	10.1.5.2		100	0	2001	11151 5623 i
*>i23.75.20.0/24	10.1.5.1		100	150	2001	11151 5623 i
* i	10.1.5.2		100	0	2001	11151 5623 i
*>i23.75.21.0/24	10.1.5.1		100	150	2001	11151 5623 i
* i	10.1.5.2		100	0	2001	11151 5623 i
*>i23.75.22.0/24	10.1.5.1		100	150	2001	11151 5623 i
* i	10.1.5.2		100	0	2001	11151 5623 i
*>i23.75.23.0/24	10.1.5.1		100	150	2001	11151 5623 i
* i	10.1.5.2		100	0	2001	11151 5623 i
*>i23.75.24.0/24	10.1.5.1		100	150	2001	11151 5623 i
* i	10.1.5.2		100	0	2001	11151 5623 i
*>i23.75.25.0/24	10.1.5.1		100	150	2001	11151 5623 i
* i	10.1.5.2		100	0	2001	11151 5623 I
*>i23.75.26.0/24	10.1.5.1		100	150	2001	11151 5623 i
	Network	Next Hop				
* i	10.1.5.2		100	0	2001	11151 5623 i

Because the WEIGHT attribute is the number one item on the BGP route selection process, modifying WEIGHT attribute causes the Tootie router to prefer routes with high WEIGHT before routes with high LOCAL_PREF.

Many Uses of the COMMUNITY Attribute

The BGP COMMUNITY attribute is one of the most powerful BGP attributes available. Communities can filter or modify routes by community number, by community list, or by adding a well-known community to a route. You can use communities for filtering routes by setting the COMMUNITY attribute for a route later use or by matching a pre-assigned community value. Along with the standard-numbered community values, there are also named values that you can use to assign a more readable value to a path. Table 9-6 shows a review of the well-known BGP community values mentioned earlier in Chapter 7.

Table 9-6. Well-Known BGP Community Values

Community Value (Hex)	Community Value (Decimal)	Community Name	Description	Cisco IOS set community Command
0x00000000 to 0x0000FFFF	0 to 65535	Reserved	This range of COMMUNITY attributes have been reserved by IANA.	Decimal number between 0 to or <i>aa:nn</i> format
0xFFFFF0000 to 0xFFFFFFFF	4294967041 to 4294967295	Reserved	This range of COMMUNITY attributes have been reserved by IANA.	Decimal number between 65,536 to 4,294,967,295 in <i>aa:nn</i> format
0	0	Internet	The default community, to which all BGP community-aware routers belong by default.	internet
0xFFFFF01	4294967041	NO_EXPORT	Routes with this COMMUNITY attribute must not be advertised outside of the local autonomous system or confederation.	no-export
0xFFFFF02	4294967042	NO_ADVERTISE	Routes with this COMMUNITY attribute must not be advertised to <i>any</i> peer.	no-advertise
0xFFFFF03	4294967043	LOCAL_AS	Routes with this COMMUNITY attribute must not be advertised to any external confederation peer, referred to as NO_EXPORT-SUBCONFED in RFC 1997.	local-as

Five steps are required to set the BGP COMMUNITY attribute:

Step 1. (Optional) Create an access or prefix list to specify the paths that are to be modified networks are not specified with a match statement, the route map will apply to all routes.

Step 2. Create a route map and specify a set community statement to change the COMMUNITY attribute using the `set community { decimal-number | aa:nn-format | additive | internet as | no-advertise | no-export | none }` command.

Step 3. If you use the *aa:nn* community format, make sure to use the `ip bgp-community format` command. This command changes the way Cisco IOS Software displays the community from the default hexadecimal view to the newer *aa:nn* view.

Step 4. Apply the route map to a neighbor or peer group using the `neighbor { ip-address | peer-group } route-map route-map-name { in | out }` command.

Step 5. Enable COMMUNITY attribute advertising by using the `neighbor { ip-address | peer-group } send-community` command.

As previously mentioned, communities are set using a route map containing a set statement; [Table 1](#) shows the possible community values that can be set within a route map in Cisco IOS Software Rel 12.2(12)T.

Table 9-7. Route Map set COMMUNITY Commands

Command	Description
Community number in <i>decimal-number</i> format	A number between 1 and 4,294,967,295
Community number in <i>aa:nn</i> -format	A BGP COMMUNITY attribute number in <i>aa:nn</i> format
additive	Adds a value to an existing community value
internet	Sets the community value to the well-known Internet value—the default for all BGP speakers
local-as	A well-known COMMUNITY attribute that specifies that the matching route must not be advertised outside the local autonomous system
no-advertise	A well-known COMMUNITY attribute that specifies that the matching route must not be advertised to <i>any</i> peer
no-export	A well-known COMMUNITY attribute that specifies that the matching route must not be advertised to any external peers
none	Removes the COMMUNITY attribute

The next example shows how you can use the BGP NO_EXPORT community to prevent a BGP neighbor from propagating a specific route. In this example, the Arnold router is advertising the 10.1.1.0/24 and 10.2.2.0/24 networks with the BGP well-known community value of NO_EXPORT. [Example 9-64](#) shows the BGP configuration for the Arnold router.

Example 9-64. Using the BGP Well-Known NO_EXPORT COMMUNITY Attribute

```
Arnold#show run | begin bgp

router bgp 645
  no synchronization
  bgp router-id 10.1.5.2
  bgp log-neighbor-changes
  neighbor 10.1.5.1 remote-as 645
  neighbor 10.1.5.1 route-reflector-client
  neighbor 10.1.5.1 next-hop-self
  neighbor 10.1.5.3 remote-as 645
```

```

neighbor 10.1.5.3 route-reflector-client
neighbor 10.1.5.3 next-hop-self
neighbor 10.1.5.4 remote-as 645
neighbor 10.1.5.4 route-reflector-client
neighbor 10.1.5.4 next-hop-self
neighbor 62.128.47.197 remote-as 2001
neighbor 62.128.47.197 send-community
neighbor 62.128.47.197 route-map community out
no auto-summary
!
ip prefix-list local-list seq 5 permit 10.1.1.0/24
ip prefix-list local-list seq 10 permit 10.2.2.0/24
!
route-map community permit 10
match ip address prefix-list local-list
set community no-export

```

In the preceding example, the Arnold router is configured to advertise the 10.1.1.0/24 and 10.2.2.0/24 networks with the NO_EXPORT community by creating the "community" route map specifying the local-list prefix list, which referenced the 10.1.1.0/24 and 10.2.2.0/24 networks. The NO_EXPORT community was assigned to the networks using the set community no-export command, the route map was applied to the 62.128.47.197 neighbor, the Willis router, and BGP community advertisement was enabled using the send-community command. [Example 9-65](#) shows the effects that this configuration had on the Willis and MrDrummond routers.

Example 9-65. Willis Router's BGP RIB Entries After Community Filtering

```

Willis#show ip bgp 10.1.1.0/24
BGP routing table entry for 10.1.1.0/24, version 191
Paths: (2 available, best #2, table Default-IP-Routing-Table, not advertised to EB
      Not advertised to any peer

```

```
645
```

```
62.128.47.194 from 62.128.47.194 (10.1.5.1)  
Origin IGP, metric 100, localpref 100, valid, external
```

```
645
```

```
62.128.47.198 from 62.128.47.198 (10.1.5.2)  
Origin IGP, localpref 100, valid, external, best  
Community: no-export
```

```
Willis#show ip bgp 10.2.2.0/24
```

```
BGP routing table entry for 10.2.2.0/24, version 192
```

```
Paths: (2 available, best #2, table Default-IP-Routing-Table, not advertised to EB  
Not advertised to any peer
```

```
645
```

```
62.128.47.194 from 62.128.47.194 (10.1.5.1)  
Origin IGP, metric 100, localpref 100, valid, external  
645  
62.128.47.198 from 62.128.47.198 (10.1.5.2)  
Origin IGP, localpref 100, valid, external, best  
Community: no-export
```

```
MrDrummand#show ip bgp 10.1.1.0/24
```

```
% Network not in table
```

```
MrDrummand#show ip bgp 10.2.2.0/24
```

```
% Network not in table
```

Notice that the Willis router now shows the route as *not advertised to EBGP peer*. This is a direct result of the NO_EXPORT community application. Also, notice that the MrDrummand router did not receive an advertisement for the 10.1.1.0/24 or 10.2.2.0/24 networks after the change. The preceding example demonstrates how the BGP COMMUNITY attribute can be used to filter a route using well-known communities. The next section shows how you can use BGP community lists to specify routes that require multiple BGP community values.

Community Lists

BGP community lists provide a way to specify a list of BGP COMMUNITY attributes that are to be matched. There are four different types of BGP community lists; the list types, command syntax, and descriptions are shown in [Table 9-8](#).

Table 9-8. Community List Guide

Community List Type	Syntax	Description
Standard numbered	ip community-list <i>number</i> { permit deny } { <i>decimal-number</i> aa: <i>nn-number</i> internet local-as no-advertise no-export }	A numbered access lists, ranging from 1 to 99, that lists BGP communities using either numbers or well-known numbers.
Expanded numbered	ip community-list <i>number</i> { permit deny } <i>regular-expression</i>	A numbered access lists, ranging from 100 to 199, that lists BGP communities using regular expressions.
Standard named	ip community-list standard/ <i>list-name</i> { permit deny } { <i>decimal-number</i> aa: <i>nn-number</i> internet local-as no-advertise no-export }	A named access lists, ranging from 1 to 99, that lists BGP communities using either numbers or well-known numbers.
Expanded named	ip community-list expanded/ <i>list-name</i> { permit deny } <i>regular-expression</i>	A named access lists, ranging from 100 to 199, that lists BGP communities using regular expressions.

The `show ip community-list` command enables you to display the local community list configuration. The `show ip bgp community` command lists any BGP paths from the RIB that match the specified community. The `show ip bgp community-list { /list-name | /list-number}` command displays RIB entries that match the specified community lists. [Example 9-66](#) shows examples of each of the community list types.

Example 9-66. Community List Examples

```
ip community-list 1 permit no-export  
ip community-list 100 permit ^645  
ip community-list standard my-community permit local_as  
ip community-list expanded your-community permit 645$
```

The first community list matches any RIB table entry with the NO_EXPORT COMMUNITY attribute. The second list matches any RIB table entry with the NO_ADVERTISE COMMUNITY attribute. The third list matches any RIB table entry with the LOCAL_AS COMMUNITY attribute. The fourth list matches any RIB table entry with the YOUR_COMMUNITY COMMUNITY attribute.

second community list, list 100, matches any RIB entry with a COMMUNITY attribute beginning with the string 645. The third community list, list my-community, matches any RIB entry with the LOCAL-ACTION COMMUNITY attribute. And the last community list matches any community ending with the string 100. Community lists are specified using a route map match statement. [Table 9-9](#) shows the community commands and their descriptions.

Table 9-9. Well-Known BGP Community match Statements

Command	Description
<code>match community { standard-list-number expanded-list-number list-name }</code>	Matches a predefined community list: Standard community lists range from 1 to 99. Expanded community lists range from 100 to 199.
<code>match extcommunity { standard-list-number expanded-list-number list-name }</code>	Matches extended multiprotocol community lists: Standard lists range from 1 to 99. Expanded lists range from 100 to 199.

The next example shows how you can use the BGP COMMUNITY attribute to set and filter BGP communities. In [Example 9-67](#), you can see that the Kimberly router is using the community route map to set two communities.

Example 9-67. Setting Community Values with a Route Map on the Kimberly Router

```
Kimberly#show run | begin bgp

router bgp 645
  no synchronization
  bgp router-id 10.1.5.1
  bgp log-neighbor-changes
  network 189.168.56.0 mask 255.255.254.0
  network 189.168.58.0 mask 255.255.254.0
  network 189.168.60.0 mask 255.255.254.0
  network 189.168.62.0 mask 255.255.254.0
```

```
neighbor 10.1.5.2 remote-as 645
neighbor 10.1.5.2 route-reflector-client
neighbor 10.1.5.2 next-hop-self
neighbor 10.1.5.3 remote-as 645
neighbor 10.1.5.3 route-reflector-client
neighbor 10.1.5.3 next-hop-self
neighbor 10.1.5.4 remote-as 645
neighbor 10.1.5.4 route-reflector-client
neighbor 10.1.5.4 next-hop-self
neighbor 62.128.47.193 remote-as 2001
neighbor 62.128.47.193 send-community
neighbor 62.128.47.193 route-map community out
no auto-summary
!
ip bgp-community new-format
!
ip prefix-list 1 seq 5 permit 189.168.56.0/22
!
ip prefix-list 2 seq 5 permit 189.168.60.0/22
!
route-map community permit 10
match ip address prefix-list 1
set community 645:100
!
route-map community permit 20
match ip address prefix-list 2
set community 645:200
!
```

```
route-map community permit 30
```

In the preceding example, the Kimberly router used the community route map to set the BGP COMMUNITY attribute for the 189.168.56.0/22 network to 645:100 and the 189.168.60.0/22 network to 645:200. A community route map was then applied to the 62.128.47.193 neighbor, the Willis router, and the COMMUNITY attribute was sent using the send-community command. [Example 9-68](#) shows how the Willis router uses the communities advertised by the Kimberly router to filter routes.

Example 9-68. Filtering Routes on the Willis Router Using the COMMUNITY Attribute

```
Willis#show run | begin bgp

router bgp 2001
  no synchronization
  bgp log-neighbor-changes
  neighbor 62.128.47.6 remote-as 11151
  neighbor 62.128.47.6 send-community
  neighbor 62.128.47.6 route-map use-community out
  neighbor 62.128.47.194 remote-as 645
  neighbor 62.128.47.198 remote-as 645
  no auto-summary
!
ip bgp-community new-format
ip community-list 1 permit 645:100
ip community-list 2 permit 645:200
!
route-map use-community permit 10
  match community 1
  set community no-advertise
!
route-map use-community permit 20
```

```

match community 2
set community no-export
!
route-map use-community permit 30
set community internet

```

In the preceding example, the Willis router uses route map use-community sequence 10 to match routes containing the 645:100 community value and advertise them with the NO_ADVERTISE COMMUNITY attribute. Sequence 20 of this route map also sets any routes containing the 645:200 COMMUNITY to the well-known NO_EXPORT community value; all other routes are set to the default Internet community value. The use-community route map is then applied to the MrDrummand router (62.128.47.6). This configuration can be verified using the `show ip bgp /p-prefix` command on the MrDrummand route shown in [Example 9-69](#).

Example 9-69. Resulting BGP RIB Entries on the MrDrummand Router

```

MrDrummand#show ip bgp 189.168.56.0/23
BGP routing table entry for 189.168.56.0/23, version 137
Paths: (1 available, best #1, table Default-IP-Routing-Table, not advertised to an
      Not advertised to any peer
      2001 645
          62.128.47.5 from 62.128.47.5 (62.128.76.1)
              Origin IGP, localpref 100, valid, external, best
              Community: no-advertise
MrDrummand#show ip bgp 189.168.58.0/23
BGP routing table entry for 189.168.58.0/23, version 138
Paths: (1 available, best #1, table Default-IP-Routing-Table, not advertised to an
      Not advertised to any peer
      2001 645
          62.128.47.5 from 62.128.47.5 (62.128.76.1)
              Origin IGP, localpref 100, valid, external, best

```

```

Community: no-advertise

MrDrummand#show ip bgp 189.168.60.0/23

BGP routing table entry for 189.168.60.0/23, version 115
Paths: (1 available, best #1, table Default-IP-Routing-Table, not advertised to EB
      Not advertised to any peer
      2001 645
      62.128.47.5 from 62.128.47.5 (62.128.76.1)
      Origin IGP, localpref 100, valid, external, best
      Community: no-export

MrDrummand#show ip bgp 189.168.62.0/23

BGP routing table entry for 189.168.62.0/23, version 116
Paths: (1 available, best #1, table Default-IP-Routing-Table, not advertised to EB
      Not advertised to any peer
      2001 645
      62.128.47.5 from 62.128.47.5 (62.128.76.1)
      Origin IGP, localpref 100, valid, external, best
      Community: no-export

```

As you can see, the MrDrummand router received the routes from the Willis router with the attribute NO-EXPORT. The MrDrummand router is not currently advertising the 189.168.56.0/22 route because it is marked with the NO-EXPORT attribute, and the route to the 189.168.60.0/22 network is not advertised because the MrDrummand router does not have any I-BGP neighbors to which it can forward the NO-EXPORT attribute.

The next example shows how communities enable you to change other BGP attributes. In this example, the Kimberly router is sending the Willis router routes containing the 645:600 BGP COMMUNITY attribute.

Example 9-70. Kimberly Router Configuration

```

Kimberly#show run | begin bgp

router bgp 645
  no synchronization

```

```

bgp router-id 10.1.5.1

bgp log-neighbor-changes

<networks omitted>

neighbor 10.1.5.2 remote-as 645

neighbor 10.1.5.2 route-reflector-client

neighbor 10.1.5.2 next-hop-self

neighbor 10.1.5.3 remote-as 645

neighbor 10.1.5.3 route-reflector-client

neighbor 10.1.5.3 next-hop-self

neighbor 10.1.5.4 remote-as 645

neighbor 10.1.5.4 route-reflector-client

neighbor 10.1.5.4 next-hop-self

neighbor 62.128.47.193 remote-as 2001

neighbor 62.128.47.193 send-community

neighbor 62.128.47.193 route-map change-attr out

no auto-summary

!

ip bgp-community new-format

!

route-map change-attr permit 10

set community 645:600

```

As you can see, the Kimberly router uses route map `change-attr` to set the `COMMUNITY` attribute for routing updates to 645:600. That route map is then applied to the Willis router (62.128.47.193). If the Willis router receives the routes, a local route map matches the 645:600 community value and sets the `LOCAL_PREF` value for the Kimberly routes, as shown in [Example 9-71](#).

Example 9-71. Using the `COMMUNITY` attribute to Change the `LOCAL_PREF` Attribute

```

Willis#show run | begin bgp

router bgp 2001

no synchronization

bgp log-neighbor-changes

neighbor 62.128.47.6 remote-as 11151

neighbor 62.128.47.194 remote-as 645

neighbor 62.128.47.194 route-map change-pref in

neighbor 62.128.47.198 remote-as 645

no auto-summary

!

ip bgp-community new-format

ip community-list standard change-pref1 permit 645:600

!

route-map change-pref permit 10

match community standard change-pref1

set local-preference 250

```

In the preceding example, the Willis router used the change-pref route map to set the LOCAL_PREF attribute for all incoming routes from the Kimberly router to 250. This makes the Willis router prefer the Kimberly router to reach all networks in AS 645. [Example 9-72](#) shows the BGP RIB for AS 645 in the Willis router.

Example 9-72. Local BGP RIB for the Willis Router

```
Willis#show ip bgp regexp ^645$
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 10.1.1.0/24	62.128.47.194	250	0	645	i
*	62.128.47.198		0	645	i
*> 10.2.2.0/24	62.128.47.194	250	0	645	i

*		62.128.47.198		0	645	i	
* >	189.168.56.0/23	62.128.47.198	0	0	645	i	
* >		62.128.47.194	0	250	0	645	i
* >	189.168.58.0/23	62.128.47.198	0	0	645	i	
* >		62.128.47.194	0	250	0	645	i
* >	189.168.60.0/23	62.128.47.198	0	0	645	i	
* >		62.128.47.194	0	250	0	645	i
* >	189.168.62.0/23	62.128.47.198	0	0	645	i	
* >		62.128.47.194	0	250	0	645	i
* >	189.168.64.0/23	62.128.47.198	0	0	645	i	
* >		62.128.47.194	0	250	0	645	i
* >	189.168.66.0/23	62.128.47.198	0	0	645	i	
* >		62.128.47.194	0	250	0	645	i
* >	189.168.68.0/23	62.128.47.198	0	0	645	i	

Using Multiple Paths

Multihoming a network to one or more providers is one of the most common tasks that you will encounter on an enterprise BGP network. You can configure multihomed networks in one of the following ways:

- One router multihomed to one service provider with multiple links
- One router multihomed to more than one service provider
- More than one router multihomed to one service provider
- More than one router multihomed to more than one service provider

Although there are a number of ways to configure a multihomed network, it is always best to follow some rules each time. Careful planning is required to achieve maximum results in a multihomed network. You always want to verify that your upstream service provider supports your configuration, before attempting to multihome your network. Most service providers have BGP policies that they provide to their customer considering a multihomed network, some of which are listed here:

- The use of `ebgp-mulithop` command (with or without load balancing)
- A list of supported BGP attributes
- Public IP address and AS number policies
- The use of service provider IP addresses and private ASNs
- Route filtering policies
- Route aggregation policies (Most service providers will not accept routes smaller than /24.)
- BGP version number
- Authentication method, policies, and passwords
- Route dampening policies

After determining your network requirements and acquiring the necessary addresses and circuits, you begin to design your multihomed solution. Because loopback interfaces never go down, they are commonly used as multihoming anchoring devices. One of the most common multihoming practices is to use a loopback interface as the BGP update source. Another requirement for a multihomed network is path filtering—you do not want your upstream service providers to use your network as a transit. A multihomed network must also filter any private address space and aggregate your internal networks prior to advertising them. Several basic tasks are required to multihome a network:

Step 1. Set up the E-BGP peer routing; your network will, most likely, be peering with a router that is not under your administrative control, so you must arrange a routing policy in advance.

Step 2. If the router will have more than one connection to another router, you should provide your loopback interface to the remote service provider and use the loopback interface's IP address as your update source. This is accomplished using the `neighbor { ip-address | peer-group} update-source/interface-name interface-number` command. If you will be using the `update-source` command, it is best to configure the router to use that IP address as the BGP router ID using the `bgp router-id ip-address` command and specify the loopback IP.

Step 3. If you will be peering with a router that is not directly connected because you used a loopback interface, you must use the neighbor { ip-address | peer-group} ebgp-multihop number-of-hops command. Because you can specify the number of hops that are allowed when using this command, it should be used with some caution; your service provider could end up routing your traffic across long distances trying to reach an interface that is only two hops away. When using the ebgp-multihop command, always specify the maximum number of hops.

Step 4. If you will be load sharing using more than one interface, use the maximum-paths number-of-paths command. This command allows the BGP process to use multiple paths, rather than one best path for load-sharing purposes.

Step 5. If you will be using more than one router at the transit peering point, use the next-hop-self command between the I-BGP peers so that routes will be advertised with a reachable NEXT_HOP attribute.

Step 6. If you will be using more than one router to peer with more than one service provider, filter all external routes using an AS path filter list containing an empty AS path (^\$). This prevents one service provider from using your AS as a transit to the other service providers network.

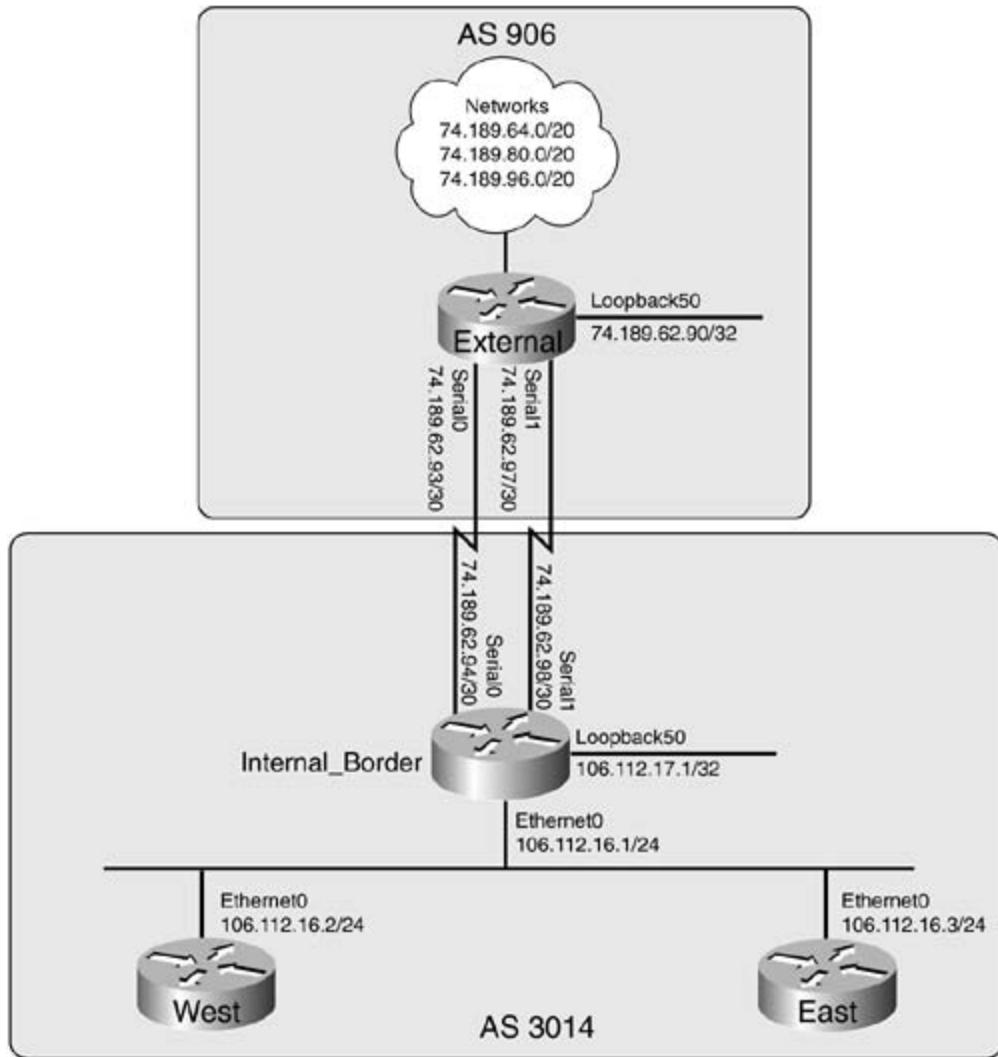
Step 7. Verify that your router is not propagating any private RFC 1918 addresses using an access list and distribute list, or route map, to specify the private networks.

Step 8. Perform route aggregation before advertising routes to your upstream provider. To conserve Internet route table space, always send the smallest prefix possible.

Step 9. Configure any BGP attributes that you will use for path selection and route policy. Set LOCAL_PREF for I-BGP routing preferences, set the MED for E-BGP AS entrance preferences, set any COMMUNITY attributes that you will use for route policy.

For instance, look at the network shown in [Figure 9-16](#). In this example, the Internal_Border route has two connections to its upstream neighbor, the External router. For the Internal_Border router to successfully use both serial links it must be configured to do so using the previously outlined steps.

Figure 9-16. Multihoming a Network to a Single Provider



[Example 9-73](#) shows the configuration used on the Internal_Border and External border routers. For example, the Internal_Border uses loopback interface 50 to peer with the loopback interface on the External router.

Example 9-73. Multihoming the External and Internal_Border Routers

```

External#show run | begin bgp

router bgp 906
  no synchronization
  bgp router-id 74.189.62.90
  network 74.189.62.92 mask 255.255.255.252
  network 74.189.62.96 mask 255.255.255.252

```

```
network 74.189.64.0 mask 255.255.240.0
network 74.189.80.0 mask 255.255.240.0
network 74.189.96.0 mask 255.255.240.0
neighbor 106.112.17.1 remote-as 3014
neighbor 106.112.17.1 ebgp-multipath 2
neighbor 106.112.17.1 update-source Loopback50
no auto-summary
!
ip route 106.112.17.1 255.255.255.255 74.189.62.94
ip route 106.112.17.1 255.255.255.255 74.189.62.98
```

```
Internal_Border # show run | begin bgp
router bgp 3014
no synchronization
bgp router-id 106.112.17.1
bgp log-neighbor-changes
network 106.112.16.0 mask 255.255.255.0
aggregate-address 106.112.16.0 255.255.248.0 summary-only
neighbor 74.189.62.90 remote-as 906
neighbor 74.189.62.90 ebgp-multipath 2
neighbor 74.189.62.90 update-source Loopback50
neighbor 106.112.16.2 remote-as 3014
neighbor 106.112.16.2 route-reflector-client
neighbor 106.112.16.2 next-hop-self
neighbor 106.112.16.3 remote-as 3014
neighbor 106.112.16.3 route-reflector-client
neighbor 106.112.16.3 next-hop-self
no auto-summary
```



```
74.0.0.0/8 is variably subnetted, 6 subnets, 3 masks
C    74.189.62.90/32 is directly connected, Loopback50
C    74.189.62.92/30 is directly connected, Serial0
C    74.189.96.0/20 is directly connected, Loopback30
C    74.189.80.0/20 is directly connected, Loopback20
C    74.189.62.96/30 is directly connected, Serial1
C    74.189.64.0/20 is directly connected, Loopback10
```

In this example, you can see that the route to the 106.112.16.0/21 network can be reached using either the 74.189.62.94 or 74.189.62.98 next-hop IP addresses; therefore, if one interface fails, the other interface can quickly resume BGP routing with little to no interruption in service. [Example 9-75](#) shows debug ip routing command output during a simulated interface failure.

NOTE

Use extreme caution when performing debug commands on production routers. Try to limit command output using access lists, disable console logging, and use a syslog server to capture log output. It is easy to crash a router by debugging on a production router.

Example 9-75. Debug Output During an Interface Failure

```
Internal_Border(config)#interface serial0
Internal_Border(config-if)#shutdown
01:59:37: is_up: 0 state: 6 sub state: 1 line: 0
01:59:37: RT: interface Serial0 removed from routing table
01:59:37: RT: del 74.189.62.92/30 via 0.0.0.0, connected metric [0/0]
01:59:37: RT: delete subnet route to 74.189.62.92/30
Comment: routes using Serial 0 interface are removed
01:59:37: RT: add 74.189.62.92/30 via 74.189.62.90, bgp metric [20/0]
01:59:38: RT: del 74.189.62.90/32 via 74.189.62.93, static metric [1/0]
Comment: route to External router loopback over Serial 0 is removed
```

```

01:59:39: %LINK-5-CHANGED: Interface Serial0, changed state to administratively do
01:59:39: is_up: 0 state: 6 sub state: 1 line: 0
01:59:40: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0, changed state t
01:59:40: is_up: 0 state: 6 sub state: 1 line: 0
01:59:41: RT: del 74.189.62.92/30 via 74.189.62.90, bgp metric [20/0]
01:59:41: RT: delete subnet route to 74.189.62.92/30
00:47:14: RT: del 74.189.64.0/20 via 74.189.62.90, bgp metric [20/0]
00:47:14: RT: delete subnet route to 74.189.64.0/20
00:47:14: RT: del 74.189.80.0/20 via 74.189.62.90, bgp metric [20/0]
00:47:14: RT: delete subnet route to 74.189.80.0/20
00:47:14: RT: del 74.189.96.0/20 via 74.189.62.90, bgp metric [20/0]
00:47:14: RT: delete subnet route to 74.189.96.0/20
00:47:38: RT: del 74.189.62.90/32 via 74.189.62.93, static metric [1/0]
00:47:38: RT: del 74.189.62.90/32 via 74.189.62.93, static metric [1/0]
00:48:14: RT: add 74.189.64.0/20 via 74.189.62.90, bgp metric [20/0]
00:48:14: RT: add 74.189.80.0/20 via 74.189.62.90, bgp metric [20/0]
00:48:14: RT: add 74.189.96.0/20 via 74.189.62.90, bgp metric [20/0]

```

Example 9-76 shows the IP routing table on the Internal_Border router during the interface outage. Notice that all the routes are still in the table and still pointing to the loopback interface; the only change is the route to the loopback interface.

Example 9-76. IP Routing Table During Interface Outage

```

Internal_Border#show ip route
106.0.0.0/8 is variably subnetted, 3 subnets, 2 masks
B      106.112.16.0/21 [200/0] via 0.0.0.0, 00:13:18, Null0
C      106.112.16.0/24 is directly connected, Ethernet0
C      106.112.17.0/24 is directly connected, Loopback50

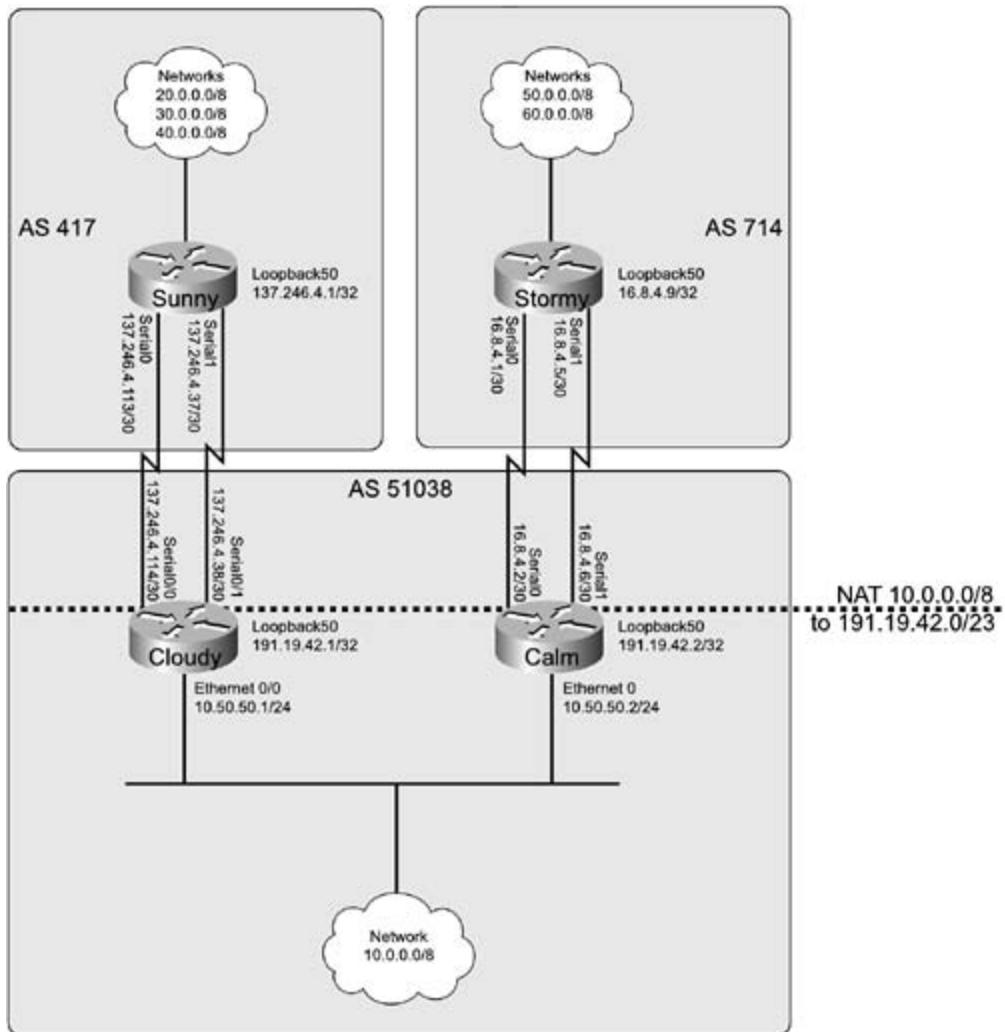
```

S 74.189.62.90/32 [1/0] via 74.189.62.97
B 74.189.96.0/20 [20/0] via 74.189.62.90, 00:45:00
B 74.189.80.0/20 [20/0] via 74.189.62.90, 00:45:00
C 74.189.62.96/30 is directly connected, Serial1
B 74.189.64.0/20 [20/0] via 74.189.62.90, 00:45:01

Practical Example: Multihoming a BGP Network

This example demonstrates all the tasks required to multihome a BGP network using two routers with multiple paths to two service providers. This example demonstrates the use of the multihoming commands, and shows how they are used in practice. [Figure 9-17](#) shows the network that is used for this example.

Figure 9-17. All-Weather Network



This example requires four Cisco routers, each with two serial interfaces; two of the routers also require an Ethernet interface. The routers in this example use the IP address and interface assignments shown in [Table 9-10](#).

Table 9-10. IP Address and Interface Assignments

Router	Interface Name/Number	IP Address
Sunny	Loopback5	20.0.0.1/8
	Loopback10	30.0.0.1/8
	Loopback15	40.0.0.1/8
	Loopback50	137.246.4.1/32
	Serial0	137.246.4.113/30
	Serial1	137.246.4.37/30
Stormy	Loopback5	50.0.0.1/8
	Loopback10	60.0.0.1/8
	Loopback15	70.0.0.1/8
	Loopback50	16.8.4.9/32
	Serial0	16.8.4.1/30
	Serial1	16.8.4.5/30
Cloudy	Ethernet0/0	10.50.50.1/24
	Serial0/0	137.246.4.114/30
	Serial0/1	137.246.4.38/30
	Loopback50	191.19.42.1/32
Calm	Ethernet 0/0	10.50.50.2/24
	Loopback50	191.19.42.2/32
	Serial0	16.8.4.2/30
	Serial1	16.8.4.6/30

Step 1. Configure IP addresses and verify that each router can ping its directly connected next hop before proceeding to Step 2.

Step 2. Before configuring BGP, make sure that the Sunny and Cloudy routers can reach each other's Loopback50 IP addresses. Do not use an IGP protocol. The following example shows the routes configured on both of the routers. [Example 9-77](#) shows the static routes configured on the Sunny and Cloudy routers.

Example 9-77. Configuring Static Routes on the Sunny and Cloudy Routers

```
Sunny#show run | begin ip route
ip route 191.19.42.1 255.255.255.255 137.246.4.114
```

```
ip route 191.19.42.1 255.255.255.255 137.246.4.38
```

```
Cloudy#show run | begin ip route
```

```
ip route 137.246.4.1 255.255.255.255 137.246.4.37
```

```
ip route 137.246.4.1 255.255.255.255 137.246.4.113
```

In this example, two very specific static routes are added to each router, allowing the routers to reach each other's loopback interface without specifying the entire network prefix.

Step 3. Configure BGP routing on the Sunny router. Assign this router to ASN 417, and use the Loopback50 IP address as the BGP router ID. Also disable auto-summarization. Advertise the three networks from the loopback interfaces using network statements. The Sunny router should peer with the Cloudy router by loopback interface only. Configure the Sunny router to peer with the Cloudy router's Loopback50 interface. [Example 9-78](#) shows the BGP configuration for the Sunny router.

Example 9-78. BGP Configuration for the Sunny Router

```
Sunny#show run | begin bgp
```

```
router bgp 417
```

```
    synchronization
```

```
    bgp router-id 137.246.4.1
```

```
    bgp log-neighbor-changes
```

```
    network 20.0.0.0
```

```
    network 30.0.0.0
```

```
    network 40.0.0.0
```

```
    neighbor 191.19.42.1 remote-as 51038
```

```
    neighbor 191.19.42.1 ebgp-multipath 2
```

```
    neighbor 191.19.42.1 update-source Loopback50
```

```
    no auto-summary
```

```
!
```

```
ip route 191.19.42.1 255.255.255.255 137.246.4.114
```

```
ip route 191.19.42.1 255.255.255.255 137.246.4.38
```

In the preceding example, BGP was configured to allow two hops between E-BGP neighbors using the `ebgp-multipath` command, the loopback interface was specified using the `update-source` command, and the BGP router ID was changed using the `bgp router-id` command.

Step 4. Configure the Cloudy router to run in AS 51,038, and configure this router to peer with the Sunny router's loopback interface. Verify that both routers can successfully start and maintain a BGP session. [Example 9-79](#) shows the BGP configuration for the Cloudy router; this example also displays the output from the `show ip bgp summary` command on the Cloudy and Sunny routers.

Example 9-79. BGP Configuration for the Cloudy Router and show ip bgp summary Command Output from the Cloudy and Sunny Routers

```
Cloudy#show run | begin bgp

router bgp 51038

    synchronization

    bgp router-id 191.19.42.1

    bgp log-neighbor-changes

    neighbor 137.246.4.1 remote-as 417

    neighbor 137.246.4.1 ebgp-multipath 2

    neighbor 137.246.4.1 update-source Loopback50

    no auto-summary

!

ip route 137.246.4.1 255.255.255.255 137.246.4.37

ip route 137.246.4.1 255.255.255.255 137.246.4.113

Cloudy#show ip bgp summary

BGP router identifier 191.19.42.1, local AS number 51038

BGP table version is 4, main routing table version 4

3 network entries and 3 paths using 411 bytes of memory

1 BGP path attribute entries using 60 bytes of memory

1 BGP AS-PATH entries using 24 bytes of memory
```

```

0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP activity 3/0 prefixes, 3/0 paths, scan interval 60 secs

```

Neighbor	V	AS	MsgRcvd	MsgSent	TblVer	InQ	OutQ	Up/Down	State/PfxRcd
137.246.4.1	4	417	7	6	4	0	0	00:02:13	3

Sunny#**show ip bgp summary**

```

BGP router identifier 137.246.4.1, local AS number 417
BGP table version is 4, main routing table version 4
3 network entries and 3 paths using 411 bytes of memory
1 BGP path attribute entries using 60 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP activity 3/0 prefixes, 3/0 paths, scan interval 60 secs

```

Neighbor	V	AS	MsgRcvd	MsgSent	TblVer	InQ	OutQ	Up/Down	State/PfxRcd
191.19.42.1	4	51038	6	7	4	0	0	00:02:43	0

Like the Sunny router, the Cloudy router is configured using loopback interfaces, ebgp-multihop, and a predefined BGP router ID.

Step 5. Configure the Cloudy router to peer with the Calm router; do not use an IGP for I-BGP peer routing. Without using any route filtering, prevent the Cloudy router from advertising any RFC 1918 networks to the Sunny router. After configuration, the networks behind the Cloudy router should still be able to ping any upstream neighbor. Use half of the 192.19.42.0/23 network for this purpose, but configure BGP to advertise one route for the entire 23-bit block. Verify that the Cloudy router can reach the Sunny router's loopback interfaces using the 10.50.50.1 source address. [Example 9-80](#) shows the configuration for the Cloudy router.

Example 9-80. Cloudy Router Configuration for Step 5

```
Cloudy#show run | begin interface Ethernet0/0

interface Ethernet0/0

ip address 10.50.50.1 255.255.255.0

ip nat inside

!

interface Serial0/0

ip address 137.246.4.114 255.255.255.252

ip nat outside

!

interface Serial0/1

ip address 137.246.4.38 255.255.255.252

ip nat outside

clockrate 1300000

Cloudy#show run | begin bgp

router bgp 51038

no synchronization

bgp router-id 191.19.42.1

bgp log-neighbor-changes

network 191.19.42.0 mask 255.255.255.0

neighbor 10.50.50.2 remote-as 51038

neighbor 10.50.50.2 next-hop-self

neighbor 137.246.4.1 remote-as 417

neighbor 137.246.4.1 ebgp-multipath 2

neighbor 137.246.4.1 update-source Loopback50

no auto-summary

!

ip nat pool public 191.19.42.3 191.19.42.254 prefix-length 24

ip nat inside source list 8 pool public
```

```

ip route 137.246.4.1 255.255.255.255 137.246.4.37
ip route 137.246.4.1 255.255.255.255 137.246.4.113
ip route 191.19.42.0 255.255.255.0 Null0 253
!
access-list 8 permit 10.0.0.0 0.255.255.255

```

The `no synchronization` command allows BGP routing with the Calm router, without the presence of an IGP. Network Address Translation (NAT) allows the Cloudy router to hide the internal RFC 1918 network 10.50.50.0/24 from the Sunny router. A NAT pool named `public` is created to NAT the rest of the 10.0.0.0/8 networks, which are not shown in the network diagram, to the public network 191.19.42.0/24. The first two IP addresses are skipped because they are already in use. A static route to Null 0, with high administrative distance, ensures that a route to the 191.19.42.0/23 network exists in the main IP routing table, so the network can be advertised via BGP to the Sunny router. If you are having trouble with NAT, use the `debug ip nat` command to debug NAT translations, and use the `show ip bgp neighbor ip-address advertised-routes` command to verify that the Sunny router is receiving the proper route to the 191.19.42.0/23 network. You can verify connectivity by using an extended ping. The output of the `debug ip nat`, `show ip bgp neighbor 137.246.4.1 advertised-routes` and extended ping tests are shown in [Example 9-81](#).

Example 9-81. Verifying Step 5

```

Cloudy#show ip bgp neighbors 137.246.4.1 advertised-routes | begin Network

```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 191.19.42.0/23	0.0.0.0			32768	i

```

Cloudy#debug ip nat

Cloudy#ping

Protocol [ip]:
Target IP address: 20.0.0.1

Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]: y
Source address or interface: 10.50.50.1

Type of service [0]:

```

```

Set DF bit in IP header? [no]:  

Validate reply data? [no]:  

Data pattern [0xABCD]:  

Loose, Strict, Record, Timestamp, Verbose[none]:  

Sweep range of sizes [n]:  

Type escape sequence to abort.  

Sending 5, 100-byte ICMP Echos to 20.0.0.1, timeout is 2 seconds:  

!!!!!  

Success rate is 100 percent (5/5), round-trip min/avg/max = 20/20/20 ms  

Cloudy#  

*Mar 5 06:16:51.307: NAT: s=10.50.50.1->191.19.42.3, d=20.0.0.1 [165]  

*Mar 5 06:16:51.327: NAT*: s=20.0.0.1, d=191.19.42.3->10.50.50.1 [165]  

*Mar 5 06:16:51.331: NAT: s=10.50.50.1->191.19.42.3, d=20.0.0.1 [166]  

*Mar 5 06:16:51.347: NAT*: s=20.0.0.1, d=191.19.42.3->10.50.50.1 [166]  

*Mar 5 06:16:51.351: NAT: s=10.50.50.1->191.19.42.3, d=20.0.0.1 [167]  

*Mar 5 06:16:51.371: NAT*: s=20.0.0.1, d=191.19.42.3->10.50.50.1 [167]  

*Mar 5 06:16:51.371: NAT: s=10.50.50.1->191.19.42.3, d=20.0.0.1 [168]  

*Mar 5 06:16:51.391: NAT*: s=20.0.0.1, d=191.19.42.3->10.50.50.1 [168]  

*Mar 5 06:16:51.395: NAT: s=10.50.50.1->191.19.42.3, d=20.0.0.1 [169]  

*Mar 5 06:16:51.415: NAT*: s=20.0.0.1, d=191.19.42.3->10.50.50.1 [169]

```

Step 6. Configure static routing between the loopback50 addresses on the Stormy and Calm routers. Verify connectivity between the Loopback50 interfaces on these routers before continuing to Step 7. [Example 9-82](#) shows the static routes configured on the Stormy and Calm routers.

Example 9-82. Static Routes on the Stormy and Calm Routers

```

stormy#show run | include ip route  

ip route 191.19.42.2 255.255.255.255 16.8.4.2

```

```
ip route 191.19.42.2 255.255.255.255 16.8.4.6
```

```
Calm#show run | include ip route  
  
ip route 16.8.4.9 255.255.255.255 16.8.4.1  
  
ip route 16.8.4.9 255.255.255.255 16.8.4.5
```

Routing between the loopbacks of the Stormy and Calm routers is configured using specific static routes.

Step 7. Now configure BGP routing on the Stormy router. Assign this router to ASN 714 and use the Loopback50 IP address as the BGP router ID. Disable auto-summarization. Configure the Stormy router to peer with the Calm router using the Loopback50 interfaces only, and advertise the three networks from the loopback interfaces using network statements. [Example 9-83](#) shows the BGP configuration for the Stormy router.

Example 9-83. BGP Configuration for the Stormy Router

```
stormy#show run | begin bgp  
  
router bgp 714  
  
no synchronization  
  
bgp router-id 16.8.4.9  
  
bgp log-neighbor-changes  
  
network 50.0.0.0  
  
network 60.0.0.0  
  
network 70.0.0.0  
  
neighbor 191.19.42.2 remote-as 51038  
  
neighbor 191.19.42.2 ebgp-multipath 2  
  
neighbor 191.19.42.2 update-source Loopback50  
  
no auto-summary  
  
!  
  
ip route 191.19.42.2 255.255.255.255 16.8.4.2  
ip route 191.19.42.2 255.255.255.255 16.8.4.6
```

Similar to the Sunny router, the Stormy router is configured using the bgp router-id, ebgp-multihop, and update-source commands.

Step 8. Configure BGP routing on the Calm router; configure this router to peer with the Stormy and Cloudy routers. Remember, the Cloudy router is not allowed to use an IGP for I-BGP routing. The Calm and Stormy routers should peer with each other's Loopback50 IP addresses. Configure the Calm router to advertise the 191.19.42.0/23 network to the Stormy router. Verify that the Cloudy router receives the full table from the Sunny and Stormy routers, and that all routers can ping all interfaces on all routers, which might require another NAT translation, before continuing to Step 9. [Example 9-84](#) shows the BGP configuration for the Calm router.

Example 9-84. BGP Configuration for the Calm Router

```
Calm#show run | begin bgp

router bgp 51038
no synchronization
bgp router-id 191.19.42.2
bgp log-neighbor-changes
network 191.19.43.0 mask 255.255.255.0
aggregate-address 191.19.42.0 255.255.254.0 summary-only
neighbor 10.50.50.1 remote-as 51038
neighbor 10.50.50.1 next-hop-self
neighbor 16.8.4.9 remote-as 714
neighbor 16.8.4.9 ebgp-multihop 2
neighbor 16.8.4.9 update-source Loopback50
no auto-summary
!
ip nat pool public 191.19.43.3 191.19.43.254 prefix-length 24
ip nat inside source list 8 pool public
ip route 16.8.4.9 255.255.255.255 16.8.4.5
ip route 16.8.4.9 255.255.255.255 16.8.4.1
```

```

ip route 191.19.43.0 255.255.255.0 Null0 253
!
access-list 8 permit 10.0.0.0 0.255.255.255

```

The Calm router is configured using the same commands as the Cloudy router. Next, NAT is enabled using a NAT pool and an access list and then applied to the inside and outside interfaces; a static route to Null0 adds the route to the IGP routing table, so the public network can be advertised to the Stormy router. Then, the next-hop-self command is added to the Calm router to ensure that the Calm and Cloudy routers advertise a valid, reachable next hop, as shown in [Example 9-85](#).

Example 9-85. BGP RI B for the Calm Router

```
Calm#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i20.0.0.0	10.50.50.1	0	100	0	417 i
*>i30.0.0.0	10.50.50.1	0	100	0	417 i
*>i40.0.0.0	10.50.50.1	0	100	0	417 i
*> 50.0.0.0	16.8.4.9	0		0	714 i
*> 60.0.0.0	16.8.4.9	0		0	714 i
*> 70.0.0.0	16.8.4.9	0		0	714 i
*> 191.19.42.0/23	0.0.0.0			32768	i
* i	10.50.50.1		100	0	i
s> 191.19.43.0/24	0.0.0.0	0		32768	i

Extended pings and the show ip nat translations command enable you to verify that all routing and NAT statements are properly configured, as shown in [Example 9-86](#).

Example 9-86. Verifying the BGP and NAT Configuration on the Calm Router

```
Calm#ping
```

```
Protocol [ip]:  
Target IP address: 20.0.0.1  
Repeat count [5]:  
Datagram size [100]:  
Timeout in seconds [2]:  
Extended commands [n]: y  
Source address or interface: 10.50.50.2  
Type of service [0]:  
Set DF bit in IP header? [no]:  
Validate reply data? [no]:  
Data pattern [0xABCD]:  
Loose, Strict, Record, Timestamp, Verbose[none]:  
Sweep range of sizes [n]:  
Type escape sequence to abort.  
Sending 5, 100-byte ICMP Echos to 20.0.0.1, timeout is 2 seconds:  
!!!!!  
Success rate is 100 percent (5/5), round-trip min/avg/max = 24/30/40 ms  
Calm#
```

```
Cloudy#ping  
Protocol [ip]:  
Target IP address: 50.0.0.1  
Repeat count [5]:  
Datagram size [100]:  
Timeout in seconds [2]:  
Extended commands [n]: y  
Source address or interface: 10.50.50.1  
Type of service [0]:
```

```

Set DF bit in IP header? [no]:  

Validate reply data? [no]:  

Data pattern [0xABCD]:  

Loose, Strict, Record, Timestamp, Verbose[none]:  

Sweep range of sizes [n]:  

Type escape sequence to abort.  

Sending 5, 100-byte ICMP Echos to 50.0.0.1, timeout is 2 seconds:  

!!!!!  

Success rate is 100 percent (5/5), round-trip min/avg/max = 4/12/32 ms  

Calm#show ip nat translations  

Pro Inside global           Inside local           Outside local           Outside global  

--- 191.19.42.3            10.50.50.1          ---                 ---
```

Step 9. Configure a route filter that prevents the Sunny and Stormy routers from reaching each other's networks using any routers in AS 51,038 as a transit network. [Example 9-87](#) shows the filter configuration for the Cloudy and Calm routers.

Example 9-87. Filtering Transit Routes

```

Cloudy#show run | begin bgp  

router bgp 51038  

  no synchronization  

  bgp router-id 191.19.42.1  

  bgp log-neighbor-changes  

  network 191.19.42.0 mask 255.255.255.0  

  aggregate-address 191.19.42.0 255.255.254.0 summary-only  

  neighbor 10.50.50.2 remote-as 51038  

  neighbor 10.50.50.2 next-hop-self  

  neighbor 137.246.4.1 remote-as 417  

  neighbor 137.246.4.1 ebgp-multihop 2
```

```
neighbor 137.246.4.1 update-source Loopback50

neighbor 137.246.4.1 filter-list 8 out
    no auto-summary
!

ip nat pool public 191.19.42.3 191.19.42.254 prefix-length 24
ip nat inside source list 8 pool public
ip classless
ip route 137.246.4.1 255.255.255.255 137.246.4.37
ip route 137.246.4.1 255.255.255.255 137.246.4.113
ip route 191.19.42.0 255.255.255.0 Null0 253
ip as-path access-list 8 permit ^$
```

```
Calm#show run | begin bgp

router bgp 51038
    no synchronization
    bgp router-id 191.19.42.2
    bgp cluster-id 1253916250
    bgp log-neighbor-changes
    network 191.19.43.0 mask 255.255.255.0
    aggregate-address 191.19.42.0 255.255.254.0 summary-only
    neighbor 10.50.50.1 remote-as 51038
    neighbor 10.50.50.1 next-hop-self
    neighbor 16.8.4.9 remote-as 714
    neighbor 16.8.4.9 ebgp-multipath 2
    neighbor 16.8.4.9 update-source Loopback50
    neighbor 16.8.4.9 filter-list 8 out
        no auto-summary
!
```

```

ip nat pool public 191.19.43.3 191.19.43.254 prefix-length 24

ip nat inside source list 8 pool public

ip route 16.8.4.9 255.255.255.255 16.8.4.1

ip route 16.8.4.9 255.255.255.255 16.8.4.5

ip route 191.19.43.0 255.255.255.0 Null0 253

ip as-path access-list 8 permit ^$


!

access-list 8 permit 10.0.0.0 0.255.255.255

```

An AS path access list number 8 is created to permit only locally generated routes containing an empty autonomous system path (indicated by the `^$` regular expression) to be advertised to the Cloudy and Calm routers' E-BGP peers. This prevents the Sunny and Stormy routers from receiving routes to each other's networks, saving AS 51,038 from becoming a transit AS as shown here. [Example 9-88](#) shows the BGP tables on the Sunny and Stormy routers after the application of the AS path filters.

Example 9-88. Viewing the Final BGP Tables on the Sunny and Stormy Routers

Sunny#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 20.0.0.0	0.0.0.0	0		32768	i
*> 30.0.0.0	0.0.0.0	0		32768	i
*> 40.0.0.0	0.0.0.0	0		32768	i
*> 191.19.42.0/23	191.19.42.1	0		0	51038 i

Stormy#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 50.0.0.0	0.0.0.0	0		32768	i
*> 60.0.0.0	0.0.0.0	0		32768	i
*> 70.0.0.0	0.0.0.0	0		32768	i

```
*> 191.19.42.0/23    191.19.42.2          0 51038 i
```

The preceding lab reviewed many of the topics covered in this chapter, including multihoming networks using loopbacks for stability, using AS path access lists to filter ASNs, and using routes to the null interface to advertise a network that is not in the IGP routing table. [Example 9-89](#) shows the complete router configurations for this practical example.

Example 9-89. Complete Router Configurations for this Experiment

```
Sunny#show run | begin Loopback

interface Loopback5
  ip address 20.0.0.1 255.0.0.0
!
interface Loopback10
  ip address 30.0.0.1 255.0.0.0
!
interface Loopback15
  ip address 40.0.0.1 255.0.0.0
!
interface Loopback50
  ip address 137.246.4.1 255.255.255.255
!
interface Serial0
  ip address 137.246.4.113 255.255.255.252
!
interface Serial1
  ip address 137.246.4.37 255.255.255.252
!
router bgp 417
  synchronization
```

```
bgp router-id 137.246.4.1
bgp log-neighbor-changes
network 20.0.0.0
network 30.0.0.0
network 40.0.0.0
neighbor 191.19.42.1 remote-as 51038
neighbor 191.19.42.1 ebgp-multipath 2
neighbor 191.19.42.1 update-source Loopback50
no auto-summary
!
ip route 191.19.42.1 255.255.255.255 137.246.4.114
ip route 191.19.42.1 255.255.255.255 137.246.4.38
```

```
Cloudy#show run | begin Loopback
interface Loopback50
  ip address 191.19.42.1 255.255.255.255
!
interface Ethernet0/0
  ip address 10.50.50.1 255.255.255.0
  ip nat inside
!
interface Serial0/0
  ip address 137.246.4.114 255.255.255.252
  ip nat outside
!
interface Serial0/1
  ip address 137.246.4.38 255.255.255.252
  ip nat outside
```

```
clockrate 1300000

!
router bgp 51038
  no synchronization
  bgp router-id 191.19.42.1
  bgp log-neighbor-changes
  network 191.19.42.0 mask 255.255.255.0
  aggregate-address 191.19.42.0 255.255.254.0 summary-only
  neighbor 10.50.50.2 remote-as 51038
  neighbor 10.50.50.2 next-hop-self
  neighbor 137.246.4.1 remote-as 417
  neighbor 137.246.4.1 ebgp-multihop 2
  neighbor 137.246.4.1 update-source Loopback50
  neighbor 137.246.4.1 filter-list 8 out
  no auto-summary
!
ip nat pool public 191.19.42.3 191.19.42.254 prefix-length 24
ip nat inside source list 8 pool public
ip route 137.246.4.1 255.255.255.255 137.246.4.37
ip route 137.246.4.1 255.255.255.255 137.246.4.113
ip route 191.19.42.0 255.255.255.0 Null0 253
ip as-path access-list 8 permit ^$
```

```
stormy#show run | begin Loopback
```

```
interface Loopback5
  ip address 50.0.0.1 255.0.0.0
```

```
!  
  
interface Loopback10  
    ip address 60.0.0.1 255.0.0.0  
  
!  
  
interface Loopback15  
    ip address 70.0.0.1 255.0.0.0  
  
!  
  
interface Loopback50  
    ip address 16.8.4.9 255.255.255.255  
  
!  
  
interface Serial0  
    ip address 16.8.4.1 255.255.255.252  
    clockrate 1300000  
  
!  
  
interface Serial1  
    ip address 16.8.4.5 255.255.255.252  
    clockrate 1300000  
  
!  
  
router bgp 714  
    no synchronization  
    bgp router-id 16.8.4.9  
    bgp log-neighbor-changes  
    network 50.0.0.0  
    network 60.0.0.0  
    network 70.0.0.0  
    neighbor 191.19.42.2 remote-as 51038  
    neighbor 191.19.42.2 ebgp-multihop 2  
    neighbor 191.19.42.2 update-source Loopback50
```

```
no auto-summary

!

ip route 191.19.42.2 255.255.255.255 16.8.4.2
ip route 191.19.42.2 255.255.255.255 16.8.4.6



---


Calm#show run | begin Loopback

interface Loopback50
    ip address 191.19.42.2 255.255.255.255

!
interface Ethernet0
    ip address 10.50.50.2 255.255.255.0
    ip nat inside

!
interface Serial0
    ip address 16.8.4.2 255.255.255.252
    ip nat outside

!
interface Serial1
    ip address 16.8.4.6 255.255.255.252
    ip nat outside

!
router bgp 51038
    no synchronization
    bgp router-id 191.19.42.2
    bgp log-neighbor-changes
    network 191.19.43.0 mask 255.255.255.0
    aggregate-address 191.19.42.0 255.255.254.0 summary-only
    neighbor 10.50.50.1 remote-as 51038
```

```
neighbor 10.50.50.1 next-hop-self
neighbor 16.8.4.9 remote-as 714
neighbor 16.8.4.9 ebgp-multipath 2
neighbor 16.8.4.9 update-source Loopback50
neighbor 16.8.4.9 filter-list 8 out
no auto-summary
!
ip nat pool public 191.19.43.3 191.19.43.254 prefix-length 24
ip nat inside source list 8 pool public
ip route 16.8.4.9 255.255.255.255 16.8.4.5
ip route 16.8.4.9 255.255.255.255 16.8.4.1
ip route 191.19.43.0 255.255.255.0 Null0 253
ip as-path access-list 8 permit ^$*
!
access-list 8 permit 10.0.0.0 0.255.255.255
```

Administrative Distance and Its Effects on BGP

When BGP and IGPs are used together for IP routing, as they generally will be in an enterprise network, you might sometimes want a router to prefer an IGP route to an E-BGP route. Under normal circumstances, this will not be possible because routers always prefer E-BGP routes because they have a lower administrative distance. The Cisco IOS Software uses the administrative distances shown in [Table 9-11](#).

Table 9-11. Default Administrative Distances

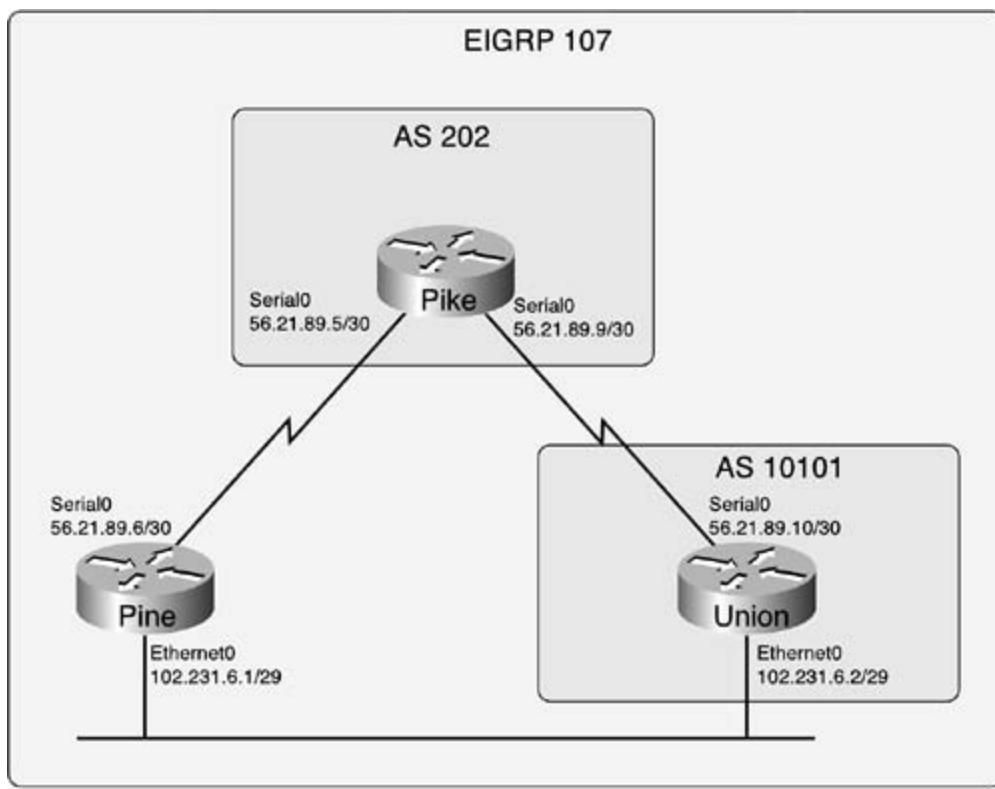
Administrative Distance	Protocol
0	Directly connected networks
1	Static routes
20	E-BGP
90	Internal EIGRP
100	IGRP
110	OSPF
115	IS-IS
120	RIP
170	External EIGRP
200	I-BGP
255	Unknown

You can deal with these situations in a couple of ways. You could increase the administrative distance of an IGP protocol or increase the administrative distance for E-BGP routers using the `distance distance-value` command (or `distance bgp external-distance internal-distance local-distance` command for E-BGP routes); however, the effects of this command are rather broad and might produce unwanted results. Another more granular approach is to use the `bgp backdoor` command to alter routes on a network-by-network basis.

What Backdoors Are and How You Use Them

BGPbackdoors are designed to change E-BGP administrative distance to allow IGP routes to have administrative preference in the IP routing table. The `BGPbackdoor` command basically takes the specified E-BGP routes and changes the administrative distance from 20 to 200, the same distance as an I-BGP route, allowing IGP routes to take administrative precedence in the routing table. In [Figure 9-18](#), for example, the Pike router has two paths to the 102.231.6.0/29 network—one by means of the Pine router and the other through the Union router.

Figure 9-18. Administrative Distance and Routing on the Downtown Network



Because the Pike and Pine routers are not BGP neighbors, the Pike router stores only one route to the 102.231.6.0/29 network. The reason the Pike router ignores the EIGRP route is that that route has an administrative distance of 90, which is higher than the Union router's E-BGP administrative distance of 20, as shown in [Example 9-90](#).

Example 9-90. Pike Router's Routing Table Before the Backdoor

```
Pike#show ip route | begin subnet

102.0.0.0/29 is subnetted, 1 subnets
B    102.231.6.0 [20/0] via 56.21.89.10, 00:05:49

56.0.0.0/30 is subnetted, 2 subnets
C    56.21.89.4 is directly connected, Serial0
C    56.21.89.8 is directly connected, Serial1
```

To allow the Pike router to use the two EIGRP routes to the 102.231.6.0/29 network, you can just configure a BGP backdoor for that network. BGP backdoors are configured using the `network network-prefixmask network-mask backdoor` command. You would be correct in thinking that the BGP `network` command cannot be used to generate a BGP advertisement for an indirectly connected network; however, in this case, the `network` command is used locally to change the administrative distance of a backdoor route. BGP does not advertise the route as a local route; the administrative distance for the route is simply altered, allowing the EIGRP routes to be administratively preferred by the main IP routing table. [Example 9-91](#) shows how the BGP backdoor command is used to change the IP routing preference for the 102.231.6.0/29 network.

Example 9-91. Changing the Administrative Distance with a BGP Backdoor

```
Pike#show run | begin eigrp

router eigrp 107

network 56.21.89.4 0.0.0.3

network 56.21.89.8 0.0.0.3

maximum-paths 2

no auto-summary

no eigrp log-neighbor-changes

!

router bgp 202

no synchronization

bgp log-neighbor-changes

network 56.21.89.8 mask 255.255.255.252

network 102.231.6.0 mask 255.255.255.248 backdoor

neighbor 56.21.89.10 remote-as 10101

no auto-summary
```

[Example 9-92](#) shows the resulting changes to the IP routing table. After this configuration is applied, the administrative distance for the BGP route is changed, and the E-BGP route is removed from the main IP routing table. At this time, the two EIGRP routes are added because they now have a lower administrative distance. Also, notice that the `show ip bgp 102.231.6.0/29` command still shows the route as the best route and the BGP `network` is still not advertised to any peer.

Example 9-92. Pike Router Configuration After the BGP Backdoor

```
Pike#show ip route | begin subnet
102.0.0.0/29 is subnetted, 1 subnets
D      102.231.6.0 [90/2195456] via 56.21.89.10, 00:01:14, Serial1
                  [90/2195456] via 56.21.89.6, 00:01:14, Serial0
56.0.0.0/30 is subnetted, 2 subnets
C      56.21.89.4 is directly connected, Serial0
C      56.21.89.8 is directly connected, Serial1
Pike#show ip bgp 102.231.6.0/29
BGP routing table entry for 102.231.6.0/29, version 6
Paths: (1 available, best #1, table Default-IP-Routing-Table)
Flag: 0x800
Not advertised to any peer
10101
56.21.89.10 from 56.21.89.10 (10.2.2.1)
      Origin IGP, metric 0, localpref 100, valid, external, best
```

Now that you understand the many ways that BGP can be configured for routing and policy enforcement, it's time to examine how BGP enables you to control Internet routing table stability, by means of route dampening, and some of the ways that BGP can be tuned to perform more efficiently.

BGP Route Dampening

BGProute dampening controls the effects of route flapping between E-BGP peers. Route dampening is generally used to help service providers prevent one customer's router or circuit problems from affecting the stability of the provider's network by withdrawing problem BGP routes. There are two ways to enable route dampening: The first is to globally enable route dampening for all BGP peers using the `bgp dampening` command; the second is to use a route map to specify certain routes that are to be dampened and the parameters that are to be applied to the dampened networks. The following syntax shows the `bgp dampening` command and its optional parameters.

```
bgp dampening [[route-map route-map-name] | [half-life] | reuse-limit start-suppress suppress-duration]]
```

Using the `bgp dampening` command, route dampening can be configured three ways:

- Global route dampening using default parameters
- Global route dampening using custom parameters
- Specific route dampening using custom parameters

[Table 9-12](#) shows the optional `bgp dampening` command parameters and their descriptions.

Table 9-12. BGP Route Dampening Parameters

Dampening Command	Description
<i>half-life</i>	The amount of time to wait before decrementing the dampening penalty, ranging from 1 to 45 minutes. The default half-life is 15 minutes.
<i>reuse-limit</i>	The value between 1 and 20,000 that is compared to the penalty value to determine route reusability. If the penalty is greater than the suppress limit, the route will be suppressed; if not, it will be reused. The default suppress limit is 750.
<i>start-suppress</i>	This value between 1 and 20,000 specifies the penalty that will be used if a route is suppressed. The default route suppression penalty is 2000 for each route flap.
<i>suppress-duration</i>	This value specifies the maximum duration that a route will be suppressed. The range for the suppress duration is from 1 to 255 minutes. The default suppress duration is 4 times the half-life, or in other words 60 minutes.
<i>route-map route-map-name</i>	Specifies that a route map will be used to specify the route dampening parameters. Route maps are used to specify the routes that dampening policies should apply to. The same route dampening parameters apply when a route map is used.

After route dampening has been activated, a route flap penalty of 1000 points is assessed to the affected route. The router maintains a history for each route that has flapped, and that history stores the dampening information on a route-by-route basis. The *half-life* value is used to decrease the time suppression penalty by one-half after a route flaps. Therefore, if a route ceases to flap, it will not be dampened and the history will eventually be cleared. If the route flaps again, another penalty is imposed, and after the *suppress-limit* has been reached, the route is dampened. When a route has been dampened, it will not be advertised to other BGP peers until the *suppress-duration* has expired.

NOTE

The BGP route dampening penalty is initially set to 1000 points and cannot be changed; however, all other parameters are user configurable. You can accept the default values or create your own custom dampening policy based on the particular network requirements.

Look at the network shown in [Figure 9-19](#). In this figure, the Service_Provider router in AS 18,901 is configured with a route dampening policy that dampens routes using the default dampening parameters with the exception of the half-life. In this case, the half-life is changed to 5 minutes, as shown in [Example 9-93](#).

Example 9-93. BGP Configuration for the Service_Provider Router

```
Service_Provider#show run | begin bgp
```

```

router bgp 18901

no synchronization

bgp log-neighbor-changes

bgp bestpath dampening 5

bgp dampening 5

network 143.68.5.200 mask 255.255.255.252

network 143.68.5.204 mask 255.255.255.252

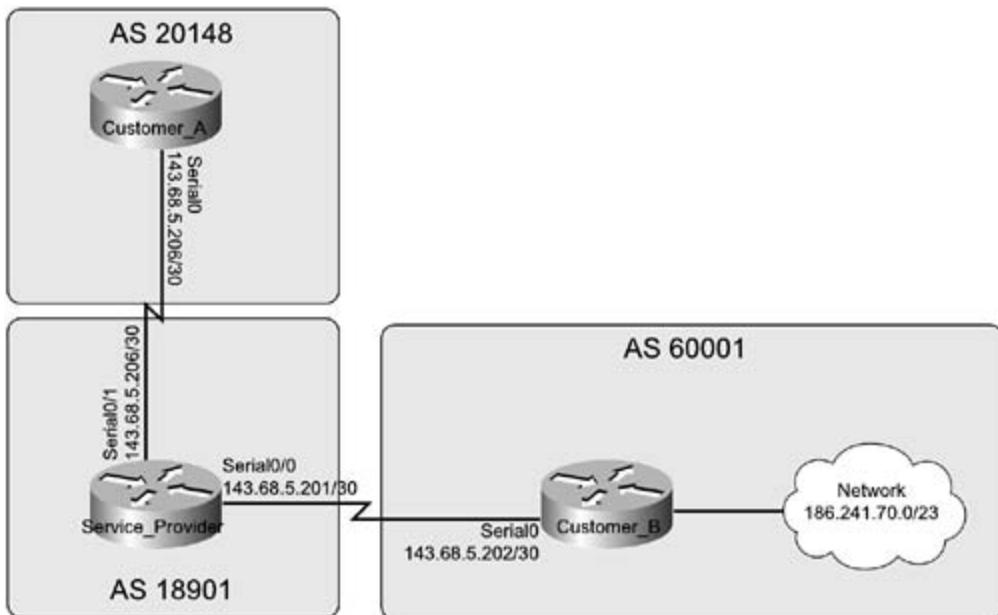
neighbor 143.68.5.202 remote-as 60001

neighbor 143.68.5.206 remote-as 20148

no auto-summary

```

Figure 9-19. Service Provider to Customer Network



By default, the `bgp best path dampening` command is automatically entered after the `bgp dampening` command has been issued in later 12.2 releases of Cisco IOS Software. This command is also used to enable and disable route dampening. There are several ways to verify and track the BGP route dampening configuration, the most detailed of which is the `show ip bgp dampened parameters` command. [Example 9-94](#) uses the `show ip bgp dampening parameters` command to show the BGP route dampening parameters for the Service_Provider router.

Example 9-94. show ip bgp dampening parameters Command

```
Service_Provider#show ip bgp dampening parameters

dampening 5 750 2000 20

Half-life time      : 5   mins      Decay Time       : 775  secs
Max suppress penalty: 12000          Max suppress time: 20  mins
Suppress penalty    : 2000          Reuse penalty     : 750
```

This command displays all the parameters for the local BGP route dampening policy, and in this case, it shows that the Service_Provider router has been configured with a 5-minute half-life. The alteration of the half-life parameter changed the maximum suppress time, so suppressed routes will not be as harshly penalized. [Example 9-95](#) shows the default BGP route dampening parameters.

Example 9-95. Default BGP Route Dampening Parameters

```
Service_Provider#show ip bgp dampening parameters

dampening 15 750 2000 60 (DEFAULT)

Half-life time      : 15  mins      Decay Time       : 2320  secs
Max suppress penalty: 12000          Max suppress time: 60  mins
Suppress penalty    : 2000          Reuse penalty     : 750
```

The `show ip bgp dampening flap-statistics` command displays detailed information for all dampened routes; in this case, the Service_Provider router has dampened the route to the 186.241.70.0/23 network because it flapped four times. [Example 9-96](#) uses the `show ip bgp dampening flap-statistics` command to show that the route has been dampened for 3 minutes and 34 seconds and will be eligible for reuse in 10 minutes and 20 seconds.

Example 9-96. show ip bgp dampening flap-statistics Command

```
Service_Provider#show ip bgp dampening flap-statistics
```

```

BGP RIB version is 13, local router ID is 1.1.1.1

Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
Origin codes: i - IGP, e - EGP, ? - incomplete

Network          From           Flaps Duration Reuse     Path
*d 186.241.70.0/23 143.68.5.202    4        00:03:34 00:10:20 60001

```

The clear ip bgp dampening command enables you to clear the dampened route and the flap statistics associated with the route.

Many steps can be taken to prevent BGP route dampening from occurring using the techniques covered earlier in this chapter; for instance, the Customer_B router could have been configured using some of the following BGP features:

- Multiple links and loopback interfaces to prevent network outages
- Aggregating routes into smaller, more stable prefixes so that one network failure will not affect all routes advertised to the upstream neighbor
- Creating static routes to Null0 to nail down unstable IGP routes

It will always be in your service provider's best interest to protect the stability of their network using BGP route dampening. Their policies might adversely affect a poorly configured network, so you should always try to configure your network with the most stable, redundant BGP configuration possible.

Tuning BGP Performance

Configuring and troubleshooting BGP sessions can be time intensive. Each time you change a BGP parameter, you must clear the session to propagate the changes. Clearing BGP sessions using the `clear ip bgp /ip-address*` command is time-consuming and causes network outages. In the past, the `neighbor { /ip-address | peer-group}` soft-reconfiguration inbound and `clear ip bgp * /ip-address` commands have helped the situation by allowing for the "soft" reconfiguration of incoming BGP routes. This meant that BGP peers were required to store the inbound BGP routing table in memory, increasing the load that the BGP configuration put on a router.

With the introduction of the route refresh capability, described in RFC 2918, and introduced to Cisco IOS Software in Release 12.2(6)T, dynamic incoming and outgoing soft resets are now both allowed. To find out whether a peer router supports the route refresh capability, use the `show ip bgp neighbors /ip-address | begin capabilities` command, as shown in [Example 9-97](#)

Example 9-97. `show ip bgp neighbors | begin capabilities` Command

```
Service_Provider#show ip bgp neighbors 143.68.5.202 | begin capabilities
```

```
Neighbor capabilities:
```

```
Route refresh: advertised and received(old & new)
```

```
Address family IPv4 Unicast: advertised and received
```

```
Received 341 messages, 2 notifications, 0 in queue
```

```
Sent 312 messages, 0 notifications, 0 in queue
```

```
Default minimum time between advertisement runs is 30 seconds
```

```
For address family: IPv4 Unicast
```

```
BGP table version 251, neighbor version 251
```

```
Index 1, Offset 0, Mask 0x2
```

```
Route refresh request: received 7, sent 1
```

```
1 accepted prefixes consume 40 bytes
```

```
Prefix advertised 462, suppressed 0, withdrawn 2
```

Notice that the preceding example shows that the 143.68.5.202 neighbor supports the route refresh capability and has used it to refresh routes seven times. After you establish that the route refresh capability is supported, you can begin using the new `clear ip bgp * soft [in | out]`, as shown in [Example 9-98](#).

Example 9-98. Debugging IP BGP During a Route Refresh Request

```
Service_Provider#clear ip bgp * soft

*Mar  1 09:18:01.817: BGP: service reset requests

*Mar  1 09:18:01.821: BGP: 143.68.5.202 sending REFRESH_REQ(5) for afi/safi: 1/1

*Mar  1 09:18:01.821: BGP: 143.68.5.202 send message type 5, length (incl.
header) 23
```

If the remote refresh capability is supported by both peers in a BGP session when a route refresh message is sent, the remote peer resends its outgoing BGP updates without clearing the BGP session. If the remote peer does not support the route refresh capability, the peer ignores the request, and you either need to use the soft-reconfiguration command for that neighbor or the standard clear ip bgp { * | ip-address | peer-group} command and reset the BGP session. The remote peer will still receive the route refresh capability but will be unable to use it; however, because the router will be unable to understand the requests, it will ignore any messages containing route refresh requests, and any subsequent route refresh capability advertisements, as shown in [Example 9-99](#).

Example 9-99. Debugging an Ignored Route Refresh

```
Older_Router#debug ip bgp

BGP debugging is on

00:20:58: BGP: 10.1.1.1 unrecognized OPEN parameter (0x2/0x6)

00:20:58: BGP: 10.1.1.1 unrecognized OPEN parameter (0x2/0x2)

Older_Router#show ip bgp neighbors

BGP neighbor is 10.1.1.1,  remote AS 8,  internal link

Index 2, Offset 0, Mask 0x4

Inbound soft reconfiguration allowed

BGP version 4, remote router ID 10.1.1.1

BGP state = Established, table version = 1, up for 00:00:53

Last read 00:00:52, hold time is 180, keepalive interval is 60 seconds
```

```
Minimum time between advertisement runs is 5 seconds

Received 10 messages, 0 notifications, 0 in queue

Sent 8 messages, 0 notifications, 0 in queue

Prefix advertised 0, suppressed 0, withdrawn 0

Connections established 2; dropped 1

Last reset 00:01:00, due to Soft reconfig change

0 accepted prefixes consume 0 bytes

0 denied but saved prefixes consume 0 bytes

0 history paths consume 0 bytes
```

Conserving Memory via BGP Configuration

BGP is a memory- and processor-intensive protocol. At some point in your career, you will most likely run into a situation where you must run BGP on a router that does not have enough resources to support the existing BGP system requirements. A couple of options can help you handle with this situation: Upgrade the memory, upgrade the router, filter incoming routes, or limit the number of prefixes that BGP will accept. Assuming that you cannot immediately upgrade the router itself, the memory, or processor, your best options will be route filtering or limiting incoming BGP prefixes. [Example 9-100](#) shows the show ip bgp summary command output obtained by using an Internet looking glass on a real Internet router. (The IP addresses have been changed.)

Example 9-100. Internet Routing Table Statistics

```
BGP router identifier 6.6.6.6, local AS number 123

BGP table version is 8438778, main routing table version 8438778

114591 network entries and 337412 paths using 23262159 bytes of memory

82050 BGP path attribute entries using 4923540 bytes of memory

15 BGP rrinfo entries using 360 bytes of memory

40359 BGP AS-PATH entries using 1046148 bytes of memory

162 BGP community entries using 7100 bytes of memory

54353 BGP route-map cache entries using 869648 bytes of memory

21745 BGP filter-list cache entries using 260940 bytes of memory
```

```
Dampening enabled. 79 history paths, 20 dampened paths  
BGP activity 227228/2798971 prefixes, 8600655/8263243 paths, scan interval 15 secs
```

Using Partial BGP Routing Tables to Minimize Memory Use

One of the best ways to limit the BGP RIB size using route filters is to accept only partial BGP RIB updates. There are two ways to run BGP with partial tables: Ask your service provider to filter outbound routes to your network and only send you partial tables; or you can filter your own incoming routes. The easiest and safest way to configure partial BGP RIBs is to use an AS path access list with a filter list that will match AS paths beginning and ending with your service provider's AS.

For example, using the network shown earlier in [Figure 9-19](#), the Customer_B router is running out of memory and can no longer handle the full Internet routing table that is being sent by the Service_Provider router. To fix this situation, you can use an AS path access list to limit the number of AS paths received from the upstream router's E-BGP neighbor, as shown in [Example 9-101](#). And the upstream service provider can send you a default route so that your router can still have a route reach to other Internet networks.

Example 9-101. Filtering for Partial BGP RI Bs

```
Customer_B#show run | begin bgp  
  
router bgp 60001  
  
no synchronization  
  
bgp log-neighbor-changes  
  
network 186.241.70.0 mask 255.255.254.0  
  
neighbor 143.68.5.201 remote-as 18901  
  
neighbor 143.68.5.201 filter-list 101 in  
  
no auto-summary  
  
!  
  
ip as-path access-list 101 permit ^18901$
```

In this example, AS path access list 101 is used to filter any routes that do not begin and end with AS number 18,901, which limits the number of incoming routes to 63, as shown in [Example 9-102](#).

Example 9-102. Customer_2 Router's BGP RIB After Incoming Route Filters Are Implemented

```
Customer_B#show ip bgp summary | begin Neighbor

Neighbor          V      AS MsgRcvd MsgSent     TblVer  InQ OutQ Up/Down  State/PfxRcd
143.68.5.201      4 18901      116      123        248      0    0 01:33:35           63
```

There are a few different ways to deal with the memory problem (listed in the order of least memory utilization):

- Accept only the default route from each service provider.
- Accept only the default and service provider–originated routes from each service provider.
- Accept only the default and service provider plus customer routes from each service provider.

The choice of implementation is up to you. Just remember that if you do not accept a full routing table, to reach any Internet network, you must accept a default route.

Configuring Incoming BGP Prefix Limitations

Another way to limit incoming BGP routes is to use the maximum-prefix command. When using the maximum-prefix command, you have two options after the number of prefixes has been reached: automatically disabling the BGP session, or sending a warning message. If you absolutely must not allow the router to exceed a certain number of routes, you can use the neighbor {ip-address | peer-group} maximum-prefix limitation-number command, with a limitation number ranging from 1 to 4,294,967,295. [Example 9-103](#) shows what happens when the maximum-prefix command is used on the Customer_B router.

Example 9-103. Using the maximum-prefix Command to Close BGP Sessions

```
Customer_B#show run | begin bgp

router bgp 60001
  no synchronization
  bgp log-neighbor-changes
  network 186.241.70.0 mask 255.255.254.0
```

```

neighbor 143.68.5.201 remote-as 18901

neighbor 143.68.5.201 maximum-prefix 50

neighbor 143.68.5.201 filter-list 101 in

no auto-summary

!

ip as-path access-list 101 permit ^18901$


Customer_B#show ip bgp summary | begin Neighbor

Neighbor      V      AS MsgRcvd MsgSent     TblVer  InQ OutQ Up/Down  State/PfxRcd
143.68.5.201  4    18901      138      147          0      0      0 00:02:20  Idle (PfxCt)

Customer_2#show logging | include %BGP

*Mar  1 02:48:01.731: %BGP-5-ADJCHANGE: neighbor 143.68.5.197 Down Neighbor
deleted

*Mar  1 02:48:53.927: %BGP-3-MAXPFXEXCEED: No. of prefix received from
143.68.5.201 (afi 0): 63 exceed limit 50

*Mar  1 03:08:05.507: %BGP-3-MAXPFXEXCEED: No. of prefix received from
143.68.5.201 (afi 0): 63 exceed limit 50

*Mar  1 03:33:04.307: %BGP-3-MAXPFXEXCEED: No. of prefix received from
143.68.5.201 (afi 0): 63 exceed limit 50

*Mar  1 03:33:04.307: %BGP-5-ADJCHANGE: neighbor 143.68.5.201 Down BGP
Notification sent

*Mar  1 03:33:04.307: %BGP-3-NOTIFICATION: sent to neighbor 143.68.5.201 3/1
(update malformed) 0 bytes

```

In the preceding example, if peer 143.68.5.201 sends more than 50 prefixes, the BGP session will be torn down, and a %BGP-3-MAXPFXEXCEED message will be logged. In this case, the BGP session will not be reinitialized until the session has manually been reset, and the maximum number of incoming routes has not been exceeded. After the situation has been corrected and the BGP connection has been restarted, the connection will come back up. Another less intrusive way to handle this situation is to use the maximum-prefix command with the optional warning-only parameter; this command issues only a warning when the maximum number of prefixes has been exceeded. When this command is used in conjunction with syslog reporting, you can monitor the number of BGP prefixes and take action when syslog messages are received. [Example 9-104](#)

shows how the maximum-prefix warning-only command sends a warning trap to the syslog server at 186.241.70.89, when 80 percent of the 50 maximum prefix limitation has been reached.

Example 9-104. Using a maximum-prefix Warning to Send Warning Traps

```
router bgp 60001
no synchronization
bgp log-neighbor-changes
network 186.241.70.0 mask 255.255.254.0
neighbor 143.68.5.201 remote-as 18901
neighbor 143.68.5.201 maximum-prefix 50 80 warning-only
neighbor 143.68.5.201 filter-list 101 in
maximum-paths 2
no auto-summary
!
ip as-path access-list 101 permit ^18901$
!
logging 186.241.70.89
Customer_2#show logging | include %BGP
*Mar  1 04:04:40.462: %BGP-4-MAXPFX: No. of prefix received from 143.68.5.201
(afi 0) reaches 41, max 50
*Mar  1 04:04:40.470: %BGP-3-MAXPFXEXCEED: No. of prefix received from
143.68.5.201 (afi 0): 51 exceed limit 50
```

Practice Scenarios

Lab 15: Multihoming a BGP Network

The previous few chapters covered BGP theory and basic and advanced BGP configuration, and briefly suggested ways that BGP can optimize Internet routing in a production environment. The following lab focuses on a multihomed BGP configuration, using a real-life BGP scenario to test advanced BGP configuration topics. HTTP web traffic tests the final network reachability.

Lab Exercise

In this lab scenario, you configure a simulated Internet web browsing experience using the 24-hour network backbone and two upstream service provider networks. The 24-hour network has two Internet border routers that peer with three upstream routers belonging to two upstream Internet service providers. This lab requires you to model an Internet connection, use common load-sharing techniques to utilize the most of the network resources, implement common security practices to mitigate simple security threats, and test the network connectivity using HTTP web browsing from an internal PC on the 24-hour network.

Lab Objectives

This lab demonstrates many of the topics covered in the preceding three chapters and shows how to use them in a redundant network design:

- BGP multihoming
- Load sharing between two autonomous systems
- Route aggregation
- BGP MD-5 authentication
- Using route reflectors for I-BGP
- I-BGP network exit preference
- Redistributing static routes
- Using peer groups to simplify configuration
- Filtering routes using AS path and community values
- Using DHCP and NAT with BGP to hide internal RFC 1918 network addresses

Equipment Needed

- One Cisco router with five serial interfaces to act as a Frame Relay switch.
- Six Cisco routers with at least one serial and one Ethernet interface.

- One Cisco router with two serial interfaces. (One of these routers requires one Ethernet interface.)
- One switch connecting the five multiaccess routers in separate VLANs.
- One PC with an Ethernet NIC capable of running TCP/IP with DHCP and a web browser.
- Portions of this lab are best suited for Cisco IOS Software versions up to or greater than 12.2(11)T.

Physical Layout and Prestaging

For this experiment, you use the network layout shown in [Figure 9-20](#). The routers in AS 104 and AS 60 simulate Internet service provider networks Internet Service Provider-1 and Internet Service Provider-2. The Drazen and Palmer routers are the 24-hour network border routers, and all other routers are internal 24-hour network routers.

- Cable the routers as shown in [Figure 9-20](#). The Myers, Gaines, Farrell, Drazen, and Palmer routers should be connected to the Frame Relay switch using the interface numbers shown in [Table 9-13](#) and can be connected using back-to-back serial cables.
- Configure the Frame Relay switch using the interfaces and DLCI numbers shown in [Table 9-13](#).

Figure 9-20. The 24-Hour Network

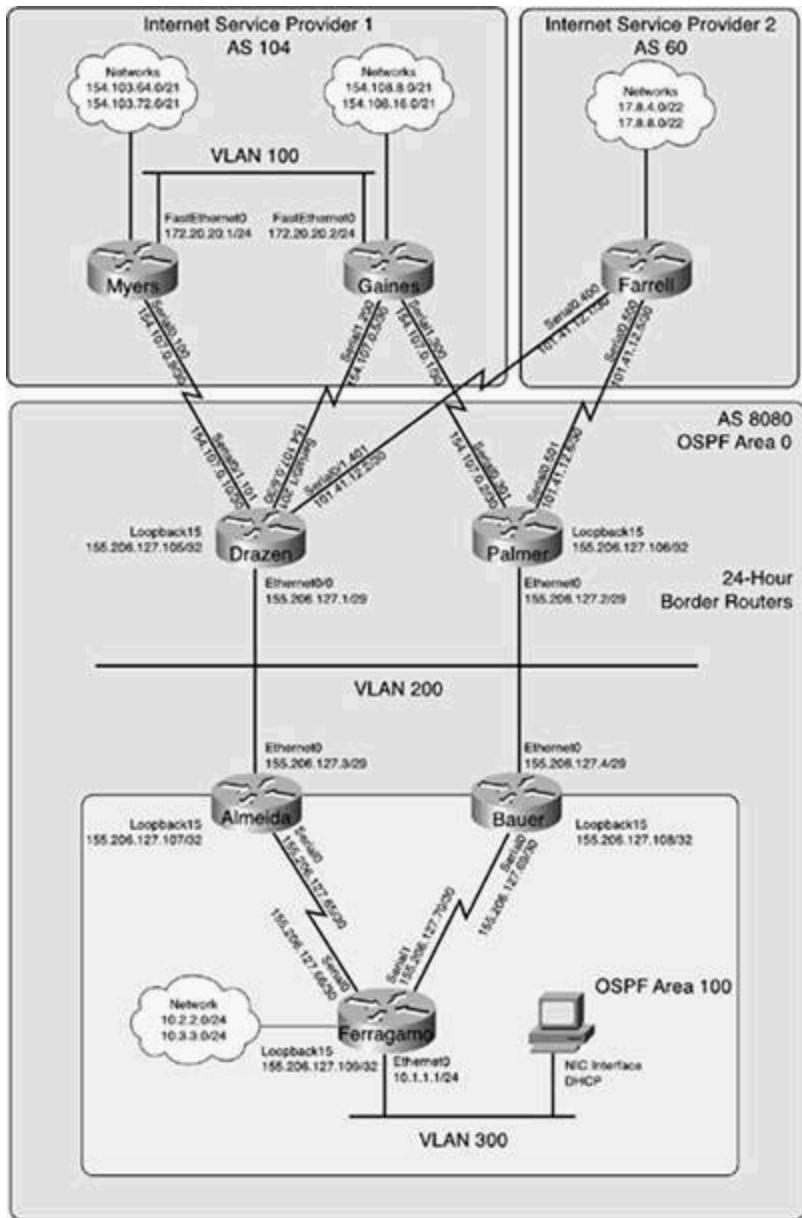


Table 9-13. Frame Relay Switch Parameters

Frame Switch Interface	Router Interface	Frame Switch Interface	Router DLCI	Router Interface	Router DLCI
Serial1	Myers	Serial0	100	Drazen	101
	Serial0.100			Serial0/1.101	
Serial2	Gaines	Serial0	200	Drazen0/1.201	201
	Serial1.200				
Serial2	Gaines	Serial3	300	Palmer	301
	Serial1.300			Serial0.301	
Serial4	Farrell	Serial0	400	Drazen	401
	Serial0.400			Serial0/1.401	
Serial4	Farrell	Serial3	500	Palmer	501
	Serial0.500			Serial0.501	

[Example 9-105](#) shows the show frame relay route command output from the Frame Relay switch.

Example 9-105. Frame Relay Switch Configuration

```
Frame-Relay-Switch # show frame-relay route
```

Input Intf	Input Dlci	Output Intf	Output Dlci	Status
Serial0	101	Serial1	100	active
Serial0	201	Serial2	200	active
Serial0	401	Serial4	400	active
Serial1	100	Serial0	101	active
Serial2	200	Serial0	201	active
Serial2	300	Serial3	301	active
Serial3	301	Serial2	300	active
Serial3	501	Serial4	500	active
Serial4	400	Serial0	401	active
Serial4	500	Serial3	501	active

- Connect the Ethernet interfaces on the Myers, Gaines, Drazen, Palmer, Almeida, and Bauer routers to the Ethernet switch, as previously shown in [Figure 9-20](#).
- Attach the Almeida and Bauer routers to the Ferragamo router, as shown in [Figure 9-20](#).
- Verify that each router interface on each router is in an up/up state.
- Do not configure DHCP on the Ferragamo router or PC yet.

Lab Exercises

Step 1. Configure all IP addresses, as shown in [Table 9-14](#), and assign all Ethernet interfaces to the VLANs shown in the same table.

Table 9-14. IP Addressing for This Network Model

Router Name	Router Interface	IP Address	Ethernet VLAN
Myers	FastEthernet0	172.20.20.1/24	100
	Loopback100	154.103.64.1/21	
	Loopback200	154.103.72.1/21	
	Serial0.100	154.107.0.9/30	
Gaines	FastEthernet0	172.20.20.2/24	100
	Loopback100	154.108.8.1/21	
	Loopback200	154.108.16.0/21	
	Serial1.200	154.107.0.5/30	
	Serial1.300	154.107.0.1/30	
Farrell	Loopback100	17.8.4.1/22	50
	Loopback200	17.8.8.0/22	
	Serial0.400	101.41.12.1/30	
	Serial0.500	101.41.12.5/30	
Drazen	Ethernet0/0	155.206.127.1/29	200
	Loopback15	155.206.127.105/32	
	Serial0/1.101	154.107.0.10/30	
	Serial0/1.201	154.107.0.6/30	
	Serial0/1.401	101.41.12.2/30	

Palmer	Ethernet0	155.206.127.2/29	200
	Loopback15	155.206.127.106/32	
	Serial0.301	154.107.0.2/30	
	Serial0.501	101.41.12.6/30	
Almeida	Ethernet0	155.206.127.3/29	200
	Loopback15	155.206.127.107/32	
	Serial0	155.206.127.65/30	
Bauer	Ethernet0	155.206.127.4/29	200
	Loopback15	155.206.127.108/32	
	Serial0	155.206.127.69/30	
Ferragamo	Ethernet0	10.1.1.1/24	300
	Loopback15	155.206.127.109/32	
	Loopback100	10.2.2.1/24	
	Loopback200	10.3.3.1/24	
	Serial0	155.206.127.66/30	
	Serial1	155.206.127.70/30	
PC	Ethernet NIC	DHCP	300

Step 2. Configure OSPF routing for the Drazen, Palmer, Almeida, Bauer, and Ferragamo routers. Put only the Ethernet interfaces of the Drazen, Palmer, Almeida, and Bauer routers in OSPF area 0:

- Assign the loopback interfaces on the Drazen and Palmer routers to area 0 as well. The Ferragamo router and the serial interfaces on the Almeida and Bauer routers should be in area 1.
- Use the Loopback15 interface IP address as the OSPF router ID for each OSPF router.
- Have the Almeida and Bauer routers send the default route to all downstream neighbors.

Step 3. Configure load balancing on the Ferragamo router so that the OSPF will use both of the upstream serial interfaces to forward packets to the 155.206.127.0/29 network. Use the appropriate commands to enable load balancing so that packets belonging to the same flow take the same route.

Step 4. Configure the Ferragamo router to be a DHCP server for the 10.1.1.0/24 network. The router should also assign the fiction.org domain name to its DHCP clients. After configuring the DHCP service on the router, configure the PC to request a DHCP lease from that router and verify the configuration by pinging the loopback interface on the Drazen router.

Step 5. After building the internal network, adding a host, and enabling routing, you can

now focus on the BGP portion of the lab. Begin by configuring the external service providers in AS 104, the Myers and Gaines routers. Enable BGP routing on the Myers and Gaines routers. After you complete this task, each router should be able to see the /21 networks that are internally advertised between these routers.

Step 6. Next, configure E-BGP routing between the Service Provider-1 routers in AS 104 and the 24-hour border routers in AS 8080. Use peer groups to simplify the BGP configurations:

- Have the AS 8080 border routers use their Loopback15 IP addresses as their BGP router IDs, and multihome each router using the loopback address as the peering point. In this instance, one static route per neighbor per router is permitted on the AS 104 routers.
- Do not allow the Service Provider-1 routers to advertise the 172.20.20.0/24 network to any external peers. You cannot use a distribute list to perform this task.
- Do not allow the service provider routers to use the AS 8080 border routers as a transit network to reach each other's /21 networks.
- After this step is complete, the routers in AS 8080 should see all /21 networks behind the AS 104 routers.

Step 7. To complete the E-BGP Internet peering sessions, you need to configure a BGP session between the Farrell router in AS 60 and the 24-hour border routers. These BGP sessions should be configured using all the rules specified in Step 6:

- Use peer groups to allow for future peer additions.
- Have the AS 8080 border routers use their Loopback15 IP addresses as their BGP router IDs; one static route per neighbor is permitted on the Farrell router.
- Do not allow the service provider routers to use the AS 8080 border routers as a transit network to reach each other's networks.
- After this step is complete, the routers in AS 8080 should see all external networks advertised by the service provider routers.

Step 8. The BGP peer configuration would not be complete if there weren't an I-BGP connection between the 24-hour border routers and their peering partners, the Almeida and Bauer routers:

- Configure I-BGP peer relationships between these routers, using the Loopback15 interfaces as the peering points.
- Use peer groups to simplify the configuration on the border routers and do not fully mesh the routers in this network.
- Summarize all 155.206.127.0 networks at the AS 8080 border routers; do not advertise any routes smaller than /24.
- Verify that configuration by pinging the Internet networks from the Ferragamo router.

Step 9. To make the most efficient use of the connections between the border routers and the service provider's networks, configure the Service Provider-1 routers to prefer routes from the Drazen router, and configure the Service Provider-2 router to prefer routes from the Palmer router; neither the MED nor AS_PATH attributes can be used to accomplish this

task. Locally generated routes should always have the highest preference:

- The Drazen router should prefer routes from the Myers router, with a secondary preference for the Farrell router; and the Palmer router should prefer routes from the Farrell, with the Gaines router as a secondary preference before the Myers router. Locally generated routes should always have the highest preference.

Step 10. As a security precaution, disable any CDP, HTTP web access, and any unnecessary features on the 24-hour border routers:

- Also create an antispoof access list that will prevent any RFC 1918 private IP addresses and internal addresses.
- Make sure that OSPF routes are not allowed out of the 24-hour network.
- Leave HTTP web service enabled on the Internet-facing routers; they will be used to simulate Internet web servers.
- Configure the HTTP services to use the IP address of the Loopback100 interface.

Step 11. To hide the RFC 1918 private networks from the Internet, configure the 24-hour border routers to NAT all internal networks to the public Internet-routable IP addresses shown in [Table 9-15](#):

- Make sure all IP address blocks are aggregated to the fullest extent. All specific routes should be suppressed; only the aggregate should be advertised to external neighbors.
- To verify customer Internet connectivity, use a web browser to enter the HTTP web configuration site on each of the service provider networks.

Table 9-15. Internal to External NAT Addresses

Internal Network	External Network
10.1.1.0/24	155.206.124.0/24
10.2.2.0/24	155.206.125.0/24
10.3.3.0/24	155.206.126.0/24

Lab Walkthrough

Step 1. Configure all IP addresses as shown in [Table 9-14](#) and assign all Ethernet interfaces to the VLANs shown in the same table.

Step 2. Configure OSPF routing for the Drazen, Palmer, Almeida, Bauer, and Ferragamo routers. Put only the Ethernet interfaces of the Drazen, Palmer, Almeida, and Bauer routers in OSPF area 0.

- Assign the loopback interfaces on the Drazen and Palmer routers to area 0 as well. The Ferragamo router and the serial interfaces on the Almeida and Bauer routers should be in area 1:
- Use the Loopback15 interface IP address as the OSPF router ID for each OSPF router.
- Have the Almeida and Bauer routers send the default route to all downstream neighbors.

This task builds the IGP routing solution for the internal 24-hour network. After OSPF has been configured, all the internal routers should be able to reach all interfaces on all other internal routers, except for the Internet-facing serial interfaces. This review begins with the Almeida and Bauer routers. One of the first, hidden tasks in this step required the configuration of a default route to the HSRP IP address for the Internet border routers. After the default route has been configured, OSPF can be enabled and interfaces should be assigned to the areas previously mentioned. The `default-information originate` command sends the default route to the other OSPF neighbors. [Example 9-106](#) shows the OSPF configuration for the Almeida router.

Example 9-106. Almeida Router's OSPF Configuration

```
Almeida#show run | begin ospf
router ospf 1
  router-id 155.206.127.107
  log-adjacency-changes
  area 1 stub
  network 155.206.127.0 0.0.0.7 area 0
  network 155.206.127.64 0.0.0.3 area 1
  network 155.206.127.107 0.0.0.0 area 0
  default-information originate always metric-type 1
!
ip route 0.0.0.0 0.0.0.0 155.206.127.5
```

After OSPF has been configured, all the internal routers should reach all OSPF-enabled interfaces. The default route should also have been advertised; this introduces a small problem, though. Unless you configure a distribution list to filter incoming routes on the Drazen or Palmer routers, they will receive the default route sent out in the LSAs originating from the Almeida and Bauer routers. After you configure and apply a distribution list denying the default route, 0.0.0.0/32, this problem should be corrected. You can test the OSPF configuration using the `show ip route` and `ping` commands on the Ferragamo, Drazen, and Palmer routers. [Example 9-](#)

[107](#) shows the routing table from the Drazen and Ferragamo routers.

Example 9-107. Drazen and Ferragamo Routing Tables

```
Drazen#show ip route | begin Gateway

Gateway of last resort is not set

    155.206.0.0/16 is variably subnetted, 7 subnets, 3 masks

C        155.206.127.0/29 is directly connected, Ethernet0/0

O        155.206.127.106/32 [110/11] via 155.206.127.2, 00:31:55, Ethernet0/0

O        155.206.127.107/32 [110/11] via 155.206.127.3, 00:31:55, Ethernet0/0

C        155.206.127.105/32 is directly connected, Loopback15

O        155.206.127.108/32 [110/11] via 155.206.127.4, 00:31:55, Ethernet0/0

O IA     155.206.127.64/30 [110/74] via 155.206.127.3, 00:31:55, Ethernet0/0

O IA     155.206.127.68/30 [110/74] via 155.206.127.4, 00:31:55, Ethernet0/0

    101.0.0.0/30 is subnetted, 1 subnets

C        101.41.12.0 is directly connected, Serial0/1.401

    154.107.0.0/30 is subnetted, 2 subnets

C        154.107.0.4 is directly connected, Serial0/1.201

C        154.107.0.8 is directly connected, Serial0/1.101

    10.0.0.0/8 is variably subnetted, 3 subnets, 2 masks

O IA     10.1.1.0/24 [110/84] via 155.206.127.3, 00:31:56, Ethernet0/0

                    [110/84] via 155.206.127.4, 00:31:56, Ethernet0/0

O IA     10.3.3.1/32 [110/75] via 155.206.127.3, 00:31:56, Ethernet0/0

                    [110/75] via 155.206.127.4, 00:31:56, Ethernet0/0

O IA     10.2.2.1/32 [110/75] via 155.206.127.3, 00:31:56, Ethernet0/0

                    [110/75] via 155.206.127.4, 00:31:56, Ethernet0/0
```

```
Ferragamo#show ip route | begin Gateway
```

```
Gateway of last resort is 155.206.127.65 to network 0.0.0.0
```

```

155.206.0.0/16 is variably subnetted, 7 subnets, 3 masks

O IA      155.206.127.0/29 [110/74] via 155.206.127.69, 00:35:02, Serial1
                                         [110/74] via 155.206.127.65, 00:35:02, Serial0

O IA      155.206.127.106/32 [110/75] via 155.206.127.69, 00:32:22, Serial1
                                         [110/75] via 155.206.127.65, 00:32:22, Serial0

O IA      155.206.127.107/32 [110/65] via 155.206.127.65, 00:35:02, Serial0

O IA      155.206.127.105/32 [110/75] via 155.206.127.65, 00:33:44, Serial0
                                         [110/75] via 155.206.127.69, 00:33:44, Serial1

O IA      155.206.127.108/32 [110/65] via 155.206.127.69, 00:35:02, Serial1

C        155.206.127.64/30 is directly connected, Serial0

C        155.206.127.68/30 is directly connected, Serial1

10.0.0.0/24 is subnetted, 3 subnets

C        10.3.3.0 is directly connected, Loopback200

C        10.2.2.0 is directly connected, Loopback100

C        10.1.1.0 is directly connected, Ethernet0

O*E1 0.0.0.0/0 [110/84] via 155.206.127.65, 00:35:03, Serial0
                                         [110/84] via 155.206.127.69, 00:35:03, Serial1

```

Step 3. Configure load balancing on the Ferragamo router so that the OSPF uses both of the upstream serial interfaces to forward packets to the 155.206.127.0/29 network. Use the appropriate commands to enable load balancing so that packets belonging to the same flow take the same route.

This step actually does not require much configuration. By default, OSPF stores up to four equal-cost paths in the routing table. To enable per-destination load balancing over the two serial interfaces, you must enable CEF switching using the `ip cef` command. Once again, by default, the `ip cef` command enables CEF switching using the universal per-destination algorithm for load balancing. You can use the IP routing table and CEF table to verify the configuration. [Example 9-108](#) shows the Ferragamo router's IP routing table and show `ip cef summary` command output.

Example 9-108. Ferragamo Router's Routing Table and CEF Summary

```

Ferragamo#show ip route | include via|is

Gateway of last resort is 155.206.127.69 to network 0.0.0.0

    155.206.0.0/16 is variably subnetted, 7 subnets, 3 masks

O IA      155.206.127.0/29 [110/74] via 155.206.127.65, 00:18:00, Serial0
                                [110/74] via 155.206.127.69, 00:18:00, Serial1

O IA      155.206.127.106/32 [110/75] via 155.206.127.65, 00:18:00, Serial0
                                [110/75] via 155.206.127.69, 00:18:00, Serial1

O IA      155.206.127.107/32 [110/65] via 155.206.127.65, 00:18:00, Serial0

O IA      155.206.127.105/32 [110/75] via 155.206.127.65, 00:18:00, Serial0
                                [110/75] via 155.206.127.69, 00:18:00, Serial1

O IA      155.206.127.108/32 [110/65] via 155.206.127.69, 00:18:00, Serial1

C        155.206.127.64/30 is directly connected, Serial0

C        155.206.127.68/30 is directly connected, Serial1

    10.0.0.0/24 is subnetted, 3 subnets

C        10.3.3.0 is directly connected, Loopback200

C        10.2.2.0 is directly connected, Loopback100

C        10.1.1.0 is directly connected, Ethernet0

O*E1 0.0.0.0/0 [110/84] via 155.206.127.69, 00:18:01, Serial1
                                [110/84] via 155.206.127.65, 00:18:01, Serial0

Ferragamo#show ip cef summary

IP CEF with switching (Table Version 28), flags=0x0

28 routes, 0 reresolve, 0 unresolved (0 old, 0 new)

31 leaves, 18 nodes, 22734 bytes, 31 inserts, 0 invalidations

4 load sharing elements, 1264 bytes, 4 references

universal per-destination load sharing algorithm, id CD1F18C5

2 CEF resets, 0 revisions of existing leaves

refcounts: 4907 leaf, 4864 node

Adjacency Table has 3 adjacencies

```

Step 4. Configure the Ferragamo router to be a DHCP server for the 10.1.1.0/24 network. The router should also assign the fiction.org domain name to its DHCP clients. After configuring the DHCP service on the router, configure the PC to request a DHCP lease from that router, and verify the configuration by pinging the loopback interface on the Drazen router.

DHCP configuration is a straightforward task, after creating a DHCP pool and assigning DHCP parameters to the pool, the only remaining task is the exclusion of the Ferragamo router's Ethernet IP address. After the DHCP server configuration is finished, and the PC has been configured to request a DHCP IP address, it should immediately be able to ping the Drazen router's IP address. [Example 9-109](#) shows the ipconfig command output and a successful ping from a Windows PC.

Example 9-109. ipconfig and ping Commands as Issued from the PC

```
G:\>ipconfig

Windows 2000 IP Configuration

Ethernet adapter Local Area Connection:

  Connection-specific DNS Suffix . : fiction.org

  IP Address. . . . . : 10.1.1.2

  Subnet Mask . . . . . : 255.255.255.0

  Default Gateway . . . . . : 10.1.1.1

G:\>ping 155.206.127.105

Pinging 155.206.127.105 with 32 bytes of data:

Reply from 155.206.127.105: bytes=32 time=20ms TTL=253
Reply from 155.206.127.105: bytes=32 time<10ms TTL=253
Reply from 155.206.127.105: bytes=32 time<10ms TTL=253
Reply from 155.206.127.105: bytes=32 time<10ms TTL=253

Ping statistics for 155.206.127.105:

  Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

  Minimum = 0ms, Maximum = 20ms, Average = 5ms
```

Step 5. After building the internal network, adding a host, and enabling routing, you can now focus on the BGP portion of the lab. Begin by configuring the external service providers in AS 104, the Myers and Gaines routers. Enable BGP routing on the Myers and Gaines routers. After you complete this task, each router should see the /21 networks that are internally advertised between these routers.

The I-BGP configuration between the Myers and Gaines routers is only dependent on one key factor: disabling IGP synchronization. After BGP is enabled, the networks and neighbors are configured, and synchronization is disabled, each router should reach its peers' /21 networks. [Example 9-110](#) shows the IP routing table for the Myers router.

Example 9-110. Myers Router's IP Routing Table

```
Myers#show ip route | include is|via

Gateway of last resort is not set

 154.103.0.0/21 is subnetted, 2 subnets
C       154.103.72.0 is directly connected, Loopback200
C       154.103.64.0 is directly connected, Loopback100

 154.108.0.0/21 is subnetted, 2 subnets
B       154.108.16.0 [200/0] via 172.20.20.2, 00:07:57
B       154.108.8.0 [200/0] via 172.20.20.2, 00:07:57

 154.107.0.0/30 is subnetted, 1 subnets
C       154.107.0.8 is directly connected, Serial0.100

 172.20.0.0/24 is subnetted, 1 subnets
C       172.20.20.0 is directly connected, FastEthernet0
```

Step 6. Next, configure E-BGP routing between the Service Provider-1 routers in AS 104 and the 24-hour border routers in AS 8080. Use peer groups to simplify the BGP configurations:

- Have the AS 8080 border routers use their Loopback15 IP addresses as their BGP router IDs, and multihome each router using the loopback address as the peering point. In this instance, one static route per neighbor per router is permitted on the AS 104 routers.
- Do not allow the Service Provider-1 routers to advertise the 172.20.20.0/24 network to any external peers. You might not use a distribute list to perform this task.

- Do not allow the service provider routers to use the AS 8080 border routers as a transit network to reach each other's /21 networks.
- After this step is complete, the routers in AS 8080 should see all /21 networks behind the AS 104 routers.

This step contains several subtasks that must be completed accurately for the remainder of the lab to work properly. To facilitate BGP routing between the Internet Service Provider-1 and 24-hour border routers, you must use the `ebgp-multihop` command on the Internet Service Provider-1 routers and `update-source Loopback 15` command on the 24-hour routers. If you do not use these commands, the BGP session between the routers will never start, and you see the following message on the Internet Service Provider-1 routers:

```
Connections established 0; dropped 0

Last reset never

External BGP neighbor not directly connected.

No active TCP connection
```

If you added a static route to each of the loopback IP addresses on the Internet Service Provider-1 routers, when the multihop and update-source commands are added to the appropriate routers, a BGP session should start. [Example 9-111](#) shows the BGP configuration for the Gaines and Drazen routers.

Example 9-111. Multihoming the Gaines and Drazen Routers

```
Gaines#show run | begin bgp

router bgp 104

no synchronization

bgp log-neighbor-changes

network 154.108.8.0 mask 255.255.248.0

network 154.108.16.0 mask 255.255.248.0

network 172.20.20.0 mask 255.255.255.0

neighbor AS8080 peer-group
```

```

neighbor AS8080 remote-as 8080

neighbor AS8080 ebgp-multipath 2

neighbor 155.206.127.105 peer-group AS8080

neighbor 155.206.127.106 peer-group AS8080

neighbor 172.20.20.1 remote-as 104

no auto-summary

!

ip route 155.206.127.105 255.255.255.255 154.107.0.6

ip route 155.206.127.106 255.255.255.255 154.107.0.2

Drazen#show run | begin bgp

router bgp 8080

no synchronization

bgp log-neighbor-changes

network 154.107.0.8 mask 255.255.255.252

network 154.206.127.0 mask 255.255.255.248

neighbor AS104 peer-group

neighbor AS104 remote-as 104

neighbor AS104 update-source Loopback15

neighbor 154.107.0.5 peer-group AS104

neighbor 154.107.0.9 peer-group AS104

no auto-summary

```

After the BGP session is established, and routes are exchanged, you need to find a way to prevent the service provider routers from advertising the 172.20.20.0/24 private network to external AS peers. Because you cannot use a route filter to accomplish this task, there is only one other way to hide that network: assigning the local AS COMMUNITY attribute to the service provider routers. This attribute allows the route to be advertised internally but prevents it from being sent to any external BGP neighbors. [Example 9-112](#) shows the BGP configuration for the Myers router.

Example 9-112. Using the Well-Known LOCAL_AS Community on the Myers Router

```

Myers#show run | begin bgp

router bgp 104

no synchronization

bgp log-neighbor-changes

network 154.103.64.0 mask 255.255.248.0

network 154.103.72.0 mask 255.255.248.0

network 172.20.20.0 mask 255.255.255.0 route-map hide-network

neighbor AS8080 peer-group

neighbor AS8080 remote-as 8080

neighbor AS8080 ebgp-multihop 2

neighbor 155.206.127.105 peer-group AS8080

neighbor 172.20.20.2 remote-as 104

no auto-summary

!

ip route 155.206.127.105 255.255.255.255 154.107.0.10

!

route-map hide-network permit 10

set community local-as

```

As you can see, the Myers router uses the hide-network route map to set the local AS community for the 172.20.20.0/24 network, and because the local AS COMMUNITY attribute does not need to be advertised beyond the local AS, you do not need to use the send-community command.

The last part of Step 3 specified that you must not allow the service provider network to use AS 8080 as a transit network to reach internally generated routes. This task requires the addition of an AS path filter list on the 24-hour routers. A simple one-line AS path access list, which allows only the advertisement of internally generated routes using the ^\$ regular expression to specify an empty AS path applied to all outgoing routes, achieves that effect. This is demonstrated by [Example 9-113](#), which shows the BGP configuration for the Palmer router.

Example 9-113. Applying a Filter List on the Palmer Router

```

Palmer#show run | begin bgp

router bgp 8080

no synchronization

bgp log-neighbor-changes

network 155.206.127.0 mask 255.255.255.248

neighbor AS104 peer-group

neighbor AS104 remote-as 104

neighbor AS104 update-source Loopback15

neighbor AS104 filter-list 100 out

neighbor 154.107.0.1 peer-group AS104

no auto-summary

!

ip as-path access-list 100 permit ^$
```

Step 7. To complete the E-BGP Internet peering sessions, you need to configure a BGP session between the Farrell router in AS 60 and the 24-hour border routers. These BGP sessions should be configured using all the rules specified in Step 6:

- Use peer groups to allow for future peer additions.
- Have the AS 8080 border routers use their Loopback15 IP addresses as their BGP router IDs; one static route per neighbor is permitted on the Farrell router.
- Do not allow the service provider routers to use the AS 8080 border routers as a transit network to reach each other's networks.
- After this step is complete, the routers in AS 8080 should see all external networks advertised by the service provider routers.

If you configured these routers using the same steps that you used in the previous step, you should have two newly established BGP sessions between the Drazen, Palmer, and Farrell routers. The Myers and Gaines routers should reach the 155.206.127.0/29 network, and the networks for each of the serial interfaces on the AS 8080 border routers, but they should not have any routes to the 17.8.4.0/22 or 17.8.8.0/22 networks. [Example 9-114](#) shows the BGP RIB for the Myers router.

Example 9-114. Myers Router's BGP RI B After the Application of a Filter List

```
Myers#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* i101.41.12.0/30	155.206.127.105	0	100	0	8080 i
*>	155.206.127.105	0		0	8080 i
*> 154.103.64.0/21	0.0.0.0	0		32768	i
*> 154.103.72.0/21	0.0.0.0	0		32768	i
* i154.107.0.4/30	155.206.127.105	0	100	0	8080 i
*>	155.206.127.105	0		0	8080 i
* i154.107.0.8/30	155.206.127.105	0	100	0	8080 i
*>	155.206.127.105	0		0	8080 i
*>i154.108.8.0/21	172.20.20.2	0	100	0	i
*>i154.108.16.0/21	172.20.20.2	0	100	0	i
* i155.206.127.0/29	155.206.127.106	0	100	0	8080 i
* i172.20.20.0/24	172.20.20.2	0	100	0	i
*>	0.0.0.0	0		32768	I

The Drazen and Palmer routers should have routes to each of their external BGP neighbors' networks, with the exception of the 172.20.20.0/24 network in AS 104. [Example 9-115](#) shows the BGP RIB for the Drazen router.

Example 9-115. Drazen Router's BGP RIB After the Filter List Application

```
Drazen#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 17.8.4.0/22	101.41.12.1	0		0	60 i
*> 17.8.8.0/22	101.41.12.1	0		0	60 i
*> 101.41.12.0/30	0.0.0.0	0		32768	i
* 154.103.64.0/21	154.107.0.5			0	104 i

```

*>          154.107.0.9      0          0 104 i
*  154.103.72.0/21  154.107.0.5      0          0 104 i
*>          154.107.0.9      0          0 104 i
*> 154.107.0.4/30  0.0.0.0      0          32768 i
*> 154.107.0.8/30  0.0.0.0      0          32768 i
*  154.108.8.0/21   154.107.0.5      0          0 104 i
*>          154.107.0.9      0          0 104 i
*  154.108.16.0/21  154.107.0.5      0          0 104 i
*>          154.107.0.9      0          0 104 i

```

And finally, the Farrell router's BGP RIB should contain entries for all the networks advertised by the Drazen and Palmer routers, except the routes to networks in AS 104, as shown in [Example 9-116](#).

Example 9-116. Farrell Router's BGP RIB After the Filter List

```
Farrell#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*> 17.8.4.0/22	0.0.0.0	0		32768	i
*> 17.8.8.0/22	0.0.0.0	0		32768	i
*> 101.41.12.0/30	155.206.127.105	0		0	8080 i
*> 154.107.0.4/30	155.206.127.105	0		0	8080 i
*> 154.107.0.8/30	155.206.127.105	0		0	8080 i
*> 155.206.127.0/29	155.206.127.106	0		0	8080 I

Step 8. The BGP peer configuration would not be complete if there weren't an I-BGP connection between the 24-hour border routers and their peering partners, the Almeida and Bauer routers:

- Configure I-BGP peer relationships between these routers, using the Loopback15 interfaces as the peering points.

- Use peer groups to simplify the configuration on the border routers and do not fully mesh the routers in this network.
- Summarize all 155.206.127.0 networks at the AS 8080 border routers. Do not advertise any routes smaller than /24.
- Verify that configuration by pinging the Internet networks from the Ferragamo router.

This step requires several steps to accomplish successful network ping test verification. First, you must configure a peer group on the Drazen and Palmer routers. This peer group should contain all the characteristics that apply to the neighbors that will be added to the peer group (namely, the Almeida and Bauer routers). Each of the border routers need to serve as route reflectors for the downstream 24-hour routers and require the use of the update-source and next-hop-self to allow for full BGP routing capabilities. [Example 9-117](#) shows the I-BGP configuration for the Drazen router.

Example 9-117. I-BGP Configuration for the Drazen Router

```
Drazen#show run | include AS8080

neighbor AS8080 peer-group

neighbor AS8080 remote-as 8080

neighbor AS8080 update-source Loopback15

neighbor AS8080 route-reflector-client

neighbor AS8080 next-hop-self

neighbor 155.206.127.106 peer-group AS8080

neighbor 155.206.127.107 peer-group AS8080

neighbor 155.206.127.108 peer-group AS8080
```

After the border routers have been configured, you can then move on and configure I-BGP for the Almeida and Bauer routers. The Bauer and Almeida routers configuration is straightforward and should require only two commands per peer: the remote-as and update-source commands. [Example 9-118](#) shows the BGP configuration and BGP RIB for the Bauer router.

Example 9-118. I-BGP Configuration and BGP RI B from the Bauer Router

```
Bauer#show run | begin bgp

router bgp 8080
```

```

no synchronization

bgp log-neighbor-changes

network 155.206.127.68 mask 255.255.255.0

neighbor 155.206.127.105 remote-as 8080

neighbor 155.206.127.105 update-source Loopback15

neighbor 155.206.127.106 remote-as 8080

neighbor 155.206.127.106 update-source Loopback15

no auto-summary

```

Bauer#**show ip bgp | begin Network**

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i17.8.4.0/22	155.206.127.105	0	100	0	60 i
* i	155.206.127.106	0	100	0	60 i
*>i17.8.8.0/22	155.206.127.105	0	100	0	60 i
* i	155.206.127.106	0	100	0	60 i
* i101.41.12.0/30	155.206.127.105	0	100	0	i
*>i	155.206.127.105	0	100	0	i
*>i154.103.64.0/21	155.206.127.105	0	100	0	104 i
* i	155.206.127.106		100	0	104 i
*>i154.103.72.0/21	155.206.127.105	0	100	0	104 i
* i	155.206.127.106		100	0	104 i
*>i154.107.0.0/30	155.206.127.105		100	0	104 i
* i	155.206.127.106	0	100	0	104 i
*>i154.107.0.4/30	155.206.127.105	0	100	0	i
* i	155.206.127.105	0	100	0	i
* i154.107.0.8/30	155.206.127.105	0	100	0	i
*>i	155.206.127.105	0	100	0	i
*>i154.108.8.0/21	155.206.127.105		100	0	104 i
* i	155.206.127.106	0	100	0	104 i

```

*>i154.108.16.0/21 155.206.127.105          100      0 104 i
* i                  155.206.127.106          0      100      0 104 i
* i155.206.127.0/24 155.206.127.106          100      0 i
*>i                  155.206.127.106          100      0 i

```

The final task in the I-BGP configuration step requires the aggregation of the 155.206.127.0/24 network and should be performed on the border routers using the summary parameter to suppress the summarized routers. Notice that the Ferragamo router cannot reach any external service provider network until this step has been completed. This is because the upstream service providers do not have a route to the 155.206.127.64/30 and 155.206.127.68/30 networks. (You should never send /30 routes to service providers; they will generally not accept any routes smaller than /24.) After you have aggregated the networks, you see that the Ferragamo router can ping all the Internet service provider networks using its default route, using a configuration similar to that shown in [Example 9-119](#).

Example 9-119. Palmer Router's Route Aggregation Configuration

```

Palmer#show run | begin bgp

router bgp 8080

no synchronization

bgp router-id 154.206.127.106

bgp cluster-id 2614001514

bgp log-neighbor-changes

network 155.206.127.0 mask 255.255.255.248

aggregate-address 155.206.127.0 255.255.255.0 summary-only

neighbor AS104 peer-group

neighbor AS104 remote-as 104

neighbor AS104 update-source Loopback15

neighbor AS104 filter-list 100 out

neighbor AS60 peer-group

neighbor AS60 remote-as 60

neighbor AS60 update-source Loopback15

neighbor AS60 filter-list 100 out

```

```

neighbor AS8080 peer-group

neighbor AS8080 remote-as 8080

neighbor AS8080 update-source Loopback15

neighbor AS8080 route-reflector-client

neighbor AS8080 next-hop-self

neighbor 101.41.12.5 peer-group AS60

neighbor 154.107.0.1 peer-group AS104

neighbor 155.206.127.105 peer-group AS8080

neighbor 155.206.127.107 peer-group AS8080

neighbor 155.206.127.108 peer-group AS8080

no auto-summary

```

After the aggregate has been added to the border routers, the Internet service provider routers should all receive a route to the 155.206.127.0/24 network, and the Ferragamo router should ping the service provider networks from all 155.206.127.0 networks, as shown in [Example 9-120](#).

Example 9-120. Farrell Postaggregation BGP RIB and the Ferragamo Ping Test

```

Farrell#show ip bgp | begin Network

      Network          Next Hop            Metric LocPrf Weight Path
* > 17.8.4.0/22      0.0.0.0                  0        32768  i
* > 17.8.8.0/22      0.0.0.0                  0        32768  i
* > 155.206.127.0/24 155.206.127.106            0    8080  i
*                   155.206.127.105            0    8080  i

```

Ferragamo#ping

Protocol [ip]:

Target IP address: 154.103.64.1

Repeat count [5]:

```
Datagram size [100]:  
Timeout in seconds [2]:  
Extended commands [n]: y  
Source address or interface: 155.206.127.66  
Type of service [0]:  
Set DF bit in IP header? [no]:  
Validate reply data? [no]:  
Data pattern [0xABCD]:  
Loose, Strict, Record, Timestamp, Verbose[none]:  
Sweep range of sizes [n]:  
Type escape sequence to abort.  
Sending 5, 100-byte ICMP Echos to 154.103.64.1, timeout is 2 seconds:  
!!!!!  
Success rate is 100 percent (5/5), round-trip min/avg/max = 8/9/16 ms
```

Step 9. To make the most efficient use of the connections between the border routers and the service provider networks, configure the Service Provider-1 router to prefer routes from the Drazen router, and configure the Service Provider-2 router to prefer routes from the Palmer router. Neither the MED nor AS_PATH attributes can accomplish this task. Locally generated routes should always have the highest preference:

- The Drazen router should prefer routes from the Myers router, with a secondary preference for the Farrell router; the Palmer router should prefer routes from the Farrell, with the Gaines router as a secondary preference before the Myers router. Routes that were locally generated from a certain router should always have the highest preference.

There are several ways to set a preferred route in BGP; one of the easiest and most common ways to set a preferred route is to prepend AS path information to the less-desirable route, or to set the MED attribute for the more desirable route. When the external peer receives the routes with the new attributes, the BGP route selection algorithm prefers the routes with the shorter AS path, or the lowest MED attribute. Another, more customizable approach to this problem is to set and match a certain BGP COMMUNITY attribute and use a route map on the receiving side to set the WEIGHT attribute to a higher value, making the route more attractive. [Example 9-121](#) shows how the Drazen router uses route map external-pref to set the BGP community value for locally generated routes specified by the match route-type local command to 104: 8080, and the COMMUNITY attribute for all other outgoing routes is set to 104: 111. The ip bgp-community new-format command allows for the use of the more readable aa:nn community format.

Example 9-121. Changing the COMMUNITY Attribute on the Drazen Router

```
Drazen#show run | include AS104|new-format

neighbor AS104 peer-group

neighbor AS104 remote-as 104

neighbor AS104 update-source Loopback15

neighbor AS104 send-community

neighbor AS104 route-map external-pref out

neighbor AS104 filter-list 100 out

neighbor 154.107.0.5 peer-group AS104

neighbor 154.107.0.9 peer-group AS104

ip bgp-community new-format

Drazen#show run | begin route-map external-pref permit 10

route-map external-pref permit 10

match route-type local

set community 104:8080

!

route-map external-pref permit 20

set community 104:111
```

After the external peers in AS 104 receive the routes with the new community attributes, they can, in turn, use the same type of route map to set the WEIGHT attribute. [Example 9-122](#) shows how the Gaines router uses IP community lists 10, 11, and 80 to match the incoming community values and to set the weight based on these values.

Example 9-122. Using the COMMUNITY Attribute to Change the Weight on the Gaines Router

```
Gaines#show run | begin AS8080

neighbor AS8080 peer-group
```

```

neighbor AS8080 remote-as 8080

neighbor AS8080 ebgp-multipath 2

neighbor AS8080 route-map preference in

neighbor 155.206.127.105 peer-group AS8080

neighbor 155.206.127.106 peer-group AS8080

neighbor 172.20.20.1 remote-as 104

no auto-summary

!

ip bgp-community new-format

ip community-list 10 permit 104:8080

ip community-list 11 permit 104:111

ip community-list 80 permit internet

!

route-map preference permit 10

match community 10

set weight 10000

!

route-map preference permit 20

match community 11

set weight 2000

!

route-map preference permit 30

match community 80

```

In the preceding example, route map preference 10 matches the community string 104:8080, from community list 10, and increase the WEIGHT attribute of matching routes from the default of 0 to a new value of 10,000. Route map preference 20 matches the 104:111 COMMUNITY attribute using community list 11, and route map preference 30 matches the default Internet community and does not alter any attribute. If the route map preference 30 had not been present, the route map would have acted like an access list and denied all other routes. [Example 9-123](#) shows the resulting BGP RIB from the Gaines router.

Example 9-123. Gaines Router BGP RI B After the New Weight Adjustment

```
Gaines#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
*>i154.103.64.0/21	172.20.20.1	0	100	0	i
*>i154.103.72.0/21	172.20.20.1	0	100	0	i
*> 154.108.8.0/21	0.0.0.0	0		32768	i
*> 154.108.16.0/21	0.0.0.0	0		32768	i
* 155.206.124.0/22	155.206.127.106			0	8080 i
* i	155.206.127.105		100	0	8080 i
*>	155.206.127.105			2000	8080 i
* i172.20.20.0/24	172.20.20.1	0	100	0	i
*>	0.0.0.0	0		32768	i

The second part of the step required the configuration of internal preference on routes coming into the 24-hour network. At first glance, you might want to use the LOCAL_PREF attribute to change the preference for the routes; if you read the question closely, however, you notice that the LOCAL_PREF attribute does not work in this case because the LOCAL_PREF attribute is passed to all neighbors inside of AS 8080, which will not produce the required results. The other way to accomplish this task is to use set and match with the COMMUNITY attribute and use that attribute to change the WEIGHT for the route like you did in the first part of this step. This time, the task is a little trickier to accomplish because there are three orders of precedence. [Example 9-124](#) shows how this was accomplished on the Drazen router.

Example 9-124. Altering Route Precedence on the Drazen Router

```
Drazen#show run | include AS104|AS60

neighbor AS104 peer-group

neighbor AS104 remote-as 104

neighbor AS104 update-source Loopback15

neighbor AS104 send-community
```

```
neighbor AS104 route-map internal-pref in
neighbor AS104 route-map external-pref out
neighbor AS104 filter-list 100 out
neighbor AS60 peer-group
neighbor AS60 remote-as 60
neighbor AS60 update-source Loopback15
neighbor AS60 send-community
neighbor AS60 route-map internal-pref in
neighbor AS60 route-map external-pref2 out
neighbor AS60 filter-list 100 out
neighbor 101.41.12.1 peer-group AS60
neighbor 154.107.0.5 peer-group AS104
neighbor 154.107.0.9 peer-group AS104
Drazen#show run | include community-list
ip community-list 4 permit 104:104
ip community-list 10 permit internet
ip community-list 14 permit 104:222
ip community-list 44 permit 104:333
Drazen#show run | begin route-map internal-pref permit 10
route-map internal-pref permit 10
match community 4
set weight 10000
!
route-map internal-pref permit 20
match community 14
set weight 2000
!
route-map internal-pref permit 30
```

```

match community 44
set weight 1000
!
route-map internal-pref permit 40
match community 10

```

In the preceding example, the internal-pref route map specifies the weight that is to be assigned to routes with each COMMUNITY attribute. Route map internal-pref 10 uses community list 4 to set the weight for all locally originated routes (routes containing the 104:104 community attribute that was set on the Myers and Gaines routers) to 10,000. The next iteration of this route map matches traffic originating from the Myers router (this value was set on the Myers router as 104:22), the next iteration specifies routes from the Gaines router (this value was set on the Gaines routers as 104:333), and the last statement permits any other routes leaving their COMMUNITY attribute untouched. [Example 9-125](#) shows the resulting BGP RIB.

Example 9-125. Specifying Preference in the Drazen BGP RIB

```
Drazen#show ip bgp | begin Network
```

Network	Next Hop	Metric	LocPrf	Weight	Path
* i17.8.4.0/22	155.206.127.106	0	100	0 60	i
*>	101.41.12.1	0		0 60	i
* i17.8.8.0/22	155.206.127.106	0	100	0 60	i
*>	101.41.12.1	0		0 60	i
* i154.103.64.0/21	155.206.127.106		100	0 104	i
*>	154.107.0.9	0		10000 104	i
*	154.107.0.5			1000 104	i
* i154.103.72.0/21	155.206.127.106		100	0 104	i
*>	154.107.0.9	0		10000 104	i
*	154.107.0.5			1000 104	i
* i154.108.8.0/21	155.206.127.106	0	100	0 104	i
*	154.107.0.9			2000 104	i
*>	154.107.0.5	0		10000 104	i

```

* i154.108.16.0/21 155.206.127.106          0      100      0 104 i
*
*           154.107.0.9                      2000 104 i
* >         154.107.0.5                      0      10000 104 i
s> 155.206.124.0/24 0.0.0.0                0      32768 i
* i155.206.124.0/22 155.206.127.106        100      0 i
* >         0.0.0.0                      32768 i
s> 155.206.125.0/24 0.0.0.0                0      32768 i
s> 155.206.126.0/24 0.0.0.0                0      32768 i
r>i155.206.127.64/30

Network          Next Hop          Metric LocPrf Weight Path
                    155.206.127.107      0      100      0 i
#

```

Step 10. As a security precaution, disable any CDP, HTTP web access, and any unnecessary features on the 24-hour border routers:

- Also create an antispoof access list that prevents any RFC 1918 private IP addresses and internal addresses.
- Make sure that OSPF routes are not allowed out of the 24-hour network.
- Leave HTTP web service enabled on the Internet-facing routers; they will be used to simulate Internet web servers.
- Configure the HTTP services to use the IP address of the Loopback100 interface.

[Example 9-126](#) shows some of the commands that might have been issued, depending on the Cisco IOS Software version.

Example 9-126. Disabling Services on a Cisco Router

```

no service pad
no service dhcp
no ip identd
no service finger
no ip source-route

```

```

no ip bootp

no service tcp-small-servers

no service tcp-small-servers

!

interface Ethernet0/0

no mop enabled

no cdp enable

ip access-group 101 in

!

router ospf 1

passive-interface Serial0/1

passive-interface Serial0/1.101

passive-interface Serial0/1.201

passive-interface Serial0/1.401

!

no ip http server

access-list 101 deny ip 10.0.0.0 0.255.255.255 any
access-list 101 deny ip 192.168.0.0 0.0.255.255 any
access-list 101 deny ip 172.0.0.0 0.31.255.255 any
access-list 101 deny ip 154.206.127.0 0.0.0.255 any
access-list 101 permit any any

!

no cdp run

```

Step 11. To hide the RFC 1918 private networks from the Internet, configure the 24-hour border routers to NAT all internal networks to the public Internet-routable IP addresses shown earlier in [Table 9-15](#):

- Make sure all IP address blocks are aggregated to the fullest extent; all specific routes should be suppressed, and only the aggregate should be advertised to external neighbors.

- To verify customer Internet connectivity, use a web browser to enter the HTTP web configuration site on each of the service provider networks.

This step requires a few NAT and BGP configuration steps to work properly. First, you must configure NAT so that any internally routed networks are statically translated to an external IP address; if this step is not configured correctly, packets will not be forwarded and returned properly. To configure NAT for this situation, you need to configure a static network translation, as shown in [Example 9-127](#).

Example 9-127. NAT Configuration for the Drazen Router

```
Drazen#show run | include nat inside source

ip nat inside source static network 10.1.1.0 155.206.124.0 /24

ip nat inside source static network 10.2.2.0 155.206.125.0 /24

ip nat inside source static network 10.3.3.0 155.206.126.0 /24
```

You can check for a successful NAT translation using the show ip nat translations command. When the PC issues a ping packet that is destined for any Internet IP address, you should see a successful translation on one of the border routers. [Example 9-128](#) shows the NAT translations for the Drazen router.

Example 9-128. Drazen Router's NAT Table

```
Drazen#show ip nat translations

Pro Inside global      Inside local       Outside local      Outside global
--- 155.206.124.2      10.1.1.2          ---                ---
                                         Outside local      Outside global
                                         ---                ---
                                         /prefix

Subnet translation:

Inside global   Inside local     Outside local   Outside global /prefix
155.206.124.0  10.1.1.0        ---           ---           /24
155.206.125.0  10.2.2.0        ---           ---           /24
155.206.126.0  10.3.3.0        ---           ---           /24
```

For the upstream Internet service provider networks to reach the newly translated IP addresses, they must be advertised on the border routers by BGP. After you add the 155.206.124.0/24, 155.206.125.0/24, and 155.206.126.0/24 networks to the BGP process, these networks can be

aggregated into one larger network—155.206.124.0/22. [Example 9-129](#) shows the new BGP configuration changes on the Drazen router.

Example 9-129. Drazen Router NAT/BGP Configuration Changes

```
network 155.206.124.0 mask 255.255.255.0  
network 155.206.125.0 mask 255.255.255.0  
network 155.206.126.0 mask 255.255.255.0  
aggregate-address 155.206.124.0 255.255.252.0 summary-only
```

After BGP has been properly configured, the last remaining step is to add local routes to the border routers so that they advertise the new BGP networks. This can be accomplished by adding three static routes to the Null0 interface, each with a high administrative distance. [Example 9-130](#) shows the resulting BGP RIB on the Gaines router.

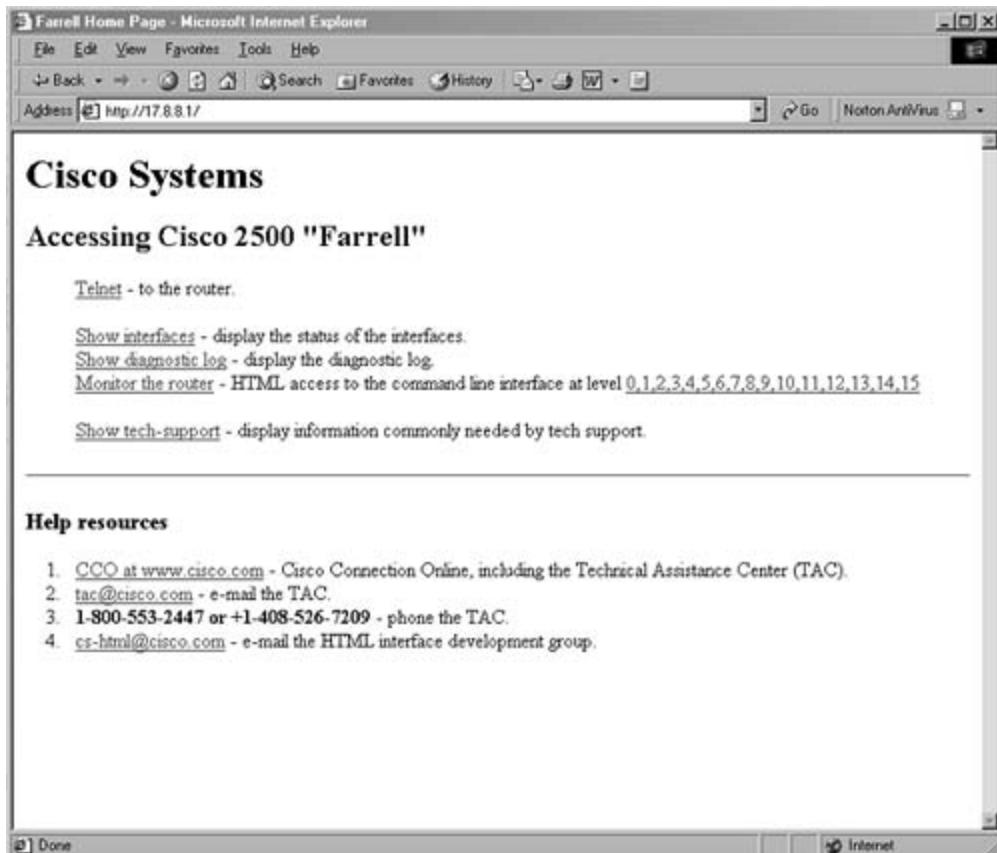
Example 9-130. Final Gaines BGP RIB

```
Gaines#show ip bgp | begin Network  
  
Network          Next Hop            Metric LocPrf Weight Path  
*>i154.103.64.0/21 172.20.20.1      0       100      0 i  
*>i154.103.72.0/21 172.20.20.1      0       100      0 i  
*> 154.108.8.0/21  0.0.0.0          0           32768 i  
*> 154.108.16.0/21 0.0.0.0          0           32768 i  
* i155.206.124.0/22 155.206.127.105    100      0 8080 i  
*>                      155.206.127.105    10000 8080 i  
*                      155.206.127.106    2000 8080 i  
* i172.20.20.0/24   172.20.20.1      0       100      0 i  
*>                      0.0.0.0          0           32768 i
```

This step in this lab calls for a test on the PC located in the 10.1.1.0/24 network. To test the routing and NAT configuration, use a web browser to open the default administrative website on

each of the Internet service provider networks. You have completed this lab after each browser session is successfully opened. [Figure 9-21](#) shows a successful web session from the PC to the Farrell router.

Figure 9-21. Successful Web Browsing Using NAT



At this point, each of the routers should reach all other networks, except for the service providers, who are not allowed to use the 24-hour network for transit service. The border routers should perform BGP Internet path selection, route aggregation, simple security services, and NAT services for internal RFC 1918 networks. The Almeida and Bauer routers should load share and forward Internet traffic toward the border routers, and the Ferragamo router should provide DHCP service for the PC in the 10.1.1.0/24 network. [Example 9-131](#) shows the complete configurations for each router in this lab.

Example 9-131. Complete Router Configurations

```
hostname Frame-Relay-Switch
```

```
!
```

```
frame-relay switching
```

```
!

interface Serial0
no ip address
encapsulation frame-relay
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 101 interface Serial1 100
frame-relay route 201 interface Serial2 200
frame-relay route 401 interface Serial4 400
!

interface Serial1
no ip address
encapsulation frame-relay IETF
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 100 interface Serial0 101
!

interface Serial2
no ip address
encapsulation frame-relay IETF
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 200 interface Serial0 201
frame-relay route 300 interface Serial3 301
!

interface Serial3
no ip address
encapsulation frame-relay IETF
```

```
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 301 interface Serial2 300
frame-relay route 501 interface Serial4 500
!
interface Serial4
no ip address
encapsulation frame-relay IETF
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 400 interface Serial0 401
frame-relay route 500 interface Serial3 501
```

```
Myers#show run | begin hostname
hostname Myers
!
interface Loopback100
ip address 154.103.64.1 255.255.248.0
!
interface Loopback200
ip address 154.103.72.1 255.255.248.0
!
interface FastEthernet0
ip address 172.20.20.1 255.255.255.0
!
interface Serial0
no ip address
encapsulation frame-relay
```

```
clockrate 1300000

frame-relay lmi-type ansi

!

interface Serial0.100 multipoint
    ip address 154.107.0.9 255.255.255.252
    frame-relay map ip 154.107.0.10 100 broadcast
    !
    no synchronization
    bgp log-neighbor-changes
    network 154.103.64.0 mask 255.255.248.0
    network 154.103.72.0 mask 255.255.248.0
    network 172.20.20.0 mask 255.255.255.0 route-map hide-network
    neighbor AS8080 peer-group
    neighbor AS8080 remote-as 8080
    neighbor AS8080 ebgp-multipath 2
    neighbor AS8080 send-community
    neighbor AS8080 route-map preference in
    neighbor AS8080 route-map external-pref out
    neighbor 155.206.127.105 peer-group AS8080
    neighbor 172.20.20.2 remote-as 104
    no auto-summary
!
ip route 155.206.127.105 255.255.255.255 154.107.0.10
ip http server
ip bgp-community new-format
ip community-list 11 permit 104:111
ip community-list 80 permit internet
```

```
!  
  
route-map preference permit 10  
    match community 11  
    set weight 2000  
!  
  
route-map preference permit 20  
    match community 80  
!  
  
route-map external-pref permit 10  
    match route-type local  
    set community 104:104  
!  
  
route-map external-pref permit 20  
    set community 104:222  
!  
  
route-map hide-network permit 10  
    set community local-as
```

```
Gaines#show run | begin host  
  
hostname Gaines  
!  
!  
interface Loopback100  
    ip address 154.108.8.1 255.255.248.0  
!  
interface Loopback200  
    ip address 154.108.16.1 255.255.248.0  
!
```

```
interface FastEthernet0
    ip address 172.20.20.2 255.255.255.0
!
interface Serial1
    no ip address
    encapsulation frame-relay
    clockrate 1300000
    frame-relay lmi-type ansi
!
interface Serial1.200 multipoint
    ip address 154.107.0.5 255.255.255.252
    frame-relay map ip 154.107.0.6 200 broadcast
!
interface Serial1.300 multipoint
    ip address 154.107.0.1 255.255.255.252
    frame-relay map ip 154.107.0.2 300 broadcast
!
router bgp 104
    no synchronization
    bgp log-neighbor-changes
    network 154.108.8.0 mask 255.255.248.0
    network 154.108.16.0 mask 255.255.248.0
    network 172.20.20.0 mask 255.255.255.0 route-map hide-network
    neighbor AS8080 peer-group
    neighbor AS8080 remote-as 8080
    neighbor AS8080 ebgp-multipath 2
    neighbor AS8080 send-community
    neighbor AS8080 route-map preference in
```

```
neighbor AS8080 route-map external-pref out
neighbor 155.206.127.105 peer-group AS8080
neighbor 155.206.127.106 peer-group AS8080
neighbor 172.20.20.1 remote-as 104
no auto-summary
!
ip route 155.206.127.105 255.255.255.255 154.107.0.6
ip route 155.206.127.106 255.255.255.255 154.107.0.2
ip http server
ip bgp-community new-format
ip community-list 10 permit 104:8080
ip community-list 11 permit 104:111
ip community-list 80 permit internet
!
route-map preference permit 10
match community 10
set weight 10000
!
route-map preference permit 20
match community 11
set weight 2000
!
route-map preference permit 30
match community 80
!
route-map external-pref permit 10
match route-type local
set community 104:104
```

```
!  
  
route-map external-pref permit 20  
    set community 104:333  
  
!  
  
route-map hide-network permit 10  
    set community local-as
```

```
Farrell#show run | begin host  
  
hostname Farrell  
  
!  
  
interface Loopback100  
    ip address 17.8.4.1 255.255.252.0  
  
!  
  
interface Loopback200  
    ip address 17.8.8.1 255.255.252.0  
  
!  
  
interface Serial0  
    no ip address  
    encapsulation frame-relay  
    clockrate 1300000  
    frame-relay lmi-type ansi  
  
!  
  
interface Serial0.400 multipoint  
    ip address 101.41.12.1 255.255.255.252  
    frame-relay map ip 101.41.12.2 400 broadcast  
  
!  
  
interface Serial0.500 multipoint  
    ip address 101.41.12.5 255.255.255.252
```

```
frame-relay map ip 101.41.12.6 500 broadcast
!
router bgp 60
  no synchronization
  bgp log-neighbor-changes
  network 17.8.4.0 mask 255.255.252.0
  network 17.8.8.0 mask 255.255.252.0
  neighbor AS8080 peer-group
  neighbor AS8080 remote-as 8080
  neighbor AS8080 ebgp-multipath 2
  neighbor AS8080 send-community
  neighbor AS8080 route-map preference in
  neighbor AS8080 route-map external-pref out
  neighbor 155.206.127.105 peer-group AS8080
  neighbor 155.206.127.106 peer-group AS8080
  no auto-summary
!
ip route 155.206.127.105 255.255.255.255 101.41.12.2
ip route 155.206.127.106 255.255.255.255 101.41.12.6
ip http server
ip bgp-community new-format
ip community-list 11 permit 60:111
ip community-list 60 permit internet
!
route-map preference permit 10
  match community 11
  set weight 2000
!
```

```
route-map preference permit 20
  match community 60
!
route-map external-pref permit 10
  match route-type local
  set community 60:60
!
route-map external-pref permit 20
  set community 60:222
```

```
Drazen#show run | begin host
hostname Drazen
!
no ip source-route
!
no ip bootp server
!
interface Loopback15
  ip address 155.206.127.105 255.255.255.255
!
interface Ethernet0/0
  ip address 155.206.127.1 255.255.255.248
  ip nat inside
!
interface Serial0/1
  no ip address
  encapsulation frame-relay
  clockrate 1300000
```

```
frame-relay lmi-type ansi

!

interface Serial0/1.101 multipoint
    ip address 154.107.0.10 255.255.255.252
    ip access-group 101 in
    ip nat outside
    frame-relay map ip 154.107.0.9 101 broadcast
!

interface Serial0/1.201 multipoint
    ip address 154.107.0.6 255.255.255.252
    ip access-group 101 in
    ip nat outside
    frame-relay map ip 154.107.0.5 201 broadcast
!

interface Serial0/1.401 multipoint
    ip address 101.41.12.2 255.255.255.252
    ip access-group 101 in
    ip nat outside
    frame-relay map ip 101.41.12.1 401 broadcast
!

router ospf 1
    router-id 155.206.127.105
    log-adjacency-changes
    passive-interface Serial0/1
    passive-interface Serial0/1.101
    passive-interface Serial0/1.201
    passive-interface Serial0/1.401
    network 155.206.127.0 0.0.0.7 area 0
```

```
network 155.206.127.105 0.0.0.0 area 0
distribute-list 1 in
!
router bgp 8080
no synchronization
bgp log-neighbor-changes
network 154.206.127.0 mask 255.255.255.248
network 155.206.124.0 mask 255.255.255.0
network 155.206.125.0 mask 255.255.255.0
network 155.206.126.0 mask 255.255.255.0
aggregate-address 155.206.124.0 255.255.252.0 summary-only
neighbor AS104 peer-group
neighbor AS104 remote-as 104
neighbor AS104 update-source Loopback15
neighbor AS104 send-community
neighbor AS104 route-map internal-pref in
neighbor AS104 route-map external-pref out
neighbor AS104 filter-list 100 out
neighbor AS60 peer-group
neighbor AS60 remote-as 60
neighbor AS60 update-source Loopback15
neighbor AS60 send-community
neighbor AS60 route-map internal-pref in
neighbor AS60 route-map external-pref2 out
neighbor AS60 filter-list 100 out
neighbor AS8080 peer-group
neighbor AS8080 remote-as 8080
neighbor AS8080 update-source Loopback15
```

```
neighbor AS8080 route-reflector-client
neighbor AS8080 next-hop-self
neighbor 101.41.12.1 peer-group AS60
neighbor 154.107.0.5 peer-group AS104
neighbor 154.107.0.9 peer-group AS104
neighbor 155.206.127.106 peer-group AS8080
neighbor 155.206.127.107 peer-group AS8080
neighbor 155.206.127.108 peer-group AS8080
no auto-summary
!
ip nat inside source static network 10.1.1.0 155.206.124.0 /24
ip nat inside source static network 10.2.2.0 155.206.125.0 /24
ip nat inside source static network 10.3.3.0 155.206.126.0 /24
ip route 155.206.124.0 255.255.255.0 Null0 254
ip route 155.206.125.0 255.255.255.0 Null0 254
ip route 155.206.126.0 255.255.255.0 Null0 254
no ip http server
ip bgp-community new-format
ip community-list 4 permit 104:104
ip community-list 10 permit internet
ip community-list 14 permit 104:222
ip community-list 44 permit 104:333
ip as-path access-list 100 permit ^$*
!
access-list 1 deny    0.0.0.0
access-list 1 permit any
access-list 101 deny   ip 10.0.0.0 0.255.255.255 any
access-list 101 deny   ip 192.168.0.0 0.0.255.255 any
```

```
access-list 101 deny    ip 172.0.0.0 0.31.255.255 any
access-list 101 deny    ip 154.206.127.0 0.0.0.255 any
access-list 101 permit ip any any
no cdp run
!
route-map external-pref2 permit 10
match route-type local
set community 60:8080
!
route-map external-pref2 permit 20
set community 60:111
!
route-map internal-pref permit 10
match community 4
set weight 10000
!
route-map internal-pref permit 20
match community 14
set weight 2000
!
route-map internal-pref permit 30
match community 44
set weight 1000
!
route-map internal-pref permit 40
match community 10
!
route-map external-pref permit 10
```

```
match route-type local  
  
    set community 104:8080  
  
!  
  
route-map external-pref permit 20  
  
    set community 104:111
```

```
Palmer#show run | begin host  
  
hostname Palmer  
  
!  
  
no ip source-route  
  
!  
  
interface Loopback15  
  
    ip address 155.206.127.106 255.255.255.255  
  
!  
  
interface Ethernet0  
  
    ip address 155.206.127.2 255.255.255.248  
  
    ip nat inside  
  
!  
  
interface Serial0  
  
    no ip address  
  
    encapsulation frame-relay  
  
    clockrate 1300000  
  
    frame-relay lmi-type ansi  
  
!  
  
interface Serial0.301 multipoint  
  
    ip address 154.107.0.2 255.255.255.252  
  
    ip access-group 101 in  
  
    ip nat outside
```

```
frame-relay map ip 154.107.0.1 301 broadcast
!
interface Serial0.501 multipoint
ip address 101.41.12.6 255.255.255.252
ip access-group 101 in
ip nat outside
frame-relay map ip 101.41.12.5 501 broadcast
!
router ospf 1
router-id 155.206.127.106
log-adjacency-changes
passive-interface Serial0
passive-interface Serial0.301
passive-interface Serial0.501
network 155.206.127.0 0.0.0.7 area 0
network 155.206.127.106 0.0.0.0 area 0
distribute-list 1 in
!
router bgp 8080
no synchronization
bgp router-id 154.206.127.106
bgp log-neighbor-changes
network 155.206.124.0 mask 255.255.255.0
network 155.206.125.0 mask 255.255.255.0
network 155.206.126.0 mask 255.255.255.0
network 155.206.127.0 mask 255.255.255.248
aggregate-address 155.206.124.0 255.255.252.0 summary-only
neighbor AS104 peer-group
```

```
neighbor AS104 remote-as 104
neighbor AS104 update-source Loopback15
neighbor AS104 send-community
neighbor AS104 route-map internal-pref in
neighbor AS104 route-map external-pref out
neighbor AS104 filter-list 100 out
neighbor AS60 peer-group
neighbor AS60 remote-as 60
neighbor AS60 update-source Loopback15
neighbor AS60 send-community
neighbor AS60 route-map internal-pref in
neighbor AS60 route-map external-pref2 out
neighbor AS60 filter-list 100 out
neighbor AS8080 peer-group
neighbor AS8080 remote-as 8080
neighbor AS8080 update-source Loopback15
neighbor AS8080 route-reflector-client
neighbor AS8080 next-hop-self
neighbor 101.41.12.5 peer-group AS60
neighbor 154.107.0.1 peer-group AS104
neighbor 155.206.127.105 peer-group AS8080
neighbor 155.206.127.107 peer-group AS8080
neighbor 155.206.127.108 peer-group AS8080
no auto-summary
!
ip nat inside source static network 10.1.1.0 155.206.124.0 /24
ip nat inside source static network 10.2.2.0 155.206.125.0 /24
ip nat inside source static network 10.3.3.0 155.206.126.0 /24
```

```
ip route 155.206.124.0 255.255.255.0 Null0 254
ip route 155.206.125.0 255.255.255.0 Null0 254
ip route 155.206.126.0 255.255.255.0 Null0 254
no ip http server
ip bgp-community new-format
ip community-list 10 permit internet
ip community-list 11 permit 60:60
ip community-list 11 permit 104:104
ip community-list 14 permit 104:333
ip community-list 60 permit 60:222
ip as-path access-list 100 permit ^$!
access-list 1 deny 0.0.0.0
access-list 1 permit any
access-list 101 deny ip 10.0.0.0 0.255.255.255 any
access-list 101 deny ip 192.168.0.0 0.0.255.255 any
access-list 101 deny ip 172.0.0.0 0.31.255.255 any
access-list 101 deny ip 154.206.127.0 0.0.0.255 any
access-list 101 permit ip any any
no cdp run
!
route-map external-pref2 permit 10
match route-type local
set community 60:8080
!
route-map external-pref2 permit 20
set community 60:111
!
```

```
route-map internal-pref permit 10
  match community 11
  set weight 10000
!
route-map internal-pref permit 20
  match community 60
  set weight 2000
!
route-map internal-pref permit 30
  match community 14
  set weight 1000
!
route-map internal-pref permit 40
  match community 10
!
route-map external-pref permit 10
  match route-type local
  set community 104:8080
!
route-map external-pref permit 20
```

```
Almeida#show run | begin host
hostname Almeida
!
ip cef
!
interface Loopback15
  ip address 155.206.127.107 255.255.255.255
```

```
!  
  
interface Ethernet0  
  ip address 155.206.127.3 255.255.255.248  
!  
  
interface Serial0  
  ip address 155.206.127.65 255.255.255.252  
  clockrate 1300000  
!  
  
router ospf 1  
  router-id 155.206.127.107  
  log-adjacency-changes network 155.206.127.0 0.0.0.7 area 0  
  network 155.206.127.64 0.0.0.3 area 1  
  network 155.206.127.107 0.0.0.0 area 0  
  default-information originate always metric-type 1  
!  
  
router bgp 8080  
  no synchronization  
  bgp log-neighbor-changes  
  network 155.206.127.64 mask 255.255.255.252  
  neighbor 155.206.127.105 remote-as 8080  
  neighbor 155.206.127.105 update-source Loopback15  
  neighbor 155.206.127.106 remote-as 8080  
  neighbor 155.206.127.106 update-source Loopback15  
  no auto-summary  
!  
  ip route 0.0.0.0 0.0.0.0 155.206.127.5
```

```
Bauer#show run | begin host
```

```
hostname Bauer

!
ip cef

!
interface Loopback15
    ip address 155.206.127.108 255.255.255.255

!
interface Ethernet0
    ip address 155.206.127.4 255.255.255.248

!
interface Serial0
    ip address 155.206.127.69 255.255.255.252
    clockrate 1300000

!
router ospf 1
    router-id 155.206.127.108
    log-adjacency-changes network 155.206.127.0 0.0.0.7 area 0
    network 155.206.127.68 0.0.0.3 area 1
    network 155.206.127.108 0.0.0.0 area 0
    default-information originate always metric-type 1

!
router bgp 8080
    no synchronization
    bgp log-neighbor-changes
    network 155.206.127.68 mask 255.255.255.0
    neighbor 155.206.127.105 remote-as 8080
    neighbor 155.206.127.105 update-source Loopback15
    neighbor 155.206.127.106 remote-as 8080
```

```
neighbor 155.206.127.106 update-source Loopback15
no auto-summary
!
ip route 0.0.0.0 0.0.0.0 155.206.127.5
```

```
Ferragamo#show run | begin host
hostname Ferragamo
!
ip dhcp excluded-address 10.1.1.1
!
ip dhcp pool workstations
  network 10.1.1.0 255.255.255.0
  default-router 10.1.1.1
  domain-name fiction.org
!
interface Loopback100
  ip address 10.2.2.1 255.255.255.0
!
interface Loopback200
  ip address 10.3.3.1 255.255.255.0
!
interface Ethernet0
  ip address 10.1.1.1 255.255.255.0
!
interface Serial0
  ip address 155.206.127.66 255.255.255.252
!
interface Serial1
```

```
ip address 155.206.127.70 255.255.255.252

!
router ospf 1

log-adjacency-changes network 10.1.1.0 0.0.0.255 area 1

network 10.2.2.0 0.0.0.255 area 1

network 10.3.3.0 0.0.0.255 area 1

network 155.206.127.64 0.0.0.3 area 1

network 155.206.127.68 0.0.0.3 area 1
```

Further Reading

RFC 2385, *Protection of BGP Sessions via the TCP MD5 Signature Option*, by A. Heffernan

Cisco IOS Dial Solutions, by Cisco Systems, Inc.

www.apnic.net—Asia Pacific Network Information Centre

www.arin.net—The American Registry for Internet Numbers

www.ripe.net—RIPE Network Coordination Centre

www.isoc.org—The Internet Society

www.nanog.org—The North American Network Operators' Group

Part VI: CCIE Practice Labs

[Chapter 10](#) CCIE Preparation and Self Assessment

Chapter 10. CCIE Preparation and Practice Labs

[CCIE Preparation](#)

[CCIE Practice Labs](#)

[CCIE Practice Lab: Broken Arrow](#)

[CCIE Practice Lab: !!! Boom . . .](#)

[CCIE Practice Lab: The Intimidator](#)

[CCIE Practice Lab: Enchilada II](#)

[CCIE Practice Lab: Kobayashi Maru](#)

CCIE Preparation

To achieve success, whatever the job we have, we must pay a price. Success is like anything worthwhile. It has a price. You have to pay the price to win and you have to pay the price to get to the point where success is possible. Most important, you must pay the price to stay there...sacrifice, perseverance, competitive drive, selflessness, and respect for authority is the price that each and every one of us must pay to achieve any goal that is worthwhile. Once you agree upon the price you and your family must pay for success, it enables you to ignore the minor hurts, the opponent's pressure, and the temporary failures.

—Vince Lombardi

Entering into the ranks of the CCIEs means you are becoming a member of the most elite and skilled groups of networking engineers in the world. And the price for membership is steep. You will be required to commit yourself, and be tested to a level few people will ever know. The pressure during the months and days leading up to the test can be immense, and you will be required to perform near flawlessly under its weight.

Fortunately, you are not alone in this quest. As we head full speed into the information age, despite the dot.com bust, the need for highly skilled network engineers will always be there. As more and more engineers prepare for this test and others, more tools are becoming available. Study groups, such as routerie.com and groupstudy.com, are great places to get help from other people studying for the tests (from the only ones "who can feel your pain"). New books on routing protocols, switching, security, and many other topics are becoming available every year.

As you can see, becoming a CCIE will require a serious commitment on your part in terms of time, finances, and personal sacrifice.

The equipment needed to model CCIE labs can be very expensive. Companies such as Ascolta Training, Skyline Computer, Network Learning, and others offer labs, ISDN switches, and CCIE prep material at a reasonable rate. This can help limit the number of routers and switches you will need in your own lab. For details on setting up your CCIE lab, refer to *CCIE Practical Studies, Volume I (CCIE PSV1)*, [Chapter 1](#), "Modeling the Internetwork."

This text will serve as only one of many that you will have to read during your studies. The following books are a brief list of the ones that will be of great value during your studies:

Stevens: *TCP/IP Illustrated*, Volume I

Comer: *Internetworking with TCP/IP*

Pearlman: *Interconnections: Routers and Bridges*, Second Edition

Doyle: *Routing TCP/IP*, Volume I

Doyle/Carroll: *Routing TCP/IP*, Volume II

Solie: *CCIE Practical Studies*, Volume I

Solie/Lynch: *CCIE Practical Studies*, Volume II

Halabi: *Internetwork Routing Architectures*, Second Edition

Clark/Hamilton: *Cisco LAN Switching*

Caslow: *Bridges, Routers, and Switches*

Cisco Press: *CCIE Design and Case Studies*, Second Edition

Diker-Pildush: *Cisco ATM Solutions*

Cisco Press: *Troubleshooting IP Routing Protocols*

Cisco IOS Software 12.1 and 12.2 configuration guides (as many as you can bear to read)

The following list is by no means a complete list of CCIE study topics. However, it does offer a solid starting point for a list of topics with which the CCIE candidate should become *very familiar*.

- Frame Relay
 - Frame Relay switching
 - Frame Relay subinterfaces
 - Point-to-point links and multipoint links
 - Frame Relay map statements: bridge, LLC, DLSW, and other keywords
 - RFC 1490 encapsulation
 - Bridging over Frame
 - Voice over Frame
 - PPP over Frame
 - Frame Relay ARP and inverse ARP operation
 - Frame Relay traffic shaping
- HDLC
- PPP
 - Compression types
 - PPP authentication: PAP/CHAP
 - PPP callback
 - PPP multilink
 - DDR techniques
 - Virtual dialer profiles
 - Compression types
 - IPCP

- ISDN
 - Dialer maps/DDR
 - Know how to handle routing protocols over ISDN, such as RIP, EIGRP, OSPF, and so on
 - Snapshot routing
 - Dialer watch
 - OSPF demand circuits
- BGP
 - BGP theory, including BGP operation on a Cisco router
 - I-BGP versus E-BGP
 - BGP synchronization rule
 - Route reflectors
 - Hiding autonomous system numbers and creating private autonomous systems
 - Authentication
 - BGP backdoors
 - Route maps and route redistribution
 - Autonomous system path filters
 - BGP path selection process and path manipulation: MED, LOCAL_PREF, WEIGHT, and so on
 - BGP confederations
 - BGP communities
 - Advertising supernets, summarization
 - BGP interaction with IGPs
 - BGP attributes
 - Autonomous system path and community filtering, including regular expressions
 - Prefix suppression
 - Conditional route advertisements
 - Route dampening
- OSPF
 - Redistribution to and from every routing protocol

- Summarization with summary address and area range statements
- OSPF over Frame
- OSPF demand circuits
- Route maps and route filters with OSPF
- OSPF costs and administrative distance
- Stub areas, NSS areas, backbone areas, and LSA propagation
- Authentication: Type I and Type II
- Authenticating area 0
- Designated router and BDR selection: priority command
- Default route propagation

- EIGRP

- EIGRP for IP
- Redistribution to and from every routing protocol
- Summarization
- Route maps and route filters with EIGRP
- MD5 authentication
- EIGRP over ISDN
- Split-horizons issues with multipoint networks
- Administrative distance of all routing protocols
- EIGRP stub networks

- RIP

- Redistribution to and from every routing protocol
- Snapshot routing/RIP over ISDN
- Split-horizons issues with multipoint networks
- RIPv1, issues from lack of VLSM support
- RIPv2
- RIP unicast updates

- IS-IS

- Redistribution to and from every routing protocol
- CLNS
- IS-IS over Frame Relay
- IS-IS type 1 and type 2 routes

- DLSw

- TCP, FST, direct and Frame Relay peers
- Backup peers
- Promiscuous peers
- Border peers and peer groups
- Costed peers
- Explorer control and LLC control with DLSw LSAP filters

- Bridging

- Transparent bridging
- Spanning-tree control
- IEEE 802.1w and IEEE 802.1s
- Bridging over Frame Relay
- Source-route bridging
- Remote source-route bridging
- Translational bridging
- Explorer control and flooding
- LSAP filters
- Integrated routing and bridging
- Default gateways

- Controlling routing and traffic

- Standard access lists
- Extended access lists
- Named access lists
- Timed access lists
- Dynamic and reflexive access lists

- Route maps and policy routing
- Propagating default routes
- Queuing
 - Generic and Frame Relay traffic shaping
 - RSVP, WRED basic configurations
 - Examining router configuration optimization
 - Route switching: process, fast, CEF, NetFlow, optimum, and distributed
 - Compression techniques—Predictor and Stacker
 - Quick ATM PVC theory and configuration review, including new IOS atm commands
 - ATM verses Frame Relay
 - ATM quality of service
 - Integrated services with RSVP
 - Differentiated services with IP ToS, Precedence, DSCP, and WRED
 - FIFO Queueing
 - Weighted Fair Queueing
 - Priority Queueing
 - Custom Queueing
 - Class-Based Weighted Fair Queueing
 - Low Latency Queueing
 - IP RTP Priority
 - Generic and Frame Relay traffic shaping and class-based shaping
 - Traffic policing
 - Committed access rate
- General IOS
 - Access server configuration
 - Jump register configuration
 - Password recovery for Catalyst and routers
 - EXEC control: timeouts, privilege levels, and so on
 - Security: encrypted tunnels, CONS, and vty access

- Console and system logging
- IOS features
 - NAT: dynamic, static, and pooled and TCP overload
 - NTP: NTP authentication and stratum settings
 - DNS
 - HSRP: tracking and priority
 - IDRP
 - DHCP
 - Snapshot routing
 - Dialer watch
 - Mobile IP
 - ARP manipulation
 - SNMP: read/write keys, set and get traps
 - UDP flooding: ip forward command
 - GRE tunneling and authentication
- Catalyst
 - Catalyst 3550 VLAN creation
 - VTP domains
 - Advanced spanning-tree control
 - Spanning Tree: IEEE 802.1b, IEEE 802.1w and IEEE 802.1s
 - Port security and IP access control
 - VLAN maps
 - ISL, 802.1Q trunking
 - VLAN propagation and control over trunks
 - Routing between VLANs
 - Multicast routing
 - SVIs and routed ports
 - Layer 3 switching/routing
 - STP load sharing with 802.1s

- Voice VLANs
- Layer 2 and Layer 3 EtherChannel
- Multicast routing
 - Joining multicast groups
 - Sparse and dense mode operation
 - IGMP and CGMP
 - Multicast issues on the Catalyst 3550
- ATM
 - Classical IP, routing over ATM
 - VPI, VCD, and VCI definition
 - ARP control
 - PVC mapping
- Voice
 - Voice over IP
 - Voice over Frame
 - Voice over ATM
 - FXO and FXS and E&M circuits
 - H.323
- VPN (mostly for the Security lab exam)
 - Encryption types
 - IPSec-protected GRE tunnels
 - IPSec transport and tunnel mode
 - Transform sets, crypto maps
 - "Key" authentication
 - CA authentication
- Removed Topics (The following topic have been removed for 2003.)
 - ATM LANE
 - AppleTalk

- LAT
- DECnet
- Apollo
- Banyan VINES
- ISO CLNS
- XNS
- X.25
- IGRP
- IPX
- Token Ring and Token Ring switching
- Catalyst 5500 or CAT-OS configuration

The official equipment list for the CCIE Routing and Switching lab (November 2003) is as follows:

- 2600 series routers
- 3600 series routers
- Catalyst 3550 series switches
- 3700 series routers
- From July 7, 2003 to August 31, 2003, the CCIE program will be migrating to Cisco IOS Software 12.2. During the migration period, all exams will still be based on Cisco IOS Software 12.1 content and objectives. Note: Cisco IOS Software 12.2-specific features and commands will not be tested until September 1, 2003.

CCIE Practice Labs

The CCIE practice labs are designed to give you an accurate representation of what a CCIE lab exam actually looks like. Some labs are complete CCIE labs, which require hardware to support voice, ATM, and two Cisco 3550s; others have less stringent hardware requirements. The labs are also designed to be easily modifiable to your own hardware requirements. We realize that everyone does not have access to ATM, voice, and 3550s; therefore, every lab has different hardware requirements.

Before each lab, a complete equipment list is provided and prestaging information is included—such as the Frame Relay switch configuration, backbone router configuration, and so on. Use this information to model your own CCIE lab.

There was some debate during the creation of *CCIE PSV1* as to whether to include the answers for the practice labs. Many people, myself included, thought that by providing the answers, people would focus more on matching the answers themselves than on practicing the lab. However, we do realize the answers are sometimes very helpful to see. A Custom Queuing problem is a good example of this. For these and by reader request, we have decided to include answers on a CD-ROM. We also have included additional information and some networking utilities on the CD-ROM for you.

For further lab information and updates, check out the Cisco Press website, www.ciscopress.com.

Do not forget that practice is the most critical part of your studies. Spending hours to get just one of these problems to work on your first time through is very common. As a matter of fact, if we don't stump you somewhere, we did not do our job well. The labs have routing loops, route-feedback issues, split horizons, and all those nice things built in to them. We have come to call these "CCIE landmines." Without actually practicing the lab, you can miss many of these *fun* adventures. Try your best to resist the temptation to look at the answers if you are puzzled by one of the problems. Sometimes the best way to learn is by spending a lot of time looking for and understanding the solution. The goal is not to come up with a solution; that is implied. The ultimate goal is *practice, practice, and practice*.

With that in mind, we present to you five CCIE practice labs.

CCIE Practice Lab: Broken Arrow

Equipment List:

- 1 Frame Relay Switch: 4 serial ports
- ISDN simulator/switch with 2 BRI ports
- ATM switch with 2 ATM interfaces
- 3 lab routers: 1 Ethernet and 1 serial interface
- 1 lab router: 1 Ethernet, 1 ATM, 1 serial, 1 ISDN BRI interface
- 1 lab router: 1 Ethernet and 1 ISDN BRI interface
- 1 lab router: 2 Ethernet interfaces
- 1 lab router: 1 Ethernet and 1 ATM interface
- 2 Ethernet 3550 switches with the EMI software, 2 fiber ports or crossover cables for interconnection

Prestaging—Frame Switch and ATM Configuration

Configure the Frame Relay switch with the PVCs as depicted in [Figure 10-1](#). Do not time yourself on this portion of the lab. The Frame Relay switch configuration is a global configuration and will be used for all labs but the third one. Not all the PVCs in the diagram are used during this lab. The PVCs indicated with a solid line are the ones used in this lab; the PVCs indicated with a dotted line are not used during this lab. Configure the ATM switch at this time, using the ATM configuration, and attach one interface to r3 and one to r7. [Example 10-1](#) lists the configurations for the Frame and ATM switches.

Example 10-1. Frame Relay and ATM Switch Configurations

```
hostname frame_switch
!
frame-relay switching
!
interface Serial0
  no ip address
  encapsulation frame-relay
```

```
no fair-queue

clockrate 2000000

frame-relay intf-type dce

frame-relay route 102 interface Serial1 101
frame-relay route 202 interface Serial5 204
frame-relay route 302 interface Serial4 206
frame-relay route 402 interface Serial3 408
frame-relay route 802 interface Serial8 708

!

interface Serial1

no ip address

encapsulation frame-relay

clockrate 2000000

frame-relay intf-type dce

frame-relay route 101 interface Serial0 102
frame-relay route 103 interface Serial5 104
frame-relay route 105 interface Serial4 106
frame-relay route 107 interface Serial3 108
frame-relay route 108 interface Serial8 808
frame-relay route 109 interface Serial2 110

!

interface Serial2

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 110 interface Serial1 109
frame-relay route 111 interface Serial3 708
```

```
!

interface Serial3

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 108 interface Serial1 107

frame-relay route 408 interface Serial0 402

frame-relay route 508 interface Serial4 506

frame-relay route 608 interface Serial5 804

frame-relay route 708 interface Serial2 111

!

interface Serial4

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 106 interface Serial1 105

frame-relay route 206 interface Serial0 302

frame-relay route 306 interface Serial5 304

frame-relay route 506 interface Serial3 508

!

interface Serial5

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 104 interface Serial1 103
```

```
frame-relay route 204 interface Serial0 202
frame-relay route 304 interface Serial4 306
frame-relay route 404 interface Serial8 108
frame-relay route 804 interface Serial3 608
!
interface Serial8
no ip address
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 108 interface Serial5 404
frame-relay route 708 interface Serial0 802
frame-relay route 808 interface Serial1 108
!
no ip classless
!
end
```

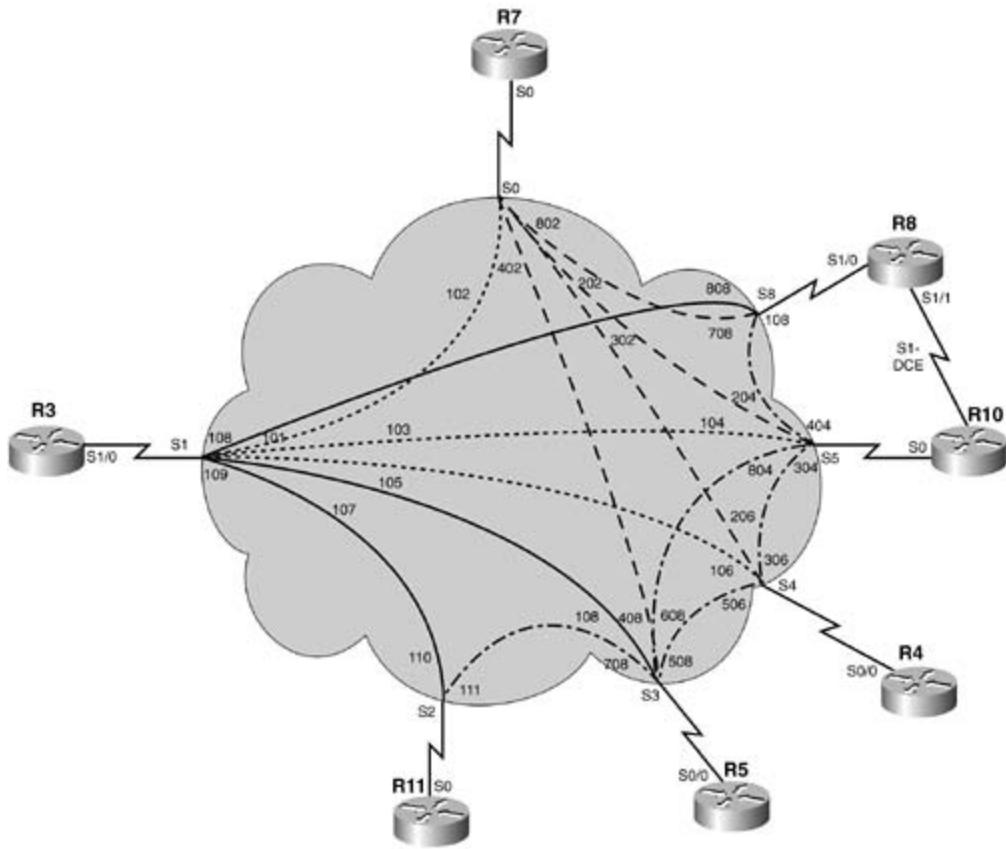
LIGHTSTREAM CONFIGURATION

```
hostname r12_ls1010
!
atm address 47.0091.8100.0000.0061.705b.4001.0061.705b.4001.00
!
interface ATM0/0/0
no keepalive
!
```

```
interface ATM0/0/1
  no keepalive
  atm pvc 1 88  interface ATM0/0/0 1 77
!
interface ATM0/0/2
  no keepalive
!
interface ATM2/0/0
  no ip address
  no keepalive
  atm maxvp-number 0
!
interface Ethernet2/0/0
  no ip address
!
no ip classless
!
line con 0
line aux 0
line vty 0 4
  login
!
end
```

Figure 10-1. Frame Relay Switch Configuration

Frame Relay DLCI Map
Not All PVCs and Interfaces Are Used



The following portion of the lab is timed and should begin after the configuration and physical installation of all hardware.

Rules

- No static routes or floating static routes are allowed unless specifically stated.
- Follow the instructions exactly. Be careful to only propagate routes where and when instructed. Only use the PVCs as directed by the instructions.
- You can use the configuration guides and the CD-ROM for your only reference material.
- You have 8.5 hours to complete this portion of the lab. Do not talk to anyone during this phase.
- It is recommended that you read the entire lab before beginning.

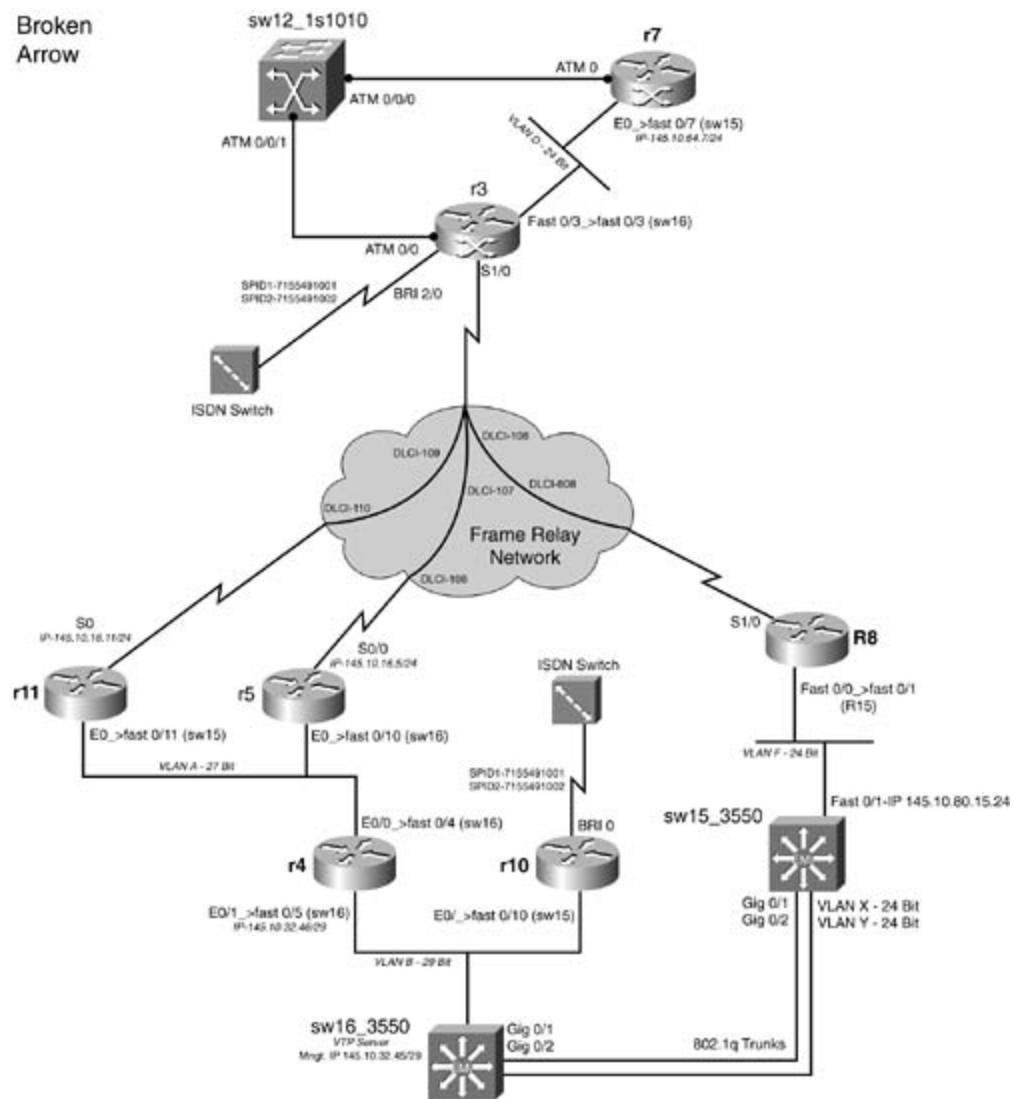
Section I: IP Setup

1. Use the IP subnet 145.10.1.19/27 on the E0 interface of r11.
2. Create virtual interfaces with the following subnets:
 - LB20-145.10.128.64/26 on r11
 - LB20-172.19.1.0/24 and LB21-172.18.1.0/24 on r10
 - LB20-206.191.1.0/24 on r5
 - VLAN X – 145.10.192.15/24 on sw15_3550
 - VLAN Y – 145.10.193.15/24 on sw15_3550
3. Use the network 145.10.0.0 for all other subnets and host addresses:
 - VLAN A: 27-bit subnet
 - VLAN B: 29-bit subnet
 - VLAN D: 24-bit subnet
 - VLAN F: 24-bit subnet

Section II: Catalyst Configuration

1. Configure an 802.1Q trunk between sw15_3550 and sw16_3550. Use the Gig 0/1 and Gig 0/2 interfaces for redundancy. Do not put IP addresses on the Gigabit interfaces. (You can use two 100BASE-T interfaces for this lab.)
2. Configure sw16_3550 to be a VTP server and sw15_3550 to be the client. Use PSV2 as the VTP domain name and ccie as the VTP password.
3. Configure the VLANs as depicted in [Figure 10-2](#). Do not use VLAN 1.

Figure 10-2. Network Diagram for Broken Arrow



4. Configure sw16_3550 as the root for all VLANs present and future, except for VLAN 800. sw16_3550 should be the root for VLAN 800 and serve as the secondary root for the remaining VLANs. If a new VLAN is created , it will follow these STP guidelines without additional configuration.
5. Configure Telnet access to all switches and do not use VLAN 1. The management addresses should be reachable from anywhere in the lab. sw16_3550 should be managed by VLAN F and VLAN B should be used for management on the sw16_3550 switch. Use cisco as the password.
6. Configure IEEE 802.1w RSTP between the two switches. Ensure that if a Gigabit Ethernet trunk drops, 99 percent of the traffic will still get through. That is, RSTP should converge the network in less than a second, not 50 seconds. Test by extended pings from r11 to r5 with a Gigabit Ethernet link failure. A 99-percent success rates indicates that RSTP is working. RSTP should converge quickly on all interfaces, including ones with routers. (The two Gigabit interfaces can be substituted with two Fast Ethernet interfaces. It will not change the functionality of the lab.)
7. Ensure that all ports in use are taking advantage of 802.1w, including host/router ports.

Section III: OSPF, RIP, and Frame Relay

1. Configure the Frame Relay network between r3, r11, and r5 such that they share the same IP subnet 145.10.16.0/24.
2. Configure the Frame Relay network to be in OSPF area 0 between the routers r3, r11, and r5. Do not configure static OSPF neighbors.
3. Configure VLAN A to be in OSPF area 100. Routers r11, r5, and r4 all have an Ethernet interface in area 100. Configure VLAN D and the Frame Relay network to be in OSPF area 0.
4. Configure the Frame Relay network between r3 and r8. Configure this network and VLAN F to be in a RIP domain.
5. Use the IP address of 145.10.80.15 on interface FastEthernet 0/1 on sw15_3550. Configure this interface to exchange unicast RIP updates with r8.
6. Configure Layer 3 switching, if needed, such that all VLANs can ping each other for full IP reachability. Ensure that you can ping an address on VLAN X and VLAN Y from r11.
7. Ensure full IP reachability between the OSPF domain and the RIP domains.
8. Configure a tag equal to the host name of the router of autonomous system boundary routers (ASBRs) for the routes redistributed into OSPF. If r2 is an ASBR, for instance, when you redistribute any routing protocols into OSPF on r2, set a tag value of 2 for those routes.
9. Configure the routers r3 and r8 such that all RIP routes have an administrative distance of 95.

Section IV: EIGRP Integration

1. Configure EIGRP with AS 2003 between r10, r4, and sw16_3550.
2. Advertise the loopback networks of LB21-172.19.1.0/24 and LB20-172.18.1.0/24 on r10 via EIGRP. Prevent the RIP domains from ever seeing the 172.19.1.0/24 route. R7 should see both 172 routes.
3. Ensure full IP reachability between the EIGRP, OSPF, and RIP domains. Be sure that r10 can ping r7, VLAN X, and VLAN Y on sw15_3550.

Section V: Traffic Control and ISDN

1. Configure r4 such that Telnet traffic from VLAN B destined toward VLAN D will pass through r5. Pings from VLAN B destined toward VLAN D will go through r11. All other traffic should follow the directions in the route/forwarding table.
2. Configure the ISDN network between r10 and r3. Use the following guidelines:

- Configure r10 to only place the calls when IP connectivity is lost in any manner.
- Use PPP CHAP for authentication; use cisco as the password.
- The dialer should not remain up all the time due to routing protocols.
- Do not use static routes; routing should be dynamic.
- You can configure additional routing protocols to route across the ISDN link.
- R10 should pick up the second B channel with minimal load.
- The link should drop after 3 minutes of idle time.

Section VI: BGP

1. Configure BGP between r4 and r10.

- All I-BGP routes should be reachable in the BGP table; no NEXT_HOP attributes can be altered. You cannot use route reflectors or confederations.
- Place both routers in AS 144.
- Each router must use its VLAN B IP address for BGP identification.
- R4 should only advertise the 145.10.0.0/18 and 206.191.1.0/24 networks. One static route to an interface only (no IP addresses) can be used for this item.
- R10 should only advertise the 145.10.64.0/18 and 145.10.128.0/18 networks.
- Neither router should advertise private address space.
- Both routers should explicitly use the BGP soft-reset enhancement.
- Both routers should also have valid, reachable BGP routes to their neighbors' aggregate networks.

2. Configure BGP between r7 and the two routers in AS 144.

- Place r7 in AS 12501.
- Configure this router to use its Ethernet IP address as the BGP router ID.
- The AS 144 routers should also peer with the Ethernet IP address.
- Create two loopback interfaces: one in the 193.164.80.0/20 network and one in the 214.148.12.0/22 network.
- Advertise those networks to the E-BGP peers.
- Make r7 prefer routes to the 145.10.0.0/18, 145.10.64.0/18, and 206.191.1.0/24 networks from r4; you can not use the AS_PATH attribute for this task.

- Add r3 to AS 12501; use the directly connected interfaces for each neighbor as BGP peering points. Do not advertise new routes from this router.
3. Add r11 and r5 to AS 144; use the directly connected interfaces for each neighbor as BGP peering points. Do not advertise new routes from these routers. These routers should use their serial interfaces as their BGP router ID.
- Make r11 peer with r3, r4, and r5.
 - Make r5 peer with r3, r11, and r4.
 - R8 and the switches should not participate in BGP routing or learn BGP routes. All BGP routers should be able to ping any other BGP-advertised networks.

Section VII: QoS and ATM

1. Configure the ATM interfaces between r7 and r3.
 - R7 should use VPI/VCI 1/77 and R3 should use 1/88.
 - Both routers should have the capability to add other multipoint connections to this circuit at some point in the future.
 - Both routers must have explicit PVC configurations; the ATM switch should not be relied upon for PVC configuration.
 - Both routers should use the best ATM class of service for bursty data traffic, with an SCR of 1.544 and a PCR of 2.048 bps.
 - Use BGP to advertise the /20 summary of the ATM network without using the network command. Do not advertise this network by means of IGP protocols. Remember not to advertise private networks.
 - During periods of congestion, the Frame Relay-attached routers should drop packets based on IP precedence values; traffic from network 145.10.32.0/29 should have the highest noncontrol precedence value.
 - Configure these routers to use the best congestion avoidance algorithm to prevent tail drop based on the IP precedence values.

Section VIII: DLSW+

1. Configure a DLSw TCP peer between VLAN B on r10 and VLAN D on r3. The peer should stay active and not disconnect while the ISDN link converges.
2. Configure another DLSw TCP peer from VLAN A on r5 to VLAN D on r3. This peer should only become active for NetBIOS traffic originating on VLAN A. The peer should drop 3 minutes after the last circuit disconnects.

3. You cannot configure remote-peer statements on r3.

CCIE Practice Lab: !!! Boom . . .

Equipment List:

- 1 Frame Relay switch: 4 serial ports
- ISDN simulator/switch with 2 BRI ports
- 2 lab routers: 1 Ethernet interface
- 1 lab router: 1 Fast Ethernet, 1 serial, 1 ATM, 1 ISDN BRI interface
- 1 lab router: 1 Ethernet, 1 ISDN BRI, 1 serial interface
- 1 lab router: 2 Ethernet interfaces
- 1 lab router: 1 Serial and 1 Ethernet interface
- 1 Ethernet 3550 switch with the EMI software, 2 fiber ports or crossover cables for interconnection
- 1 Ethernet 35xx Ethernet switch capable of Fast or Gigabit EtherChannel

Prestaging—Frame Relay Switch, Backbone Routers, and ATM Configuration

Configure the Frame Relay switch with the PVCs as depicted in [Figure 10-3](#). Do not time yourself on this portion of the lab. Not all the PVCs in the diagram are used. The PVCs indicated by the solid lines are the ones you will use. Also configure the backbone routers r5 and r11 and the ATM switch. [Example 10-2](#) lists the configurations for the Frame and ATM switches. [Example 10-3](#) lists the configuration for the backbone routers r5 and r11.

Example 10-2. Frame Relay and ATM Switch Configurations

```
hostname frame_switch
!
frame-relay switching
!
interface Ethernet0
  no ip address
  shutdown
```

```
!

interface Serial0

no ip address

encapsulation frame-relay

no fair-queue

clockrate 2000000

frame-relay intf-type dce

frame-relay route 102 interface Serial1 101

frame-relay route 202 interface Serial5 204

frame-relay route 302 interface Serial4 206

frame-relay route 402 interface Serial3 408

frame-relay route 802 interface Serial8 708

!

interface Serial1

no ip address

encapsulation frame-relay

clockrate 2000000

frame-relay intf-type dce

frame-relay route 101 interface Serial0 102

frame-relay route 103 interface Serial5 104

frame-relay route 105 interface Serial4 106

frame-relay route 107 interface Serial3 108

frame-relay route 108 interface Serial8 808

frame-relay route 109 interface Serial2 110

!

interface Serial2

no ip address

encapsulation frame-relay
```

```
clockrate 64000

frame-relay intf-type dce

frame-relay route 110 interface Serial1 109
frame-relay route 111 interface Serial3 708

!

interface Serial3

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 108 interface Serial1 107
frame-relay route 408 interface Serial0 402
frame-relay route 508 interface Serial4 506
frame-relay route 608 interface Serial5 804
frame-relay route 708 interface Serial2 111

!

interface Serial4

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 106 interface Serial1 105
frame-relay route 206 interface Serial0 302
frame-relay route 306 interface Serial5 304
frame-relay route 506 interface Serial3 508

!

interface Serial5

no ip address
```

```
encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 104 interface Serial1 103
frame-relay route 204 interface Serial0 202
frame-relay route 304 interface Serial4 306
frame-relay route 404 interface Serial8 110
frame-relay route 804 interface Serial3 608

!

interface Serial6
no ip address

!

interface Serial7
no ip address

!

interface Serial8
no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 108 interface Serial5 404
frame-relay route 708 interface Serial0 802
frame-relay route 808 interface Serial1 108

!

interface Serial9
no ip address

shutdown

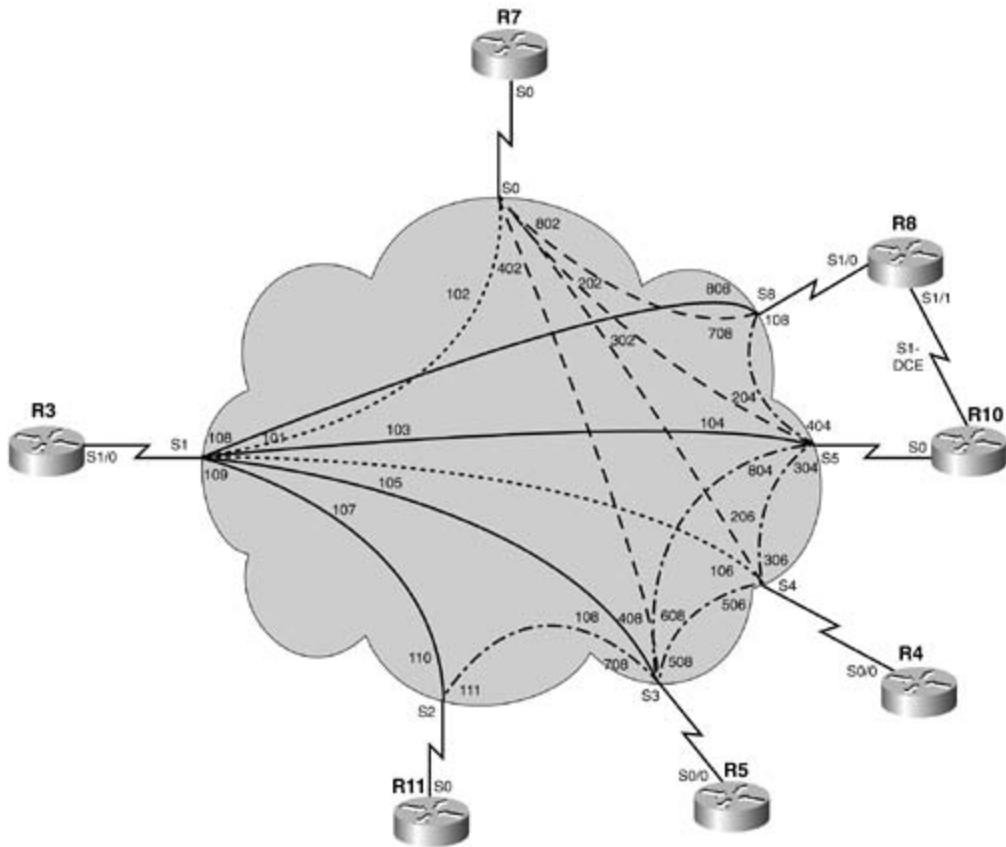
!
```

```
interface BRI0
  no ip address
  shutdown
!
no ip classless
!
line con 0
line aux 0
line vty 0 4
login
!
end
```

----- backbone routers -----ô

Figure 10-3. Frame Relay Switch Configuration

Master Frame Relay DLCI Map
Not All PVCs and Interfaces Will Be Used



Example 10-3. Backbone Router r5 and Backbone Router r11 Configurations

```
hostname backbone_router_r5
!
clns routing
!
voice-port 1/0/0
!
voice-port 1/0/1
!
```

```
voice-port 1/1/0
!
voice-port 1/1/1
!
dlsw local-peer peer-id 141.200.5.5 promiscuous
dlsw icanreach netbios-name backbone_rtr5
dlsw bridge-group 1
!
interface Ethernet0/0
    ip address 141.200.5.5 255.255.255.0
    ip router isis
    bridge-group 1
!
interface Serial0/0
    no ip address
    encapsulation frame-relay
    no ip mroute-cache
!
interface Serial0/0.1 point-to-point
    ip address 140.200.1.1 255.255.255.0
    ip router isis
    no ip mroute-cache
    frame-relay interface-dlci 108
!
interface Serial0/1
    no ip address
    shutdown
    clns router isis
```

```
!  
  
router isis  
  
    redistribute connected metric 30 metric-type internal level-1  
    distance 140  
  
    net 00.0001.0050.736b.7800.00  
  
!  
  
ip classless  
  
!  
  
!  
  
bridge 1 protocol ieee  
  
!  
  
end  
  
-----→  
  
hostname backbone_router_r11  
  
!  
  
ip subnet-zero  
  
!  
  
isdn voice-call-failure 0  
  
!  
  
interface Loopback20  
  
    ip address 192.200.16.11 255.255.255.0  
  
    no ip directed-broadcast  
  
!  
  
interface Loopback21  
  
    ip address 192.200.17.11 255.255.255.0  
  
    no ip directed-broadcast  
  
!  
  
interface Loopback22
```

```
ip address 192.200.18.11 255.255.255.0
no ip directed-broadcast
!
interface Loopback23
ip address 192.200.19.11 255.255.255.0
no ip directed-broadcast
!
interface Loopback24
ip address 192.200.20.11 255.255.255.0
no ip directed-broadcast
!
interface Ethernet0
description to fast 0/11 on sw15_3550
ip address 129.200.17.11 255.255.255.0
no ip directed-broadcast
!
<<<text omitted>>>
!
router rip
network 129.200.0.0
network 192.200.16.0
network 192.200.17.0
network 192.200.18.0
network 192.200.19.0
network 192.200.20.0
!
end
```

The following portion of the lab is timed and should begin after the configuration and physical installation of all hardware.

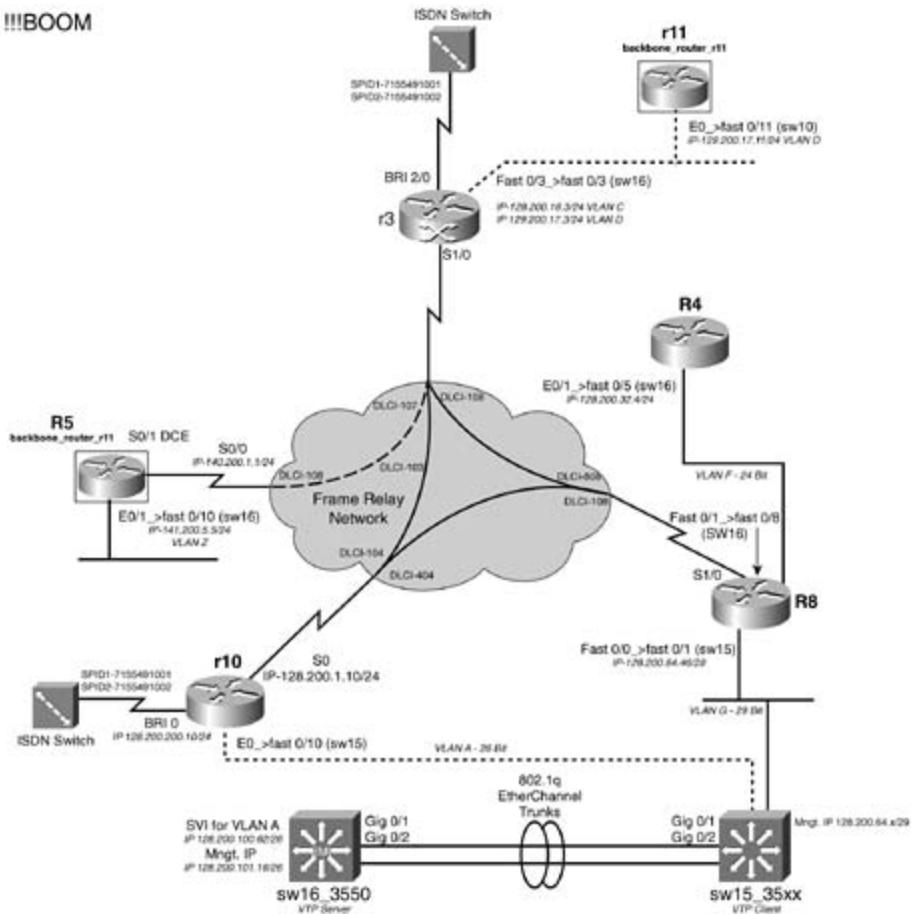
Rules

- No static routes or floating static routes are allowed unless specifically stated.
- Follow the instructions exactly. Be careful to only propagate routes where and when instructed. Only use the PVCs as directed by the instructions.
- You can use the configuration guides and the CD-ROM for your only reference material.
- You have 8.5 hours to complete this portion of the lab. Do not talk to anyone during this phase.
- It is recommended that you read the entire lab before beginning.

Section I: IP Setup

1. Use the IP addresses as depicted in [Figure 10-4](#) and address the network accordingly.
Note: Not all the IP addresses can be assigned at this time.

Figure 10-4. Network Diagram for !!! Boom . . .



2. Use the IP addresses 128.200.16.3/24 and 129.200.17.3/24 on the Fast 3/0 interface of r3. Use VLAN C for subnet 128.200.16.0/24 and VLAN D for the 129.200.17.0/24 subnet.
3. Use the IP address of 128.200.32.4/24 on r4's E0/1. This interface is in VLAN F.
4. R8 has the Fast 0/1 interface in VLAN F and the Fast 0/0 interface in VLAN G. Use the IP address of 128.200.64.46/29 on the Fast 0/0 interface.
5. R10 will use the IP address of 128.200.1.10/24 on its s0 interface.
6. Use the network 128.200.0.0 for all other subnets and host addresses:
 - VLAN A: 26-bit subnet
 - VLANs C, D, F, X, Z: 24-bit subnet
 - VLAN G: 6 usable host addresses

Section II: Catalyst Configuration

1. Configure an 802.1Q Gigabit EtherChannel trunk between sw15_35xx and sw16_3550 using the Gig 0/1 and Gig 0/2 interfaces. (You can substitute 100BASE-T interfaces for this

lab.) Do not put IP addresses on the Gigabit interfaces. The EtherChannel trunk should be configured for PAgP.

2. Configure the VLANs as depicted in [Figure 10-4](#).
3. Configure sw16_3550 to be a VTP server and sw15_35xx to be the client. Use ccie as the VTP domain name and password protect it.
4. Allow full configuration access to the switches by doing the following:
 - Configure a management address of 128.200.101.16/24 on VLAN X on sw16_3550. Configure a management address in VLAN G on sw15_3550. Users should authenticate with the username ccie and use a password of psv2.
 - Allow only two Telnet sessions per switch. If a third Telnet session is opened to the same switch, it will fail. The switches should be configurable and reachable from all routers in the lab.

Section III: OSPF, Layer 3 Switching, and Frame Relay

1. Configure a fully meshed Frame Relay network between r3, r10, and r8 such that they share the same IP subnet 128.200.1.0/24. You can only use subinterfaces on r3. You cannot change the IP OSPF network type on Frame Relay interfaces.
2. Configure the Frame Relay network to be in OSPF area 0 between r3, r10, and r8.
3. Configure VLAN A to be in OSPF area 200.
4. Do not run OSPF on the backbone to r11 VLAN D, r8 VLAN F, and r8 VLAN G.
5. Configure VLAN X on sw16_3550 to be in OSPF area 300. Configure VLAN A on the sw16_3550 to be in OPSF area 200.
6. When a link-state type 5 is created on a router, it should be tagged with the router number that created it. If r4 creates a link-state type 5, for example, it should have a tag of 4. Ensure that the OSPF domain will have full IP connectivity to the RIP, EIGRP, and IS-IS domains.

Section IV: RIP, EIGRP, IS-IS Integration

1. Configure VLAN D to be in a RIP domain, which connects to the backbone router r11. When you connect to the backbone router r11, you should receive the following RIP routes: 192.200.16.0/24, 192.200.17.0/24, 192.200.18.0/24, 192.200.19.0/24, and 192.200.20.0/24. Ensure that all OSPF routers can reach these routes.
2. Configure EIGRP on VLAN F and VLAN G only. Do not use the passive interface commands to accomplish this. Allow full reachability between the EIGRP, OSPF, and RIP domains.
3. Configure IS-IS between r3 and the backbone r5. Ensure that you see the IS-IS route 141.200.5.0/24 from the backbone r5.

4. Ensure that all routing domains can reach each other. Ensure that sw16_3550 can send 100 straight pings to all the OSPF and IS-IS Frame Relay interfaces, the IS-IS route 141.200.5.0/24, and 192.200.x.x routes from the RIP domain.

Section V: Route Filtering and Control

1. Prevent the backbone r11 from seeing any of the IS-IS routes, 140.200.1.0/24, and 141.200.5.0/24. Accomplish this with a two-line ACL.
2. Allow r4 to see only the even subnets from the RIP domain. Accomplish this with a two-line ACL.

Section VI: ISDN

1. Configure the ISDN network between r10 and r3. Use the following guidelines:
 - Use the IP address of 128.200.200.10/24 on r10. This subnet should be in OSPF area 0.
 - The dialer should not remain up all the time due to routing protocols. Configure r10 to only place the calls upon loss from the Frame Relay service.
 - Use PPP CHAP for authentication; use cisco_isdn as the password.
 - Do not use static routes; routing should be dynamic.
 - R10 should pick up the second B channel when the link is used over 32 kbps of outbound traffic.
 - The link should drop after 5 minutes of idle time.

Section VII: BGP

Unless otherwise specified, static routes are not allowed in this section. Do not advertise BRI interfaces into BGP. Unless otherwise specified, BGP routes cannot be redistributed into IGP routing protocols. All routers should prefer IGP routes to any BGP routes. All BGP routes should be aggregated to the smallest network prefix before being advertised to E-BGP neighbors. Have each BGP peer relationship use a static update source and BGP router ID. All routers should use the least possible configuration lines for their BGP configuration; BGP peers should be organized according to autonomous system number.

1. Configure BGP routing for r3, r8, and r10; put all of these routers in AS 5300. Have each of these routers peer with router 5 over the frame relay network. All AS 5300 routers should advertise all directly connected networks, and routes advertised to external peer should be summarized using the least number of network prefixes.

2. In addition to the previous configuration items, r3 should be configured to peer with r11, propagating all r11 routes to its I-BGP peers.
3. Configure BGP routing on r5; put this router in AS 12 and configure it to peer with the routers in AS 5300. Advertise the connected networks; then create loopbacks on the 4.0.0.0/8 and 5.5.0.0/16 networks and advertise these networks to all BGP neighbors.
4. The BGP router on r11 is in AS 500. Configure it to peer with r3. This router should use BGP authentication with all neighbors, using the password abc123. Create two loopbacks on r11, assigning them to networks 11.0.0.0/8 and 12.0.0.0/8, and advertise these networks to all BGP peers. Configure this router so that the routes sent to routers in AS 5300 will not propagate the route; no changes can be made on the AS 5300 routers to support this configuration.
5. Configure BGP routing on r4. Put this router in AS 101 and configure it to peer with router r8. Create two loopback interfaces on r4, assigning one to the 118.116.0.0/24 network and the other to the 117.116.115.0/24 network; advertise this network and all other connected networks to r8.
6. Configure r8 to hide r4's 117.116.115.0/24 network from r5 and, without making changes on r3 or r10, prevent the other AS 5300 routers from advertising that network to any peers.
7. Configure a single static route on sw16_3550 to the network 141.200.5.0/24 on backbone router r5. Do not use a default route.

Section VIII: QoS

1. Configure r8 with a policy that limits bandwidth consumption on its Frame Relay interface based on packet size. Use the packet size and bandwidth percentages shown in [Table 10-1](#). Follow Cisco's interface bandwidth and queuing recommendations when allocating bandwidth restrictions.

Table 10-1. r8 Policy Parameters

Packet Size	Bandwidth Limitation
64 to 127	28%
128 to 255	10%
256 to 511	18%
512 to 767	9%
768 to 1024	6%
Other	Queue using WFQ

Section IX: DLSW+

1. Configure a DLSw TCP peer between VLAN A on r10 and 141.200.5.5 on r5, the backbone router. You should see backbone_rtr5 in the DLSW reachability cache when this is complete.
2. If you lose connectivity to the 141.200.5.5 peer, another peer should become active on r5 that peers to r4's VLAN F, where the backup server resides. You cannot use a remote-peer statement on r5.
3. When the peer is active from r10 to r4, r4 should advertise the NetBIOS host backup r4. This peer should remain active up to 3 minutes after connectivity to the primary peer is restored.

CCIE Practice Lab: The Intimidator

Equipment List:

- 1 Frame Relay switch: 4 serial ports
- 7 lab routers: 1 Ethernet and 2 serial interfaces
- 2 lab routers: 1 Fast Ethernet, 2 serial, and 1 voice (1750s)
- 1 Ethernet 35xx Ethernet switch capable of extended VLANs

Prestaging—Frame Relay Switch and Backbone Router Configuration

Configure the Frame Relay switch with the PVCs as depicted in [Figure 10-5](#). Do not time yourself on this portion of the lab. Configure the backbone routers bb-1, bb-2, and bb-3. [Example 10-4](#) lists the configurations for the Frame Relay switch and the backbone routers, bb-1, bb-2, and bb-3.

Example 10-4. Frame Relay and Backbone Router Configurations

```
hostname frame_switch
!
ip subnet-zero
!
no ip domain-lookup
!
frame-relay switching
!
interface Serial0
  no ip address
  encapsulation frame-relay IETF
  frame-relay lmi-type ansi
  frame-relay intf-type dce
  frame-relay route 304 interface Serial1 403
```

```
frame-relay route 305 interface Serial2 503
frame-relay route 306 interface Serial3 603
!
interface Serial1
no ip address
encapsulation frame-relay IETF
clockrate 1300000
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 403 interface Serial0 304
!
interface Serial2
no ip address
encapsulation frame-relay IETF
clockrate 1300000
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 503 interface Serial0 305
!
interface Serial3
no ip address
encapsulation frame-relay IETF
logging event dlcstatus-change
frame-relay lmi-type ansi
frame-relay intf-type dce
frame-relay route 603 interface Serial0 306
!
no cdp run
```

```
!
end
----- bb-1 config ----- →
hostname bb-1
!
logging buffered 4096 debugging
no logging console
ip subnet-zero
no ip source-route
!
no ip domain lookup
!
interface Loopback10
ip address 177.164.12.1 255.255.252.0
!
interface Loopback20
ip address 177.164.16.1 255.255.252.0
!
interface Loopback30
ip address 2.0.0.1 255.0.0.0
!
interface Loopback40
ip address 8.0.0.1 255.0.0.0
!
interface Loopback50
ip address 16.0.0.1 255.0.0.0
!
interface Ethernet0/0
```

```
ip address 55.9.6.1 255.255.255.248
half-duplex
!
interface Serial0/0
ip address 177.164.8.5 255.255.255.252
clockrate 1300000
!
interface Serial0/1
ip address 177.164.8.9 255.255.255.252
!
interface Serial0/2
no ip address
shutdown
!
ip classless
no ip http server
!
end
----- bb-2 config ----- →
hostname bb-2
no logging console
!
ip subnet-zero
no ip domain lookup
!
interface Loopback10
ip address 55.9.8.1 255.255.248.0
!
```

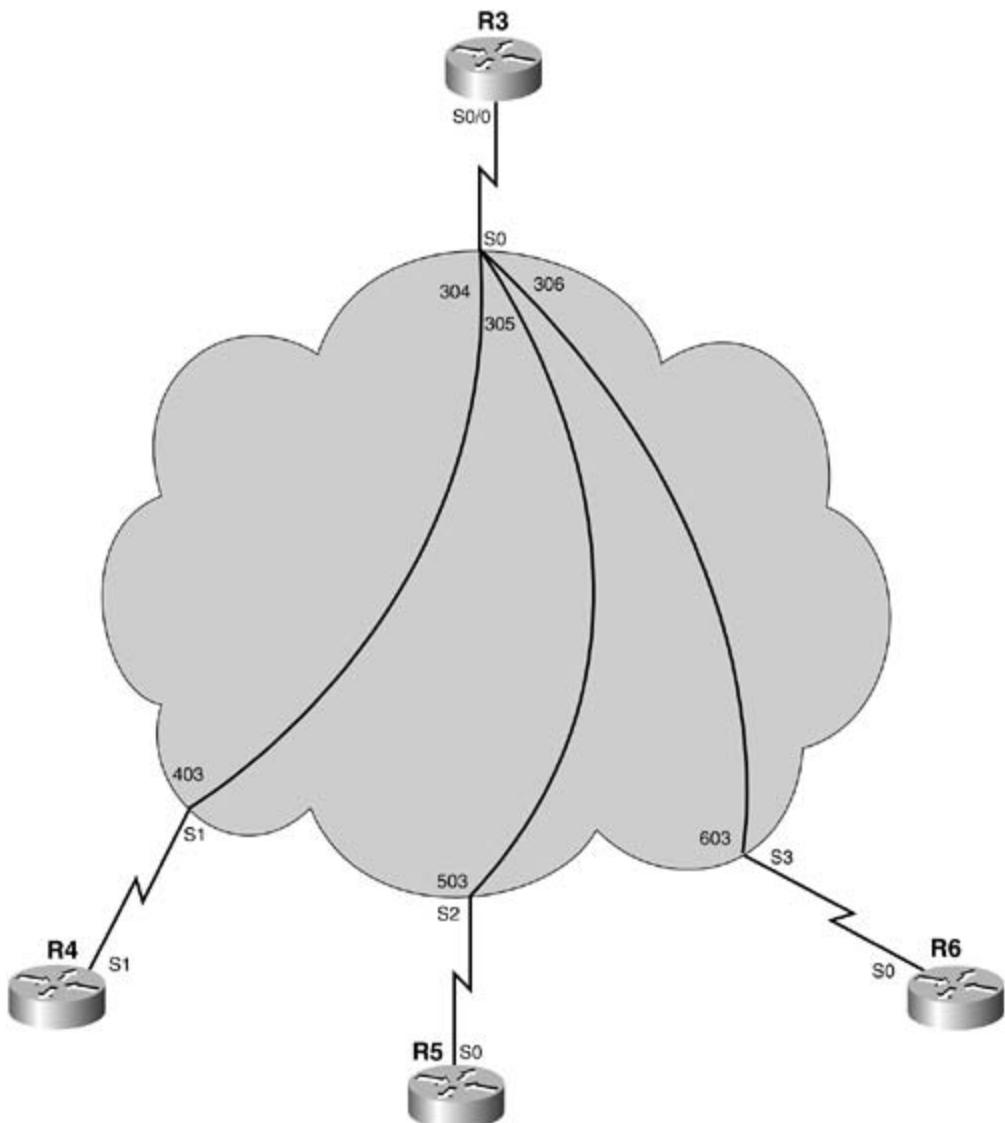
```
interface Loopback20
    ip address 55.9.16.1 255.255.248.0
!
interface Loopback30
    ip address 2.0.0.2 255.0.0.0
!
interface Loopback40
    ip address 8.0.0.2 255.0.0.0
!
interface Loopback50
    ip address 16.0.0.2 255.0.0.0
!
interface Ethernet0
    ip address 55.9.6.2 255.255.255.248
!
interface Serial0
    ip address 55.9.5.6 255.255.255.252
    clockrate 1300000
!
interface Serial1
    ip address 55.9.5.10 255.255.255.252
!
ip classless
ip http server
!
end
----- bb-3 config -----→
hostname bb-3
```

```
!  
logging buffered 4096 debugging  
no logging console  
!  
ip subnet-zero  
!  
no ip domain lookup  
!  
interface Loopback10  
ip address 168.101.12.1 255.255.252.0  
!  
interface Loopback20  
ip address 168.101.16.1 255.255.252.0  
!  
interface Loopback30  
ip address 2.0.0.3 255.0.0.0  
!  
interface Loopback40  
ip address 8.0.0.3 255.0.0.0  
!  
interface Loopback50  
ip address 16.0.0.3 255.0.0.0  
!  
interface FastEthernet0  
ip address 55.9.6.3 255.255.255.248  
speed auto  
!  
interface Serial0
```

```
ip address 192.168.2.1 255.255.255.252
!
interface Serial1
  ip address 168.101.8.1 255.255.255.252
  clockrate 1300000
!
ip classless
no ip http server
!
call rsvp-sync
!
voice-port 2/0
!
voice-port 2/1
!
dial-peer cor custom
!
!
end
```

Figure 10-5. Frame Relay Switch Configuration

Frame Relay DLCI Map



The following portion of the lab is timed and should begin after the configuration and physical installation of all hardware.

Rules

- No static routes or floating static routes are allowed unless specifically stated. This lab allows you to use a very limited amount of static routes. When you can use a static route, it is clearly noted.
- Follow the instructions exactly. Be careful to only propagate routes where and when instructed. Only use the PVCs as directed by the instructions.
- You can use the configuration guides and the CD-ROM for your only reference material.

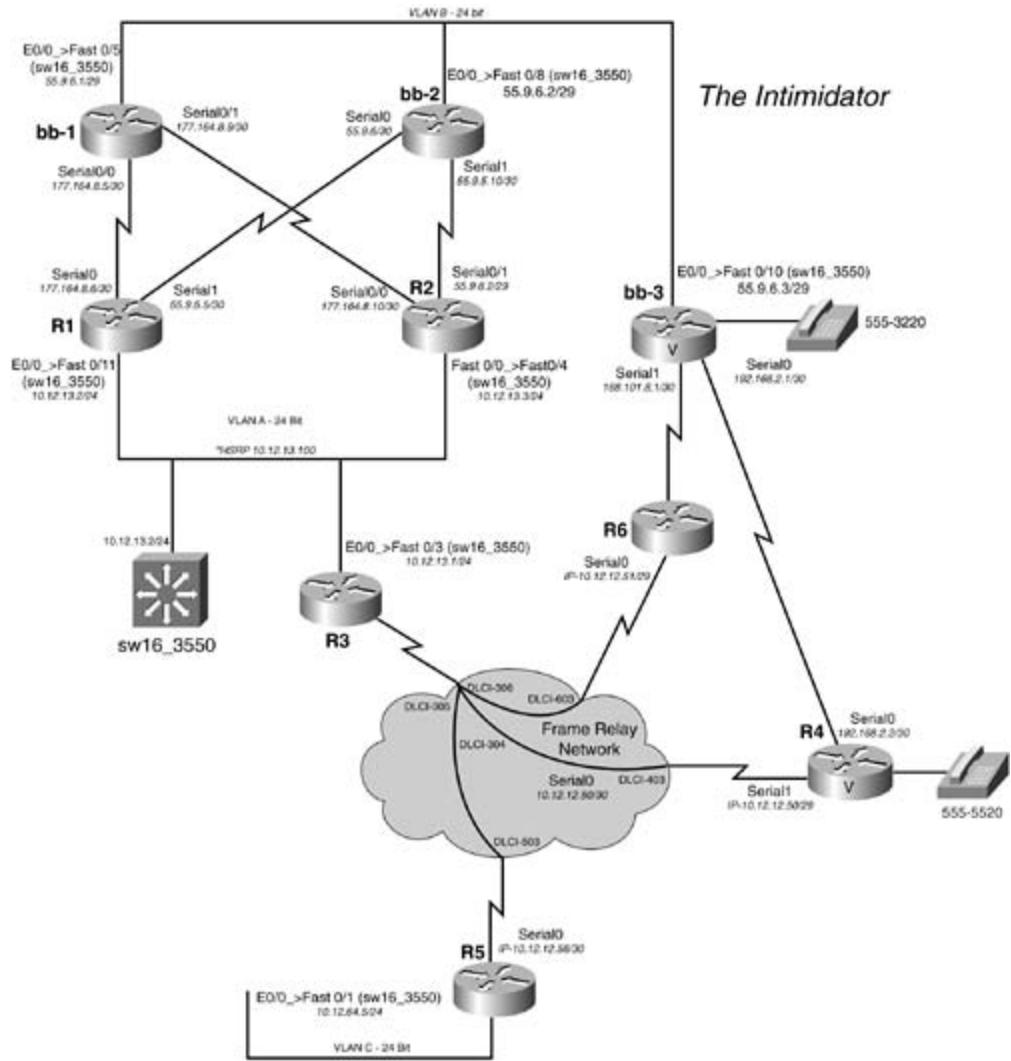
- You have 8.5 hours to complete this portion of the lab. Do not talk to anyone during this phase.
- It is recommended that you read the entire lab before beginning.

Section I: IP Setup

1. Use the IP addresses as depicted in [Figure 10-6](#) and address the network accordingly.
Note: Not all the IP addresses can be assigned at this time.

- Use the IP subnet of 10.12.13.0/24 for VLAN A, joining r1, r2, and r3.
- Use the IP address of 10.12.64.5 on r5's E0 port. This interface is in VLAN C.
- R4 will use the IP address of 192.168.2.2/30 on its s0 interface to the backbone router bb-3.
- R6, r4, and r3 all share the same IP subnet on the WAN and should be configured as such. R6 serial 0 interface should have an IP address of 10.12.12.51/29, and r4 should have an IP address of 10.12.12.50/29 on its serial interface.
- Use the network 10.12.0.0 for all other subnets and host addresses:
VLANs A, B, C: 24-bit subnet

Figure 10-6. Network Diagram for the Intimidator



Section II: Catalyst Configuration

- Configure all the VLANs as depicted in [Figure 10-6](#). Do not use VLAN 1. The valid VLAN range you can use is 2000 to 3000.
- Name the VTP domain name labx. Configure STP such that if new switches are added to the backbone subnet of 55.9.6.0/29, sw16_3550 will remain root.
- Configure the switch with the IP address of 10.12.13.2/24. Configure the switch such that it can be reachable via IP. The switch should be reachable if r1, r2, or r3 goes down.

Section III: OSPF and Frame Relay

- Configure a partial-mesh Frame Relay network between r3, r6, and r4 such that they share

- the same IP subnet. You can only use subinterfaces on r3.
2. Configure VLAN A to be in OSPF area 0.
 3. Configure the Frame Relay network to be in OSPF area 100 between the routers r3, r6, and r4. You cannot use neighbor statements.
 4. Configure area 100 such that all external link states will appear as link-state type 7s on r6 and r4.

Section IV: EIGRP Integration

1. Configure EIGRP on VLAN C and the Frame Relay network between r3 and r5.
2. Configure r5 to be an EIGRP stub router. Ensure that r5 will advertise VLAN C. Allow full reachability between the EIGRP and OSPF domains. Ensure that r5 can ping the serial interfaces of bb-3 and the LAN interfaces of r1 and r2.

Section V: HSRP

1. Configure HSRP for VLAN A, such that r1 will be primary. Use the IP address of 10.12.13.100 as the shared IP address.
2. If r1 loses its serial interface, r2 will be primary. If r1 and r2 lose both of their serial interfaces, r3 should become primary.

Section VI: BGP

1. Each router should use an explicitly configured BGP router ID. This ID should be the lowest IP address belonging to the locally generated public address space. For example, bb-1 would use 177.164.8.5 for its BGP router ID. All BGP speakers should use the largest available update packet size. Do not allow the backbone routers (bb-1, bb-2, or bb-3) to use the lab routers (r1, r2, and r6) as a transit.
2. Configure BGP for the backbone routers using the information shown in [Table 10-2](#).
3. Wherever possible, network prefixes should be aggregated to the smallest mask size.
4. Routers bb-1 and bb-3 should use bb-2 as a transit network to reach each other.

Table 10-2. Backbone BGP Configuration

Router	Autonomous System Number	Remote Peer	Advertised Networks
bb-1	65	bb-2's Ethernet0 interface	177.164.8.0/22 177.164.12.0/22 177.164.16.0/22
		R2's serial0/0 interface	177.164.8.0/22 177.164.12.0/22 177.164.16.0/22 2.0.0.0/8 8.0.0.0/8 16.0.0.0/8
		R1's serial0 interface	177.164.8.0/22 177.164.12.0/22 177.164.16.0/22 2.0.0.0/8 8.0.0.0/8 16.0.0.0/8
bb-2	104	bb-1's Ethernet0/0 interface	55.9.0.0/21 55.9.8.0/21 55.9.16.0/21
		R1's serial1 interface	55.9.0.0/21 55.9.8.0/21 55.9.16.0/21 2.0.0.0/8 8.0.0.0/8 16.0.0.0/8

		R2's serial0/1 interface	55.9.0.0/21 55.9.8.0/21 55.9.16.0/21 2.0.0.0/8 8.0.0.0/8 16.0.0.0/8
bb-3	12	R6's serial1 interface	168.101.8.0/22 168.101.12.0/22 168.101.16.0/22 2.0.0.0/8 8.0.0.0/8 16.0.0.0/8
		bb-2's Ethernet0 interface	168.101.8.0/22 168.101.12.0/22 168.101.16.0/22
		bb-1's Ethernet0/0 interface	168.101.8.0/22 168.101.12.0/22 168.101.16.0/22

5. Enable BGP routing on r1.
6. Put this router in AS 10142 and advertise the locally connected 196.200.32.0/20 network to all neighbors.
7. This router should peer with bb-1, bb-2, and r2; each peer should be set up to use the directly connected IP address for BGP peering.
8. Locally originated routes should be aggregated to the smallest prefix size.
9. This router should also advertise the other 196.200.x.0 networks from r2 and r6; however, these routes should be advertised so that their external peers prefer the routes from their originating peer router. The AS_PATH attribute cannot be used for this step. Two static routes can be added to this router for this step.
10. Enable BGP routing on r2.
11. Put this router in AS 10142 and advertise the locally connected 196.200.48.0/20 network to all neighbors.
12. This router should peer with bb-1, bb-2, and r1; each peer should be set up to use the directly connected IP address for BGP peering.

13. Locally originated routes should be aggregated to the smallest prefix size.
14. This router should also advertise the other 196.200.x.0 networks from r1 and r6; however, these routes should be advertised so that their external peers prefer the routes from their originating peer router. The AS_PATH attribute cannot be used for this step. Two static routes can be added to this router for this step.
15. Configure r1 so that it prefers routes to the 2.0.0.0/8 and 8.0.0.0/8 networks from bb-1 and the route to 16.0.0.0/8 network from bb-2. These settings should not be passed to any routers, and the AS_PATH attribute cannot be used for this step.
16. Enable BGP routing on r6.
17. Put this router in AS 10142 and advertise the locally connected 196.200.64.0/20 network to all neighbors.
18. This router should peer with bb-3, r1, and r2; each peer should be set up to use the directly connected IP address for BGP peering.
19. Locally originated routes should be aggregated to the smallest prefix size.
20. This router should also advertise the other 196.200.x.0 networks from r1 and r2; however, these routes should be advertised so that their external peers prefer the routes from their originating peer router. The AS_PATH attribute cannot be used for this step. Two static routes can be added to this router for this step.
21. Configure BGP routing between r1 and r6 and r2 and r6. Configure these routers to reach each other's locally originating BGP networks using Layer 2 VPN interfaces.

Section VII: Voice

1. Configure Voice over IP between these two routers using the 192.168.2.0/30 network as follows:
2. Attach a phone to port 2/0 on r4. This phone will be assigned the 555-5520 phone number.
3. Attach a phone to port 2/0 on bb-3. This phone will use the 555-3220 phone number.
4. Use the g723r63 codec for each voice connection.
5. Configure r5 so that when the phone is picked up, it automatically calls bb-3.
6. Configure bb-3 so that it dials r5 whenever either the 555-5520 or 811 numbers are dialed.

Section VIII: QoS

1. Configure each outbound backbone connection on routers r1, r2, and r6 so that they will drop traffic based on IP precedence values during periods of congestion.
2. Configure r3 with the following policy:

- All traffic on TCP port 80 should be limited to 20% of the Ethernet0/0 interface's bandwidth. Any HTTP traffic should proactively be dropped using WRED.
- All other traffic should be queued using Weighted Fair Queuing.
- Configure RSVP for all voice calls between the two Voice over IP callers; make sure that RSVP only allows enough bandwidth for the two callers and that the EF-PHB is used for all calls.
- Configure each Voice over IP session to request guaranteed rate QoS and use the EF-PHB for all incoming calls.

Section IX: DLSw+

1. Configure a DLSw+ peer between VLAN A on r3 and VLAN C on r5. Configure the peer such that it supports RFC 1490, with reliable delivery and local acknowledgment.
2. Configure the peer such that only SNA traffic will be allowed to cross the DLSw+ connection.

CCIE Practice Lab: Enchilada II

Equipment List:

- 1 Frame Relay switch: 5 serial ports
- ISDN simulator/switch with 2 BRI ports
- ATM switch with 2 ATM interfaces
- 2 lab routers: 1 Ethernet and 1 serial interface
- 1 lab router: 1 Fast Ethernet, 1 serial, 1 ATM, and 1 ISDN BRI
- 1 lab router: 1 Ethernet, 1 ISDN BRI, and 1 serial
- 1 lab router: 2 Ethernet and 1 serial
- 1 lab router: 1 ATM
- 1 lab router: 1 Ethernet
- 1 Ethernet 3550 switch with the EMI software, with 2 fiber ports or crossover cables for interconnection
- 1 Ethernet 35xx Ethernet switch

Prestaging—Frame Relay Switch, Backbone Routers, and ATM Configuration

Configure the Frame Relay switch with the PVCs as depicted in [Figure 10-7](#). Do not time yourself on this portion of the lab. Not all the PVCs in the diagram are used. Also, configure the backbone routers r5 and r11 and the ATM switch. [Example 10-5](#) lists the configurations for the Frame and ATM switches. [Example 10-6](#) lists the configuration for the backbone routers r5 and r11.

Example 10-5. Frame Relay and ATM Switch Configurations

```
hostname frame_switch
!
frame-relay switching
!
interface Ethernet0
  no ip address
```

```
shutdown

!

interface Serial0
    no ip address
    encapsulation frame-relay
    no fair-queue
    clockrate 2000000
    frame-relay intf-type dce
    frame-relay route 102 interface Serial1 101
    frame-relay route 202 interface Serial5 204
    frame-relay route 302 interface Serial4 206
    frame-relay route 402 interface Serial3 408
    frame-relay route 802 interface Serial8 708

!

interface Serial1
    no ip address
    encapsulation frame-relay
    clockrate 2000000
    frame-relay intf-type dce
    frame-relay route 101 interface Serial0 102
    frame-relay route 103 interface Serial5 104
    frame-relay route 105 interface Serial4 106
    frame-relay route 107 interface Serial3 108
    frame-relay route 108 interface Serial8 808
    frame-relay route 109 interface Serial2 110

!

interface Serial2
    no ip address
```

```
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 110 interface Serial1 109
frame-relay route 111 interface Serial3 708
!
interface Serial3
no ip address
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 108 interface Serial1 107
frame-relay route 408 interface Serial0 402
frame-relay route 508 interface Serial4 506
frame-relay route 608 interface Serial5 804
frame-relay route 708 interface Serial2 111
!
interface Serial4
no ip address
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 106 interface Serial1 105
frame-relay route 206 interface Serial0 302
frame-relay route 306 interface Serial5 304
frame-relay route 506 interface Serial3 508
!
interface Serial5
```

```
no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 104 interface Serial1 103

frame-relay route 204 interface Serial0 202

frame-relay route 304 interface Serial4 306

frame-relay route 404 interface Serial8 110

frame-relay route 804 interface Serial3 608

!

interface Serial6

no ip address

!

interface Serial7

no ip address

!

interface Serial8

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 108 interface Serial5 404

frame-relay route 708 interface Serial0 802

frame-relay route 808 interface Serial1 108

!

interface Serial9

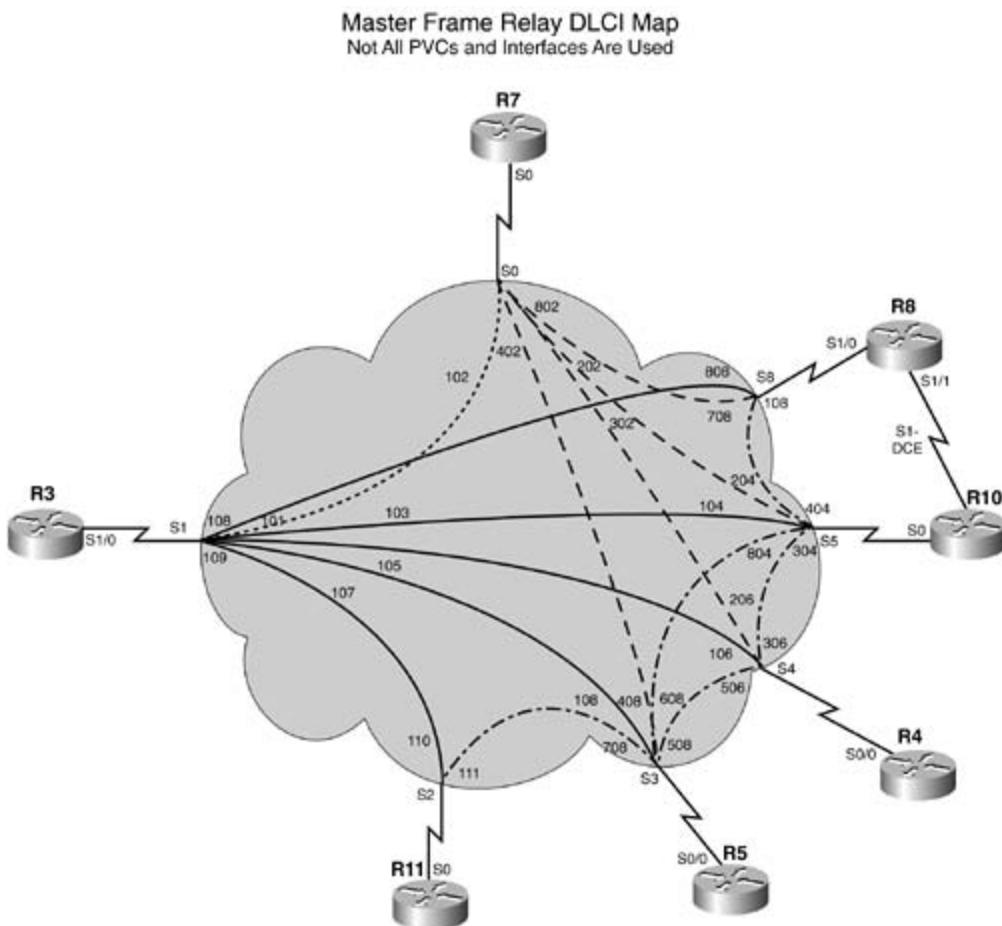
no ip address

shutdown
```

```
!  
  
interface BRI0  
  
    no ip address  
  
    shutdown  
  
!  
  
    no ip classless  
  
!  
  
end  
  
----- ATM -----→  
  
hostname ls1010  
  
!  
  
!  
  
atm address 47.0091.8100.0000.0061.705b.4001.0061.705b.4001.00  
  
!  
  
interface ATM0/0/0  
  
    no keepalive  
  
    no atm auto-configuration  
  
    no atm address-registration  
  
    no atm ilmi-enable  
  
    no atm ilmi-lecs-implied  
  
!  
  
interface ATM0/0/1  
  
    no keepalive  
  
    no atm auto-configuration  
  
    no atm address-registration  
  
    no atm ilmi-enable  
  
    no atm ilmi-lecs-implied  
  
atm pvc 1 101 interface ATM0/0/0 1 102
```

```
!  
  
interface ATM0/0/2  
    no keepalive  
!  
  
interface ATM0/0/3  
    no keepalive  
!  
  
interface ATM1/1/3  
    no keepalive  
!  
  
interface ATM2/0/0  
    no ip address  
    no keepalive  
    atm maxvp-number 0  
!  
  
interface Ethernet2/0/0  
    no ip address  
!  
    no ip classless  
    logging buffered  
!  
line con 0  
line aux 0  
line vty 0 4  
    login  
!  
end
```

Figure 10-7. Frame Relay Switch Configuration



Example 10-6. Backbone Router r5 and Backbone Router r11 Configurations

```
hostname backbone_router_r5
!
ip tcp path-mtu-discovery
!
voice-port 1/0/0
```

```
!  
voice-port 1/0/1  
!  
voice-port 1/1/0  
!  
voice-port 1/1/1  
!  
interface Loopback0  
  ip address 201.201.5.5 255.255.255.0  
!  
interface Loopback4  
  ip address 4.4.4.4 255.0.0.0  
!  
interface Loopback6  
  ip address 6.6.6.6 255.0.0.0  
!  
interface Loopback12  
  ip address 12.1.1.1 255.0.0.0  
!  
interface Loopback55  
  ip address 5.5.5.5 255.255.0.0  
!  
interface Ethernet0/0  
  ip address 10.1.2.5 255.255.255.0  
!  
interface Serial0/0  
  ip address 10.1.1.5 255.255.255.0  
  encapsulation frame-relay
```

```
ip ospf network point-to-point
no ip mroute-cache
frame-relay interface-dlci 108
!
interface Serial0/1
no ip address
shutdown
!
router ospf 2003
network 10.1.0.0 0.0.255.255 area 500
area 500 stub
!
router bgp 65001
no synchronization
bgp router-id 10.1.1.5
bgp confederation identifier 10001
bgp confederation peers 65002
network 4.0.0.0
network 5.5.0.0 mask 255.255.0.0
network 6.0.0.0
network 12.0.0.0
neighbor AS65001 peer-group
neighbor AS65001 remote-as 65001
neighbor AS65001 route-reflector-client
neighbor AS65001 update-source Serial0/0
neighbor AS65001 next-hop-self
neighbor 10.1.1.3 peer-group AS65001
no auto-summary
```

```
!  
ip classless  
!  
logging buffered 4096 debugging  
!  
end  
  
-----→  
hostname backbone_router_r11  
!  
ip subnet-zero  
ip tcp path-mtu-discovery  
!  
isdn voice-call-failure 0  
!  
interface Loopback20  
ip address 192.200.16.11 255.255.255.0  
no ip directed-broadcast  
!  
interface Loopback21  
ip address 192.200.17.11 255.255.255.0  
no ip directed-broadcast  
!  
interface Loopback22  
ip address 192.200.18.11 255.255.255.0  
no ip directed-broadcast  
!  
interface Loopback23
```

```
ip address 192.200.19.11 255.255.255.0
no ip directed-broadcast
!
interface Loopback24
ip address 192.200.20.11 255.255.255.0
no ip directed-broadcast
!
interface Loopback88
ip address 88.8.8.8 255.255.0.0
no ip directed-broadcast
!
interface Ethernet0
description to fast 0/11 on sw15_3550
ip address 192.168.2.11 255.255.255.0
no ip directed-broadcast
ip ospf message-digest-key 2 md5 trustnol
!
interface Serial0
no ip address
no ip directed-broadcast
no ip mroute-cache
shutdown
!
interface Serial1
no ip address
no ip directed-broadcast
shutdown
!
```

```

router ospf 2003

area 0 authentication message-digest

network 192.168.2.11 0.0.0.0 area 0

network 192.200.0.0 0.0.255.255 area 200

!

router bgp 96

bgp router-id 192.168.2.11

bgp cluster-id 2177372427

network 88.8.0.0 mask 255.255.0.0

neighbor 192.168.2.1 remote-as 10001

neighbor 192.168.2.1 password :)router

neighbor 192.168.2.1 update-source Ethernet0

!

ip classless

no ip http server

!

end

```

The following portion of the lab is timed and should begin after the configuration and physical installation of all hardware.

Rules

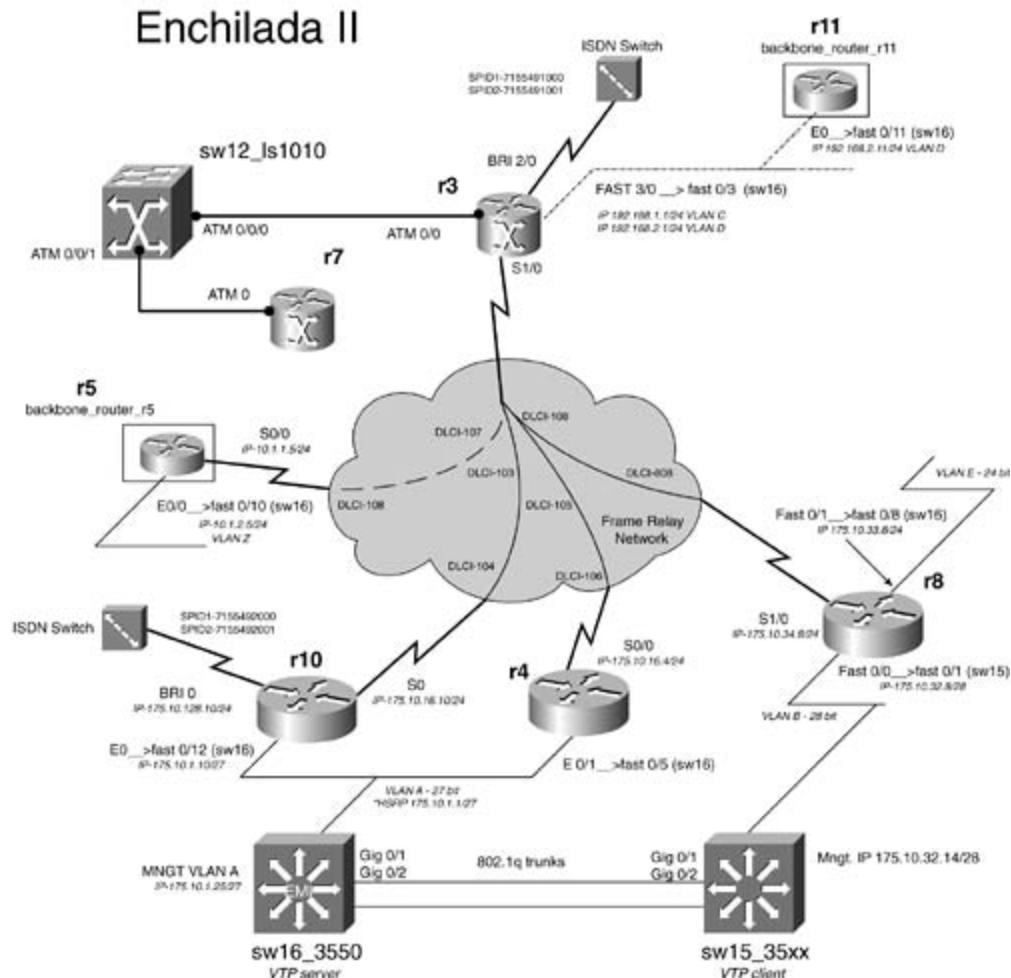
- No static routes or floating static routes are allowed unless specifically stated.
- Follow the instructions exactly. Be careful to only propagate routes where and when instructed. Only use the PVCs as directed by the instructions.
- You can use the configuration guides and the CD-ROM for your only reference material.
- You have 8.5 hours to complete this portion of the lab. Do not talk to anyone during this phase.
- It is recommended that you read the entire lab before beginning.

- Make an accurate and precise network illustration.

Section I: IP Setup

1. Use the IP addresses as depicted in [Figure 10-8](#) and address the network accordingly.
Note: Not all the IP addresses can be assigned at this time.

Figure 10-8. Network Diagram for Enchilada II



2. Use the IP subnets 192.168.1.0/24 and 192.168.2.0/24 on the Fast 3/0 interface of r3. Use VLAN C for subnet 192.168.1.0/24 and VLAN D for the 192.168.2.0/24 subnet.
3. Use the IP address of 175.10.1.10/27 on r10's E0 interface. This interface is in VLAN A, along with r4's e0/1 interface.
4. R8 has the Fast 0/1 interface in VLAN E and the Fast 0/0 interface in VLAN B. Use the IP address of 175.10.33.8/24 on the Fast 0/1 interface and 175.10.32.8/28 on the Fast 0/0 interface.

5. Use the network 175.10.0.0 for all other subnets and host addresses:

- VLAN: 27-bit subnet
- VLAN B: 28-bit subnet
- VLANs C, D, E, Z: 24-bit subnet

Section II: Catalyst Configuration

1. Configure an 802.1Q Gigabit trunk between sw15_35xx and sw16_3550 using the Gig 0/1 and Gig 0/2 interfaces. (You can substitute 100BASE-T interfaces for this lab.) Do not put IP addresses on the Gigabit interfaces.
2. Configure the VLANs as depicted in [Figure 10-8](#). Do not use VLAN 1.
3. Configure sw16_3550 to be a VTP server and sw15_35xx to be the client. Use PSV2 as the VTP domain name and authenticate VTP with the password cisco.
4. Configure sw16_3550 to support 802.1w RSTP and 802.1s MSTP. Create three STP instances; use the following guidelines:
 - Instance 0: VLAN 1, STP priority 8192
 - Instance 1: VLANs 100–200, STP priority 4096
 - Instance 2: VLANs 2–99, 201–4094, STP priority 16834
 - Make sure 802.1w works with 802.1d on the sw15_35xx switch. That is, the VLAN priority for the VLANs noted above should be the same on sw15_35xx.
 - Ensure that ports on the switch that are connected to hosts are configured for 802.1w.
5. Sw16_3550 should be reachable using the IP address 175.10.1.25/27, and sw15_35xx should be reachable via the IP address 175.10.32.14/28. You cannot configure a default or static route on sw16_3550.

Section III: EIGRP, Layer 3 Switching, and Frame Relay

1. Configure a partial-mesh Frame Relay network between r3, r10, and r4. You can only use subinterfaces on r3.
2. Configure EIGRP over the Frame Relay network between r3, r10, and r4. Use the autonomous system ID of 2003.
3. Configure EIGRP on VLAN A between r10, r4, and sw16_3550. Enable Layer 3 switching on sw16_3550 to accomplish this.

Section IV: RIP, OSPF Integration

1. Configure OSPF between r3 and the backbone router r11. Configure VLAN C to be in OSPF area 100 and VLAN D in OSPF area 0.
Authenticate OSPF area 0 with Type II authentication.
2. When you connect to the backbone router r11, you should receive the following OSPF routes: 192.200.16.0/24, 192.200.17.0/24, 192.200.18.0/24, 192.200.19.0/24, and 192.200.20.0/24. Ensure that all routers can reach these routes, including the RIP and EIGRP domains.
3. Configure OSPF between r3 and the backbone router r5 over the Frame Relay network. Configure the Frame Relay network to be in area 500. Area 500 should be configured as a stub area.
4. Configure RIPv2 between r3 and r8. VLAN E and VLAN B should run RIPv2, too.

Use MD5 authentication for RIP updates over the Frame Relay link.

Section V: Route Filtering and HSRP

1. R10 and r4 should have EIGRP external routes 192.200.16.0/24, 192.200.17.0/24, 192.200.18.0/24, 192.200.19.0/24, and 192.200.20.0/24. R10 should only propagate the odd 192.200.0.0 subnets to sw16_3550. R4 should only propagate the even 192.200.0.0 subnets to sw16_3550.
2. Configure HSRP between r10, r4, and sw16_3550. Use 175.10.1.1/27 for the HSRP address.

Authenticate HSRP updates between all devices. Use the password trustno1.

R10 should be the default primary router. If r10 loses its serial interface, r4 should become primary. If r4 loses its serial interface and the r10 serial interface is down, sw16_3550 should become the HSRP primary.

Section VI: ISDN

1. Configure the ISDN network between r10 and r3. Use the following guidelines:
 - Use the IP address of 175.10.128.10/24 on r10. This subnet should be in the EIGRP domain.
 - The dialer should not remain up all the time due to routing protocols. Configure r10 to only place the calls upon losing the 192.168.2.0/24 and 192.168.1.0/24 routes.

- Use CHAP for authentication; use cisco_isdn as the password
- Do not use static routes; routing should be dynamic.
- The link should drop after 5 minutes of idle time.

Section VII: ATM

1. Configure an ATM PVC from r3's atm0/0 port to r7's atm0 port; use subinterface for this purpose.
2. Use the ATM encapsulation method that is most suited to bursty data traffic.
3. Configure the ATM circuit to support bursty delay-tolerant VBR traffic; this circuit should be configured to use a sustained cell rate of 8 T1s and a peak cell rate that supports the full bandwidth of the interface.
4. Use the 62.1.8.0 network with a 30-bit subnet mask for this network.

Section VIII: BGP

1. All BGP routers should peer with each other using statically assigned BGP router IDs; BGP routing updates should use the largest possible packet sizes. Unless otherwise specified, you cannot use route reflectors to accomplish tasks in this lab. BGP will only be used to advertise loopback networks; do not configure BGP to advertise any 10 networks. When routers have more than one peer in the same autonomous system, use a peer group to simplify the configuration. At the end of this section, all BGP routes should be reachable on all BGP routers. Add and advertise the following networks shown in [Table 10-3](#).

Table 10-3. Lab 4 BGP Networks

Advertising Router	Network
r3	62.1.8.0/24 3.0.0.0/8
r4	32.1.1.0/24 32.2.2.0/24
r5	4.0.0.0/8 5.5.0.0/16 6.0.0.0/8 12.0.0.0/8
r7	52.1.1.0/24 54.1.0.0/16 62.1.8.0/30
r10	22.1.1.0/24 24.24.24.24/24

2. Enable BGP routing on routers r3, r5, and r7. Configure all of these routers to peer with each other in AS 65001; these routers should also belong to parent AS 10001.

Configure r3 to peer with r11 in AS 96; these routers should use BGP authentication using the password ":)router".

R3 should also peer with r7 over the ATM network and r5 over the Frame Relay network; one route reflector statement is allowed on r3, r5, and r7 for this purpose.

R7 should be able to reach all networks r3 can reach; one default route is allowed on r7 for this purpose.

3. Configure BGP routing on routers r4 and r10; put these routers in AS 65002; these routers also belong to parent AS 10001.

R4 should also peer with r3 in AS 65001. All routers in AS 65002 should receive and be able to reach all BGP routes sent by r3 and vice versa.

Section IX: DLSW+

1. Configure a DLSw TCP peer between VLAN A on r4 and VLAN B or r8. Explorers and DLSw traffic from r4's VLAN A should only be allowed onto r8's VLAN B.
2. Configure a DLSw TCP peer between VLAN D on r3 and VLAN E of r8. Only explorers and DLSw traffic from VLAN D can reach r8's VLAN E.
3. DLSw traffic from these two peers should not interact with each other.

Section X: NAT

1. Configure NAT such that all users on VLAN B share a single IP address when accessing any internal lab equipment. If sw15_35xx issues a ping to r3, for instance, it should be translated.

Section XI: Multicast Routing

1. Configure multicast routing on r3, r10, and r7.
2. Use a rendezvous address of 175.10.16.3. R10 and r3 should both be able to ping the multicast address of 224.0.10.10 on the ATM interface of r7.

CCIE Practice Lab: Kobayashi Maru

Equipment List

- 1 Frame Relay switch: 4 serial ports
- ISDN simulator/switch with 2 BRI ports
- ATM switch with 2 ATM interfaces
- 1 lab router: 1 Ethernet and 1 serial interface
- 1 lab router: 1 Ethernet, 1 serial interface, and 1 FXS voice port
- 1 lab router: 1 Fast Ethernet, 1 serial, 1 ATM, and 1 ISDN BRI
- 1 lab router: 1 Ethernet, 1 ISDN BRI, and 2 serial
- 1 lab router: 2 Ethernet and 1 FXS voice port
- 1 lab router: 2 Ethernet and 1 serial
- 1 lab router: 1 ATM
- 1 Ethernet 3550 switch with the EMI software, 1 fiber port or crossover cable for interconnection
- 1 Ethernet 35xx Ethernet switch

Prestaging—Frame Relay Switch, Backbone Routers, and ATM Configuration

Configure the Frame Relay switch with the PVCs as depicted in [Figure 10-9](#). Do not time yourself on this portion of the lab. Not all the PVCs in the diagram are used. [Example 10-7](#) lists the configurations for the Frame Relay and ATM switches.

Example 10-7. Frame Relay and ATM Switch Configurations

```
hostname frame_switch
!
frame-relay switching
!
interface Ethernet0
  no ip address
```

```
shutdown

!

interface Serial0
    no ip address
    encapsulation frame-relay
    no fair-queue
    clockrate 2000000
    frame-relay intf-type dce
    frame-relay route 102 interface Serial1 101
    frame-relay route 202 interface Serial5 204
    frame-relay route 302 interface Serial4 206
    frame-relay route 402 interface Serial3 408
    frame-relay route 802 interface Serial8 708

!

interface Serial1
    no ip address
    encapsulation frame-relay
    clockrate 2000000
    frame-relay intf-type dce
    frame-relay route 101 interface Serial0 102
    frame-relay route 103 interface Serial5 104
    frame-relay route 105 interface Serial4 106
    frame-relay route 107 interface Serial3 108
    frame-relay route 108 interface Serial8 808
    frame-relay route 109 interface Serial2 110

!

interface Serial2
    no ip address
```

```
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 110 interface Serial1 109
frame-relay route 111 interface Serial3 708
!
interface Serial3
no ip address
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 108 interface Serial1 107
frame-relay route 408 interface Serial0 402
frame-relay route 508 interface Serial4 506
frame-relay route 608 interface Serial5 804
frame-relay route 708 interface Serial2 111
!
interface Serial4
no ip address
encapsulation frame-relay
clockrate 64000
frame-relay intf-type dce
frame-relay route 106 interface Serial1 105
frame-relay route 206 interface Serial0 302
frame-relay route 306 interface Serial5 304
frame-relay route 506 interface Serial3 508
!
interface Serial5
```

```
no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 104 interface Serial1 103

frame-relay route 204 interface Serial0 202

frame-relay route 304 interface Serial4 306

frame-relay route 404 interface Serial8 110

frame-relay route 804 interface Serial3 608

!

interface Serial6

no ip address

!

interface Serial7

no ip address

!

interface Serial8

no ip address

encapsulation frame-relay

clockrate 64000

frame-relay intf-type dce

frame-relay route 108 interface Serial5 404

frame-relay route 708 interface Serial0 802

frame-relay route 808 interface Serial1 108

!

interface Serial9

no ip address

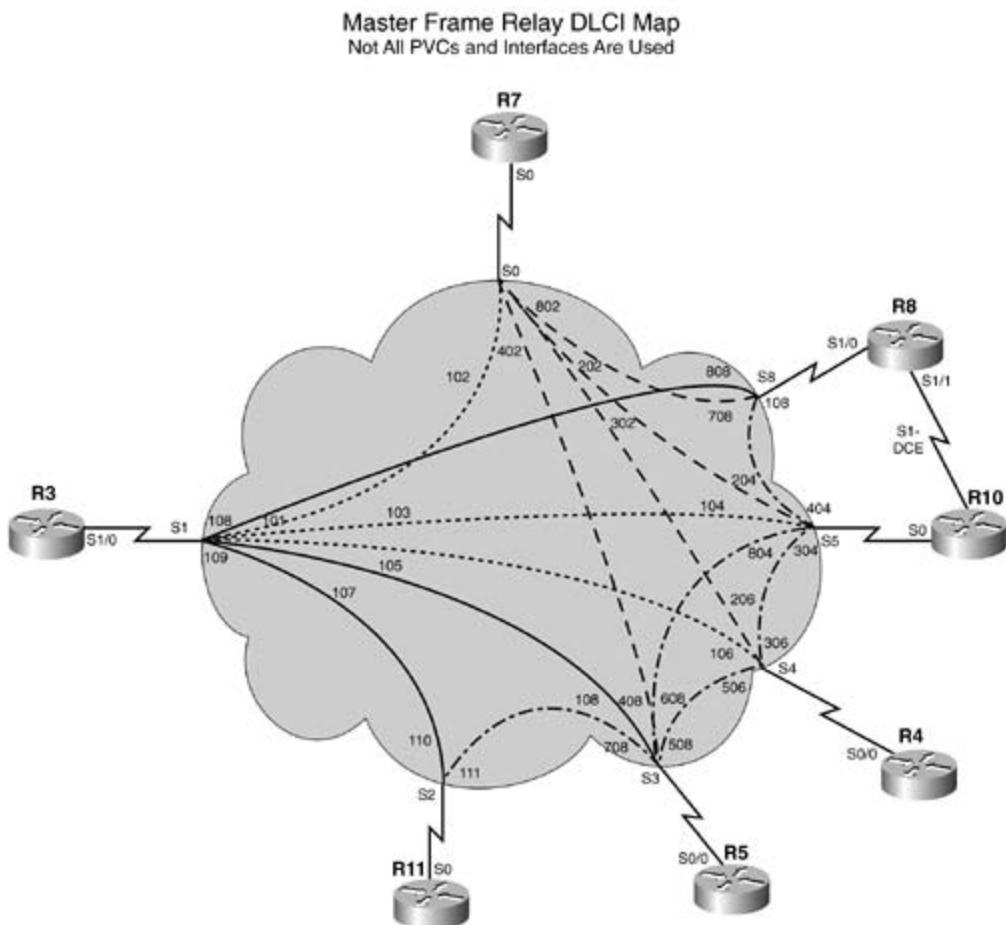
shutdown
```

```
!  
  
interface BRI0  
  
    no ip address  
  
    shutdown  
  
!  
  
    no ip classless  
  
!  
  
end  
  
----- ATM Switch ----- →  
  
hostname ls1010  
  
!  
  
atm address 47.0091.8100.0000.0061.705b.4001.0061.705b.4001.00  
  
!  
  
interface ATM0/0/0  
  
    no keepalive  
  
    no atm auto-configuration  
  
    no atm address-registration  
  
    no atm ilmi-enable  
  
    no atm ilmi-lecs-implied  
  
!  
  
interface ATM0/0/1  
  
    no keepalive  
  
    no atm auto-configuration  
  
    no atm address-registration  
  
    no atm ilmi-enable  
  
    no atm ilmi-lecs-implied  
  
    atm pvc 1 101 interface ATM0/0/0 1 102  
  
    atm pvc 3 103 interface ATM0/0/0 7 107
```

!

```
interface ATM0/0/2
  no keepalive
end
```

Figure 10-9. Frame Relay Switch Configuration



The following portion of the lab is timed and should begin after the configuration and physical installation of all hardware.

Rules

- No static routes or floating static routes are allowed unless specifically stated.

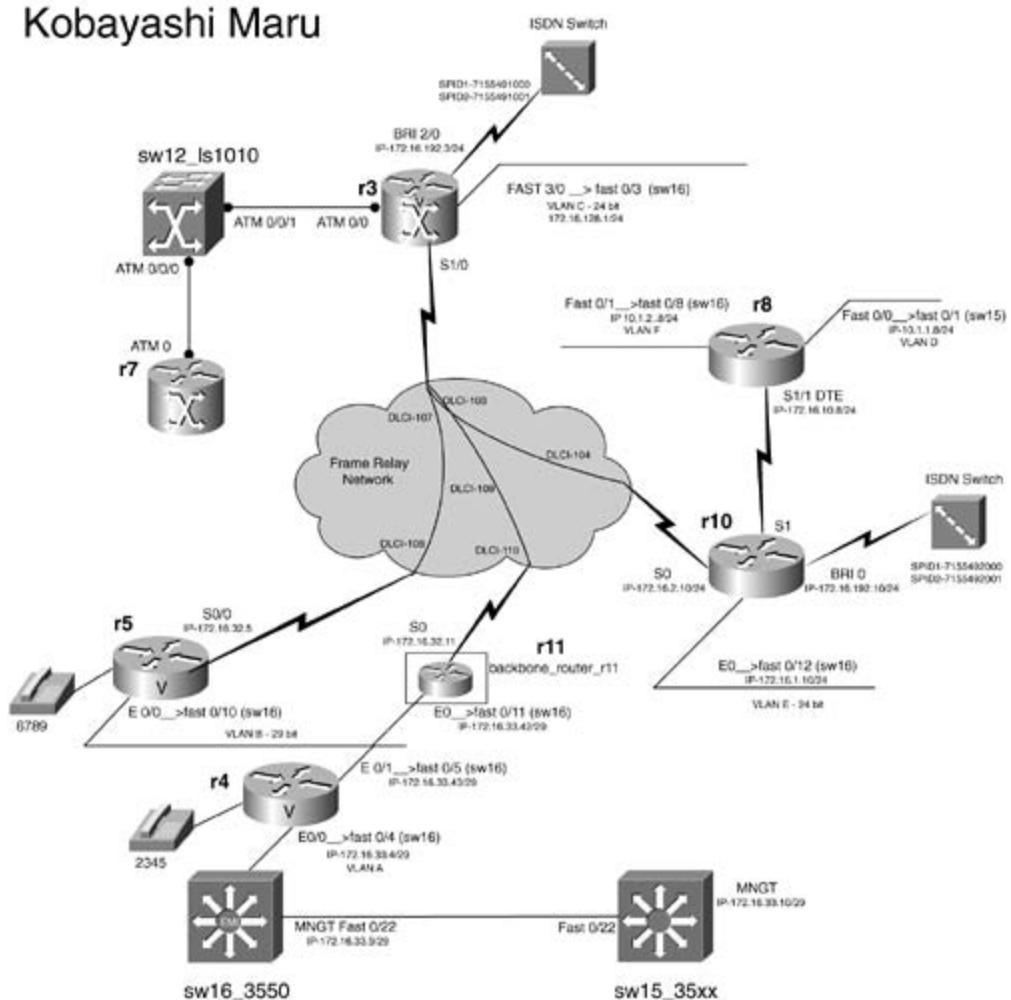
- Follow the instructions exactly. Be careful to only propagate routes where and when instructed. Only use the PVCs as directed by the instructions.
- You can use the configuration guides and the CD-ROM for your only reference material.
- You have 8.5 hours to complete this portion of the lab. Do not talk to anyone during this phase.
- It is recommended that you read the entire lab before beginning.

Section I: IP Setup

- Use the IP addresses as depicted in [Figure 10-10](#) and address the network accordingly.
Note: Not all the IP addresses can be assigned at this time.

Figure 10-10. Network Diagram for Kobayashi Maru

Kobayashi Maru



- Use the IP address 172.16.128.1 on the Fast 3/0 interface of r3. Subnet 172.16.128.0/24

- will be VLAN C.
3. Use the IP address of 172.16.33.42/29 on r11's E0 interface. This interface is in VLAN B, along with r4's e0/1 interface and r5's e 0/0 interface.
 4. R8 has the Fast 0/1 interface in VLAN F and the Fast 0/0 interface in VLAN D. Use the IP address of 10.1.2.8/24 on the Fast 0/1 interface and 10.1.1.8/24 on the Fast 0/0 interface.
 5. R10 has its e0 interface in VLAN E; use the IP address of 172.16.1.10/24 for it.
 6. R4's e 0/0 interface is in VLAN A and has the IP address of 172.16.33.4/29.
 7. Use the network 172.16.0.0 for all other subnets and host addresses:
 - VLAN A: 29-bit subnet
 - VLAN B: 29-bit subnet
 - VLANs C, D, E, F: 24-bit subnet

Section II: Catalyst Configuration

1. Configure the VLANs as depicted in [Figure 10-8](#). Do not use VLAN 1:
 - VLAN A = VLAN 2034
 - VLAN B = VLAN 2033
 - VLAN C = VLAN 1026
 - VLAN D = VLAN 10 (on sw15_35xx)
 - VLAN E = VLAN 1025
 - VLAN F = VLAN 10
2. Connect the Catalyst switches together via back-to-back cable. Ensure that both switches are reachable from the lab using the following address: sw16_3550 = 172.16.33.9/29 and sw15_35xx = 172.16.33.10/29. Do not configure 802.1Q or ISL trunks. You cannot configure a default or static route on sw16_3550.
3. Configure sw16_3550 and the sw15_35xx to use ccie_psv2 as the VTP domain name. Choose the VTP mode that is most desirable to your network design.
4. Configure sw16_3550 to support 802.1w RSTP and 802.1s MSTP. Configure any host ports to support RSTP.
5. Configure MSTP such that all extended VLANs on sw16_3550 will be the root for spanning tree. Normal-range VLANs should use the default STP values.
6. Configure a MAC address of 0001.0001.aaaa on VLAN 2034 of sw16_3550.

Section III: OSPF, EIGRP, Layer 3 Switching, and Frame Relay

1. Configure a partial-mesh Frame Relay network between r3, r5, and r11. You can use subinterfaces wherever you desire.
2. Configure OSPF over the Frame Relay network between r3, r5, and r11. The Frame Relay network is in OSPF area 0. Configure VLAN C on r3 to be in area 51.
3. Configure VLAN B between r5, r11, and r4 to be in OSPF area 100.
4. Change the OSPF hello timer of r5's S0/0 interface to 60 seconds.
5. Configure EIGRP on VLAN A between r4 and sw16_3550. Use the autonomous system ID of 2003. Enable Layer 3 switching on sw16_3550 to accomplish this.
6. EIGRP-originated routes should appear as OSPF external type 1 routes with a tag of 4 on all OSPF routers.
7. Ensure full IP reachability from the EIGRP and OSPF domain. Sw15_35xx should be able to ping VLAN C and vice versa.

Section IV: IS-IS and RIP Integration

1. Configure IS-IS between r3 and r10 over the Frame Relay network. Advertise VLAN E via IS-IS.
2. Configure the serial link between r10 and r8. Configure the link such that it supports Lempel-Ziv (LZ)-based compression algorithms.
3. Configure RIP between r10 and r8. Do not advertise VLAN D and VLAN F via RIP. RIP should not use broadcast routing updates.
4. Integrate RIP and IS-IS fully into the existing OSPF/EIGRP domains. Ensure full reachability between all routing domains.
5. On r3, tag any redistributed routes with an original administrative distance of 0 with a tag of 3333. Tag redistributed routes with an original administrative distance of 115 with a tag of 3, and tag routes with an original administrative distance of 1 with a tag of 777.

Section V: NAT and DHCP

1. Configure NAT on r8 using the following guidelines:
 - Users on VLAN D, 10.1.1.0/24, will share 5 IP addresses (172.16.16.2 through 172.16.16.6).
 - R8 Fast 0/0 IP address, 10.1.1.8, will always be translated to 172.16.16.100.

- Users on VLAN F will use PAT.
2. Ensure that users on VLAN D and VLAN F can ping sw16_3550 and sw15_35xx and are translated accordingly.
 3. Configure the users on VLAN C on r3 to use DHCP. The server should advertise 172.16.128.1 as the default gateway. Reserve four host addresses on VLAN C in the DHCP pool for future use.

Section VI: Multicast Routing and NTP

1. Configure r8 as an NTP server and sw16_3550 to receive NTP updates. When sw16_3550 synchronizes with the server, it should have a stratum of 6.
2. Configure multicast routing on r3, r4, and r5. Use sparse mode and configure the multicast address of 224.0.10.3 on the Fast 3/0 interface of r3.
3. Configure r4 and r5 such that they can ping the multicast address of 224.0.10.3.

Section VII: ISDN

1. Configure the ISDN network between r10 and r3. Use the following guidelines:
 - Use the IP address of 172.16.192.10/24 on r10.
 - The dialer should not remain up all the time due to routing protocols.
 - Configure r10 to only place the calls upon losing the 172.16.128.0/24 route/VLAN C. Both B channels should pick up immediately.
 - Use PPP CHAP for authentication; use cisco_isdn as the password.
 - You can use static routes.
 - The link should drop after 5 minutes of idle time.

Section VIII: ATM

1. Configure an ATM PVC from r3's atm0/0 port to r7's atm0 port; use subinterfaces for this purpose.
2. Use the ATM encapsulation method that is most suited to bursty data traffic.
3. Configure the ATM circuit to support bursty delay-tolerant traffic with an unspecified bit rate; this circuit should be configured with a peak cell rate that supports the full bandwidth of the interface.

4. Use the 10.55.1.8 network with a 30-bit subnet mask for this network.

Section IX: BGP

1. All BGP routers should peer with each other using statically assigned BGP router IDs; BGP routing updates should use the largest possible packet sizes. BGP will only be used to advertise loopback networks; do not configure BGP to advertise any 10 networks. When routers have more than one peer in the same autonomous system, use a peer group to simplify the configuration. At the end of this section, all BGP routes should be reachable on all BGP routers. Add and advertise the networks shown in [Table 10-4](#).

Table 10-4. Lab 5 BGP Networks

Advertising Router	Network
r3	198.201.5.0/24 109.201.11.0/24 10.55.1.8/30
r4	164.8.8.0/24 164.10.10.0/24
r5	36.101.11.0/24 37.101.12.0/24
r7	208.161.8.0/24 208.164.8.0/24

2. Configure BGP on r3 and r7; put both of these routers in AS 97.
3. Configure r7 to peer with r3 over its ATM interface. R7 should be configured so that the 208.164.8.0/24 network will never be propagated beyond AS 97; one configuration line is allowed on r3 for this purpose.
4. R3 should peer with r5 and r11 in AS 148 over the Frame Relay network.
5. Configure BGP on routers r5 and r11.
6. R5 should peer with r3, r4, and r11.
7. R11 will peer with r3, r4, and r5.
8. Configure r11 so that routes from r4 will be less desirable to any other router that receives routes from this router.
9. Configure BGP on r4; put this router in AS 65 and configure it to peer with r5 and r11 over

its Ethernet interface.

Section X: Voice

1. Configure Voice over IP between r5 and r4.
2. R4 should use the 2345 phone number on its 1/0/0 voice port. This lab requires that you use the 164.8.8.1 IP address for voice calls.
3. R5 should use the 6789 phone number on its 1/0/0 port, and you must use the 36.101.11.1 IP address for all voice calls.
4. Callers from r4 should also be able to reach r5 when the 411 phone number is dialed; only one command is allowed on r4 for this purpose.

Section XI: DLSW+

1. Configure a DLSw Fast Sequence Transport peer between r10 VLAN E and VLAN B or r5. Configure DLSw such that only NetBIOS traffic can traverse the peer.

Part VII: Appendixes

[Appendix A](#) Cisco IOS Software Limitations and Restrictions

[Appendix B](#) RFCs

[Appendix C](#) Bibliography

[Appendix D](#) IP Prefix Lists

Appendix A. Cisco IOS Software Limitations and Restrictions

[Cisco IOS Software Limitations and Restrictions](#)

[Cluster Limitations and Restrictions](#)

[Cluster Management Suite Limitations and Restrictions](#)

[Important Notes](#)

Cisco IOS Software Limitations and Restrictions

These limitations apply to Cisco IOS Software Release 12.1(11)EA1:

- Storm control or traffic suppression (configured by using the storm-control { broadcast | multicast | unicast} level/*level*[./*level*] interface configuration command) is supported only on physical interfaces; it is not supported on EtherChannel port channels even though you can enter these commands through the command-line interface (CLI).
- The Cisco RPS 300 Redundant Power System (RPS) supports the Catalyst 3550 multilayer switch and provides redundancy for up to six connected devices until one of these devices requires backup power. If a connected device has a power failure, the RPS immediately begins supplying power to that device and sends status information to other connected devices that it is no longer available as a backup power source. As described in the device documentation, when the RPS LED is amber, the RPS is connected but down. However, this might merely mean that the RPS is in standby mode. Press the Standby/Active button on the RPS to put it into active mode. You can view RPS status through the CLI by using the show rps privileged EXEC command. For more information, refer to the *RPS 300 Hardware Installation Guide*.
- You can connect the switch to a PC by using the switch console port, the supplied rollover cable, and the DB-9 adapter. You need to provide a RJ-45-to-DB-25 female DTE adapter if you want to connect the switch console port to a terminal. You can order a kit (part number ACS-DSBUAS) with this RJ-45-to-DB-25 female DTE adapter from Cisco.
- Modifying a multicast boundary access list does not prevent packets from being forwarded by multicast routes that were in existence before the access list was modified if the packets arriving at the input interface do not violate the boundary. However, no new multicast routes that violate the updated version of the multicast boundary access list are learned, and any multicast routes that were in violation of the updated access list are not relearned if they age out.

After updating a multicast boundary, the workaround is to use the clear ip mroute privileged EXEC command to delete any existing multicast routes that violate the updated boundary. (Error code: CSCdr79083)

- When an IP packet with a cyclic redundancy check (CRC) error is received, the per-packet per-DSCP counter (for DSCP 0) is incremented. Normal networks should not have packets with CF errors. (Error code: CSCdr85898)
- The mac-address interface configuration command does not properly assign a MAC address to an interface. This command is not supported on Catalyst 3550 switches. (Error code: CSCds1132)
- If you configure the Dynamic Host Configuration Protocol (DHCP) server to allocate addresses from a pool to the switch, two devices on the network might have the same IP address. Pooled addresses are temporarily allocated to a device and are returned to the pool when not in use. If you save the configuration file after the switch receives such an address, the pooled address is saved, and the switch does not attempt to access the DHCP server after a reboot to receive a new IP address. As a result, two devices might have the same IP address.

The workaround is to make sure that you configure the DHCP server with reserved leases that are bound to each switch by the switch hardware address. (Error code: CSCds55220)

- The show ip mroute count privileged EXEC command might display incorrect packet counts in certain transient states (for example, when a multicast stream is forwarded only to the CPU during the route-learning process and the CPU is programming this route into the hardware), a mult

stream packet count might be counted twice. Do not trust the counter during this transient state. (Error code: CSCds61396)

- When changing the link speed of a Gigabit Ethernet port from 1000 Mbps to 100 Mbps, there is a slight chance that the port will stop transmitting packets. If this occurs, shut down the port and then enable it by using the shutdown and no shutdown interface configuration commands. (Error code: CSCds84279)
- In IP multicast routing and fallback bridging, certain hardware features are used to replicate packets for the different VLANs of an outgoing trunk port. If the incoming speed is line rate, the outgoing interface cannot duplicate that speed (because of the replication of the packets). As a result, certain replicated packets are dropped. (Error code: CSCdt06418)
- When you use the no interface port-channel global configuration command to remove an EtherChannel group, the ports in the port group change to the administratively down state.

When you remove an EtherChannel group, enter the no shutdown interface configuration command on the interfaces that belonged to the port group to bring them back on line. (Error code: CSCdt10825)

- In the output displayed after a show interface/*interface-id* privileged EXEC command, the *Output Buffer Failures* field shows the number of packets lost before replication, whereas the Packets Output field shows the successful transmitted packets after replication. To determine actual discarded frames, multiply the output buffer failures by the number of VLANs on which the multicast data is replicated. (Error code: CSCdt26928)
- Internet Group Management Protocol (IGMP) packets classified by quality of service (QoS) to the differentiated services code point (DSCP) value and the class of service (CoS) value in a C policy map might only modify the DSCP property and leave the CoS value at zero. (Error code: CSCdt27705)
- If you assign both tail-drop threshold percentages to 100 percent by using the wrr-queue threshold interface configuration command and display QoS information for this interface by the show mls qos interface statistics privileged command, the drop-count statistics are always zero even if the thresholds were exceeded. To display the total number of discarded packets, the show controllers ethernet-controllers/*interface-id* privileged EXEC command. In the display, the number of discarded frames includes the frames that were dropped when the tail-drop thresholds were exceeded. (Error code: CSCdt29703)
- Open Shortest Path First (OSPF) path costs and Interior Gateway Routing Protocol (IGRP) metrics are incorrect for switch virtual interface (SVI) ports. You can manually configure the bandwidth for the SVI by using the bandwidth interface configuration command. Changing the bandwidth of an interface changes the routing metric for the routes when the SVI is used as an outgoing interface. (Error code: CSCdt29806)
- On the Catalyst 3550, coldStart and warmStart traps are not consistently sent. (Error code: CSCdt33779)
- Remote Monitoring (RMON) collection functions on physical interfaces, but it is not supported on EtherChannels and SVIs. (Error code: CSCdt36101)
- Multicast router information is displayed in the show ip igmp snooping mrouter privileged EXEC command when IGMP snooping is disabled. Multicast VLAN Registration (MVR) and IGMP snooping use the same commands to display multicast router information. In this case, MVR is enabled when IGMP snooping is disabled. (Error code: CSCdt48002)
- When a VLAN interface has been disabled and restarted multiple times by using the shutdown and no shutdown interface configuration commands, the interface might not restart following a power failure.

shutdown command. To restart the interface, re-enter a shutdown and no shutdown command sequence. (Error code: CSCdt54435)

- When you configure the ip pim spt-threshold infinity interface configuration command, you tell all sources for the specified group to use the shared tree and not use the source tree. However, the switch does not automatically start to use the shared tree. No connectivity problem occurs, but the switch continues to use the shortest-path tree for multicast group entries already installed in the multicast routing table. You can enter the clear ip mroute * privileged EXEC command to force a change to the shared tree. (Error code: CSCdt60412)
- If the number of multicast routes configured on the switch is greater than the switch can support, the switch might run out of available memory, which can cause it to reboot. This is a limitation in the platform-independent code.

The workaround is to not configure the switch to operate with more than the maximum number of supported multicast routes. You can use the show sdm prefer and show sdm prefer routing privileged EXEC commands to view approximate maximum configuration guidelines for the current SDM template and the routing template. (Error code: CSCdt63354)

- Configuring too many multicast groups might result in an extremely low memory condition and cause the software control data structure to go out of sync, causing unpredictable forwarding behavior. The memory resources can only be recovered by issuing the clear ip mroute privileged EXEC command. To prevent this situation, do not configure more than the recommended number of multicast routes on the switch. (Error code: CSCdt63480)
- The *dec* keyword is not supported in the *bridgebridge-groupprotocol* global configuration command. If two Catalyst 3550 switches are connected to each other through an interface that is configured for IP routing and fallback bridging, and the bridge group is configured with the *bridge-groupprotocol dec* command, both switches act as if they were the spanning-tree root. Therefore, spanning-tree loops might be undetected. (Error code: CSCdt63589)
- When you configure an EtherChannel between a Catalyst 3550 and a Catalyst 1900 switch, some Catalyst 3550 links in the EtherChannel might go down, but one link in the channel remains up so connectivity is maintained.

The workaround is to disable the Port Aggregation Protocol (PAgP) on both devices by using the *channel-groupchannel-group-number* mode on interface configuration command. PAgP negotiation between these two devices is not reliable. (Error code: CSCdt78727)

- When the switch is operating with equal-cost routes and it is required to learn more unicast routes than it can support, the CPU might run out of memory, and the switch might fail.

The workaround is to remain within the documented recommended and supported limits. (Error code: CSCdt79172)

- The behavior of a software access control list (ACL) with QoS differs from a hardware ACL with QoS. On the Catalyst 3550 switch, when the QoS hardware rewrites the DSCP of a packet, the rewriting of this field happens before software running on the CPU examines the packet, and the CPU sees only the new value and not the original DSCP value.

When the security hardware ACL matches a packet on input, the match uses the original DSCP value. For output security ACLs, the security ACL hardware should match against the final, possibly changed, DSCP value as set by the QoS hardware. Under some circumstances, a match to a security ACL in hardware prevents the QoS hardware from rewriting the DSCP and causes the switch to use the original DSCP.

If a security ACL is applied in software (because the ACL did not fit into hardware, and packets were sent to the CPU for examination), the match probably uses the new DSCP value as determined by the software.

by the QoS hardware, regardless of whether the ACL is applied at the input or at the output. If packets are logged by the ACL, this problem can also affect whether or not a match is logged to CPU, even if the ACL fits into hardware and the permit or deny filtering was completed in hardware.

To avoid these issues, whenever the switch rewrites the DSCP of any packet to a value different from the original DSCP, security ACLs should not test against DSCP values in any of their access control elements (ACEs), regardless of whether the ACL is being applied to an IP access group or a VLAN map. This restriction does not apply to ACLs used in QoS class maps.

If the switch is not configured to rewrite the DSCP value of any packet, it is safe to match against DSCP in ACLs used for IP access groups or for VLAN maps because the DSCP does not change before the packet is processed by the switch.

The DSCP field of an IP packet encompasses the two fields that were originally designated IP Precedence and ToS (type of service). Statements relating to DSCP apply equally to either IP precedence or IP ToS. (Error code: CSCdt94355)

- Disabling autonegotiation on a gigabit interface converter (GBIC) interface by using the speed nonegotiate interface configuration command might cause the interface to show that the physical link is up, even when it is not connected. (Error code: CSCdv29722)
- If you configure a trunk port for Dynamic Trunking Protocol (DTP) nonegotiate mode and change the encapsulation type from Inter-Switch Link (ISL) to 802.1Q by using the switchport trunk encapsulation interface configuration command, the port becomes an access port and is no longer trunking. (Error code: CSCdv46715)
- On earlier versions of Catalyst 3550-24 switches, if a 10/100BASE-TX port on the switch is connected to a Catalyst 2820 or Catalyst 1900 switch through an ISL trunk at 100 Mbps, bidirectional communication cannot be established. The Catalyst 2820 or Catalyst 1900 switch identifies the Catalyst 3550-24 switch as a Cisco Discovery Protocol (CDP) neighbor, but the Catalyst 3550-24 switch does not recognize the Catalyst 2820 or Catalyst 1900 switch. On these switches, you should not use ISL trunks between the Catalyst 3550-24 and a Catalyst 2820 or Catalyst 1900 switch. Configure the link as an access link instead of a trunk link.

This problem has been fixed in hardware on Catalyst 3550-24 switches with motherboard assembly number 73-5700-08 or later. To determine the board level on your switch, enter the show version privileged EXEC. Motherboard information appears toward the end of the output display. (Error code: CSCdv68158)

- When IGMP filtering is enabled and you use the ip igmp profile global configuration command to create an IGMP filter, reserved multicast addresses cannot be filtered. Because IGMP filtering uses only Layer 3 addresses to filter IGMP reports and due to mapping between Layer 3 multicast addresses and Ethernet multicast addresses, reserved groups (224.0.0.x) are always allowed through the switch. In addition, aliased groups can leak through the switch. For example, if a user is allowed to receive reports from group 225.1.2.3, but not from group 230.1.2.3, aliasing will cause the user to receive reports from 230.1.2.3. Aliasing of reserved addresses means that all groups of the form y.0.0.x are allowed through. (Error code: CSCdv73626)

If you use the ip igmp max-groups interface configuration command to set the maximum number of IGMP groups for an interface to 0, the port still receives group reports from reserved multicast groups (224.0.0.x) and their Layer 2 aliases (y.0.0.x). (Error code: CSCdv79832)

- The switch might reload when it is executing the no snmp-server host global configuration command. This is a rare condition that can happen if SNMP traps or informs are enabled and the SNMP agent attempts to send a trap to the host just as it is being removed from the configuration and if the IP address of the host (or the gateway to reach the host) has not been resolved by Address Resolution Protocol (ARP).

The workaround is to ensure that the target host or the next-hop gateway to that host is in the cache (for example, by issuing a ping command) before removing it from the SNMP configuration. Alternatively, disable all SNMP traps and informs before removing any hosts from the SNMP configuration. (Error code: CSCdw44266)

- When you access CISCO-STACK-MIB portTable, the mapping might be off by one from the mapping given by the switch. The objects in this table are indexed by two numbers: portModuleIndex and portIndex. The allowable values for portModuleIndex are 1 through 16. Because 0 is not an allowable value, the value 1 represents module 0.

The workaround is to use the value 1 to represent module 0. (Error code: CSCdw71848)

- If a port on the Catalyst 3550 switch that is running the Multiple Spanning Tree Protocol (MST) connected to another switch that belongs to a different Multiple Spanning Tree (MST) region, Catalyst 3550 port is not recognized as a boundary port when you start the protocol migration process by using the clear spanning-tree detected-protocols interface *interface-id* privileged EXEC command. This problem occurs only on the root bridge, and when the root bridge is cleared, the boundary ports are not shown because the designated ports do not receive any bridge protocol data units (BPDUs) unless a topology change occurs. This is the intended behavior.

The workaround is to configure the Catalyst 3550 switch for Per VLAN Spanning Tree (PVST) instead of MSTP by using the spanning-tree mode pvst global configuration command on the bridge, and then change back to MSTP by using the spanning-tree mode mst global configuration command. (Error code: CSCdx10808)

- If you apply an ACL to an interface that has a QoS policy map attached and the ACL is configured so that the packet should be forwarded by the CPU, or if the configured ACL cannot fit into the ternary content addressable memory (TCAM), all packets received from this interface are forwarded to the CPU. Because traffic forwarded to the CPU cannot be policed by the policer configured on the interface, this traffic is not accurately rate limited to the configured police rate.

The workaround, when QoS rate limiting is configured on an interface, is to configure applied ACLs so that packets are not forwarded by the CPU or reduce the number of ACEs in the ACL so that they can fit into the TCAM. (Error code: CSCdx30485)

- Catalyst 3550 switches do not take into account the Preamble and Inter Frame Gap (IFG) when rate limiting traffic, which could result in a slightly inaccurate policing rate on a long burst of small frames, where the ratio of the Preamble and IFG to frame size is more significant. This should not be an issue in an environment where the frames are a mix of different sizes.
- If the switch fails for any reason while you are exiting VLAN configuration mode (accessed by entering the vlan database privileged EXEC command), there is a slight chance that the VLAN database might get corrupted. After resetting from the switch, you might see these messages on the console:

```
%SW_VLAN-4-VTP_INVALID_DATABASE_DATA: VLAN manager received bad data of type c  
type: value 0 from vtp database  
$SW_VLAN-3-VTP_PROTOCOL_ERROR: VTP protocol code internal error
```

The workaround is to use the delete flash:vlan.dat privileged EXEC command to delete the corrupted VLAN database. Then reload the switch by using the reload privileged EXEC command. (Error code: CSCdx19540)

- When a Cisco RPS 300 Redundant Power System provides power to a switch, after the switch supply is restored, the RPS 300 continues to provide power until the RPS mode button is pressed. At this point, some switches restart, depending on how quickly the switches' internal power supplies resume operation. (Error code: CSCdx81023)
- Inserting GigaStack gigabit interface converter (GBIC) modules in the switch causes an increase in the CPU usage. (Error code: CSCdx90515)
- Hot Standby Routing Protocol (HSRP) does not support configuration of overlapping addresses in different VPN routing and forwarding (VRF) tables. (Error code: CSCdy14520)
- When 1000 VLANs and more than 40 trunk ports are configured, and the spanning-tree mode changes from MSTP to PVST or vice versa, this message appears on the console:

```
%ETHCNTR-3-RA_ALLOC_ERROR: RAM Access write pool I/O memory allocation failure
```

There is no workaround. However, it is recommended that you reload the switch by using the reload privileged EXEC command. To avoid this problem, configure the system with fewer VLANs and fewer trunk ports, or use the switchport trunk allowed vlan interface configuration command to reduce the number of active VLANs on each trunk port. (Error code: CSCdx2010)

Cluster Limitations and Restrictions

These limitations apply to cluster configuration:

- When there is a transition from the cluster active command switch to the standby command switch, Catalyst 1900, Catalyst 2820, and Catalyst 2900 4-MB switches that are cluster members might lose their cluster configuration. You must manually add these switches back to the cluster. (Error codes: CSCds32517, CSCds44529, CSCds55711, CSCds55787, CSCdt70872)
- When a Catalyst 2900 XL or Catalyst 3500 XL cluster command switch is connected to a Catalyst 3550 switch, the command switch does not find any cluster candidates beyond the Catalyst 3550 switch if it is not a member of the cluster. You must add the Catalyst 3550 switch to the cluster. You can then see any cluster candidates connected to it. (Error code: CSCdt09918)
- When clustering is enabled, do not configure SNMP community strings of more than 59 bytes, or clustering SNMP might not work correctly. (Error code: CSCdt39616)
- If both the active command-switch and the standby command switch fail at the same time, the cluster is not automatically re-created. Even if there is a third passive command switch, it might not re-create all cluster members because it might not have all the latest cluster configuration information. You must manually re-create the cluster if both the active and standby command switches simultaneously fail. (Error code: CSCdt43501)

Cluster Management Suite Limitations and Restrictions

These limitations apply to Cluster Management Suite (CMS) configuration:

- Host names and Domain Name System (DNS) server names that contain commas on a cluster command switch, member switch, or candidate switch can cause CMS to behave unexpectedly. You can avoid this instability in the interface by not using commas in host names or DNS names. Also, do not enter commas when entering multiple DNS names in the IP Configuration tab of the IP Management window in CMS.
- ACEs that contain the host keyword precede all other ACEs in standard ACLs. You can reposition the ACEs in a standard ACL with one restriction: No ACE with the any keyword or a wildcard mask can precede an ACE with the host keyword.
- CMS performance degrades if the topology view is open for several hours on a Solaris machine. The cause might be a memory leak.

The workaround is to close the browser, reopen it, and launch CMS again. (Error code: CSCds29230)

- If you are printing a topology view or front-panel view that contains many devices and are running Solaris 2.6 with JDK1.2.2, you might get an "Out of Memory" error message.

The workaround is to close the browser, reopen it, and launch CMS again. Before you perform any other task, bring up the view that you want to print, and click Print in the CMS menu. (Error code: CSCds80920)

- If a PC running CMS has low memory and CMS is running continuously for 2 to 3 days, the PC runs out of memory.

The workaround is to relaunch CMS. (Error code: CSCdv88724)

- When a VLAN or a range of VLANs is already configured and you specify VLAN filter for a SPAN session, the current configuration for that session is overwritten with the new entry. Although the CLI appends new entries after the existing ones, CMS re-creates the whole session, overwrites the current entry, and provides only a single VLAN filter per entry.

The workaround is to use the CLI; it is the only method for specifying multiple VLANs for filtering in a Switched Port Analyzer (SPAN) session. (Error code: CSCdw93904)

Important Notes

Cisco IOS Software Notes

These notes apply to Cisco IOS Software configuration:

- If you configure a port ACL on a physical interface on a switch that has VLAN maps or input router ACLs configured, or if you configure a VLAN map or input router ACL on a switch that has port ACLs configured, a "CONFLICT" message is generated but the configuration is accepted. The port ACL action has priority on that port over actions in a router ACL or VLAN map applied to the VLAN which the port belongs.

The result is that packets received on that physical port will be permitted or denied based on the port ACL action without regard to any permit or deny statements in router ACL or VLAN map, while packets received on other physical ports in the VLAN will still be permitted or denied based on the router ACLs or VLAN maps applied to the VLAN. If the port ACL is applied to a trunk port, it overrides other input ACLs applied to all VLANs on the trunk port.

- The default system maximum transmission unit (MTU) for traffic on the Catalyst 3550 switch is 1500 bytes. The 802.1Q tunneling feature increases the frame size by 4 bytes. Therefore, when you configure 802.1Q tunneling, you must configure all switches in the 802.1Q network to be able to process maximum frames by increasing the switch system MTU size to at least 1504 bytes. You can configure the system MTU size by using the system mtu global configuration command.
- Beginning with Cisco IOS Software Release 12.1(8)EA1, to configure traffic suppression (previously configured by using the switchport broadcast, switchport multicast, and switchport untagged interface configuration commands), you use the storm-control { broadcast | multicast | unknown } level [level] interface configuration commands. For more information about these commands, refer to the *Catalyst 3550 Multilayer Switch Command Reference*.
- When you are configuring a cascaded stack of Catalyst 3550 switches by using the GigaStack feature and want to include more than one VLAN in the stack, be sure to configure all the GigaStack member interfaces as trunk ports by using the switchport mode trunk interface configuration command. You can also use the same encapsulation method by using the switchport encapsulation { isl | dot1q } interface configuration command. For more information about these commands, refer to the *Catalyst 3550 Multilayer Switch Command Reference*.
- If the 1000BASE-T GBIC (WS-G5482) is not securely inserted, the switch might fail to recognize it and might display an incorrect media type following a show interface privileged EXEC command. If this happens, remove and reinsert the GBIC.
- Beginning with Cisco IOS Software Release 12.1(11)EA1, the mac address-table aging-time command replaces the mac-address-table aging-time command (with the hyphen). The mac address-table aging-time command (with the hyphen) will become obsolete in a future release.
- Beginning with Cisco IOS Software Release 12.1(11)EA1, the vtp privileged EXEC command and its keywords are available in the vtp global configuration command. The vtp privileged EXEC command will become obsolete in a future release.

Cluster Notes

This note applies to cluster configuration:

- The cluster setup privileged EXEC command and the standby mac-address interface config command have been removed from the CLI and the documentation because they did not function correctly.

CMS Notes

These notes apply to CMS configuration:

- If you use CMS on Windows 2000, it might not apply configuration changes if the enable password has been changed from the CLI during your CMS session. You have to restart CMS and enter the new password when prompted. Platforms other than Windows 2000 prompt you for the new enable password when it is changed.
- CMS does not display QoS classes that are created through the CLI if these classes have multiple match statements. When using CMS, you cannot create classes that match more than one match statement. CMS does not display policies that have such classes.
- If you use Internet Explorer version 5.5 and select a URL with a nonstandard port at the end of the address (for example, www.add.com: 84), you must enter `http://` as the URL prefix. Otherwise, CMS cannot launch CMS.
- Within an ACL, you can change the sequence of ACEs that have the host keyword. However, if such ACEs are independent of each other, the change has no effect on the way the ACL filters traffic.
- If you use the Netscape browser to view the CMS GUI and you resize the browser window while CMS is initializing, CMS does not resize to fit the window.

Resize the browser window again when CMS is not busy.

- CMS does not start if the temporary directory on your computer runs out of memory. This problem can occur because of a bug in the 1.2.2 version of the Java plug-in. The plug-in creates temporary files in the directory whenever it runs CMS, and the directory eventually runs out of plug-in space.

The workaround is to remove all the `jar_cache*.tmp` files from the temporary directory. The path to the directory is different for different operating systems:

- Solaris: `/var/tmp`
- Windows NT and Windows 2000: `\TEMP`
- Windows 95 and 98: `\Windows\Temp`

Read-Only Mode in CMS

CMS provides two levels of access to the configuration options. If your privilege level is 15, you have write access to CMS. If your privilege level is from 1 to 14, you have read-only access to CMS. In the read-only mode, some data is not displayed, and an error message appears when these switches are run on these software releases:

- Catalyst 2900 XL or Catalyst 3500 XL member switches running Release 12.0(5)WC2 or earlier
- Catalyst 2950 member switches running Release 12.0(5)WC2 or earlier
- Catalyst 3550 member switches running Release 12.1(6)EA1 or earlier

In the front-panel view or topology view, CMS does not display error messages. In the front-panel topology view, if the member is a Long-Reach Ethernet (LRE) switch, the customer premises equipment (CPE) connected to the switch does not appear. The Bandwidth and Link graphs also do not appear in these views.

To view switch information, you need to upgrade the member switch software. For information about upgrading switch software, see the "Downloading Software" section.

Unsupported CLI Commands in Release 12.1(11)EA1

This section lists some of the CLI commands that are displayed when you enter the question mark at the Catalyst 3550 switch prompt but are not supported in this release, either because they are not supported or because of Catalyst 3550 hardware limitations. This is not a complete list. The unsupported commands are listed by software feature and command mode.

Access Control Lists: Unsupported Privileged EXEC Commands

```
access-enable [host] [timeout minutes]

access-template [access-list-number | name] [dynamic-name] [source] [destination]
[timeout minutes]

clear access-template [access-list-number | name] [dynamic-name] [source] [destination]
```

ARP: Unsupported Global Configuration Commands

```
arp ip-address hardware-address smds  
arp ip-address hardware-address srp-a  
arp ip-address hardware-address srp-b
```

ARP: Unsupported Interface Configuration Commands

```
arp probe  
ip probe proxy
```

FallBack Bridging: Unsupported Privileged EXEC Commands

```
clear bridge [bridge-group] multicast [router-ports | groups | counts] [group-addr  
[interface-unit] [counts]  
clear vlan statistics  
show bridge [bridge-group] circuit-group [circuit-group] [-mac-address]  
[dst-mac-address]  
show bridge [bridge-group] multicast [router-ports | groups] [group-address]  
show bridge vlan  
show interfaces crb  
show interfaces {ethernet | fastethernet} [interface | slot/port] irb
```

```
show subscriber-policy range
```

FallBack Bridging: Unsupported Global Configuration Commands

```
bridge bridge-group bitswap_13_addresses  
bridge bridge-group bridge ip  
bridge bridge-group circuit-group circuit-group pause milliseconds  
bridge bridge-group circuit-group circuit-group source-based  
bridge cmf  
bridge crb  
bridge bridge-group domain domain-name  
bridge irb  
bridge bridge-group mac-address-table limit number  
bridge bridge-group multicast-source  
bridge bridge-group route protocol  
bridge bridge-group subscriber policy policy  
subscriber-policy policy [[no | default] packet [permit | deny]]
```

FallBack Bridging: Unsupported Interface Configuration Commands

```
bridge-group bridge-group cbus-bridging

bridge-group bridge-group circuit-group circuit-number

bridge-group bridge-group input-address-list access-list-number

bridge-group bridge-group input-lat-service-deny group-list

bridge-group bridge-group input-lat-service-permit group-list

bridge-group bridge-group input-lsap-list access-list-number

bridge-group bridge-group input-pattern-list access-list-number

bridge-group bridge-group input-type-list access-list-number

bridge-group bridge-group lat-compression

bridge-group bridge-group output-address-list access-list-number

bridge-group bridge-group output-lat-service-deny group-list

bridge-group bridge-group output-lat-service-permit group-list

bridge-group bridge-group output-lsap-list access-list-number

bridge-group bridge-group output-pattern-list access-list-number

bridge-group bridge-group output-type-list access-list-number

bridge-group bridge-group sse

bridge-group bridge-group subscriber-loop-control

bridge-group bridge-group subscriber-trunk

bridge bridge-group lat-service-filtering

frame-relay map bridge dlci broadcast

interface bvi bridge-group

x25 map bridge x.121-address broadcast [options-keywords]
```

HSRP: Unsupported Global Configuration Commands

```
interface Async  
interface BVI  
interface Dialer  
interface Group-Async  
interface Lex  
interface Multilink  
interface Virtual-Template  
interface Virtual-Tokenring
```

HSRP: Unsupported Interface Configuration Commands

```
mtu  
standby mac-refresh seconds  
standby use-bia
```

HSRP: Interface Configuration Commands

```
switchport broadcast level  
switchport multicast level  
switchport unicast level
```

NOTE

These commands were replaced in Cisco IOS Software Release 12.1(8)EA1 by the `storm-control { broadcast | multicast | unicast} level /eve/[.level]` interface configuration command.

IP Multicast Routing: Unsupported Privileged EXEC Commands

debug ip packet

Displays packets received by the switch CPU. It does not display packets that are hardware switched.

debug ip mcache

Affects packets received by the switch CPU. It does not display packets that are hardware switched.

debug ip mpacket [detail] [access-list-number [group-name-or-address]]

Affects only packets received by the switch CPU. Because most multicast packets are hardware switched, use this command only when you know that the route will forward the packet to the CPU.

```
debug ip pim atm  
show frame-relay ip rtp header-compression [interface type number]  
show ip mcache
```

Displays entries in the cache for those packets that are sent to the switch CPU. Because most multicast packets are switched in hardware without CPU involvement, you can use this command, but multicasting information is not displayed.

```
show ip mpacket
```

Supported but is only useful for packets received at the switch CPU. If the route is hardware switched, this command has no effect because the CPU does not receive the packet and cannot display it.

```
show ip pim vc [group-address | name] [type number]  
show ip rtp header-compression [type number] [detail]
```

Displays PIM and RTP header compression information.

IP Multicast Routing: Unsupported Global Configuration Commands

```
ip pim accept-rp {address | auto-rp} [group-access-list-number]  
ip pim message-interval seconds
```

IP Multicast Routing: Unsupported Interface Configuration Commands

```
frame-relay ip rtp header-compression [active | passive]  
frame-relay map ip ip-address dlci [broadcast] compress  
frame-relay map ip ip-address dlci rtp header-compression [active | passive]  
ip igmp helper-address ip-address  
ip multicast helper-map {group-address | broadcast} {broadcast-address | multicast  
address} extended-access-list-number  
ip multicast rate-limit {in | out} [video | whiteboard] [group-list access-list] [  
list access-list] kbps  
ip multicast use-functional  
ip pim minimum-vc-rate pps  
ip pim multipoint-signalling  
ip pim nbma-mode
```

```
ip pim vc-count number  
ip rtp compression-connections number  
ip rtp header-compression [passive]
```

IP Unicast Routing: Unsupported Privileged EXEC or User EXEC Commands

```
clear ip accounting [checkpoint]  
clear ip bgp {* | address | peer-group-name} soft [in | out]  
clear ip bgp dampening  
clear ip bgp address flap-statistics  
clear ip bgp prefix-list  
show cef [drop | not-cef-switched]  
show ip accounting [checkpoint] [output-packets | access-violations]  
show ip bgp dampened-paths  
show ip bgp flap-statistics  
show ip bgp inconsistent-as  
show ip bgp regexp regular expression  
show ip prefix-list regular expression
```

IP Unicast Routing: Unsupported Global Configuration Commands

```
ip accounting-list ip-address wildcard  
ip as-path access-list  
ip accounting-transits count  
ip cef accounting [per-prefix] [non-recursive]  
ip cef traffic-statistics [load-interval seconds] [update-rate seconds]]  
ip flow-aggregation  
ip flow-cache  
ip flow-export  
ip gratuitous-arps  
ip local  
ip prefix-list  
ip reflexive-list  
router bgp  
router egp  
router-isis  
router iso-igrp  
router mobile  
router odr  
router static
```

IP Unicast Routing: Unsupported Interface Configuration Commands

```
ip accounting  
ip load-sharing [per-packet]
```

```
ip mtu bytes  
ip route-cache  
ip verify  
ip unnumbered type number
```

All ip security commands.

Unsupported BGP Router Configuration Commands

NOTE

These Border Gateway Protocol (BGP) commands have not been tested for the Catalyst 3550 ;
are not supported for the switch in Cisco IOS Software Release 12.1(11)EA1. This is not a
complete list.

```
address-family vpnv4  
address-family ipv4 [multicast | unicast]  
default-information originate  
neighbor advertise-map  
neighbor advertisement-interval  
neighbor allowas-in  
neighbor default-originate  
neighbor description  
neighbor distribute-list  
neighbor prefix-list  
neighbor route-reflector client
```

```
neighbor soft-reconfiguration  
neighbor version  
network backdoor  
table-map
```

Unsupported VPN Configuration Commands

All

NOTE

The switch does support the multi-VPN routing/forwarding (multi-VRF) commands shown in the command reference for this release.

Unsupported Route Map Commands

```
match route-type { level-1 | level-2}  
  
set as-path {tag | prepend as-path-string}  
  
set automatic-tag  
  
set dampening half-life reuse suppress max-suppress-time  
  
set ip destination ip-address mask  
  
set ip next-hop  
  
set ip precedence value  
  
set ip qos-group  
  
set metric-type internal  
  
set tag tag-value
```

MSDP: Unsupported Privileged EXEC Commands

```
show access-expression  
show exception  
show location  
show pm LINE  
show smf [interface-id]  
show subscriber-policy [policy-number]  
show template [template-name]
```

MSDP: Unsupported Global Configuration Commands

```
ip msdp default-peer ip-address | name [prefix-list list]
```

Because BGP/Multiprotocol BGP (MBGP) is not supported, use the ip msdp peer command instead command.

RADIUS: Unsupported Global Configuration Commands

```
aaa nas port extended  
radius-server attribute nas-port  
radius-server configure  
radius-server extended-portnames
```

SNMP: Unsupported Global Configuration Commands

```
snmp-server enable informs
```

Spanning Tree: Unsupported Global Configuration Commands

```
spanning-tree etherchannel guard misconfig
```

VLANs: Unsupported User EXEC Commands

ifindex

private-vlan

Appendix B. RFCs

[Table B-1](#) lists some of the more common RFCs found throughout this book. You can find all RFCs online at www.rfc-editor.org/cgi-bin/rfcsearch.pl. Just insert the RFC number in the search field.

Table B-1. RFCs Referenced in This Book

Document	Title	Update Notes
RFC 3392	<i>Capabilities Advertisement with BGP-4</i>	
RFC 3260	<i>New Terminology and Clarifications for Diffserv</i>	
RFC 3248	<i>A Delay Bound Alternative Revision of RFC 2598</i>	
RFC 3065	<i>Autonomous System Confederations for BGP</i>	
RFC 2918	<i>Route Refresh Capability for BGP-4</i>	
RFC 2892	<i>Capabilities Advertisement with BGP-4</i>	
RFC 2796	<i>BGP Route Reflection — An Alternative to Full Mesh IBGP</i>	
RFC 2750	<i>RSVP Extensions for Policy Control</i>	
RFC 2697	<i>A Single Rate Three Color Marker</i>	
RFC 2598	<i>An Expedited Forwarding PHB</i>	Updated by RFC 3246
RFC 2597	<i>Assured Forwarding PHB Group</i>	Updated by RFC 3260
RFC 2519	<i>A Framework for Inter-Domain Route Aggregation</i>	
RFC 2475	<i>An Architecture for Differentiated Services</i>	Updated by RFC 3260
RFC 2474	<i>Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers</i>	Updated by RFC 3260
RFC 3392	<i>Capabilities Advertisement with BGP-4</i>	
RFC 2385	<i>Protection of BGP Sessions via the TCP MD5 Signature Option</i>	
RFC 2362	<i>Protocol Independent Multicast-Sparse Mode</i>	

RFC 2309	<i>Recommendations on Queue Management and Congestion Avoidance in the Internet</i>	
RFC 2330	<i>Framework for IP Performance Metrics</i>	
RFC 2205	<i>Resource ReSerVation Protocol (RSVP) — Version 1 Functional Specification</i>	Updated by RFC 2750
RFC 1998	<i>An Application of the BGP Community Attribute in Multi-home Routing</i>	
RFC 1105	<i>Border Gateway Protocol (BGP)</i>	Obsoleted by RFC 1163
RFC 1075	<i>Distance Vector Multicast Routing Protocol</i>	

Appendix C. Bibliography

The following table provides information about the sources consulted during the creation of this book.

Resource	Title	Web Page
<i>Bridging and IBM Networking Command Reference, Cisco IOS Software Release 12.0</i>		
<i>Cisco — Configuring IP Multicast Guides</i>		
<i>Cisco — Understanding Service Access Point Access Control Lists</i>	"Understanding Service Access Point Access Control Lists"	
<i>Cisco IOS Desktop Switching Software Configuration Guide</i>	"Creating and Maintaining VLANs"	
<i>Router Products Configuration Guide</i>	"Configuring DLSw+"	
<i>Software Configuration Guide – Release 5.4</i>	"Configuring Fast EtherChannel and Gigabit EtherChannel"	
<i>Software Configuration Guide – Release 6.1</i>		
<i>Cisco IOS 12.1 and 12.2 Configuration Guides and Command Reference</i>		

<i>Software Configuration Guide, Release 5.2</i>	"Configuring Spanning Tree"	
<i>Statement of Direction</i>	"10 Gigabit Ethernet Position Statement"	
Website	"Understanding and Configuring FastEtherChannel on Cisco Switching and Routing Devices"	www.cisco.com
Website	"Understanding and Configuring Spanning-Tree Protocol (STP) on Catalyst Switches"	Cisco.com/warp/public/473/5.html
Website	"Using the border Gateway Protocol for Interdomain Routing"	www.cisco.com
Website	"Configuring a Gateway of Last Resort Using IP Commands"	Cisco.com/warp/public/105/default.html
Data sheet	"Cisco 1000BASE-T GBIC"	
<i>Router Products Configuration and Reference</i>	"Configuring Transparent Bridging"	
Website	"Connectors and Cables"	Cisco.com/univercd/cc/td/doc/product/lan/c2900x1/gbic/ig
<i>Layer 3 Switching Software Feature and Configuration Guide</i>	"Configuring Bridging"	
Website	"Configuring BGP"	Cisco.com/univercd/cc/td/doc/product/software/ios113ed/1
Website	"Configuring ISO CLNS"	Cisco.com/univercd/cc/td/doc/product/software/ios113ed/1

Website	"The American Registry for Internet Numbers"	www.arin.net
Website	"The Internet Society"	www.isoc.org
Website	"The North American Network Operators' Group"	www.nanog.org
Website	"Asia Pacific Network Information Centre"	www.apnic.net
Website	"RIPE Network Coordination Centre"	www.ripe.net
	"BGP4 Inter-Domain Routing in the Internet"	
Website	"Catalyst 3550 limitation and Restrictions"	www.cisco.com
<i>CCIE Practical Studies, Volume I</i>		
<i>Cisco BGP-4 Command and Configuration Handbook</i>		
<i>Cisco Catalyst 3550 Software and Hardware Configuration Guides and Command Reference</i>	"Configuring 802.1s and 802.1w STP"	www.cisco.com
<i>Cisco Internetwork Troubleshooting</i>		
<i>Cisco IOS 12.0 Quality of Service</i>		
<i>Cisco IOS Configuration Fundamentals</i>		

<i>Cisco IOS Dial Solutions</i>		
<i>CCIE Professional Development: Cisco LAN Switching</i>		
<i>Cisco Voice Over Frame Relay, ATM, and IP</i>		www.cisco.com
<i>Converged Network Architectures</i>		
<i>Deploying Cisco Voice Over IP Solutions</i>		www.cisco.com
<i>Developing IP Multicast Networks, Volume I</i>		
<i>Integrating Voice and Data Networks</i>		
<i>Interconnections: Bridges, Routers, Switches, and Internetworking Protocols</i>		
<i>Internet Performance Survival Guide</i>		
<i>Internet Routing Architectures, Second Edition</i>		
<i>Internet Routing Architectures, Second Edition</i>		
<i>Internetworking SNA with Cisco Solutions</i>		
<i>Internetworking Troubleshooting Handbook, Second Edition</i>		

<i>Internetworking Troubleshooting Handbook, Third Edition</i>		
<i>Internetworking with TCP/IP, Volume I</i>		
<i>IP Quality of Service</i>		
<i>IP Telephony</i>		
<i>Managing Cisco Network Security</i>		
<i>Network Consultants Handbook</i>		
<i>Network Routing Architectures</i>		
<i>Performance and Fault Management</i>		
<i>Putting VoIP to Work: Softswitch Network Design and Testing</i>		
<i>Routing TCP/IP, Volume 1</i>		
<i>Routing TCP/IP, Volume II</i>		

<i>TCP/IP Principle, Protocols, and Architectures</i>		
<i>The Protocols TCP/IP Illustrated, Volume I</i>		

Appendix D. IP Prefix Lists

Prefix lists became available in Cisco IOS Software Release 12.0(3)T. You can use prefix lists as a simpler alternative to standard IP access lists for routing advertisement filtering with routing protocols. Although prefix lists are most commonly put to use in Border Gateway Protocol (BGP) configurations, this appendix demonstrates other ways that you can use prefix lists to support other routing protocols such as Enhanced Interior Gateway Routing Protocol (EIGRP). Prefix lists introduce a more streamlined way to create filters for network prefix advertisements by following these rules:

- Like access lists, prefix lists are processed sequentially from top to bottom. When a match is made, processing stops and the rest of the entries are not read.
- Entries can be added to the prefix lists at any time.
- An empty prefix lists permits all prefixes by default.
- Prefix lists do not use wildcard masks like access lists; they use a subnet length mask (for instance, /24).
- Unlike access lists, lines in prefix lists can be edited by the use of the sequence number.
- Prefix lists contain an implicit deny any at the end of each list.
- Sequence numbers are automatically generated; however, automatic sequence generation can be stopped.

Prefix lists are configured from global configuration mode using the following command:

```
ip prefix-list list-name | list-number [sequence sequence-value] deny | permit  
network-address/length [gege-value] [lele-value]
```

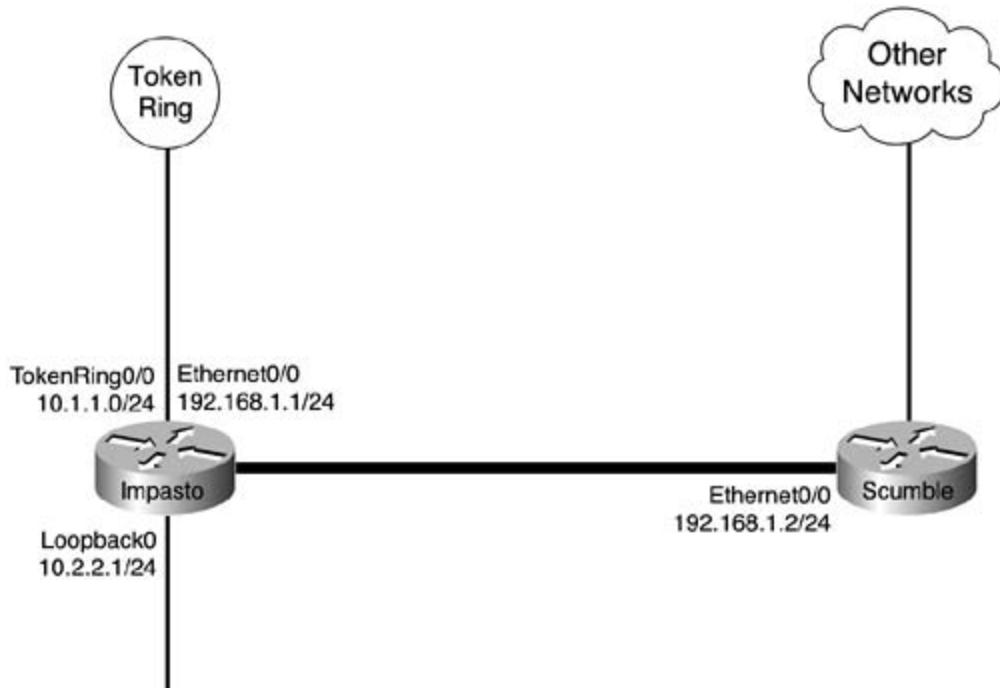
[Table D-1](#) shows the meaning for the prefix list syntax.

Table D-1. IP Prefix List Syntax

Command/Argument	Description
list-name list-number	Specifies the name or number of the prefix list.
seq <i>sequence-value</i>	(Optional) Sequence number. If the sequence number is not entered manually, an automatic sequence number is generated. These numbers are generated sequentially starting with 5 and incrementing by 5.
deny permit	Specifies whether prefixes are permitted or denied upon a match.
<i>network-address</i>	Network address to be matched, entered in dotted-decimal format.
<i>l length</i>	Length of the subnet mask in bits.
<i>ge ge-value</i>	(Optional) Specifies the minimum range of prefixes to be matched.
<i>le le-value</i>	(Optional) Specifies the maximum range of prefixes to be matched.

As previously mentioned, you can use prefix lists with distribute lists in router configuration mode to filter routing advertisements. Configuration of IP prefix lists is straightforward; changes in prefix lists are simple to configure as well. [Figure D-1](#) provides a step-by-step introduction to prefix list configuration using the network.

Figure D-1. Artista Network



The following example shows how prefix lists can be used to filter incoming routing updates with the EIGRP routing protocol:

Step 1. Define your prefix lists; in this example, prefix list Internal is used to specify eight 192.168.0.0/24 network prefixes:

```
ip prefix-list Internal seq 5 deny 192.168.0.0/24
ip prefix-list Internal seq 10 deny 192.168.1.0/24
ip prefix-list Internal seq 15 deny 192.168.2.0/24
ip prefix-list Internal seq 20 deny 192.168.3.0/24
ip prefix-list Internal seq 25 deny 192.168.4.0/24
ip prefix-list Internal seq 30 deny 192.168.5.0/24
ip prefix-list Internal seq 35 deny 192.168.6.0/24
ip prefix-list Internal seq 40 deny 192.168.7.0/24
```

Step 2. Create a distribution list that specifies your previously configured prefix list:

```
router eigrp 100
distribute-list prefix Internal in
```

To verify that the prefix list worked, from another router issue a show ip route command. [Example D-1](#) shows what the routing table looked like before the distribution list was configured.

Example D-1. Routing Table Prior to Distribution List

```
Impasto#show ip route eigrp

D    192.168.10.0/24 [90/409600] via 192.168.1.2, 00:00:03, Ethernet0/0
D    192.168.11.0/24 [90/409600] via 192.168.1.2, 00:00:03, Ethernet0/0
D    192.168.4.0/24 [90/409600] via 192.168.1.2, 00:00:47, Ethernet0/0
D    192.168.5.0/24 [90/409600] via 192.168.1.2, 00:00:47, Ethernet0/0
D    192.168.6.0/24 [90/409600] via 192.168.1.2, 00:00:47, Ethernet0/0
D    192.168.7.0/24 [90/409600] via 192.168.1.2, 00:00:47, Ethernet0/0
D    192.168.2.0/24 [90/409600] via 192.168.1.2, 00:00:47, Ethernet0/0
D    192.168.3.0/24 [90/409600] via 192.168.1.2, 00:00:47, Ethernet0/0
```

[Example D-2](#) shows the same routing table after applying the distribution list and clearing the routing from the Impasto router.

Example D-2. Routing Table After Distribution List Application

```
Impasto#clear ip route *
Impasto#show ip route eigrp

D    192.168.10.0/24 [90/409600] via 192.168.1.2, 00:00:41, Ethernet0/0
D    192.168.11.0/24 [90/409600] via 192.168.1.2, 00:00:41, Ethernet0/0
```

Notice that the routes mentioned by the prefix list have been removed from the routing tables. [Example D-3](#) shows the full configuration for the Impasto router used in this example.

Example D-3. Using IP Prefix Lists

```
interface Loopback0
  ip address 10.2.2.1 255.255.255.0
!
interface Ethernet0/0
```

```

ip address 192.168.1.1 255.255.255.0

!
interface TokenRing0/0
  ip address 10.1.1.1 255.255.255.0
!
router eigrp 100
  network 10.0.0.0
  network 192.168.1.0
  distribute-list prefix Internal in
  no auto-summary
!
ip prefix-list Internal seq 5 deny 192.168.0.0/24
ip prefix-list Internal seq 10 deny 192.168.1.0/24
ip prefix-list Internal seq 15 deny 192.168.2.0/24
ip prefix-list Internal seq 20 deny 192.168.3.0/24
ip prefix-list Internal seq 25 deny 192.168.4.0/24
ip prefix-list Internal seq 30 deny 192.168.5.0/24
ip prefix-list Internal seq 35 deny 192.168.6.0/24
ip prefix-list Internal seq 40 deny 192.168.7.0/24
ip prefix-list Internal seq 45 permit 0.0.0.0/0 le 32

```

Example D-4 demonstrates how you can use the ge and le arguments to filter routes based on minimum and maximum prefix matches. For this example, you need the same two routers with the same configurations. On the Impasto, create four loopback interfaces with the addresses 11.1.1.1/24, 11.2.1.1/16, 11.30.1.1/13, and 11.200.1.1/10. The Impasto and Scumble routers will run EIGRP in autonomous system number 100; the Impasto router will advertise networks 10.0.0.0, 192.168.1.0, and 11.0.0.0; and summarization should be disabled on both routers.

Example D-4. Preparing the Impasto Router

```
interface Loopback0
    ip address 10.2.2.1 255.255.255.0
    no ip directed-broadcast
!
interface Loopback10
    ip address 11.1.1.1 255.255.255.0
!
interface Loopback11
    ip address 11.2.1.1 255.255.0.0
!
interface Loopback12
    ip address 11.30.1.1 255.248.0.0
!
interface Loopback13
    ip address 11.200.1.1 255.192.0.0
!
interface Ethernet0/0
    ip address 192.168.1.2 255.255.255.0
!
router eigrp 100
    network 10.0.0.0
    network 11.0.0.0
    network 192.168.1.0 0.0.0.255
    no auto
```

[Example D-5](#) shows the addition of the new 11.0.0.0 networks, displaying the routing table on the Scumble router.

Example D-5. R2's Routing Table

```

Scumble#show ip route | include is|via

Gateway of last resort is not set

C    192.168.10.0/24 is directly connected, Loopback10
C    192.168.11.0/24 is directly connected, Loopback20
C    192.168.4.0/24 is directly connected, Loopback2
C    192.168.5.0/24 is directly connected, Loopback3

    10.0.0.0/24 is subnetted, 2 subnets

D      10.2.2.0 [90/156160] via 192.168.1.1, 00:02:02, FastEthernet0
D      10.1.1.0 [90/178688] via 192.168.1.1, 00:02:02, FastEthernet0

C    192.168.6.0/24 is directly connected, Loopback4

    11.0.0.0/8 is variably subnetted, 4 subnets, 4 masks

D      11.2.0.0/16 [90/156160] via 192.168.1.1, 00:02:02, FastEthernet0
D      11.1.1.0/24 [90/156160] via 192.168.1.1, 00:02:02, FastEthernet0
D      11.24.0.0/13 [90/156160] via 192.168.1.1, 00:02:02, FastEthernet0
D      11.192.0.0/10 [90/156160] via 192.168.1.1, 00:02:02, FastEthernet0

C    192.168.7.0/24 is directly connected, Loopback5
C    192.168.1.0/24 is directly connected, FastEthernet0
C    192.168.2.0/24 is directly connected, Loopback0
C    192.168.3.0/24 is directly connected, Loopback1

```

After creating the loopbacks and verifying EIGRP operation, create an IP prefix list that allows only the Impasto router to advertise the 11.1.0.0 networks with prefixes ranging from /16 to /32. Apply this prefix list to filter EIGRP routes leaving the Impasto router as shown in [Example D-6](#).

Example D-6. Applying the IP Prefix List

```
ip prefix-list Trial-2 seq 5 permit 11.1.0.0/16 le 32
```

```
!
```

```
router eigrp 100  
  
distribute-list prefix Trial-2 out
```

After you apply the prefix list on the Impasto router, the Scumble router's routing table will contain only the route to the 11.1.1.0/24 network. The other 11.0.0.0 networks with masks that range from 16 to 32 bits have been removed, and network 10.2.2.0/24 has also been removed, as shown in [Example D-7](#).

Example D-7. Scumble Router's Routing Table After IP Prefix List

```
Scumble#show ip route | include is|via  
  
Gateway of last resort is not set  
  
C    192.168.10.0/24 is directly connected, Loopback10  
C    192.168.11.0/24 is directly connected, Loopback20  
C    192.168.4.0/24 is directly connected, Loopback2  
C    192.168.5.0/24 is directly connected, Loopback3  
C    192.168.6.0/24 is directly connected, Loopback4  
      11.0.0.0/24 is subnetted, 1 subnets  
D      11.1.1.0 [90/156160] via 192.168.1.1, 00:02:30, FastEthernet0  
C    192.168.7.0/24 is directly connected, Loopback5  
C    192.168.1.0/24 is directly connected, FastEthernet0  
C    192.168.2.0/24 is directly connected, Loopback0  
C    192.168.3.0/24 is directly connected, Loopback1
```

Now, remove the 11.1.1.1/24 interface and add loopback interfaces 11.1.1.0/29, 11.1.1.32/29, and 11.1.1.64/29 to the configuration on the Impasto router; check the routing table on the Scumble router again. It should look like [Example D-8](#).

Example D-8. Experimenting with an IP Prefix List

```

Impasto(config)#interface loopback 11
Impasto(config-if)#ip address 11.1.1.1 255.255.255.248
Impasto(config-if)#interface loopback 14
Impasto(config-if)#ip address 11.1.1.33 255.255.255.248
Impasto(config-if)#interface loopback 15
Impasto(config-if)#ip address 11.1.1.65 255.255.255.248

Impasto#show ip route | include is|via
Gateway of last resort is not set

D    192.168.10.0/24 [90/409600] via 192.168.1.2, 00:06:53, Ethernet0/0
D    192.168.11.0/24 [90/409600] via 192.168.1.2, 00:06:53, Ethernet0/0
      10.0.0.0/24 is subnetted, 2 subnets
C      10.2.2.0 is directly connected, Loopback0
C      10.1.1.0 is directly connected, TokenRing0/0
      11.0.0.0/8 is variably subnetted, 6 subnets, 4 masks
C      11.2.0.0/16 is directly connected, Loopback11
C      11.1.1.0/29 is directly connected, Loopback10
C      11.24.0.0/13 is directly connected, Loopback12
C      11.1.1.32/29 is directly connected, Loopback14
C      11.1.1.64/29 is directly connected, Loopback15
C      11.192.0.0/10 is directly connected, Loopback13
C      192.168.1.0/24 is directly connected, Ethernet0/0

```

For the next part of this experiment, remove the outgoing Trial-2 prefix from EIGRP 100 and change the prefix list to any 11.1.0.0/16 network prefixes greater than 25 bits in length. (This will include the loopback interfaces that were just created in the preceding step but permit everything else.) After you have edited the prefix list, reapply it, as shown in [Example D-9](#).

Example D-9. Experimentation Continued

```

router eigrp 100

no distribute-list prefix- Trial-2 out

ip prefix-list Trial-2 seq 5 deny 11.1.0.0/16 ge 25
ip prefix-list Trial-2 seq 10 permit 0.0.0.0/0 le 32

router eigrp 100

distribute-list prefix- Trial-2 out

```

After you have applied the changes, the Scumble router's routing table should show the reappearance of the 10.0.0.0 networks and the 11.0.0.0 networks with masks greater than 16. The loopbacks created in the preceding step should have been removed, as shown in [Example D-10](#).

Example D-10. Scumble Router's Routing Table After Changing Prefix List Trial-2

```

Scumble#clear ip route *
Scumble#show ip route | include is|via
Gateway of last resort is not set

C    192.168.10.0/24 is directly connected, Loopback10
C    192.168.11.0/24 is directly connected, Loopback20
C    192.168.4.0/24 is directly connected, Loopback2
C    192.168.5.0/24 is directly connected, Loopback3

          10.0.0.0/24 is subnetted, 2 subnets
D      10.2.2.0 [90/156160] via 192.168.1.1, 00:00:16, FastEthernet0
D      10.1.1.0 [90/178688] via 192.168.1.1, 00:00:16, FastEthernet0
C    192.168.6.0/24 is directly connected, Loopback4

```

```
11.0.0.0/8 is variably subnetted, 3 subnets, 3 masks  
D      11.2.0.0/16 [90/156160] via 192.168.1.1, 00:00:16, FastEthernet0  
D      11.24.0.0/13 [90/156160] via 192.168.1.1, 00:00:16, FastEthernet0  
D      11.192.0.0/10 [90/156160] via 192.168.1.1, 00:00:16, FastEthernet0  
C      192.168.7.0/24 is directly connected, Loopback5  
C      192.168.1.0/24 is directly connected, FastEthernet0  
C      192.168.2.0/24 is directly connected, Loopback0  
C      192.168.3.0/24 is directly connected, Loopback1
```

[Example D-11](#) shows the completed configuration for the Impasto router.

Example D-11. Complete Configuration for the Impasto Router

```
interface Loopback0  
  ip address 10.2.2.1 255.255.255.0  
  
!  
  
interface Loopback10  
  ip address 11.1.1.1 255.255.255.248  
  
!  
  
interface Loopback11  
  ip address 11.2.1.1 255.255.0.0  
  
!  
  
interface Loopback12  
  ip address 11.30.1.1 255.248.0.0  
  
!  
  
interface Loopback13  
  ip address 11.200.1.1 255.192.0.0  
  
!
```

```
interface Loopback14
  ip address 11.1.1.33 255.255.255.248
!
interface Loopback15
  ip address 11.1.1.65 255.255.255.248
!
interface Ethernet0/0
  ip address 192.168.1.1 255.255.255.0
!
interface TokenRing0/0
  ip address 10.1.1.1 255.255.255.0
!
router eigrp 100
  network 10.0.0.0
  network 11.0.0.0
  network 192.168.1.0
  neighbor 192.168.1.2
  distribute-list prefix Trial-2 out
  distribute-list prefix Internal in
  no auto-summary
!
ip prefix-list Internal seq 5 deny 192.168.0.0/24
ip prefix-list Internal seq 10 deny 192.168.1.0/24
ip prefix-list Internal seq 15 deny 192.168.2.0/24
ip prefix-list Internal seq 20 deny 192.168.3.0/24
ip prefix-list Internal seq 25 deny 192.168.4.0/24
ip prefix-list Internal seq 30 deny 192.168.5.0/24
ip prefix-list Internal seq 35 deny 192.168.6.0/24
```

```
ip prefix-list Internal seq 40 deny 192.168.7.0/24
ip prefix-list Internal seq 45 permit 0.0.0.0/0 le 32
!
ip prefix-list Trial-2 seq 5 deny 11.1.0.0/16 ge 25
ip prefix-list Trial-2 seq 10 permit 0.0.0.0/0 le 32
```

With a little practice, you might use the simpler prefix lists in place of access lists for all routing protocols, not just for BGP.

[\[SYMBOL\]](#) [\[A\]](#) [\[B\]](#) [\[C\]](#) [\[D\]](#) [\[E\]](#) [\[F\]](#) [\[G\]](#) [\[H\]](#) [\[I\]](#) [\[J\]](#) [\[K\]](#) [\[L\]](#) [\[M\]](#) [\[N\]](#) [\[O\]](#) [\[P\]](#) [\[Q\]](#) [\[R\]](#) [\[S\]](#) [\[T\]](#) [\[U\]](#) [\[V\]](#) [\[W\]](#) [\[Z\]](#)

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? (question mark)

[Catalyst 3550 help system](#)

10BASE-T Ethernet

[NLP](#)

[802.1Q trunking](#)

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