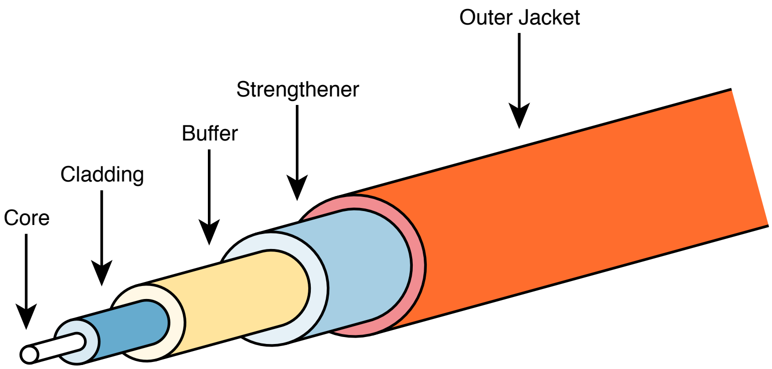

Figure 2-15 *Components of a Fiber-Optic Cable*

The three outer layers of the cable protect the interior of the cable and make the cables easier to install and manage, while the inner *cladding* and *core* work together to create the environment to allow transmission of light over the cable. A light source, called the *optical transmitter*, shines a light into the core. Light can pass through the core; however, light reflects off the cladding back into the core. Figure 2-16 shows an example with a light emitting diode (LED) transmitter. You can see how the cladding reflects the light back into the core as it travels through the core.

Key Topic

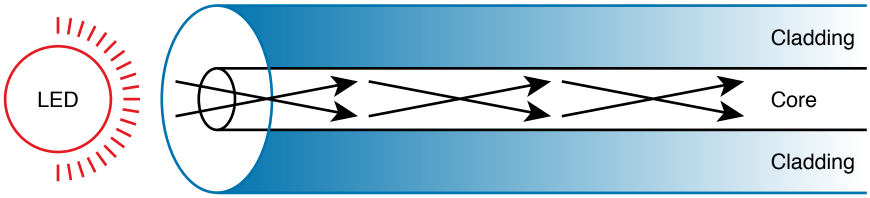

Figure 2-16 *Transmission on Multimode Fiber with Internal Reflection*

The figure shows the normal operation of a multimode fiber, characterized by the fact that the cable allows for multiple angles (modes) of light waves entering the core.

In contrast, single-mode fiber uses a smaller-diameter core, around one-fifth the diameter of common multimode cables (see Figure 2-17). To transmit light into a much smaller core, a laser-based transmitter sends light at a single angle (hence the name *single-mode*).

Figure 2-17 *Transmission on Single-Mode Fiber with Laser Transmitter*

Both multimode and single-mode cabling have important roles in Ethernet and meet different needs. Multimode improves the maximum distances over UTP, and it uses less expensive transmitters as compared with single-mode. Standards do vary; for instance, the standards for 10 Gigabit Ethernet over Fiber allow for distances up to 400m, which would often allow for connection of devices in different buildings in the same office park. Single-mode allows distances into the tens of kilometers, but with slightly more expensive SFP/SFP+ hardware.

To transmit between two devices, you need two cables, one for each direction, as shown in Figure 2-18. The concept works much like having two electrical circuits with the original UTP Ethernet standards. Note that the transmit port on one device connects to a cable that connects to a receive port on the other device, and vice versa with the other cable.

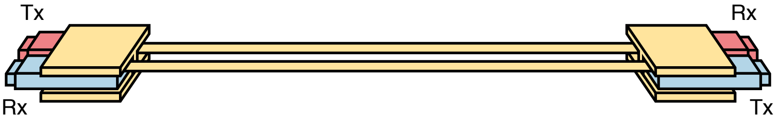

Figure 2-18 *Two Fiber Cables with Tx Connected to Rx on Each Cable*

Using Fiber with Ethernet

To use fiber with Ethernet switches, you need to use a switch with either built-in ports that support a particular optical Ethernet standard, or a switch with modular ports that allow you to change the Ethernet standard used on the port. Refer back to Figure 2-8, which shows a photo of a switch with two SFP+ ports, into which you could insert any of the supported SFP+ modules. Those SFP+ ports support a variety of 10-Gbps standards like those listed in Table 2-4.

Table 2-4 A Sampling of IEEE 802.3 10-Gbps Fiber Standards

Standard	Cable Type	Max Distance*
10GBASE-S	MM	400m
10GBASE-LX4	MM	300m
10GBASE-LR	SM	10km
10GBASE-E	SM	30km

* The maximum distances are based on the IEEE standards with no repeaters.

For instance, to build an Ethernet LAN in an office park, you might need to use some multimode and single-mode fiber links. In fact, many office parks might already have fiber cabling installed for the expected future use by the tenants in the buildings. If each building was within a few hundred meters of at least one other building, you could use multimode fiber between the buildings and connect switches to create your LAN.

NOTE Outside the need to study for CCNA, if you need to look more deeply at fiber Ethernet and SFP/SFP+, check out tmgmatrix.cisco.com as a place to search for and learn about compatible SFP/SFP+ hardware from Cisco.

Although distance might be the first criterion to consider when thinking about whether to use UTP or fiber cabling, a few other tradeoffs exist as well. UTP wins again on cost, because the cost goes up as you move from UTP, to multimode, and then to single-mode, due to the extra cost for the transmitters like the SFP and SFP+ modules. UTP has some negatives, however. First, UTP might work poorly in some electrically noisy environments such as factories, because UTP can be affected by electromagnetic interference (EMI). Also, UTP cables emit a faint signal outside the cable, so highly secure networks may choose to use fiber, which does not create similar emissions, to make the network more secure. Table 2-5 summarizes these tradeoffs.

Key Topic

Table 2-5 Comparisons Between UTP, MM, and SM Ethernet Cabling

Criteria	UTP	Multimode	Single-Mode
Relative Cost of Cabling	Low	Medium	Medium
Relative Cost of a Switch Port	Low	Medium	High
Approximate Max Distance	100m	500m	40km
Relative Susceptibility to Interference	Some	None	None
Relative Risk of Copying from Cable Emissions	Some	None	None

Sending Data in Ethernet Networks

Although physical layer standards vary quite a bit, other parts of the Ethernet standards work the same regardless of the type of physical Ethernet link. Next, this final major section of this chapter looks at several protocols and rules that Ethernet uses regardless of the type of link. In particular, this section examines the details of the Ethernet data-link layer protocol, plus how Ethernet nodes, switches, and hubs forward Ethernet frames through an Ethernet LAN.

Ethernet Data-Link Protocols

One of the most significant strengths of the Ethernet family of protocols is that these protocols use the same data-link standard. In fact, the core parts of the data-link standard date back to the original Ethernet standards.

The Ethernet data-link protocol defines the Ethernet frame: an Ethernet header at the front, the encapsulated data in the middle, and an Ethernet trailer at the end. Ethernet actually defines a few alternate formats for the header, with the frame format shown in Figure 2-19 being commonly used today.

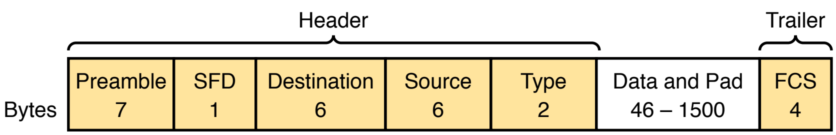

Figure 2-19 *Commonly Used Ethernet Frame Format*

While all the fields in the frame matter, some matter more to the topics discussed in this book. Table 2-6 lists the fields in the header and trailer and a brief description for reference, with the upcoming pages including more detail about a few of these fields.

Table 2-6 IEEE 802.3 Ethernet Header and Trailer Fields

Field	Bytes	Description
Preamble	7	Synchronization.
Start Frame Delimiter (SFD)	1	Signifies that the next byte begins the Destination MAC Address field.
Destination MAC Address	6	Identifies the intended recipient of this frame.
Source MAC Address	6	Identifies the sender of this frame.
Type	2	Defines the type of protocol listed inside the frame; today, most likely identifies IP version 4 (IPv4) or IP version 6 (IPv6).
Data and Pad*	46– 1500	Holds data from a higher layer, typically an L3PDU (usually an IPv4 or IPv6 packet). The sender adds padding to meet the minimum length requirement for this field (46 bytes).
Frame Check Sequence (FCS)	4	Provides a method for the receiving NIC to determine whether the frame experienced transmission errors.

* The IEEE 802.3 specification limits the data portion of the 802.3 frame to a minimum of 46 and a maximum of 1500 bytes. The *term maximum transmission unit* (MTU) defines the maximum Layer 3 packet that can be sent over a medium. Because the Layer 3 packet rests inside the data portion of an Ethernet frame, 1500 bytes is the largest IP MTU allowed over an Ethernet.

Ethernet Addressing

The source and destination Ethernet address fields play a huge role in how Ethernet LANs work. The general idea for each is relatively simple: the sending node puts its own address in the source address field and the intended Ethernet destination device's address in the destination address field. The sender transmits the frame, expecting that the Ethernet LAN, as a whole, will deliver the frame to that correct destination.

Ethernet addresses, also called Media Access Control (MAC) addresses, are 6-byte-long (48-bit-long) binary numbers. For convenience, most computers list MAC addresses as 12-digit hexadecimal numbers. Cisco devices typically add some periods to the number for easier readability as well; for example, a Cisco switch might list a MAC address as 0000.0C12.3456.

Most MAC addresses represent a single NIC or other Ethernet port, so these addresses are often called a *unicast* Ethernet address. The term *unicast* is simply a formal way to refer to the fact that the address represents one interface to the Ethernet LAN. (This term also contrasts with two other types of Ethernet addresses, *broadcast* and *multicast*, which will be defined later in this section.)

The entire idea of sending data to a destination unicast MAC address works well, but it works only if all the unicast MAC addresses are unique. If two NICs tried to use the same MAC address, there could be confusion. (The problem would be like the confusion caused to the postal service if you and I both tried to use the same mailing address—would the postal service deliver mail to your house or mine?) If two PCs on the same Ethernet tried to use the same MAC address, to which PC should frames sent to that MAC address be delivered?

Ethernet solves this problem using an administrative process so that, at the time of manufacture, all Ethernet devices are assigned a universally unique MAC address. Before a manufacturer can build Ethernet products, it must ask the IEEE to assign the manufacturer a universally unique 3-byte code, called the organizationally unique identifier (OUI). The manufacturer agrees to give all NICs (and other Ethernet products) a MAC address that begins with its assigned 3-byte OUI. The manufacturer also assigns a unique value for the last 3 bytes, a number that manufacturer has never used with that OUI. As a result, the MAC address of every device in the universe is unique.

NOTE The IEEE also calls these universal MAC addresses global MAC addresses.

Figure 2-20 shows the structure of the unicast MAC address, with the OUI.

Key Topic

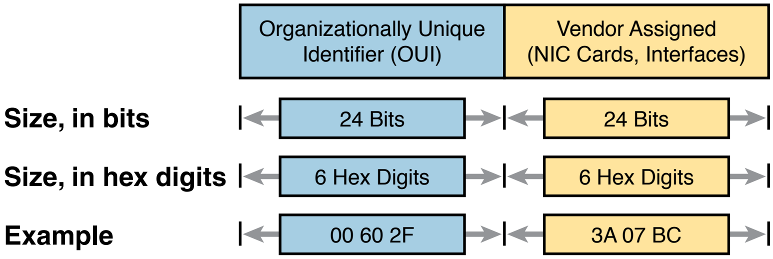

Figure 2-20 *Structure of Unicast Ethernet Addresses*

Ethernet addresses go by many names: LAN address, Ethernet address, hardware address, burned-in address, physical address, universal address, or MAC address. For example, the term burned-in address (BIA) refers to the idea that a permanent MAC address has been encoded (burned into) the ROM chip on the NIC. As another example, the IEEE uses the term *universal address* to emphasize the fact that the address assigned to a NIC by a manufacturer should be unique among all MAC addresses in the universe.

In addition to unicast addresses, Ethernet also uses group addresses. *Group addresses* identify more than one LAN interface card. A frame sent to a group address might be delivered to a small set of devices on the LAN, or even to all devices on the LAN. In fact, the IEEE defines two general categories of group addresses for Ethernet:

Broadcast address: Frames sent to this address should be delivered to all devices on the Ethernet LAN. It has a value of FFFF.FFFF.FFFF.

Multicast addresses: Frames sent to a multicast Ethernet address will be copied and forwarded to a subset of the devices on the LAN that volunteers to receive frames sent to a specific multicast address.

Table 2-7 summarizes most of the details about MAC addresses.

Table 2-7 LAN MAC Address Terminology and Features

LAN Addressing Term or Feature	Description
MAC	Media Access Control. 802.3 (Ethernet) defines the MAC sublayer of IEEE Ethernet.
Ethernet address, NIC address, LAN address	Other names often used instead of MAC address. These terms describe the 6-byte address of the LAN interface card.
Burned-in address	The 6-byte address assigned by the vendor making the card.
Unicast address	A term for a MAC address that represents a single LAN interface.
Broadcast address	An address that means "all devices that reside on this LAN right now."
Multicast address	On Ethernet, a multicast address implies some subset of all devices currently on the Ethernet LAN.

Identifying Network Layer Protocols with the Ethernet Type Field

While the Ethernet header's address fields play an important and more obvious role in Ethernet LANs, the Ethernet Type field plays a much less obvious role. The Ethernet Type field, or EtherType, sits in the Ethernet data-link layer header, but its purpose is to directly help the network processing on routers and hosts. Basically, the Type field identifies the type of network layer (Layer 3) packet that sits inside the Ethernet frame.

First, think about what sits inside the data part of the Ethernet frame shown earlier in Figure 2-14. Typically, it holds the network layer packet created by the network layer protocol on some device in the network. Over the years, those protocols have included IBM Systems Network Architecture (SNA), Novell NetWare, Digital Equipment Corporation's DECnet, and Apple Computer's AppleTalk. Today, the most common network layer protocols are both from TCP/IP: IP version 4 (IPv4) and IP version 6 (IPv6).

The original host has a place to insert a value (a hexadecimal number) to identify the type of packet encapsulated inside the Ethernet frame. However, what number should the sender put in the header to identify an IPv4 packet as the type? Or an IPv6 packet? As it turns out, the IEEE manages a list of EtherType values, so that every network layer protocol that needs a unique EtherType value can have a number. The sender just has to know the list. (Anyone can view the list; just go to www.ieee.org and search for *EtherType*.)

For example, a host can send one Ethernet frame with an IPv4 packet and the next Ethernet frame with an IPv6 packet. Each frame would have a different Ethernet Type field value, using the values reserved by the IEEE, as shown in Figure 2-21.

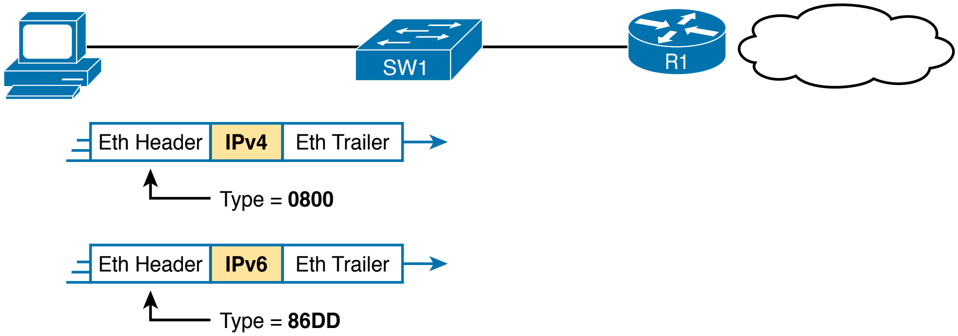

Figure 2-21 *Use of Ethernet Type Field*

Error Detection with FCS

Ethernet also defines a way for nodes to find out whether a frame's bits changed while crossing over an Ethernet link. (Usually, the bits could change because of some kind of electrical interference, or a bad NIC.) Ethernet, like most data-link protocols, uses a field in the data-link trailer for the purpose of error detection.

The Ethernet Frame Check Sequence (FCS) field in the Ethernet trailer—the only field in the Ethernet trailer—gives the receiving node a way to compare results with the sender, to discover whether errors occurred in the frame. The sender applies a complex math formula to the frame before sending it, storing the result of the formula in the FCS field. The receiver applies the same math formula to the received frame. The receiver then compares its own results with the sender's results. If the results are the same, the frame did not change; otherwise, an error occurred, and the receiver discards the frame.

Note that *error detection* does not also mean *error recovery*. Ethernet defines that the errored frame should be discarded, but Ethernet does not attempt to recover the lost frame. Other protocols, notably TCP, recover the lost data by noticing that it is lost and sending the data again.

Sending Ethernet Frames with Switches and Hubs

Ethernet LANs behave slightly differently depending on whether the LAN has mostly modern devices, in particular, LAN switches instead of some older LAN devices called LAN hubs. Basically, the use of more modern switches allows the use of full-duplex logic, which is much faster and simpler than half-duplex logic, which is required when using hubs. The final topic in this chapter looks at these basic differences.

Sending in Modern Ethernet LANs Using Full Duplex

Modern Ethernet LANs use a variety of Ethernet physical standards, but with standard Ethernet frames that can flow over any of these types of physical links. Each individual link can run at a different speed, but each link allows the attached nodes to send the bits in the frame to the next node. They must work together to deliver the data from the sending Ethernet node to the destination node.

The process is relatively simple, on purpose; the simplicity lets each device send a large number of frames per second. Figure 2-22 shows an example in which PC1 sends an Ethernet frame to PC2.

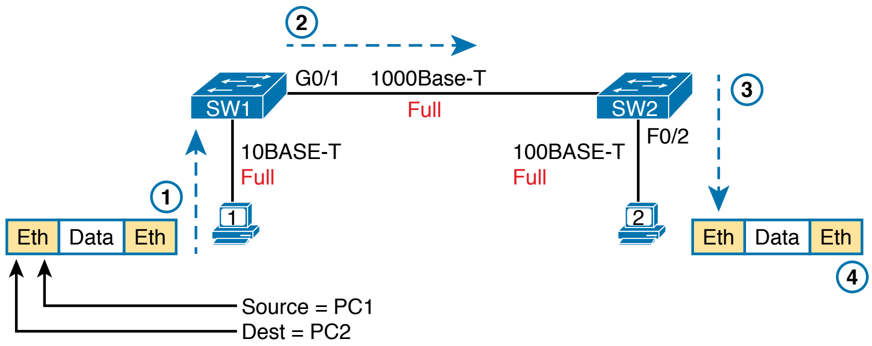

Figure 2-22 *Example of Sending Data in a Modern Ethernet LAN*

Following the steps in the figure:

1. PC1 builds and sends the original Ethernet frame, using its own MAC address as the source address and PC2's MAC address as the destination address.
2. Switch SW1 receives and forwards the Ethernet frame out its G0/1 interface (short for Gigabit interface 0/1) to SW2.
3. Switch SW2 receives and forwards the Ethernet frame out its F0/2 interface (short for Fast Ethernet interface 0/2) to PC2.
4. PC2 receives the frame, recognizes the destination MAC address as its own, and processes the frame.

The Ethernet network in Figure 2-22 uses full duplex on each link, but the concept might be difficult to see.

Full duplex means that that the NIC or switch port has no half-duplex restrictions. So, to understand full duplex, you need to understand half duplex, as follows:

Key Topic

Half duplex: The device must wait to send if it is currently receiving a frame; in other words, it cannot send and receive at the same time.

Full duplex: The device does not have to wait before sending; it can send and receive at the same time.

So, with all PCs and LAN switches, and no LAN hubs, all the nodes can use full duplex. All nodes can send and receive on their port at the same instant in time. For example, in Figure 2-22, PC1 and PC2 could send frames to each other simultaneously, in both directions, without any half-duplex restrictions.

Using Half Duplex with LAN Hubs

To understand the need for half-duplex logic in some cases, you have to understand a little about an older type of networking device called a LAN hub. When the IEEE first introduced 10BASE-T in 1990, Ethernet switches did not exist yet; instead, networks used a device called a LAN hub. Like a switch, a LAN hub provided a number of RJ-45 ports as a place to connect links to PCs; however, hubs used different rules for forwarding data.

LAN hubs forward data using physical layer standards rather than data-link standards and are therefore considered to be Layer 1 devices. When an electrical signal comes in one hub port, the hub repeats that electrical signal out all other ports (except the incoming port). By doing so, the data reaches all the rest of the nodes connected to the hub, so the data hopefully reaches the correct destination. The hub has no concept of Ethernet frames, of addresses, making decisions based on those addresses, and so on.

The downside of using LAN hubs is that if two or more devices transmitted a signal at the same instant, the electrical signal collides and becomes garbled. The hub repeats all received electrical signals, even if it receives multiple signals at the same time. For example, Figure 2-23 shows the idea, with PCs Archie and Bob sending an electrical signal at the same instant of time (at Steps 1A and 1B) and the hub repeating both electrical signals out toward Larry on the left (Step 2).

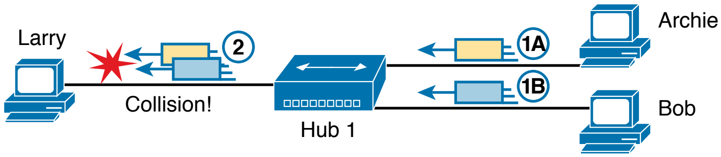

Figure 2-23 *Collision Occurring Because of LAN Hub Behavior*

NOTE For completeness, note that the hub floods each frame out all other ports (except the incoming port). So, Archie's frame goes to both Larry and Bob; Bob's frame goes to Larry and Archie.

If you replace the hub in Figure 2-23 with a LAN switch, the switch prevents the collision on the left. The switch operates as a Layer 2 device, meaning that it looks at the data-link header and trailer. A switch would look at the MAC addresses, and even if the switch needed to forward both frames to Larry on the left, the switch would send one frame and queue the other frame until the first frame was finished.

Now back to the issue created by the hub's logic: collisions. To prevent these collisions, the Ethernet nodes must use half-duplex logic instead of full-duplex logic. A problem occurs only when two or more devices send at the same time; half-duplex logic tells the nodes that if someone else is sending, wait before sending.

For example, back in Figure 2-23, imagine that Archie began sending his frame early enough so that Bob received the first bits of that frame before Bob tried to send his own frame. Bob, at Step 1B, would notice that he was receiving a frame from someone else, and using half-duplex logic, would simply wait to send the frame listed at Step 1B.

Nodes that use half-duplex logic actually use a relatively well-known algorithm called carrier sense multiple access with collision detection (CSMA/CD). The algorithm takes care of the obvious cases but also the cases caused by unfortunate timing. For example, two nodes could check for an incoming frame at the exact same instant, both realize that no other node is sending, and both send their frames at the exact same instant, causing a collision. CSMA/CD covers these cases as well, as follows:

Step 1. A device with a frame to send listens until the Ethernet is not busy.

Step 2. When the Ethernet is not busy, the sender begins sending the frame.

Step 3. The sender listens while sending to discover whether a collision occurs; collisions might be caused by many reasons, including unfortunate timing. If a collision occurs, all currently sending nodes do the following:

A. They send a jamming signal that tells all nodes that a collision happened.

B. They independently choose a random time to wait before trying again, to avoid unfortunate timing.

C. The next attempt starts again at Step 1.

Although most modern LANs do not often use hubs and therefore do not need to use half duplex, enough old hubs still exist in enterprise networks so that you need to be ready to understand duplex issues. Each NIC and switch port has a duplex setting. For all links between PCs and switches, or between switches, use full duplex. However, for any link connected to a LAN hub, the connected LAN switch and NIC port should use half duplex. Note that the hub itself does not use half-duplex logic, instead just repeating incoming signals out every other port.

Figure 2-24 shows an example, with full-duplex links on the left and a single LAN hub on the right. The hub then requires SW2's F0/2 interface to use half-duplex logic, along with the PCs connected to the hub.

Key Topic

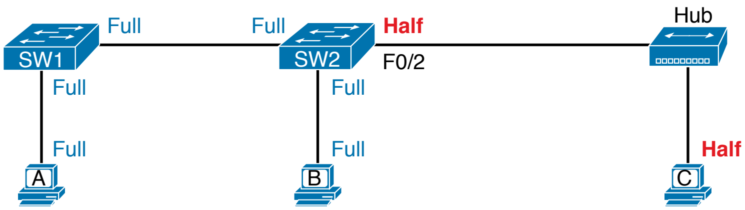

Figure 2-24 *Full and Half Duplex in an Ethernet LAN*

Before closing the chapter, note that the discussion of full and half duplex connects to two specific terms from CCNA exam topic 1.3.b, but those connections may not be obvious. First, the term *Ethernet shared media* (from the exam topic) refers to designs that use hubs, require CSMA/CD, and therefore share the bandwidth. The idea behind the term comes from the fact that the devices connected to the hub share the network because they must use CSMA/CD, and CSMA/CD enforces rules that allow only one device to successfully send a frame at any point in time.

By contrast, the term *Ethernet point-to-point* in that same exam topic emphasizes the fact that in a network built with switches, each (point-to-point) link works independently of the others. Because of the full-duplex logic discussed in this section, a frame can be sent on every point-to-point link in an Ethernet at the same time.

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 2-8 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 2-8 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Review memory tables		Book, website

Review All the Key Topics

Key Topic

Table 2-9 Key Topics for Chapter 2

Key Topic Element	Description	Page Number
Figure 2-3	Drawing of a typical wired and wireless enterprise LAN	36
Table 2-2	Several types of Ethernet LANs and some details about each	37
Figure 2-9	Conceptual drawing of transmitting in one direction each over two different electrical circuits between two Ethernet nodes	43
Figure 2-10	10- and 100-Mbps Ethernet straight-through cable pinouts	43
Figure 2-12	10- and 100-Mbps Ethernet crossover cable pinouts	44
Table 2-3	List of devices that transmit on wire pair 1,2 and pair 3,6	45
Figure 2-13	Typical uses for straight-through and crossover Ethernet cables	45
Figure 2-16	Physical transmission concepts in a multimode cable	47
Table 2-5	Comparison between UTP, MM, and SM Ethernet Cabling	49
Figure 2-20	Format of Ethernet MAC addresses	51
List	Definitions of half duplex and full duplex	54
Figure 2-24	Examples of which interfaces use full duplex and which interfaces use half duplex	56

Key Terms You Should Know

Ethernet, IEEE, wired LAN, wireless LAN, Ethernet frame, 10BASE-T, 100BASE-T, 1000BASE-T, Fast Ethernet, Gigabit Ethernet, Ethernet link, RJ-45, Ethernet port, network interface card (NIC), straight-through cable, crossover cable, Ethernet address, MAC address, unicast address, broadcast address, Frame Check Sequence, transceiver, Multimode (MM), single-mode (SM), electromagnetic Interference (EMI), core, cladding, fiber-optic cable

CHAPTER 3

Fundamentals of WANs and IP Routing

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.1 Explain the role and function of network components

1.1.a Routers

1.2 Describe characteristics of network topology architectures

1.2.d WAN

This chapter introduces WANs and the various features of the TCP/IP network layer.

First, for WANs, note that the current CCNA blueprint does not examine WANs in detail as an end to themselves. However, to understand IP routing, you need to understand the basics of the two types of WAN links introduced in the first major section of this chapter: serial links and Ethernet WAN links. In their most basic form, these WAN links connect routers that sit at sites that can be miles to hundreds of miles apart, allowing communications between remote sites.

The rest of the chapter then turns to the TCP/IP Network layer, with IP as the center of the discussion. The second section of the chapter discusses the major features of IP: routing, addressing, and routing protocols. The final section of the chapter examines a few protocols other than IP that also help the TCP/IP Network layer create a network that allows end-to-end communication between endpoints.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 3-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Wide-Area Networks	1, 2
IP Routing	3–6
Other Network Layer Functions	7

1. Which of the following fields in the HDLC header used by Cisco routers does Cisco add, beyond the ISO standard HDLC?
   a. Flag
   b. Type
   c. Address
   d. FCS

2. Two routers, R1 and R2, connect using an Ethernet over MPLS service. The service provides point-to-point service between these two routers only, as a Layer 2 Ethernet service. Which of the following are the most likely to be true about this WAN? (Choose two answers.)
   a. R1 will connect to a physical Ethernet link, with the other end of the cable connected to R2.
   b. R1 will connect to a physical Ethernet link, with the other end of the cable connected to a device at the WAN service provider point of presence.
   c. R1 will forward data-link frames to R2 using an HDLC header/trailer.
   d. R1 will forward data-link frames to R2 using an Ethernet header/trailer.

3. Imagine a network with two routers that are connected with a point-to-point HDLC serial link. Each router has an Ethernet, with PC1 sharing the Ethernet with Router1 and PC2 sharing the Ethernet with Router2. When PC1 sends data to PC2, which of the following is true?
   a. Router1 strips the Ethernet header and trailer off the frame received from PC1, never to be used again.
   b. Router1 encapsulates the Ethernet frame inside an HDLC header and sends the frame to Router2, which extracts the Ethernet frame for forwarding to PC2.
   c. Router1 strips the Ethernet header and trailer off the frame received from PC1, which is exactly re-created by Router2 before forwarding data to PC2.
   d. Router1 removes the Ethernet, IP, and TCP headers and rebuilds the appropriate headers before forwarding the packet to Router2.

4. Which of the following does a router normally use when making a decision about routing TCP/IP packets?
   a. Destination MAC address
   b. Source MAC address
   c. Destination IP address
   d. Source IP address
   e. Destination MAC and IP addresses

5. Which of the following are true about a LAN-connected TCP/IP host and its IP routing (forwarding) choices?
   a. The host always sends packets to its default gateway.
   b. The host never sends packets to its default gateway.
   c. The host sends packets to its default gateway if the destination IP address is in a different subnet than the host.
   d. The host sends packets to its default gateway if the destination IP address is in the same subnet as the host.
6. Which of the following are functions of a routing protocol? (Choose two answers.)
   a. Advertising known routes to neighboring routers
   b. Learning routes for subnets directly connected to the router
   c. Learning routes and putting those routes into the routing table for routes advertised to the router by its neighboring routers
   d. Forwarding IP packets based on a packet's destination IP address
7. A company implements a TCP/IP network, with PC1 sitting on an Ethernet LAN. Which of the following protocols and features requires PC1 to learn information from some other server device?
   a. ARP
   b. ping
   c. DNS
   d. None of these answers is correct.

Foundation Topics

Wide-Area Networks

Imagine a typical day at the branch office at some enterprise. The user sits at some endpoint device: a PC, tablet, phone, and so on. It connects to a LAN, either via an Ethernet cable or using a wireless LAN. However, the user happens to be checking information on a website, and that web server sits at the home office of the company. To make that work, the data travels over one or more wide-area network (WAN) links.

WAN technologies define the physical (Layer 1) standards and data-link (Layer 2) protocols used to communicate long distances. This first section examines two such technologies: leased-line WANs and Ethernet WANs. Leased-line WANs have been an option for networks for half a century, are becoming much less common today, but you may still see some leased-line WAN links in the exam. Ethernet WAN links do use the same data-link protocols as Ethernet LANs, but they use additional features to make the links work over the much longer distances required for WANs. The next few pages examine leased-line WANs first, followed by Ethernet WANs.

Leased-Line WANs

To connect LANs using a WAN, the internetwork uses a router connected to each LAN, with a WAN link between the routers. First, the enterprise's network engineer would order some kind of WAN link. A router at each site connects to both the WAN link and the LAN, as shown in Figure 3-1. Note that a crooked line between the routers is the common way to represent a leased line when the drawing does not need to show any of the physical details of the line.

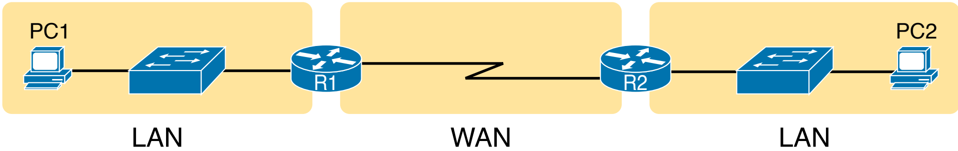

Figure 3-1 *Small Enterprise Network with One Leased Line*

This section begins by examining the physical details of leased lines, followed by a discussion of the default data-link protocol for leased lines (HDLC).

Physical Details of Leased Lines

The leased line service delivers bits in both directions, at a predetermined speed, using full-duplex logic. In fact, conceptually it acts as if you had a full-duplex crossover Ethernet link between two routers, as shown in Figure 3-2. The leased line uses two pairs of wires, one pair for each direction of sending data, which allows full-duplex operation.

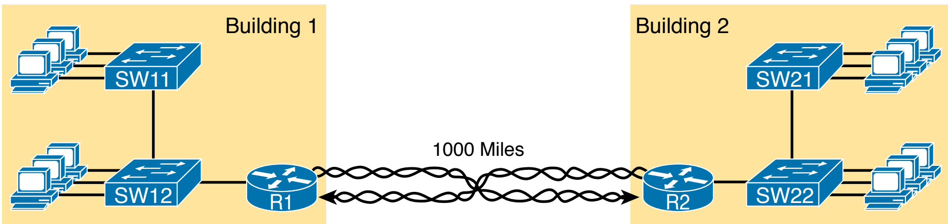

Figure 3-2 *Conceptual View of the Leased-Line Service*

Of course, leased lines have many differences compared to an Ethernet crossover cable. To create such possibly long links, or circuits, a leased line does not actually exist as a single long cable between the two sites. Instead, the telephone company (telco) that creates the leased line installs a large network of cables and specialized switching devices to create its own computer network. The telco network creates a service that acts like a crossover cable between two points, but the physical reality is hidden from the customer.

Leased lines come with their own set of terminology as well. First, the term *leased line* refers to the fact that the company using the leased line does not own the line but instead pays a monthly lease fee to use it. Table 3-2 lists some of the many names for leased lines, mainly so that in a networking job, you have a chance to translate from the terms each person uses with a basic description as to the meaning of the name.

Table 3-2 Different Names for a Leased Line

Name	Meaning or Reference
Leased circuit, Circuit	The words *line* and *circuit* are often used as synonyms in telco terminology; *circuit* makes reference to the electrical circuit between the two endpoints.
Serial link, Serial line	The words *link* and *line* are also often used as synonyms. *Serial* in this case refers to the fact that the bits flow serially and that routers use serial interfaces.
Point-to-point link, Point-to-point line	These terms refer to the fact that the topology stretches between two points, and two points only. (Some older leased lines allowed more than two devices.)
T1	This specific type of leased line transmits data at 1.544 megabits per second (1.544 Mbps).
WAN link, Link	Both of these terms are very general, with no reference to any specific technology.
Private line	This term refers to the fact that the data sent over the line cannot be copied by other telco customers, so the data is private.

To create a leased line, some physical path must exist between the two routers on the ends of the link. The physical cabling must leave the customer buildings where each router sits. However, the telco does not simply install one cable between the two buildings. Instead, it uses what is typically a large and complex network that creates the appearance of a cable between the two routers.

Figure 3-3 gives a little insight into the cabling that could exist inside the telco for a short leased line. Telcos put their equipment in buildings called central offices (CO). The telco installs cables from the CO to most every other building in the city, expecting to sell services to the people in those buildings one day. The telco would then configure its switches to use some of the capacity on each cable to send data in both directions, creating the equivalent of a crossover cable between the two routers.

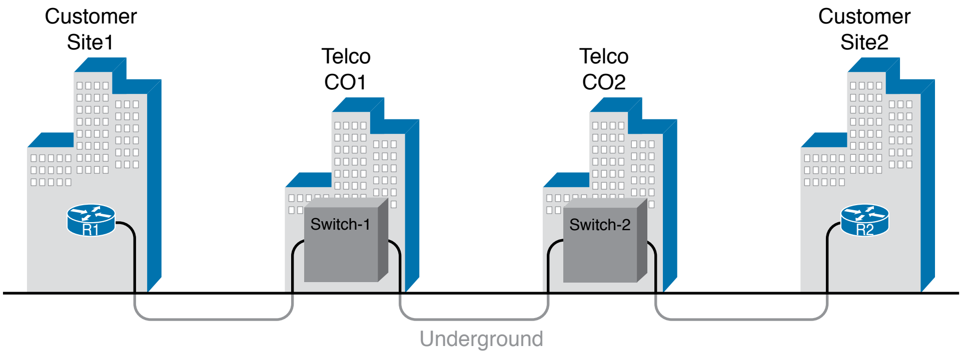

Figure 3-3 *Possible Cabling Inside a Telco for a Short Leased Line*

Answers to the "Do I Know This Already?" quiz:

1 B **2** B, D **3** A **4** C **5** C **6** A, C **7** C

Although the customer does not need to know all the details of how a telco creates a particular leased line, enterprise engineers do need to know about the parts of the link that exist inside the customer's building at the router. However, for the purposes of CCNA, you can think of any serial link as a point-to-point connection between two routers.

HDLC Data-Link Details of Leased Lines

A leased line provides a Layer 1 service. In other words, it promises to deliver bits between the devices connected to the leased line. However, the leased line itself does not define a data-link layer protocol to be used on the leased line.

Because leased lines define only the Layer 1 transmission service, many companies and standards organizations have created data-link protocols to control and use leased lines. Today, the two most popular data-link layer protocols used for leased lines between two routers are High-Level Data Link Control (HDLC) and Point-to-Point Protocol (PPP).

All data-link protocols perform a similar role: to control the correct delivery of data over a physical link of a particular type. For example, the Ethernet data-link protocol uses a destination address field to identify the correct device that should receive the data and an FCS field that allows the receiving device to determine whether the data arrived correctly. HDLC provides similar functions.

HDLC has less work to do than Ethernet because of the simple point-to-point topology of a leased line. When one router sends an HDLC frame, the frame can go only one place: to the other end of the link. So, while HDLC has an address field, the destination is implied, and the actual address is unimportant. The idea is sort of like when I have lunch with my friend Gary, and only Gary. I do not need to start every sentence with "Hey, Gary"—he knows I am talking to him.

HDLC has other fields and functions similar to Ethernet as well. Table 3-3 lists the HDLC fields, with the similar Ethernet header/trailer field, just for the sake of learning HDLC based on something you have already learned about (Ethernet).

Table 3-3 Comparing HDLC Header Fields to Ethernet

HDLC Field	Ethernet Equivalent	Description
Flag	Preamble, SFD	Lists a recognizable bit pattern so that the receiving nodes realize that a new frame is arriving.
Address	Destination Address	Identifies the destination device.
Control	N/A	Mostly used for purposes no longer in use today for links between routers.
Type	Type	Identifies the type of Layer 3 packet encapsulated inside the frame.
FCS	FCS	Identifies a field used by the error detection process. (It is the only trailer field in this table.)

HDLC exists today as a standard of the International Organization for Standardization (ISO), the same organization that brought us the OSI model. However, ISO standard HDLC does not have a Type field, and routers need to know the type of packet inside the frame. So, Cisco routers use a Cisco-proprietary variation of HDLC that adds a Type field, as shown in Figure 3-4.

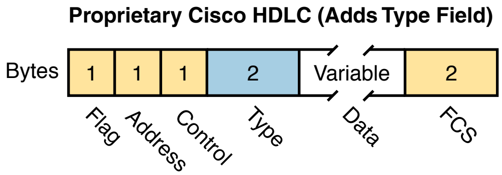

Figure 3-4 *HDLC Framing*

How Routers Use a WAN Data Link

Leased lines connect to routers, and routers focus on delivering packets to a destination host. However, routers physically connect to both LANs and WANs, with those LANs and WANs requiring that data be sent inside data-link frames. So, now that you know a little about HDLC, it helps to think about how routers use the HDLC protocol when sending data.

First, the TCP/IP network layer focuses on forwarding IP packets from the sending host to the destination host. The underlying LANs and WANs just act as a way to move the packets to the next router or end-user device. Figure 3-5 shows that network layer perspective.

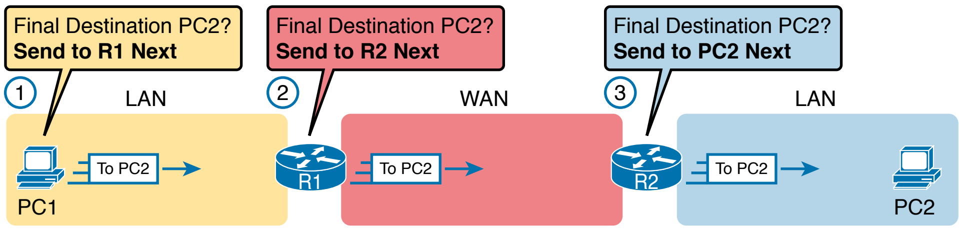

Figure 3-5 *IP Routing Logic over LANs and WANs*

Following the steps in the figure, for a packet sent by PC1 to PC2's IP address:

1. PC1's network layer (IP) logic tells it to send the packet to a nearby router (R1).
2. Router R1's network layer logic tells it to forward (route) the packet out the leased line to Router R2 next.
3. Router R2's network layer logic tells it to forward (route) the packet out the LAN link to PC2 next.

While Figure 3-5 shows the network layer logic, the PCs and routers must rely on the LANs and WANs in the figure to actually move the bits in the packet. Figure 3-6 shows the same figure, with the same packet, but this time showing some of the data-link layer logic used by the hosts and routers. Basically, three separate data-link layer steps encapsulate the packet, inside a data-link frame, over three hops through the internetwork: from PC1 to R1, from R1 to R2, and from R2 to PC2.

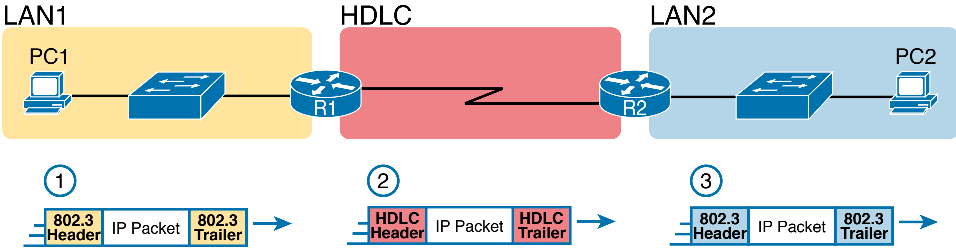

Figure 3-6 *General Concept of Routers De-encapsulating and Re-encapsulating IP Packets*

Following the steps in the figure, again for a packet sent by PC1 to PC2's IP address:

1. To send the IP packet to Router R1 next, PC1 encapsulates the IP packet in an Ethernet frame that has the destination MAC address of R1.
2. Router R1 de-encapsulates (removes) the IP packet from the Ethernet frame, encapsulates the packet into an HDLC frame using an HDLC header and trailer, and forwards the HDLC frame to Router R2 next.
3. Router R2 de-encapsulates (removes) the IP packet from the HDLC frame, encapsulates the packet into an Ethernet frame that has the destination MAC address of PC2, and forwards the Ethernet frame to PC2.

In summary, a leased line with HDLC creates a WAN link between two routers so that they can forward packets for the devices on the attached LANs. The leased line itself provides the physical means to transmit the bits, in both directions. The HDLC frames provide the means to encapsulate the network layer packet correctly so that it crosses the link between routers.

Leased lines have many benefits that have led to their relatively long life in the WAN marketplace. These lines are simple for the customer, are widely available, are of high quality, and are private. However, they do have some negatives as well compared to newer WAN technologies, including a higher cost and typically longer lead times to get the service installed. Additionally, by today's standards, leased-line LANs are slow, with faster speeds in the tens of megabits per second (Mbps). New faster WAN technology has been replacing leased lines for a long time, including the second WAN technology discussed in this book: Ethernet.

Ethernet as a WAN Technology

For the first several decades of the existence of Ethernet, Ethernet was only appropriate for LANs. The restrictions on cable lengths and devices might allow a LAN that stretched a kilometer or two, to support a campus LAN, but that was the limit.

As time passed, the IEEE improved Ethernet standards in ways that made Ethernet a reasonable WAN technology. For example, the 1000BASE-LX standard uses single-mode fiber cabling, with support for a 5-km cable length; the 1000BASE-ZX standard supports an even longer 70-km cable length. As time went by, and as the IEEE improved cabling distances for fiber Ethernet links, Ethernet became a reasonable WAN technology.

Today, many WAN service providers (SP) offer WAN services that take advantage of Ethernet. SPs offer a wide variety of these Ethernet WAN services, with many different names. But all of them use a similar model, with Ethernet used between the customer site and the SP's network, as shown in Figure 3-7.

Key Topic

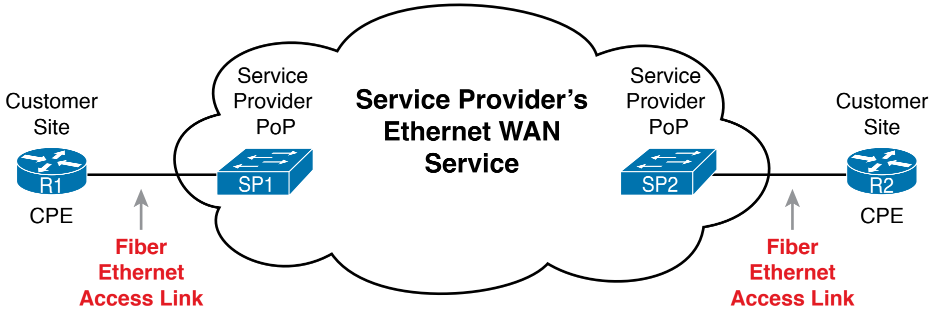

Figure 3-7 *Fiber Ethernet Link to Connect a CPE Router to a Service Provider's WAN*

The model shown in Figure 3-7 has many of the same ideas of how a telco creates a leased line, as shown earlier in Figure 3-3, but now with Ethernet links and devices. The customer connects to an Ethernet link using a router interface. The (fiber) Ethernet link leaves the customer building and connects to some nearby SP location called a point of presence (PoP). Instead of a telco switch as shown in Figure 3-3, the SP uses an Ethernet switch. Inside the SP's network, the SP uses any technology that it wants to create the specific Ethernet WAN services.

Ethernet WANs That Create a Layer 2 Service

Ethernet WAN services include a variety of specific services that vary in ways that change how routers use those services. However, for the purposes of CCNA, you just need to understand the most basic Ethernet WAN service, one that works much like an Ethernet crossover cable—just over a WAN. In other words:

- Logically, behaves like a point-to-point connection between two routers
- Physically, behaves as if a physical fiber Ethernet link existed between the two routers

NOTE For perspective about the broad world of the service provider network shown in Figure 3-7, look for more information about the Cisco CCNA, CCNP Service Provider, and CCIE Service Provider certifications. See www.cisco.com/go/certifications for more details.

This book refers to this particular Ethernet WAN service with a couple of the common names:

Ethernet WAN: A generic name to differentiate it from an Ethernet LAN.

Ethernet Line Service (E-Line): A term from the Metro Ethernet Forum (MEF) for the kind of point-to-point Ethernet WAN service shown throughout this book.

Ethernet emulation: A term emphasizing that the link is not a literal Ethernet link from end to end.

Ethernet over MPLS (EoMPLS): A term that refers to Multiprotocol Label Switching (MPLS), a technology that can be used to create the Ethernet service for the customer.

So, if you can imagine two routers, with a single Ethernet link between the two routers, you understand what this particular EoMPLS service does, as shown in Figure 3-8. In this case, the two routers, R1 and R2, connect with an EoMPLS service instead of a serial link. The routers use Ethernet interfaces, and they can send data in both directions at the same time. Physically, each router actually connects to some SP PoP, as shown earlier in Figure 3-7, but logically, the two routers can send Ethernet frames to each other over the link.

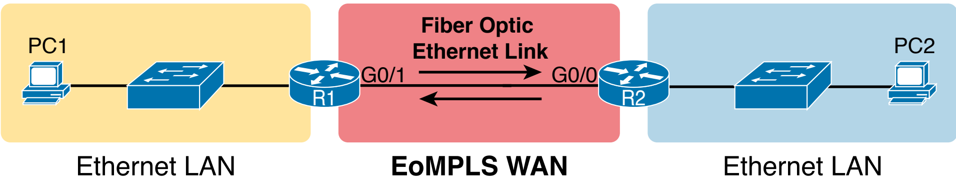

Figure 3-8 *EoMPLS Acting Like a Simple Ethernet Link Between Two Routers*

3

How Routers Route IP Packets Using Ethernet Emulation

WANs, by their very nature, give IP routers a way to forward IP packets from a LAN at one site, over the WAN, and to another LAN at another site. Routing over an EoMPLS WAN link still uses the WAN like a WAN, as a way to forward IP packets from one site to another. However, the WAN link happens to use the same Ethernet protocols as the Ethernet LAN links at each site.

The EoMPLS link uses Ethernet for both Layer 1 and Layer 2 functions. That means the link uses the same familiar Ethernet header and trailer, as shown in the middle of Figure 3-9. Note that the figure shows a small cloud over the Ethernet link as a way to tell us that the link is an Ethernet WAN link, rather than an Ethernet LAN link.

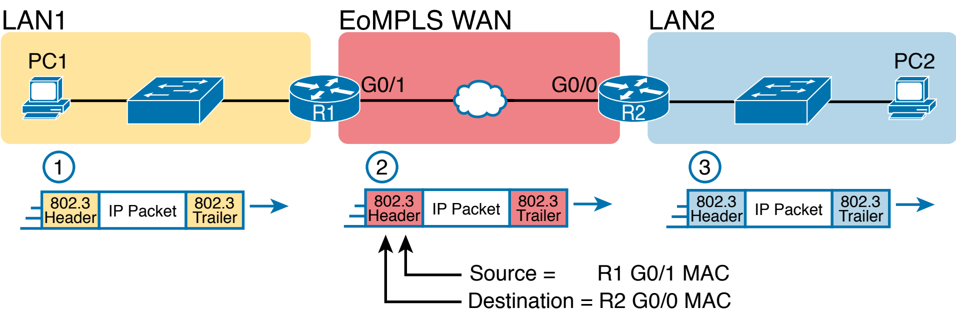

Figure 3-9 *Routing over an EoMPLS Link*

NOTE The 802.3 headers/trailers in the figure are different at each stage! Make sure to notice the reasons in the step-by-step explanations that follow.

The figure shows the same three routing steps as shown with the serial link in the earlier Figure 3-6. In this case, all three routing steps use the same Ethernet (802.3) protocol. However, note that each frame's data-link header and trailer are different. Each router discards the old data-link header/trailer and adds a new set, as described in these steps. Focus mainly on Step 2, because compared to the similar example shown in Figure 3-6, Steps 1 and 3 are unchanged:

1. To send the IP packet to Router R1 next, PC1 encapsulates the IP packet in an Ethernet frame that has the destination MAC address of R1.
2. Router R1 de-encapsulates (removes) the IP packet from the Ethernet frame and encapsulates the packet into a new Ethernet frame, with a new Ethernet header and trailer. The destination MAC address is R2's G0/0 MAC address, and the source MAC address is R1's G0/1 MAC address. R1 forwards this frame over the EoMPLS service to R2 next.
3. Router R2 de-encapsulates (removes) the IP packet from the Ethernet frame, encapsulates the packet into an Ethernet frame that has the destination MAC address of PC2, and forwards the Ethernet frame to PC2.

Throughout this book, the WAN links (serial and Ethernet) will connect routers as shown here, with the focus being on the LANs and IP routing. The rest of the chapter turns our attention to a closer look at IP routing.

IP Routing

Many protocol models have existed over the years, but today the TCP/IP model dominates. And at the network layer of TCP/IP, two options exist for the main protocol around which all other network layer functions revolve: IP version 4 (IPv4) and IP version 6 (IPv6). Both IPv4 and IPv6 define the same kinds of network layer functions, but with different details. This chapter introduces these network layer functions for IPv4.

NOTE All references to IP in this chapter refer to the older and more established IPv4.

Internet Protocol (IP) focuses on the job of routing data, in the form of IP packets, from the source host to the destination host. IP does not concern itself with the physical transmission of data, instead relying on the lower TCP/IP layers to do the physical transmission of the data. Instead, IP concerns itself with the logical details, rather than physical details, of delivering data. In particular, the network layer specifies how packets travel end to end over a TCP/IP network, even when the packet crosses many different types of LAN and WAN links.

This next major section of the chapter examines IP routing in more depth. First, IP defines what it means to route an IP packet from sending host to destination host, while using successive data-link protocols. This section then examines how IP addressing rules help to make IP routing much more efficient by grouping addresses into subnets. This section closes by looking at the role of IP routing protocols, which give routers a means by which to learn routes to all the IP subnets in an internetwork.

Network Layer Routing (Forwarding) Logic

Routers and end-user computers (called *hosts* in a TCP/IP network) work together to perform IP routing. The host operating system (OS) has TCP/IP software, including the software that implements the network layer. Hosts use that software to choose where to send IP packets, often to a nearby router. Those routers make choices of where to send the IP packet next. Together, the hosts and routers deliver the IP packet to the correct destination, as shown in the example in Figure 3-10.

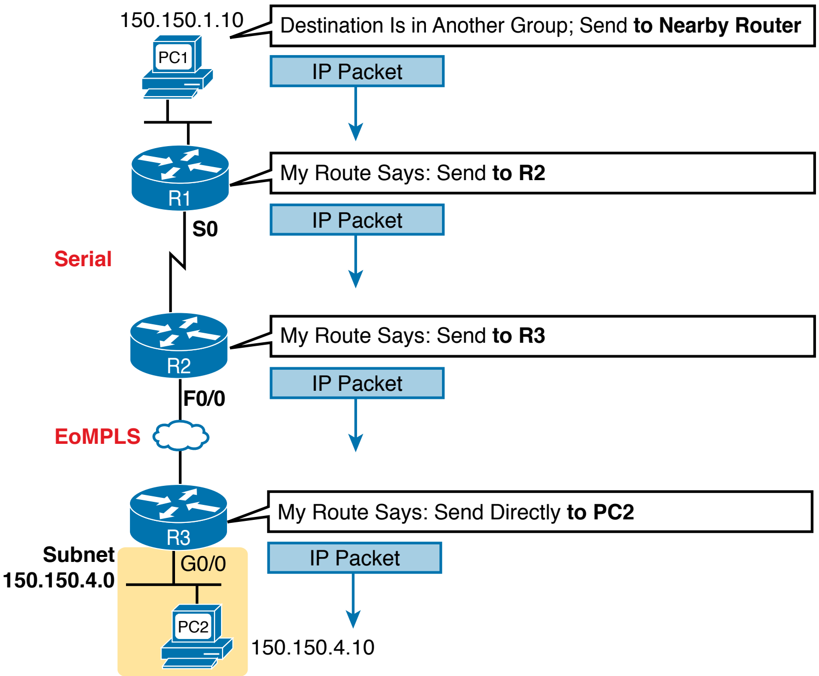

Figure 3-10 *Routing Logic: PC1 Sending an IP Packet to PC2*

The IP packet, created by PC1, goes from the top of the figure all the way to PC2 at the bottom of the figure. The next few pages discuss the network layer routing logic used by each device along the path.

NOTE The term *path selection* is sometimes used to refer to the routing process shown in Figure 3-10. At other times, it refers to routing protocols, specifically how routing protocols select the best route among the competing routes to the same destination.

Host Forwarding Logic: Send the Packet to the Default Router

In this example, PC1 does some basic analysis and then chooses to send the IP packet to the router so that the router will forward the packet. PC1 analyzes the destination address and realizes that PC2's address (150.150.4.10) is not on the same LAN as PC1. So PC1's logic tells it to send the packet to a device whose job it is to know where to route data: a nearby router, on the same LAN, called PC1's default router.

To send the IP packet to the default router, the sender sends a data-link frame across the medium to the nearby router; this frame includes the packet in the data portion of the frame. That frame uses data-link layer (Layer 2) addressing in the data-link header to ensure that the nearby router receives the frame.

NOTE The *default router* is also referred to as the *default gateway*.

R1 and R2's Logic: Routing Data Across the Network

All routers use the same general process to route the packet. Each router keeps an *IP routing table*. This table lists IP address *groupings*, called *IP networks* and *IP subnets*. When a router receives a packet, it compares the packet's destination IP address to the entries in the routing table and makes a match. This matching entry also lists directions that tell the router where to forward the packet next.

In Figure 3-10, R1 would have matched the destination address (150.150.4.10) to a routing table entry, which in turn told R1 to send the packet to R2 next. Similarly, R2 would have matched a routing table entry that told R2 to send the packet, over an Ethernet WAN link, to R3 next.

The routing concept works a little like driving down the freeway when approaching a big interchange. You look up and see signs for nearby towns, telling you which exits to take to go to each town. Similarly, the router looks at the IP routing table (the equivalent of the road signs) and directs each packet over the correct next LAN or WAN link (the equivalent of a road).

R3's Logic: Delivering Data to the End Destination

The final router in the path, R3, uses almost the same logic as R1 and R2, but with one minor difference. R3 needs to forward the packet directly to PC2, not to some other router. On the surface, that difference seems insignificant. In the next section, when you read about how the network layer uses LANs and WANs, the significance of the difference will become obvious.

How Network Layer Routing Uses LANs and WANs

While the network layer routing logic ignores the physical transmission details, the bits still have to be transmitted. To do that work, the network layer logic in a host or router must hand off the packet to the data-link layer protocols, which, in turn, ask the physical layer to actually send the data. The data-link layer adds the appropriate header and trailer to the packet, creating a frame, before sending the frames over each physical network.

The routing process forwards the network layer packet from end to end through the network, while each data-link frame only takes a smaller part of the trip. Each successive data-link layer frame moves the packet to the next device that thinks about network layer logic. In short, the network layer thinks about the bigger view of the goal, like "Send this packet to the specified next router or host…," while the data-link layer thinks about the specifics, like "Encapsulate the packet in a data-link frame and transmit it." The following list summarizes the major steps in a router's internal network layer routing for each packet beginning with the a frame arriving in a router interface:

Key Topic

Step 1. Use the data-link Frame Check Sequence (FCS) field to ensure that the frame had no errors; if errors occurred, discard the frame.

Step 2. Assuming that the frame was not discarded at Step 1, discard the old data-link header and trailer, leaving the IP packet.

Step 3. Compare the IP packet's destination IP address to the routing table, and find the route that best matches the destination address. This route identifies the outgoing interface of the router and possibly the next-hop router IP address.

Step 4. Encapsulate the IP packet inside a new data-link header and trailer, appropriate for the outgoing interface, and forward the frame.

Figure 3-11 works through a repeat example of a packet sent by PC1 to PC2, followed by a detailed analysis of each device's routing logic. Each explanation includes the details about how PC1 and each of the three routers builds the appropriate new data-link headers.

Key Topic

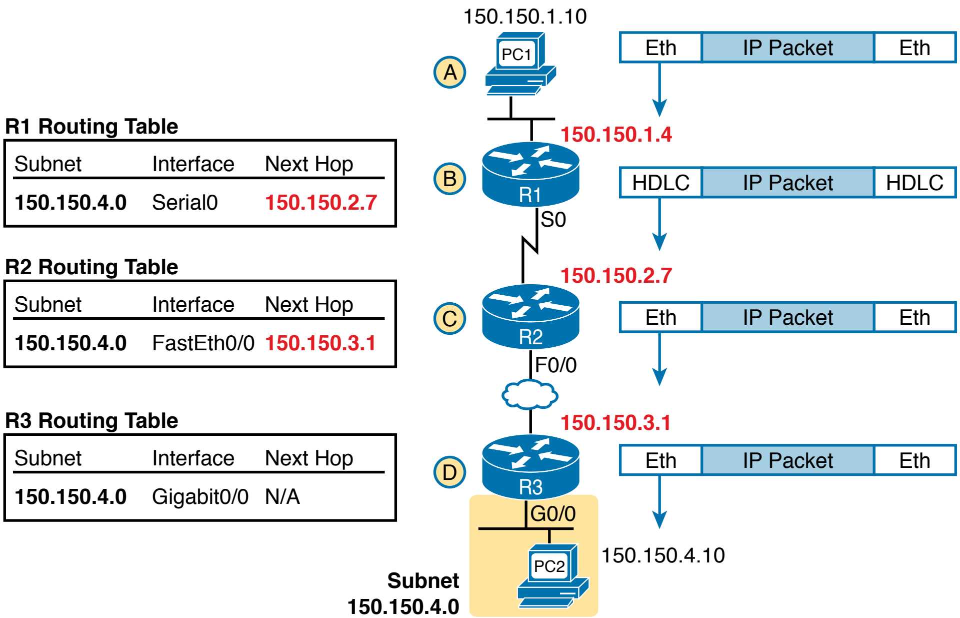

Figure 3-11 *Network Layer and Data-Link Layer Encapsulation*

The following list explains the forwarding logic at each router, focusing on how the routing integrates with the data link.

Step A. **PC1 sends the packet to its default router.** PC1's network layer logic builds the IP packet, with a destination address of PC2's IP address (150.150.4.10). The network layer also performs the analysis to decide that 150.150.4.10 is not in the local IP subnet, so PC1 needs to send the packet to R1 (PC1's default router). PC1 places the IP packet into an Ethernet data-link frame, with a destination Ethernet address of R1's Ethernet address. PC1 sends the frame on to the Ethernet.

Step B. **R1 processes the incoming frame and forwards the packet to R2.** Because the incoming Ethernet frame has a destination MAC of R1's Ethernet MAC, R1 decides to process the frame. R1 checks the frame's FCS for errors, and if none, R1 discards the Ethernet header and trailer. Next, R1 compares the packet's destination address (150.150.4.10) to its routing table and finds the entry for subnet 150.150.4.0. Because the destination address of 150.150.4.10 is in that subnet, R1 forwards the packet out the interface listed in that matching route (Serial0) to next-hop Router R2 (150.150.2.7). R1 must first encapsulate the IP packet into an HDLC frame.

Step C. **R2 processes the incoming frame and forwards the packet to R3.** R2 repeats the same general process as R1 when R2 receives the HDLC frame. R2 checks the FCS field and finds that no errors occurred and then discards the HDLC header and trailer. Next, R2 compares the packet's destination address (150.150.4.10) to its routing table and finds the entry for subnet 150.150.4.0, a route that directs R2 to send the packet out interface Fast Ethernet 0/0 to next-hop router 150.150.3.1 (R3). But first, R2 must encapsulate the packet in an Ethernet header. That header uses R2's MAC address and R3's MAC address on the Ethernet WAN link as the source and destination MAC address, respectively.

Step D. **R3 processes the incoming frame and forwards the packet to PC2.** Like R1 and R2, R3 checks the FCS, discards the old data-link header and trailer, and matches its own route for subnet 150.150.4.0. R3's routing table entry for 150.150.4.0 shows that the outgoing interface is R3's Ethernet interface, but there is no next-hop router because R3 is connected directly to subnet 150.150.4.0. All R3 has to do is encapsulate the packet inside a new Ethernet header and trailer, but with a destination Ethernet address of PC2's MAC address.

Because the routers build new data-link headers and trailers, and because the new headers contain data-link addresses, the PCs and routers must have some way to decide what data-link addresses to use. An example of how the router determines which data-link address to use is the IP Address Resolution Protocol (ARP). *ARP dynamically learns the data-link address of an IP host connected to a LAN*. For example, at the last step, at the bottom of Figure 3-11, Router R3 would use ARP once to learn PC2's MAC address before sending any packets to PC2.

How IP Addressing Helps IP Routing

IP defines network layer addresses that identify any host or router interface that connects to a TCP/IP network. The idea basically works like a postal address: Any interface that expects to receive IP packets needs an IP address, just like you need a postal address before receiving mail from the postal service. This next short topic introduces the idea of IP networks and subnets, which are the groups of addresses defined by IP.

NOTE IP defines the word *network* to mean a very specific concept. To avoid confusion when writing about IP addressing, this book (and others) often avoids using the term *network* for other uses. In particular, this book uses the term *internetwork* to refer more generally to a network made up of routers, switches, cables, and other equipment.

Rules for Groups of IP Addresses (Networks and Subnets)

TCP/IP groups IP addresses together so that IP addresses used on the same physical network are part of the same group. IP calls these address groups an *IP network* or an *IP subnet*. Using that same postal service analogy, each IP network and IP subnet works like a postal code (or in the United States, a ZIP code). All nearby postal addresses are in the same postal code (ZIP code), while all nearby IP addresses must be in the same IP network or IP subnet.

IP defines specific rules about which IP address should be in the same IP network or IP subnet. Numerically, the addresses in the same group have the same value in the first part of the addresses. For example, Figures 3-10 and 3-11 could have used the following conventions:

- Hosts on the top Ethernet: Addresses start with 150.150.1
- Hosts on the R1–R2 serial link: Addresses start with 150.150.2
- Hosts on the R2–R3 EoMPLS link: Addresses start with 150.150.3
- Hosts on the bottom Ethernet: Addresses start with 150.150.4

From the perspective of IP routing, the grouping of IP addresses means that the routing table can be much smaller. A router can list one routing table entry for each IP network or subnet, instead of one entry for every single IP address.

While the list shows just one example of how IP addresses may be grouped, the rules for how to group addresses using subnets will require some work to master the concepts and math. Part III of this book details IP addressing and subnetting, and you can find other subnetting video and practice products listed in the Introduction to the book. However, the brief version of two of the foundational rules of subnetting can be summarized as follows:

Key Topic

- Two IP addresses, not separated from each other by a router, must be in the same group (subnet).
- Two IP addresses, separated from each other by at least one router, must be in different groups (subnets).

It's similar to the USPS ZIP code system and how it requires local governments to assign addresses to new buildings. It would be ridiculous to have two houses next door to each other, whose addresses had different postal/ZIP codes. Similarly, it would be silly to have people who live on opposite sides of the country to have addresses with the same postal/ZIP code.

The IP Header

The routing process also makes use of the IPv4 header, as shown in Figure 3-12. The header lists a 32-bit source IP address, as well as a 32-bit destination IP address. The header, of course, has other fields, a few of which matter for other discussions in this book. The book will refer to this figure as needed, but otherwise, be aware of the 20-byte IP header and the existence of the source and destination IP address fields. Note that in the examples so far in this chapter, while routers remove and add data-link headers each time it routes a packet, the IP header remains, with the IP addresses unchanged by the IP routing process.

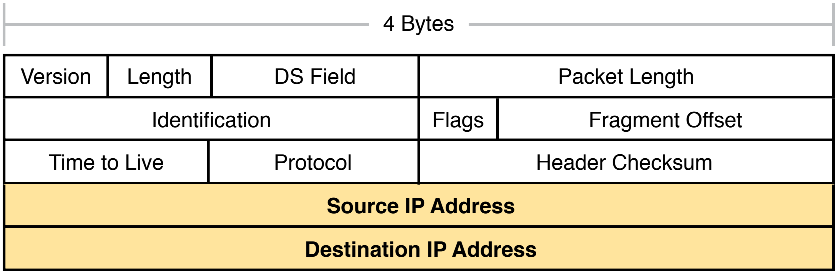

Figure 3-12 *IPv4 Header, Organized as 4 Bytes Wide for a Total of 20 Bytes*

How IP Routing Protocols Help IP Routing

For routing logic to work on both hosts and routers, each host and router needs to know something about the TCP/IP internetwork. Hosts need to know the IP address of their default router so that hosts can send packets to remote destinations. Routers, however, need to know routes so they forward packets to each and every reachable IP network and IP subnet.

The best method for routers to know all the useful routes is to configure the routers to use the same IP routing protocol. Alternately, a network engineer could configure (type) all the required routes, on every router. However, if you enable the same routing protocol on all the routers in a TCP/IP internetwork, with the correct settings, the routers will send routing protocol messages to each other. As a result, all the routers will learn routes for all the IP networks and subnets in the TCP/IP internetwork.

IP supports a small number of different IP routing protocols. All use some similar ideas and processes to learn IP routes, but different routing protocols do have some internal differences; otherwise, you would not need more than one routing protocol. However, many routing protocols use the same general steps for learning routes:

Key Topic

Step 1. Each router, independent of the routing protocol, adds a route to its routing table for each subnet directly connected to the router.

Step 2. Each router's routing protocol tells its neighbors about the routes in its routing table, including the directly connected routes and routes learned from other routers.

Step 3. After learning a new route from a neighbor, the router's routing protocol adds a route to its IP routing table, with the next-hop router of that route typically being the neighbor from which the route was learned.

Also, note that at the final step, routers may have to choose between multiple routes to reach a single subnet. When that happens, routers place the best currently available route to reach a subnet (based on a measurement called a metric) into the routing table.

Figure 3-13 shows an example of how a routing protocol works, using the same diagram as in Figures 3-10 and 3-11. In this case, IP subnet 150.150.4.0, which consists of all addresses that begin with 150.150.4.0, sits on the Ethernet at the bottom of the figure. The figure shows the advertisement of routes for subnet 150.150.4.0 from bottom to top, as described in detail following the figure.

Key Topic

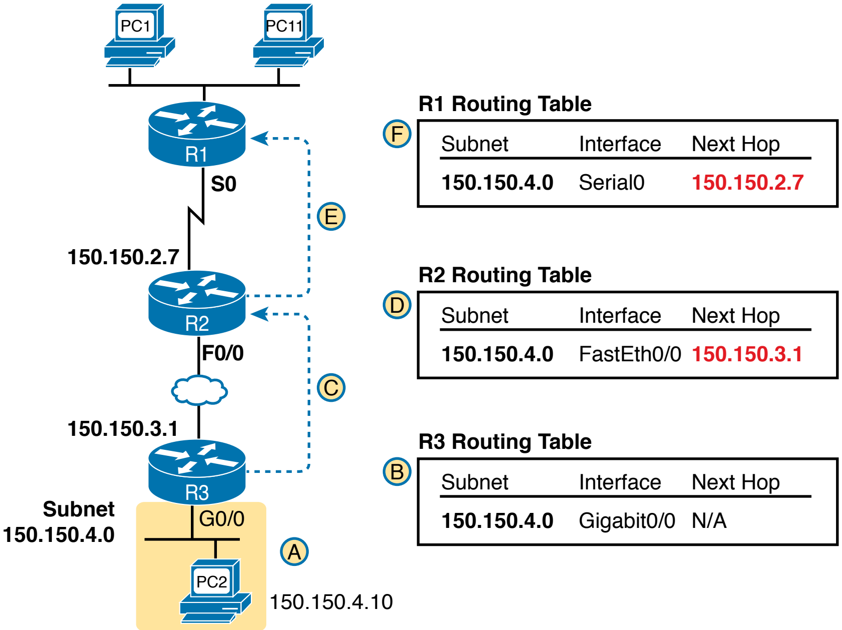

Figure 3-13 *Example of How Routing Protocols Advertise About Networks and Subnets*

Follow items A through F shown in the figure to see how each router learns its route to 150.150.4.0.

Step A. Subnet 150.150.4.0 exists as a subnet at the bottom of the figure, connected to Router R3.

Step B. R3 adds a connected route for 150.150.4.0 to its IP routing table; this happens without help from the routing protocol.

Step C. R3 sends a routing protocol message, called a *routing update*, to R2, causing R2 to learn about subnet 150.150.4.0.

Step D. R2 adds a route for subnet 150.150.4.0 to its routing table.

Step E. R2 sends a similar routing update to R1, causing R1 to learn about subnet 150.150.4.0.

Step F. R1 adds a route for subnet 150.150.4.0 to its routing table. The route lists R1's own Serial0 as the outgoing interface and R2 as the next-hop router IP address (150.150.2.7).

Other Network Layer Features

The TCP/IP network layer defines many functions beyond IP. Sure, IP plays a huge role in networking today, defining IP addressing and IP routing. However, other protocols and standards, defined in other Requests For Comments (RFC), play an important role for network layer functions as well. For example, routing protocols like Open Shortest Path First (OSPF) exist as separate protocols, defined in separate RFCs.

This last short section of the chapter introduces three other network layer features that should be helpful to you when reading through the rest of this book. These last three topics just help fill in a few holes, helping to give you some perspective and helping you make sense of later discussions as well. The three topics are

- Domain Name System (DNS)
- Address Resolution Protocol (ARP)
- Ping

Using Names and the Domain Name System

Can you imagine a world in which every time you used an application, you had to refer to it by IP address? Instead of using easy names like google.com or facebook.com, you would have to remember and type IP addresses, like 64.233.177.100. (At press time, 64.233.177.100 was an address used by Google, and you could reach Google's website by typing that address in a browser.) Certainly, asking users to remember IP addresses would not be user friendly and could drive some people away from using computers at all.

Thankfully, TCP/IP defines a way to use *hostnames* to identify other computers. The user either never thinks about the other computer or refers to the other computer by name. Then, protocols dynamically discover all the necessary information to allow communications based on that name.

For example, when you open a web browser and type in the hostname **www.google.com**, your computer does not send an IP packet with destination IP address www.google.com; it sends an IP packet to an IP address used by the web server for Google. TCP/IP needs a way to let a computer find the IP address used by the listed hostname, and that method uses the Domain Name System (DNS).

Enterprises use the DNS process to resolve names into the matching IP address, as shown in the example in Figure 3-14. In this case, PC11, on the left, needs to connect to a server named Server1. At some point, the user either types in the name Server1 or some application on PC11 refers to that server by name. At Step 1, PC11 sends a DNS message—a DNS query—to the DNS server. At Step 2, the DNS server sends back a DNS reply that lists Server1's IP address. At Step 3, PC11 can now send an IP packet to destination address 10.1.2.3, the address used by Server1.

Key Topic

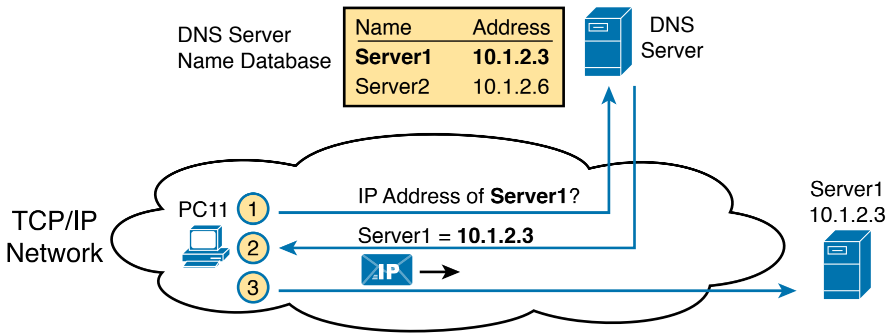

Figure 3-14 *Basic DNS Name Resolution Request*

Note that the example in Figure 3-14 shows a cloud for the TCP/IP network because the details of the network, including routers, do not matter to the name resolution process. Routers treat the DNS messages just like any other IP packet, routing them based on the destination IP address. For example, at Step 1 in the figure, the DNS query will list the DNS server's IP address as the destination address, which any routers will use to forward the packet.

Finally, DNS defines much more than just a few messages. DNS defines protocols, as well as standards for the text names used throughout the world, and a worldwide set of distributed DNS servers. The domain names that people use every day when web browsing, which look like www.example.com, follow the DNS naming standards. Also, no single DNS server knows all the names and matching IP addresses, but the information is distributed across many DNS servers. So, the DNS servers of the world work together, forwarding queries to each other, until the server that knows the answer supplies the desired IP address information.

The Address Resolution Protocol

As discussed in depth throughout this chapter, IP routing logic requires that hosts and routers encapsulate IP packets inside data-link layer frames. For Ethernet interfaces, how does a router know what MAC address to use for the destination? It uses ARP.

On Ethernet LANs, whenever a host or router needs to encapsulate an IP packet in a new Ethernet frame, the host or router knows all the important facts to build that header—except for the destination MAC address. The host knows the IP address of the next device, either another host IP address or the default router IP address. A router knows the IP route used for forwarding the IP packet, which lists the next router's IP address. However, the hosts and routers do not know those neighboring devices' MAC addresses beforehand.

TCP/IP defines the Address Resolution Protocol (ARP) as the method by which any host or router on a LAN can dynamically learn the MAC address of another IP host or router on the same LAN. ARP defines a protocol that includes the *ARP Request*, which is a message that makes the simple request "if this is your IP address, please reply with your MAC address." ARP also defines the *ARP Reply* message, which indeed lists both the original IP address and the matching MAC address.

Figure 3-15 shows an example that uses the same router and host from the bottom part of the earlier Figure 3-13. The figure shows the ARP Request sent by router R3, on the left of the figure, as a LAN broadcast. All devices on the LAN will then process the received frame. On the right, at Step 2, host PC2 sends back an ARP Reply, identifying PC2's MAC address. The text beside each message shows the contents inside the ARP message itself, which lets PC2 learn R3's IP address and matching MAC address, and R3 learn PC2's IP address and matching MAC address.

Note that hosts and routers remember the ARP results, keeping the information in their *ARP cache* or *ARP table*. A host or router only needs to use ARP occasionally, to build the ARP cache the first time. Each time a host or router needs to send a packet encapsulated in an Ethernet frame, it first checks its ARP cache for the correct IP address and matching MAC address. Hosts and routers will let ARP cache entries time out to clean up the table, so occasional ARP Requests can be seen.

Key Topic

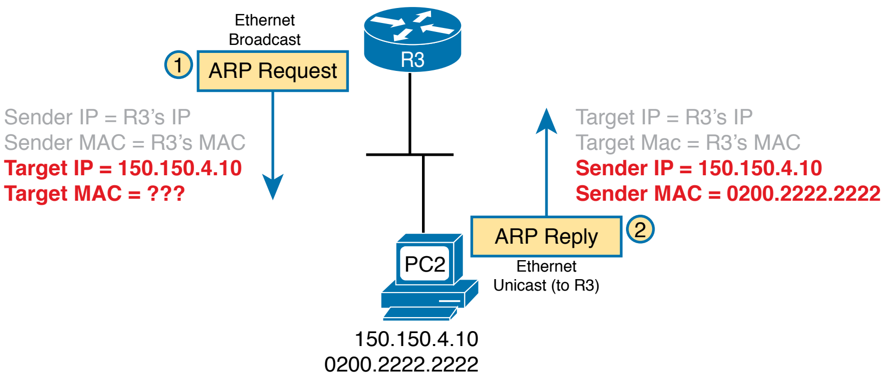

Figure 3-15 *Sample ARP Process*

> **NOTE** You can see the contents of the ARP cache on most PC operating systems by using the **arp -a** command from a command prompt.

ICMP Echo and the ping Command

After you have implemented a TCP/IP internetwork, you need a way to test basic IP connectivity without relying on any applications to be working. The primary tool for testing basic network connectivity is the **ping** command.

Ping (Packet Internet Groper) uses the Internet Control Message Protocol (ICMP), sending a message called an *ICMP echo request* to another IP address. The computer with that IP address should reply with an *ICMP echo reply*. If that works, you successfully have tested the IP network. In other words, you know that the network can deliver a packet from one host to the other and back. ICMP does not rely on any application, so it really just tests basic IP connectivity—Layers 1, 2, and 3 of the OSI model. Figure 3-16 outlines the basic process.

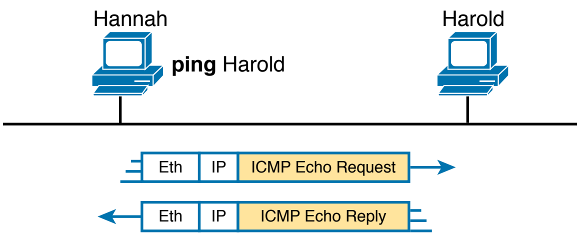

Figure 3-16 *Sample Network,* ***ping*** *Command*

Note that while the **ping** command uses ICMP, ICMP does much more. ICMP defines many messages that devices can use to help manage and control the IP network.

Chapter Review

The "Your Study Plan" element, just before Chapter 1, discusses how you should study and practice the content and skills for each chapter before moving on to the next chapter. That element introduces the tools used here at the end of each chapter. If you haven't already done so, take a few minutes to read that section. Then come back here and do the useful work of reviewing the chapter to help lock into memory what you just read.

Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Table 3-4 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 3-4 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Review memory tables		Book, website

Review All the Key Topics

Key Topic

Table 3-5 Key Topics for Chapter 3

Key Topic Element	Description	Page Number
Figure 3-7	Ethernet over MPLS—physical connections	66
List	Four-step process of how routers route (forward) packets	70
Figure 3-11	IP Routing and Encapsulation	71
List	Two statements about how IP expects IP addresses to be grouped into networks or subnets	73
List	Three-step process of how routing protocols learn routes	74
Figure 3-13	IP Routing Protocol Basic Process	75
Figure 3-14	Example that shows the purpose and process of DNS name resolution	76
Figure 3-15	Example of the purpose and process of ARP	78

Key Terms You Should Know

leased line, wide-area network (WAN), telco, serial interface, HDLC, Ethernet over MPLS, Ethernet Line Service (E-Line), default router (default gateway), routing table, IP network, IP subnet, IP packet, routing protocol, dotted-decimal notation (DDN), IPv4 address, unicast IP address, subnetting, hostname, DNS, ARP, ping

Part I Review

Keep track of your part review progress with the checklist shown in Table P1-1. Details on each task follow the table.

Table P1-1 Part I Review Checklist

Activity	1st Date Completed	2nd Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		

Repeat All DIKTA Questions

For this task, answer the “Do I Know This Already?” questions again for the chapters in this part of the book, using the PTP software. Refer to the Introduction to this book, the section titled “How to View Only DIKTA Questions by Chapter or Part,” for help with how to make the PTP software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PTP software. Refer to the Introduction to this book, the section titled “How to View Part Review Questions,” for help with how to make the PTP software show you Part Review questions for this part only. (Note that if you use the questions but then want even more, get the Premium Edition of the book, as detailed in the Introduction, in the section “Other Features,” under the item labeled “eBook.”)

Review Key Topics

Browse back through the chapters and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics, or use the Key Topics application(s) found on the companion website.

Use Per-Chapter Interactive Review Elements

Using the companion website, browse through the interactive review elements, like memory tables and key term flashcards, to review the content from each chapter.

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Part I provided a broad look at the fundamentals of all parts of networking, focusing on Ethernet LANs, WANs, and IP routing. Parts II and III now drill into depth about the details of Ethernet, which was introduced in Chapter 2, "Fundamentals of Ethernet LANs."

Part II begins that journey by discussing the basics of building a small Ethernet LAN with Cisco Catalyst switches. The journey begins by showing how to access the user interface of a Cisco switch so that you can see evidence of what the switch is doing and configure the switch to act in the ways you want it to act. At this point, you should start using whatever lab practice option you chose in the "Your Study Plan" section that preceded Chapter 1, "Introduction to TCP/IP Networking." (And if you have not yet finalized your plan for how to practice your hands-on skills, now is the time.)

After you complete Chapter 4 and see how to get into the command-line interface (CLI) of a switch, the next three chapters step through some important foundations of how to implement LANs—foundations used by every company that builds LANs with Cisco gear. Chapter 5 takes a close look at Ethernet switching—that is, the logic used by a switch—and how to know what a particular switch is doing. Chapter 6 shows the ways to configure a switch for remote access with Telnet and Secure Shell (SSH), along with a variety of other useful commands that will help you when you work with any real lab gear, simulator, or any other practice tools. Chapter 7, the final chapter in Part II, shows how to configure and verify the operation of switch interfaces for several important features, including speed, duplex, and autonegotiation.

Part II

Implementing Ethernet LANs

CHAPTER 4

Using the Command-Line Interface

This chapter covers the following exam topics:

None

This chapter explains foundational skills required before you can learn about the roughly 15 exam topics that use the verbs *configure* and *verify*. However, Cisco does not list the foundational skills described in this chapter as a separate exam topic, so there are no specific exam topics included in this chapter.

To create an Ethernet LAN, network engineers start by planning. They consider the requirements, create a design, buy the switches, contract to install cables, and configure the switches to use the right features.

The CCNA exam focuses on skills like understanding how LANs work, configuring different switch features, verifying that those features work correctly, and finding the root cause of the problem when a feature is not working correctly. The first skill you need to learn before doing all the configuration and verification tasks is to learn how to access and use the user interface of the switch, called the command-line interface (CLI).

This chapter begins that process by showing the basics of how to access the switch's CLI. These skills include how to access the CLI and how to issue verification commands to check on the status of the LAN. This chapter also includes the processes of how to configure the switch and how to save that configuration.

Note that this chapter focuses on processes that provide a foundation for most every exam topic that includes the verbs *configure* and/or *verify*. Most of the rest of the chapters in Parts II and III of this book then go on to include details of the particular commands you can use to verify and configure different switch features.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 4-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Accessing the Cisco Catalyst Switch CLI	1–3
Configuring Cisco IOS Software	4–6

1. In what modes can you type the command **show mac address-table** and expect to get a response with MAC table entries? (Choose two answers.)
   a. User mode
   b. Enable mode
   c. Global configuration mode
   d. Interface configuration mode
2. In which of the following modes of the CLI could you type the command **reload** and expect the switch to reboot?
   a. User mode
   b. Enable mode
   c. Global configuration mode
   d. Interface configuration mode
3. Which of the following is a difference between Telnet and SSH as supported by a Cisco switch?
   a. SSH encrypts the passwords used at login, but not other traffic; Telnet encrypts nothing.
   b. SSH encrypts all data exchange, including login passwords; Telnet encrypts nothing.
   c. Telnet is used from Microsoft operating systems, and SSH is used from UNIX and Linux operating systems.
   d. Telnet encrypts only password exchanges; SSH encrypts all data exchanges.
4. What type of switch memory is used to store the configuration used by the switch when it is up and working?
   a. RAM
   b. ROM
   c. Flash
   d. NVRAM
   e. Bubble
5. What command copies the configuration from RAM into NVRAM?
   a. **copy running-config tftp**
   b. **copy tftp running-config**
   c. **copy running-config start-up-config**
   d. **copy start-up-config running-config**
   e. **copy startup-config running-config**
   f. **copy running-config startup-config**

6. A switch user is currently in console line configuration mode. Which of the following would place the user in enable mode? (Choose two answers.)
   a. Using the **exit** command once
   b. Using the **end** command once
   c. Pressing the Ctrl+Z key sequence once
   d. Using the **quit** command

Foundation Topics

Accessing the Cisco Catalyst Switch CLI

Cisco uses the concept of a command-line interface (CLI) with its router products and most of its Catalyst LAN switch products. The CLI is a text-based interface in which the user, typically a network engineer, enters a text command and presses Enter. Pressing Enter sends the command to the switch, which tells the device to do something. The switch does what the command says, and in some cases, the switch replies with some messages stating the results of the command.

Cisco Catalyst switches also support other methods to both monitor and configure a switch. For example, a switch can provide a web interface so that an engineer can open a web browser to connect to a web server running in the switch. Switches also can be controlled and operated using network management software.

This book discusses only Cisco Catalyst enterprise-class switches, and in particular, how to use the Cisco CLI to monitor and control these switches. This first major section of the chapter first examines these Catalyst switches in more detail and then explains how a network engineer can get access to the CLI to issue commands.

Cisco Catalyst Switches

Within the Cisco Catalyst brand of LAN switches, Cisco produces a wide variety of switch series or families. Each switch series includes several specific models of switches that have similar features, similar price-versus-performance tradeoffs, and similar internal components.

For example, at the time this book was published, the Cisco 2960-XR series of switches was a current switch model series. Cisco positions the 2960-XR series (family) of switches as full-featured, low-cost wiring closet switches for enterprises. That means that you would expect to use 2960-XR switches as access switches in a typical campus LAN design.

Figure 4-1 shows a photo of 10 different models from the 2960-XR switch model series from Cisco. Each switch series includes several models, with a mix of features. For example, some of the switches have 48 RJ-45 unshielded twisted-pair (UTP) 10/100/1000 ports, meaning that these ports can autonegotiate the use of 10BASE-T (10 Mbps), 100BASE-T (100 Mbps), or 1000BASE-T (1 Gbps) Ethernet.

Figure 4-1 *Cisco 2960-XR Catalyst Switch Series*

Cisco refers to a switch's physical connectors as either *interfaces* or *ports*, with an interface type and interface number. The interface type, as used in commands on the switch, is either Ethernet, Fast Ethernet, Gigabit Ethernet, and so on for faster speeds. For Ethernet interfaces that support running at multiple speeds, the permanent name for the interface refers to the fastest supported speed. For example, a 10/100/1000 interface (that is, an interface that runs at 10 Mbps, 100 Mbps, or 1000 Mbps) would be called Gigabit Ethernet no matter what speed is currently in use.

To uniquely number each different interface, some Catalyst switches use a two-digit interface number (*x/y*), while others have a three-digit number (*x/y/z*). For instance, two 10/100/1000 ports on many older Cisco Catalyst switches would be called GigabitEthernet 0/0 and GigabitEthernet 0/1, while on the newer 2960-XR series, two interfaces would be GigabitEthernet 1/0/1 and GigabitEthernet 1/0/2.

Accessing the Cisco IOS CLI

Like any other piece of computer hardware, Cisco switches need some kind of operating system software. Cisco calls this OS the Internetwork Operating System (IOS).

Cisco IOS Software for Catalyst switches implements and controls logic and functions performed by a Cisco switch. Besides controlling the switch's performance and behavior, Cisco IOS also defines an interface for humans called the CLI. The Cisco IOS CLI allows the user to use a terminal emulation program, which accepts text entered by the user. When the user presses Enter, the terminal emulator sends that text to the switch. The switch processes the text as if it is a command, does what the command says, and sends text back to the terminal emulator.

The switch CLI can be accessed through three popular methods—the console, Telnet, and Secure Shell (SSH). Two of these methods (Telnet and SSH) use the IP network in which the switch resides to reach the switch. The console is a physical port built specifically to allow access to the CLI. Figure 4-2 depicts the options.

Key Topic

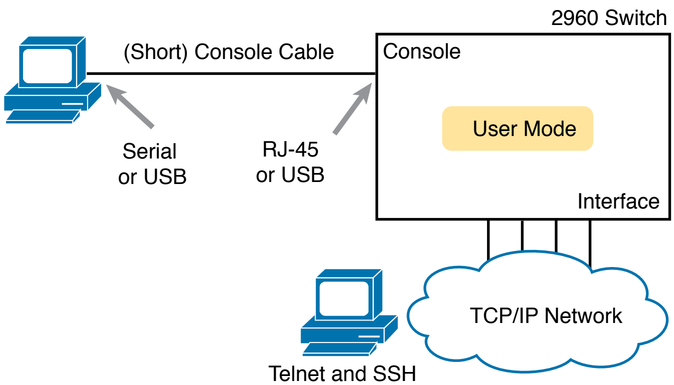

Figure 4-2 *CLI Access Options*

Console access requires both a physical connection between a PC (or other user device) and the switch's console port, as well as some software on the PC. Telnet and SSH require software on the user's device, but they rely on the existing TCP/IP network to transmit data. The next few pages detail how to connect the console and set up the software for each method to access the CLI.

Cabling the Console Connection

The physical console connection, both old and new, uses three main components: the physical console port on the switch, a physical serial port on the PC, and a cable that works with the console and serial ports. However, the physical cabling details have changed slowly over time, mainly because of advances and changes with serial interfaces on PC hardware. For this next topic, the text looks at three cases: newer connectors on both the PC and the switch, older connectors on both, and a third case with the newer (USB) connector on the PC but with an older connector on the switch.

Most PCs today use a familiar standard USB cable for the console connection. Cisco has been including USB ports as console ports in newer routers and switches as well. All you have to do is look at the switch to make sure you have the correct style of USB cable end to match the USB console port. In the simplest form, you can use any USB port on the PC, with a USB cable, connected to the USB console port on the switch or router, as shown on the far right side of Figure 4-3.

Key Topic

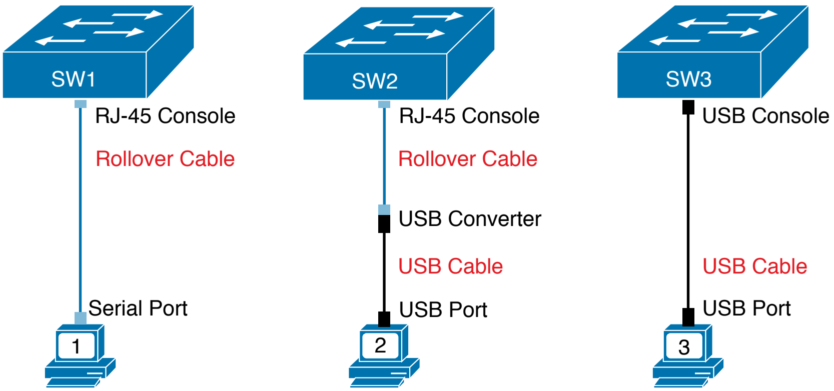

Figure 4-3 *Console Connection to a Switch*

Older console connections use a PC serial port that pre-dates USB, a UTP cable, and an RJ-45 console port on the switch, as shown on the left side of Figure 4-3. The PC serial port typically has a D-shell connector (roughly rectangular) with nine pins (often called a DB-9). The console port looks like any Ethernet RJ-45 port (but is typically colored in blue and with the word *console* beside it on the switch).

The cabling for this older-style console connection can be simple or require some effort, depending on what cable you use. You can use the purpose-built console cable that ships with new Cisco switches and routers and not think about the details. However, you can make

Answers to the "Do I Know This Already?" quiz:

1 A, B **2** B **3** B **4** A **5** F **6** B, C your own cable with a standard serial cable (with a connector that matches the PC), a standard RJ-45 to DB-9 converter plug, and a UTP cable. However, the UTP cable does not use the same pinouts as Ethernet; instead, the cable uses rollover cable pinouts rather than any of the standard Ethernet cabling pinouts. The rollover pinout uses eight wires, rolling the wire at pin 1 to pin 8, pin 2 to pin 7, pin 3 to pin 6, and so on.

As it turns out, USB ports became common on PCs before Cisco began commonly using USB for its console ports. So, you also have to be ready to use a PC that has only a USB port and not an old serial port, but a router or switch that has the older RJ-45 console port (and no USB console port). The center of Figure 4-3 shows that case. To connect such a PC to a router or switch console, you need a USB converter that converts from the older console cable to a USB connector, and a rollover UTP cable, as shown in the middle of Figure 4-3.

NOTE When using the USB options, you typically also need to install a software driver so that your PC's OS knows that the device on the other end of the USB connection is the console of a Cisco device. Also, you can easily find photos of these cables and components online, with searches like "cisco console cable," "cisco usb console cable," or "console cable converter."

The 2960-XR series, for instance, supports both the older RJ-45 console port and a USB console port. Figure 4-4 points to the two console ports; you would use only one or the other. Note that the USB console port uses a mini-B port rather than the more commonly seen rectangular standard USB Type A port.

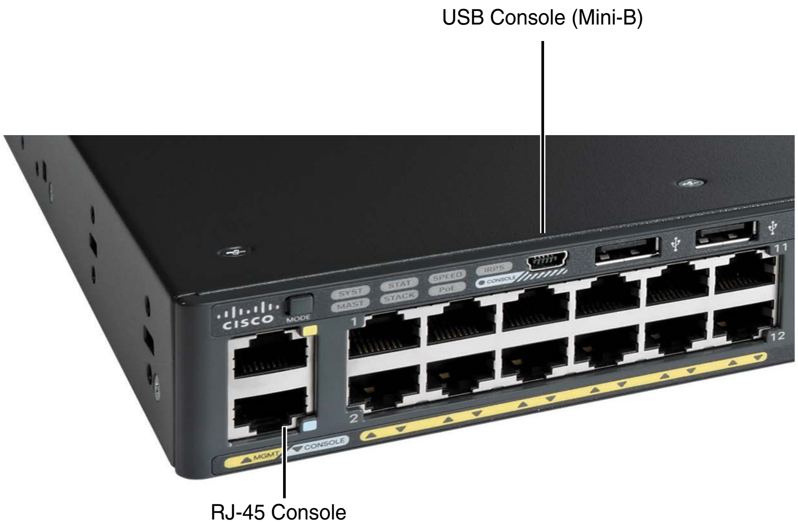

Figure 4-4 *A Part of a 2960-XR Switch with Console Ports Shown*

After the PC is physically connected to the console port, a terminal emulator software package must be installed and configured on the PC. The terminal emulator software treats all data as text. It accepts the text typed by the user and sends it over the console connection to the switch. Similarly, any bits coming into the PC over the console connection are displayed as text for the user to read.

The emulator must be configured to use the PC's serial port to match the settings on the switch's console port settings. The default console port settings on a switch are as follows. Note that the last three parameters are referred to collectively as 8N1:

Key Topic

- 9600 bits/second
- No hardware flow control
- 8-bit ASCII
- No parity bits
- 1 stop bit

Figure 4-5 shows one such terminal emulator. The image shows the window created by the emulator software in the background, with some output of a **show** command. The foreground, in the upper right, shows a settings window that lists the default console settings as listed just before this paragraph.

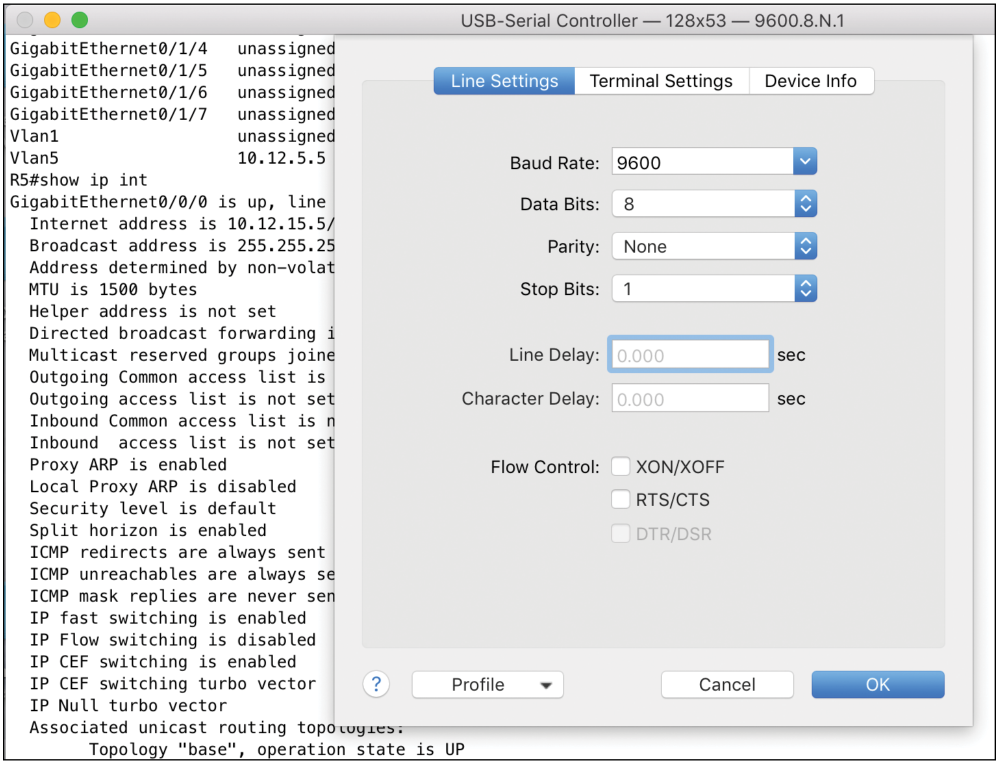

Figure 4-5 *Terminal Settings for Console Access*

Accessing the CLI with Telnet and SSH

For many years, terminal emulator applications have supported far more than the ability to communicate over a serial port to a local device (like a switch's console). Terminal emulators support a variety of TCP/IP applications as well, including Telnet and SSH. Telnet and SSH both allow the user to connect to another device's CLI, but instead of connecting through a console cable to the console port, the traffic flows over the same IP network that the networking devices are helping to create.

Telnet uses the concept of a Telnet client (the terminal application) and a Telnet server (the switch in this case). A *Telnet client*, the device that sits in front of the user, accepts keyboard input and sends those commands to the *Telnet server*. The Telnet server accepts the text, interprets the text as a command, and replies back.

Cisco Catalyst switches enable a Telnet server by default, but switches need a few more configuration settings before you can successfully use Telnet to connect to a switch. Chapter 6, "Configuring Basic Switch Management," covers switch configuration to support Telnet and SSH in detail.

Using Telnet in a lab today makes sense, but Telnet poses a significant security risk in production networks. Telnet sends all data (including any username and password for login to the switch) as clear-text data. SSH gives us a much better option.

Think of SSH as the much more secure Telnet cousin. Outwardly, you still open a terminal emulator, connect to the switch's IP address, and see the switch CLI, no matter whether you use Telnet or SSH. The differences exist behind the scenes: SSH encrypts the contents of all messages, including the passwords, avoiding the possibility of someone capturing packets in the network and stealing the password to network devices.

User and Enable (Privileged) Modes

All three CLI access methods covered so far (console, Telnet, and SSH) place the user in an area of the CLI called *user EXEC mode*. User EXEC mode, sometimes also called *user mode*, allows the user to look around but not break anything. The "EXEC mode" part of the name refers to the fact that in this mode, when you enter a command, the switch executes the command and then displays messages that describe the command's results.

NOTE If you have not used the CLI before, you might want to experiment with the CLI from the Sim Lite product, or view the video about CLI basics. You can find these resources on the companion website as mentioned in the Introduction.

Cisco IOS supports a more powerful EXEC mode called *enable* mode (also known as *privileged* mode or *privileged EXEC* mode). Enable mode gets its name from the **enable** command, which moves the user from user mode to enable mode, as shown in Figure 4-6. The other name for this mode, *privileged mode*, refers to the fact that powerful (or privileged) commands can be executed there. For example, you can use the **reload** command, which tells the switch to reinitialize or reboot Cisco IOS, only from enable mode.

NOTE If the command prompt lists the hostname followed by a >, the user is in user mode; if it is the hostname followed by the #, the user is in enable mode.

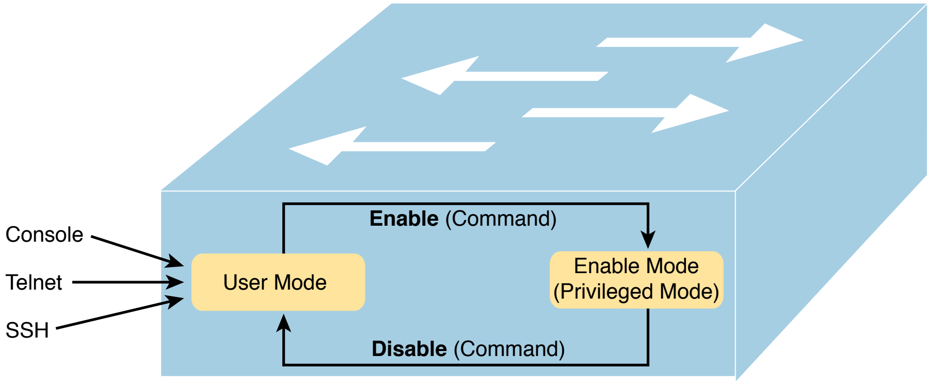

Figure 4-6 *User and Privileged Modes*

Example 4-1 demonstrates the differences between user and enable modes. The example shows the output that you could see in a terminal emulator window, for instance, when connecting from the console. In this case, the user sits at the user mode prompt ("Certskills1>") and tries the **reload** command. The **reload** command tells the switch to reinitialize or reboot Cisco IOS, so IOS allows this powerful command to be used only from enable mode. IOS rejects the **reload** command when used in user mode. Then the user moves to enable mode—also called privileged mode—(using the **enable** EXEC command). At that point, IOS accepts the **reload** command now that the user is in enable mode.

Example 4-1 *Example of Privileged Mode Commands Being Rejected in User Mode*

```
Press RETURN to get started.

User Access Verification

Password:
Certskills1>
Certskills1> reload
Translating "reload"
% Unknown command or computer name, or unable to find computer address
Certskills1> enable
Password:
Certskills1#
Certskills1# reload

Proceed with reload? [confirm] y
00:08:42: %SYS-5-RELOAD: Reload requested by console. Reload Reason: Reload Command.
```

NOTE The commands that can be used in either user (EXEC) mode or enable (EXEC) mode are called EXEC commands.

This example is the first instance of this book showing you the output from the CLI, so it is worth noting a few conventions. The bold text represents what the user typed, and the non-bold text is what the switch sent back to the terminal emulator. Also, the typed passwords do not show up on the screen for security purposes. Finally, note that this switch has been preconfigured with a hostname of Certskills1, so the command prompt on the left shows that hostname on each line.

Password Security for CLI Access from the Console

A Cisco switch, with default settings, remains relatively secure when locked inside a wiring closet, because by default, a switch allows console access only. By default, the console requires no password at all, and no password to reach enable mode for users that happened to connect from the console. The reason is that if you have access to the physical console port of the switch, you already have pretty much complete control over the switch. You could literally get out your screwdriver and walk off with it, or you could unplug the power, or follow well-published procedures to go through password recovery to break into the CLI and then configure anything you want to configure.

However, many people go ahead and set up simple password protection for console users. Simple passwords can be configured at two points in the login process from the console: when the user connects from the console, and when any user moves to enable mode (using the **enable** EXEC command). You may have noticed that back in Example 4-1, the user saw a password prompt at both points.

Example 4-2 shows the additional configuration commands that were configured prior to collecting the output in Example 4-1. The output holds an excerpt from the EXEC command **show running-config**, which lists the current configuration in the switch.

Example 4-2 *Nondefault Basic Configuration*

```
Certskills1# show running-config
! Output has been formatted to show only the parts relevant to this discussion
hostname Certskills1
!
enable secret love
!
line console 0
 login
 password faith
! The rest of the output has been omitted
Certskills1#
```

Working from top to bottom, note that the first configuration command listed by the **show running-config** command sets the switch's hostname to Certskills1. You might have noticed that the command prompts in Example 4-1 all began with Certskills1, and that's why the command prompt begins with the hostname of the switch.

Next, note that the lines with a ! in them are comment lines, both in the text of this book and in the real switch CLI.

The **enable secret love** configuration command defines the password that all users must use to reach enable mode. So, no matter whether users connect from the console, Telnet, or SSH, they would use the password love when prompted for a password after typing the **enable** EXEC command.

Finally, the last three lines configure the console password. The first line (**line console 0**) is the command that identifies the console, basically meaning "these next commands apply to the console only." The **login** command tells IOS to perform simple password checking (at the console). Remember, by default, the switch does not ask for a password for console users. Finally, the **password faith** command defines the password the console user must type when prompted.

This example just scratches the surface of the kinds of security configuration you might choose to configure on a switch, but it does give you enough detail to configure switches in your lab and get started (which is the reason I put these details in this first chapter of Part II). Note that Chapter 6 shows the configuration steps to add support for Telnet and SSH (including password security), and Chapter 5 of the *CCNA 200-301 Official Cert Guide, Volume 2*, "Securing Network Devices," shows additional security configuration as well.

CLI Help Features

If you printed the Cisco IOS Command Reference documents, you would end up with a stack of paper several feet tall. No one should expect to memorize all the commands—and no one does. You can use several very easy, convenient tools to help remember commands and save time typing. As you progress through your Cisco certifications, the exams will cover progressively more commands. However, you should know the methods of getting command help.

Table 4-2 summarizes command-recall help options available at the CLI. Note that, in the first column, *command* represents any command. Likewise, *parm* represents a command's parameter. For example, the second row lists *command* **?**, which means that commands such as **show ?** and **copy ?** would list help for the **show** and **copy** commands, respectively.

Table 4-2 Cisco IOS Software Command Help

What You Enter	What Help You Get
?	Provides help for all commands available in this mode.
command **?**	With a space between the command and the **?**, the switch lists text to describe all the first parameter options for the command.
*com***?**	Lists commands that start with **com**.
*command parm***?**	Lists all parameters beginning with the **parameter typed so far**. (Notice that there is no space between *parm* and the **?**.)
command parm<Tab>	Pressing the Tab key causes IOS to spell out the rest of the word, assuming that you have typed enough of the word so there is only one option that begins with that string of characters.
command parm1 **?**	If a space is inserted before the question mark, the CLI lists all the next parameters and gives a brief explanation of each.

When you enter the **?**, the Cisco IOS CLI reacts immediately; that is, you don't need to press the Enter key or any other keys. The device running Cisco IOS also redisplays what you entered before the **?** to save you some keystrokes. If you press Enter immediately after the **?**, Cisco IOS tries to execute the command with only the parameters you have entered so far.

The information supplied by using help depends on the CLI mode. For example, when **?** is entered in user mode, the commands allowed in user mode are displayed, but commands available only in enable mode (not in user mode) are not displayed. Also, help is available in configuration mode, which is the mode used to configure the switch. In fact, configuration mode has many different subconfiguration modes, as explained in the section "Configuration Submodes and Contexts," later in this chapter. So, you can get help for the commands available in each configuration submode as well. (Note that this might be a good time to use the free Sim Lite product on the companion website—open any lab, use the question mark, and try some commands.)

Cisco IOS stores the commands that you enter in a history buffer, storing ten commands by default. The CLI allows you to move backward and forward in the historical list of commands and then edit the command before reissuing it. These key sequences can help you use the CLI more quickly on the exams. Table 4-3 lists the commands used to manipulate previously entered commands.

Table 4-3 Key Sequences for Command Edit and Recall

Keyboard Command	What Happens
Up arrow or Ctrl+P	This displays the most recently used command. If you press it again, the next most recent command appears, until the history buffer is exhausted. (The *P* stands for previous.)
Down arrow or Ctrl+N	If you have gone too far back into the history buffer, these keys take you forward to the more recently entered commands. (The *N* stands for next.)
Left arrow or Ctrl+B	This moves the cursor backward in the currently displayed command without deleting characters. (The *B* stands for back.)
Right arrow or Ctrl+F	This moves the cursor forward in the currently displayed command without deleting characters. (The *F* stands for forward.)
Backspace	This moves the cursor backward in the currently displayed command, deleting characters.

The debug and show Commands

By far, the single most popular Cisco IOS command is the **show** command. The **show** command has a large variety of options, and with those options, you can find the status of almost every feature of Cisco IOS. Essentially, the **show** command lists the currently known facts about the switch's operational status. The only work the switch does in reaction to **show** commands is to find the current status and list the information in messages sent to the user.

For example, consider the output from the **show mac address-table dynamic** command listed in Example 4-3. This **show** command, issued from user mode, lists the table the switch uses to make forwarding decisions. A switch's MAC address table basically lists the data a switch uses to do its primary job.

Example 4-3 *Nondefault Basic Configuration*

```
Certskills1> show mac address-table dynamic
 Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
  31    0200.1111.1111    DYNAMIC     Gi0/1
  31    0200.3333.3333    DYNAMIC     Fa0/3
  31    1833.9d7b.0e9a    DYNAMIC     Gi0/1
  10    1833.9d7b.0e9a    DYNAMIC     Gi0/1
  10    30f7.0d29.8561    DYNAMIC     Gi0/1
   1    1833.9d7b.0e9a    DYNAMIC     Gi0/1
  12    1833.9d7b.0e9a    DYNAMIC     Gi0/1
Total Mac Addresses for this criterion: 7
Certskills1>
```

The **debug** command also tells the user details about the operation of the switch. However, while the **show** command lists status information at one instant of time—more like a photograph—the **debug** command acts more like a live video camera feed. Once you issue a **debug** command, IOS remembers, issuing messages that any switch user can choose to see. The console sees these messages by default. Most of the commands used throughout this book to verify operation of switches and routers are **show** commands.

Configuring Cisco IOS Software

You will want to configure every switch in an Enterprise network, even though the switches will forward traffic even with default configuration. This section covers the basic configuration processes, including the concept of a configuration file and the locations in which the configuration files can be stored. Although this section focuses on the configuration process, and not on the configuration commands themselves, you should know all the commands covered in this chapter for the exams, in addition to the configuration processes.

Configuration mode is another mode for the Cisco CLI, similar to user mode and privileged mode. User mode lets you issue nondisruptive commands and displays some information. Privileged mode supports a superset of commands compared to user mode, including commands that might disrupt switch operations. However, not one of the commands in user or privileged mode changes the switch's configuration. Configuration mode accepts *configuration commands*—commands that tell the switch the details of what to do and how to do it. Figure 4-7 illustrates the relationships among configuration mode, user EXEC mode, and privileged EXEC mode.

Key Topic

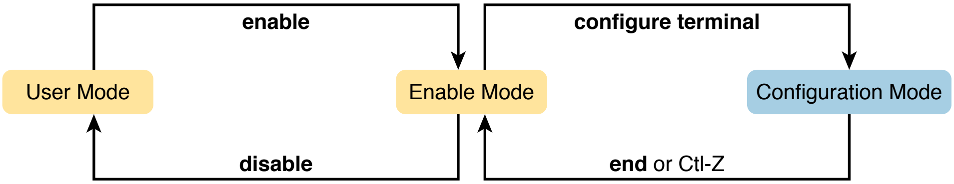

Figure 4-7 *CLI Configuration Mode Versus EXEC Modes*

Commands entered in configuration mode update the active configuration file. *These changes to the configuration occur immediately each time you press the Enter key at the end of a command.* Be careful when you enter a configuration command!

Configuration Submodes and Contexts

4

Configuration mode itself contains a multitude of commands. To help organize the configuration, IOS groups some kinds of configuration commands together. To do that, when using configuration mode, you move from the initial mode—global configuration mode—into subcommand modes. *Context-setting commands* move you from one configuration subcommand mode, or context, to another. These context-setting commands tell the switch the topic about which you will enter the next few configuration commands. More importantly, the context tells the switch the topic you care about right now, so when you use the **?** to get help, the switch gives you help about that topic only.

NOTE *Context-setting* is not a Cisco term. It is just a description used here to help make sense of configuration mode.

The best way to learn about configuration submodes is to use them, but first, take a look at these upcoming examples. For instance, the **interface** command is one of the most commonly used context-setting configuration commands. For example, the CLI user could enter interface configuration mode by entering the **interface FastEthernet 0/1** configuration command. Asking for help in interface configuration mode displays only commands that are useful when configuring Ethernet interfaces. Commands used in this context are called *subcommands*—or, in this specific case, *interface subcommands*. When you begin practicing with the CLI with real equipment, the navigation between modes can become natural. For now, consider Example 4-4, which shows the following:

- Movement from enable mode to global configuration mode by using the **configure terminal** EXEC command
- Using a **hostname Fred** global configuration command to configure the switch's name
- Movement from global configuration mode to console line configuration mode (using the **line console 0** command)
- Setting the console's simple password to **hope** (using the **password hope** line subcommand)
- Movement from console configuration mode to interface configuration mode (using the **interface** *type number* command)

- Setting the speed to 100 Mbps for interface Fa0/1 (using the **speed 100** interface subcommand)
- Movement from interface configuration mode back to global configuration mode (using the **exit** command)

Example 4-4 *Navigating Between Different Configuration Modes*

```
Switch# configure terminal
Switch(config)# hostname Fred
Fred(config)# line console 0
Fred(config-line)# password hope
Fred(config-line)# interface FastEthernet 0/1
Fred(config-if)# speed 100
Fred(config-if)# exit
Fred(config)#
```

The text inside parentheses in the command prompt identifies the configuration mode. For example, the first command prompt after you enter configuration mode lists (config), meaning global configuration mode. After the **line console 0** command, the text expands to (config-line), meaning line configuration mode. Each time the command prompt changes within config mode, you have moved to another configuration mode.

Table 4-4 shows the most common command prompts in configuration mode, the names of those modes, and the context-setting commands used to reach those modes.

Key Topic

Table 4-4 Common Switch Configuration Modes

Prompt	Name of Mode	Context-Setting Command(s) to Reach This Mode
hostname(config)#	Global	None—first mode after **configure terminal**
hostname(config-line)#	Line	**line console 0** **line vty 0 15**
hostname(config-if)#	Interface	**interface** *type number*
hostname(vlan)#	VLAN	**vlan** *number*

You should practice until you become comfortable moving between the different configuration modes, back to enable mode, and then back into the configuration modes. However, you can learn these skills just doing labs about the topics in later chapters of the book. For now, Figure 4-8 shows most of the navigation between global configuration mode and the four configuration submodes listed in Table 4-4.

NOTE You can also move directly from one configuration submode to another, without first using the **exit** command to move back to global configuration mode. Just use the commands listed in bold in the center of the figure.

Key Topic

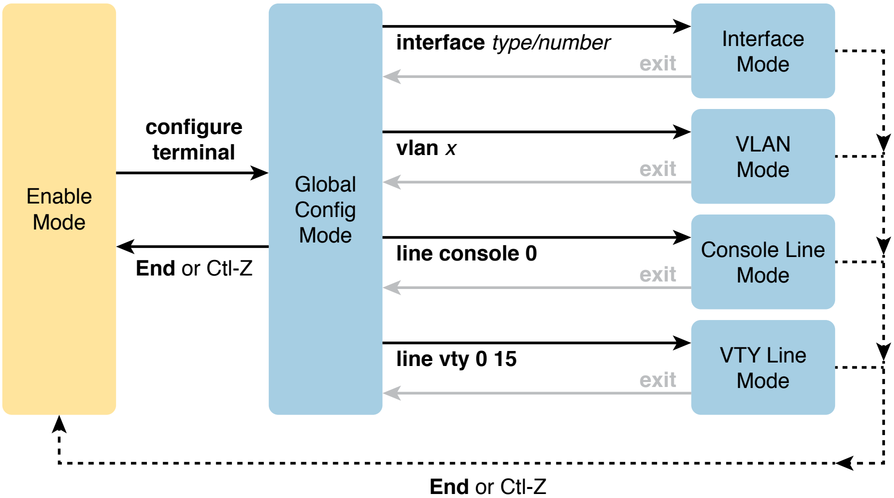

Figure 4-8 *Navigation In and Out of Switch Configuration Modes*

You really should stop and try navigating around these configuration modes. If you have not yet decided on a lab strategy, install the Pearson Sim Lite software from the companion website. It includes the simulator and a couple of lab exercises. Start any lab, ignore the instructions, and just get into configuration mode and move around between the configuration modes shown in Figure 4-8.

No set rules exist for what commands are global commands or subcommands. Generally, however, when multiple instances of a parameter can be set in a single switch, the command used to set the parameter is likely a configuration subcommand. Items that are set once for the entire switch are likely global commands. For example, the **hostname** command is a global command because there is only one hostname per switch. Conversely, the **speed** command is an interface subcommand that applies to each switch interface that can run at different speeds, so it is a subcommand, applying to the particular interface under which it is configured.

Storing Switch Configuration Files

When you configure a switch, it needs to use the configuration. It also needs to be able to retain the configuration in case the switch loses power. Cisco switches contain random-access memory (RAM) to store data while Cisco IOS is using it, but RAM loses its contents when the switch loses power or is reloaded. To store information that must be retained when the switch loses power or is reloaded, Cisco switches use several types of more permanent memory, none of which has any moving parts. By avoiding components with moving parts (such as traditional disk drives), switches can maintain better uptime and availability.

The following list details the four main types of memory found in Cisco switches, as well as the most common use of each type:

- **RAM:** Sometimes called DRAM, for dynamic random-access memory, RAM is used by the switch just as it is used by any other computer: for working storage. The running (active) configuration file is stored here.

- **Flash memory:** Either a chip inside the switch or a removable memory card, flash memory stores fully functional Cisco IOS images and is the default location where the switch gets its Cisco IOS at boot time. Flash memory also can be used to store any other files, including backup copies of configuration files.
- **ROM:** Read-only memory (ROM) stores a bootstrap (or boothelper) program that is loaded when the switch first powers on. This bootstrap program then finds the full Cisco IOS image and manages the process of loading Cisco IOS into RAM, at which point Cisco IOS takes over operation of the switch.
- **NVRAM:** Nonvolatile RAM (NVRAM) stores the initial or startup configuration file that is used when the switch is first powered on and when the switch is reloaded.

Figure 4-9 summarizes this same information in a briefer and more convenient form for memorization and study.

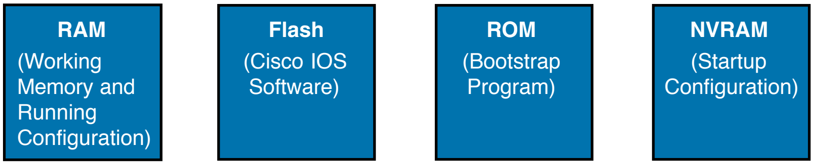

Figure 4-9 *Cisco Switch Memory Types*

Cisco IOS stores the collection of configuration commands in a *configuration file*. In fact, switches use multiple configuration files—one file for the initial configuration used when powering on, and another configuration file for the active, currently used running configuration as stored in RAM. Table 4-5 lists the names of these two files, their purpose, and their storage location.

Key Topic

Table 4-5 Names and Purposes of the Two Main Cisco IOS Configuration Files

Configuration Filename	Purpose	Where It Is Stored
startup-config	Stores the initial configuration used anytime the switch reloads Cisco IOS.	NVRAM
running-config	Stores the currently used configuration commands. This file changes dynamically when someone enters commands in configuration mode.	RAM

Essentially, when you use configuration mode, you change only the running-config file. This means that the configuration example earlier in this chapter (Example 4-4) updates only the running-config file. However, if the switch lost power right after that example, all that configuration would be lost. If you want to keep that configuration, you have to copy the running-config file into NVRAM, overwriting the old startup-config file.

Example 4-5 demonstrates that commands used in configuration mode change only the running configuration in RAM. The example shows the following concepts and steps:

Step 1. The example begins with both the running and startup-config having the same hostname, per the **hostname hannah** command.

Step 2. The hostname is changed in configuration mode using the **hostname harold** command.

Step 3. The **show running-config** and **show startup-config** commands show the fact that the hostnames are now different, with the **hostname harold** command found only in the running-config.

Example 4-5 *How Configuration Mode Commands Change the Running-Config File, Not the Startup-Config File*

```
! Step 1 next (two commands)
!
hannah# show running-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

hannah# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)
! Step 2 next. Notice that the command prompt changes immediately after
! the hostname command.

hannah# configure terminal
hannah(config)# hostname harold
harold(config)# exit
! Step 3 next (two commands)
!
harold# show running-config
! (lines omitted) - just showing the part with the hostname command
hostname harold
!
harold# show startup-config
! (lines omitted) - just showing the part with the hostname command
hostname hannah
```

Copying and Erasing Configuration Files

The configuration process updates the running-config file, which is lost if the router loses power or is reloaded. Clearly, IOS needs to provide us a way to copy the running configuration so that it will not be lost, so it will be used the next time the switch reloads or powers on. For instance, Example 4-5 ended with a different running configuration (with the **hostname harold** command) versus the startup configuration.

In short, the EXEC command **copy running-config startup-config** backs up the running-config to the startup-config file. This command overwrites the current startup-config file with what is currently in the running-configuration file.

In addition, in the lab, you may want to just get rid of all existing configuration and start over with a clean configuration. To do that, you can erase the startup-config file using three different commands:

```
write erase
erase startup-config
erase nvram:
```

Once the startup-config file is erased, you can reload or power off/on the switch, and it will boot with the now-empty startup configuration.

Note that Cisco IOS does not have a command that erases the contents of the running-config file. To clear out the running-config file, simply erase the startup-config file, and then **reload** the switch, and the running-config will be empty at the end of the process.

NOTE Cisco uses the term *reload* to refer to what most PC operating systems call rebooting or restarting. In each case, it is a re-initialization of the software. The **reload** EXEC command causes a switch to reload.

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or on the book's companion website. Refer to the "Your Study Plan" element section titled "Step 2: Build Your Study Habits Around the Chapter" for more details. Table 4-6 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 4-6 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Repeat DIKTA questions		Book, PTP
Review memory tables		Book, website
Review command tables		Book

Review All the Key Topics

Key Topic

Table 4-7 Key Topics for Chapter 4

Key Topic Element	Description	Page Number
Figure 4-2	Three methods to access a switch CLI	87
Figure 4-3	Cabling options for a console connection	88
List	A Cisco switch's default console port settings	90
Figure 4-7	Navigation between user, enable, and global config modes	97
Table 4-4	A list of configuration mode prompts, the name of the configuration mode, and the command used to reach each mode	98
Figure 4-8	Configuration mode context-setting commands	99
Table 4-5	The names and purposes of the two configuration files in a switch or router	100

Key Terms You Should Know

command-line interface (CLI), Telnet, Secure Shell (SSH), enable mode, user mode, configuration mode, startup-config file, running-config file

Command References

Tables 4-8 and 4-9 list configuration and verification commands used in this chapter, respectively. As an easy review exercise, cover the left column in a table, read the right column, and try to recall the command without looking. Then repeat the exercise, covering the right column, and try to recall what the command does.

Table 4-8 Chapter 4 Configuration Commands

Command	Mode and Purpose
line console 0	Global command that changes the context to console configuration mode.
login	Line (console and vty) configuration mode. Tells IOS to prompt for a password (no username).
password *pass-value*	Line (console and vty) configuration mode. Sets the password required on that line for login if the **login** command (with no other parameters) is also configured.
interface *type port-number*	Global command that changes the context to interface mode—for example, **interface FastEthernet 0/1**.
hostname *name*	Global command that sets this switch's hostname, which is also used as the first part of the switch's command prompt.
exit	Moves back to the next higher mode in configuration mode.

Command	Mode and Purpose
end	Exits configuration mode and goes back to enable mode from any of the configuration submodes.
Ctrl+Z	This is not a command, but rather a two-key combination (pressing the Ctrl key and the letter Z) that together do the same thing as the **end** command.

Table 4-9 Chapter 4 EXEC Command Reference

Command	Purpose
no debug all **undebug all**	Enable mode EXEC command to disable all currently enabled debugs.
reload	Enable mode EXEC command that reboots the switch or router.
copy running-config startup-config	Enable mode EXEC command that saves the active config, replacing the startup-config file used when the switch initializes.
copy startup-config running-config	Enable mode EXEC command that merges the startup-config file with the currently active config file in RAM.
show running-config	Lists the contents of the running-config file.
write erase **erase startup-config** **erase nvram:**	These enable mode EXEC commands erase the startup-config file.
quit	EXEC command that disconnects the user from the CLI session.
show startup-config	Lists the contents of the startup-config (initial config) file.
enable	Moves the user from user mode to enable (privileged) mode and prompts for a password if one is configured.
disable	Moves the user from enable mode to user mode.
configure terminal	Enable mode command that moves the user into configuration mode.

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CHAPTER 5

Analyzing Ethernet LAN Switching

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.1 Explain the role and function of network components

1.1.b L2 and L3 Switches

1.13 Describe switching concepts

1.13.a MAC learning and aging

1.13.b Frame switching

1.13.c Frame flooding

1.13.d MAC address table

2.0 Network Access

2.5 Describe the need for and basic operations of Rapid PVST+ Spanning Tree Protocol and identify basic operations

When you buy a Cisco Catalyst Ethernet switch, the switch is ready to work. All you have to do is take it out of the box, power on the switch by connecting the power cable to the switch and a power outlet, and connect hosts to the switch using the correct unshielded twisted-pair (UTP) cables. You do not have to configure anything else, or connect to the console and login, or do anything: the switch just starts forwarding Ethernet frames.

In Part II of this book, you will learn how to build, configure, and verify the operation of Ethernet LANs. In Chapter 4, "Using the Command-Line Interface," you learned how to move around in the CLI, issue commands, and configure the switch. This chapter takes a short but important step in that journey by explaining the logic a switch uses when forwarding Ethernet frames.

This chapter breaks the content into two major sections. The first reviews and then further develops the concepts behind LAN switching, which were first introduced back in Chapter 2, "Fundamentals of Ethernet LANs." The second section then uses IOS show commands to verify that Cisco switches actually learned the MAC addresses, built the MAC address table, and forwarded frames.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 5-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
LAN Switching Concepts	1–4
Verifying and Analyzing Ethernet Switching	5–6

1. Which of the following statements describes part of the process of how a switch decides to forward a frame destined for a known unicast MAC address?
   - **a.** It compares the unicast destination address to the bridging, or MAC address, table.
   - **b.** It compares the unicast source address to the bridging, or MAC address, table.
   - **c.** It forwards the frame out all interfaces in the same VLAN except for the incoming interface.
   - **d.** It compares the destination IP address to the destination MAC address.
   - **e.** It compares the frame's incoming interface to the source MAC entry in the MAC address table.
2. Which of the following statements describes part of the process of how a LAN switch decides to forward a frame destined for a broadcast MAC address?
   - **a.** It compares the unicast destination address to the bridging, or MAC address, table.
   - **b.** It compares the unicast source address to the bridging, or MAC address, table.
   - **c.** It forwards the frame out all interfaces in the same VLAN except for the incoming interface.
   - **d.** It compares the destination IP address to the destination MAC address.
   - **e.** It compares the frame's incoming interface to the source MAC entry in the MAC address table.
3. Which of the following statements best describes what a switch does with a frame destined for an unknown unicast address?
   - **a.** It forwards out all interfaces in the same VLAN except for the incoming interface.
   - **b.** It forwards the frame out the one interface identified by the matching entry in the MAC address table.
   - **c.** It compares the destination IP address to the destination MAC address.
   - **d.** It compares the frame's incoming interface to the source MAC entry in the MAC address table.
4. Which of the following comparisons does a switch make when deciding whether a new MAC address should be added to its MAC address table?
   - **a.** It compares the unicast destination address to the bridging, or MAC address, table.
   - **b.** It compares the unicast source address to the bridging, or MAC address, table.
   - **c.** It compares the VLAN ID to the bridging, or MAC address, table.
   - **d.** It compares the destination IP address's ARP cache entry to the bridging, or MAC address, table.

5. A Cisco Catalyst switch has 24 10/100 ports, numbered 0/1 through 0/24. Ten PCs connect to the 10 lowest numbered ports, with those PCs working and sending data over the network. The other ports are not connected to any device. Which of the following answers lists facts displayed by the show interfaces status command?

- **a.** Port Ethernet 0/1 is in a connected state.
- **b.** Port Fast Ethernet 0/11 is in a connected state.
- **c.** Port Fast Ethernet 0/5 is in a connected state.
- **d.** Port Ethernet 0/15 is in a notconnected state.

6. Consider the following output from a Cisco Catalyst switch:

```
SW1# show mac address-table dynamic
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1     02AA.AAAA.AAAA    DYNAMIC     Gi0/1
   1     02BB.BBBB.BBBB    DYNAMIC     Gi0/2
   1     02CC.CCCC.CCCC    DYNAMIC     Gi0/3
Total Mac Addresses for this criterion: 3
```

Which of the following answers is true about this switch?

- **a.** The output proves that port Gi0/2 connects directly to a device that uses address 02BB.BBBB.BBBB.
- **b.** The switch has learned three MAC addresses since the switch powered on.
- **c.** The three listed MAC addresses were learned based on the destination MAC address of frames forwarded by the switch.
- **d.** 02CC.CCCC.CCCC was learned from the source MAC address of a frame that entered port Gi0/3.

Foundation Topics

LAN Switching Concepts

A modern Ethernet LAN connects user devices as well as servers into some switches, with the switches then connecting to each other, sometimes in a design like Figure 5-1. Part of the LAN, called a campus LAN, supports the end-user population as shown on the left of the figure. End-user devices connect to LAN switches, which in turn connect to other switches so that a path exists to the rest of the network. The campus LAN switches sit in wiring closets close to the end users. On the right, the servers used to provide information to the users also connect to the LAN. Those servers and switches often sit in a closed room called a *data center*, with connections to the campus LAN to support traffic to/from the users.

To forward traffic from a user device to a server and back, each switch performs the same kind of logic, independently from each other. The first half of this chapter examines the logic: how a switch chooses to forward an Ethernet frame, when the switch chooses to not forward the frame, and so on.

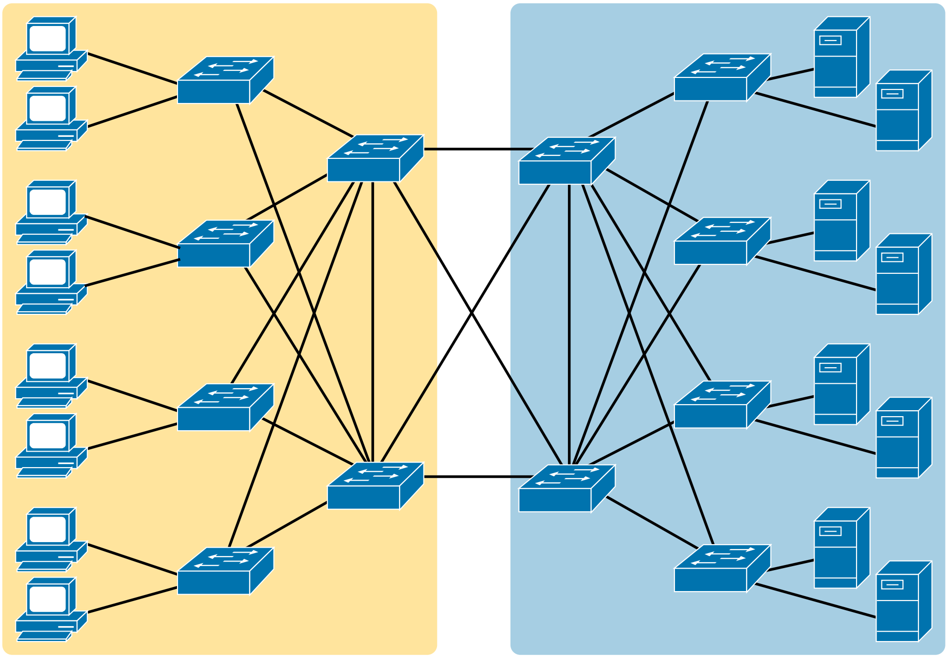


Figure 5-1 *Campus LAN and Data Center LAN, Conceptual Drawing*

Overview of Switching Logic

Ultimately, the role of a LAN switch is to forward Ethernet frames. LANs exist as a set of user devices, servers, and other devices that connect to switches, with the switches connected to each other. The LAN switch has one primary job: to forward frames to the correct destination (MAC) address. And to achieve that goal, switches use logic—logic based on the source and destination MAC address in each frame's Ethernet header.

LAN switches receive Ethernet frames and then make a switching decision: either forward the frame out some other ports or ignore the frame. To accomplish this primary mission, switches perform three actions:

Key Topic

1. Deciding when to forward a frame or when to filter (not forward) a frame, based on the destination MAC address
2. Preparing to forward frames by learning MAC addresses by examining the source MAC address of each frame received by the switch
3. Preparing to forward only one copy of the frame to the destination by creating a (Layer 2) loop-free environment with other switches by using Spanning Tree Protocol (STP)

The first action is the switch's primary job, whereas the other two items are overhead functions.

NOTE Throughout this book's discussion of LAN switches, the terms *switch port* and *switch interface* are synonymous.

Although Chapter 2's section titled "Ethernet Data-Link Protocols" already discussed the frame format, this discussion of Ethernet switching is pretty important, so reviewing the Ethernet frame at this point might be helpful. Figure 5-2 shows one popular format for an Ethernet frame. Basically, a switch would take the frame shown in the figure, make a decision of where to forward the frame, and send the frame out that other interface.

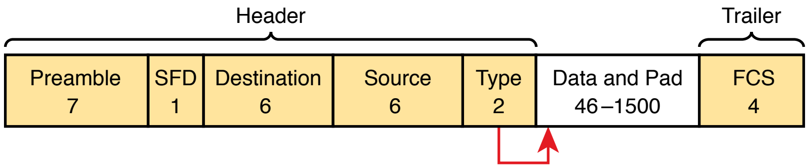


Figure 5-2 *IEEE 802.3 Ethernet Frame (One Variation)*

Most of the upcoming discussions and figures about Ethernet switching focus on the use of the destination and source MAC address fields in the header. All Ethernet frames have both a destination and source MAC address. Both are 6-bytes long (represented as 12 hex digits in the book) and are a key part of the switching logic discussed in this section. Refer back to Chapter 2's discussion of the header in detail for more info on the rest of the Ethernet frame.

NOTE The companion website includes a video that explains the basics of Ethernet switching.

Now on to the details of how Ethernet switching works!

Forwarding Known Unicast Frames

To decide whether to forward a frame, a switch uses a dynamically built table that lists MAC addresses and outgoing interfaces. Switches compare the frame's destination MAC address to this table to decide whether the switch should forward a frame or simply ignore it. For example, consider the simple network shown in Figure 5-3, with Fred sending a frame to Barney.

In this figure, Fred sends a frame with destination address 0200.2222.2222 (Barney's MAC address). The switch compares the destination MAC address (0200.2222.2222) to the MAC address table, matching the bold table entry. That matched table entry tells the switch to forward the frame out port F0/2, and only port F0/2.

Answers to the "Do I Know This Already?" quiz:

1 A **2** C **3** A **4** B **5** C **6** D

NOTE A switch's MAC address table is also called the *switching table*, or *bridging table*, or even the *Content-Addressable Memory (CAM) table*, in reference to the type of physical memory used to store the table.

Key Topic

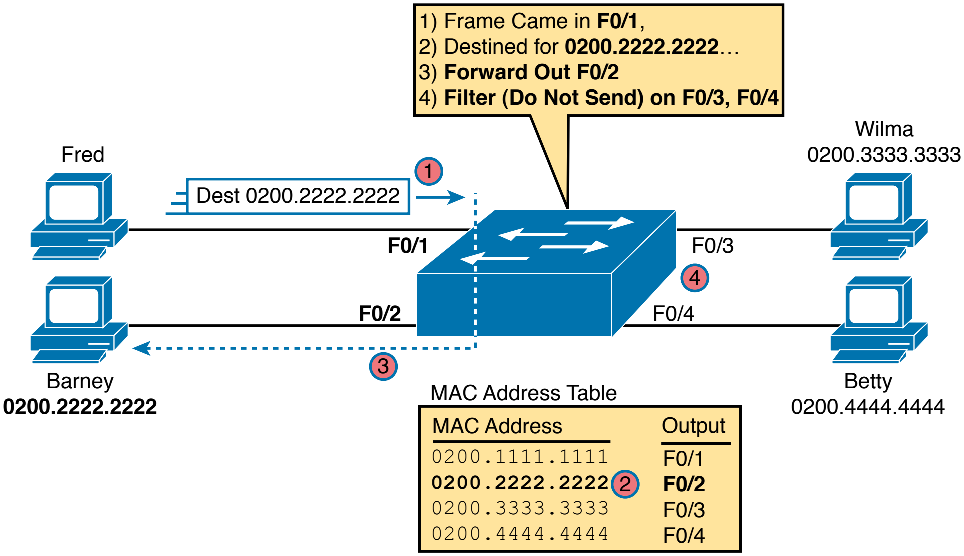


Figure 5-3 *Sample Switch Forwarding and Filtering Decision*

A switch's MAC address table lists the location of each MAC relative to that one switch. In LANs with multiple switches, each switch makes an independent forwarding decision based on its own MAC address table. Together, they forward the frame so that it eventually arrives at the destination.

For example, Figure 5-4 shows the first switching decision in a case in which Fred sends a frame to Wilma, with destination MAC 0200.3333.3333. The topology has changed versus the previous figure, this time with two switches, and Fred and Wilma connected to two different switches. Figure 5-3 shows the first switch's logic, in reaction to Fred sending the original frame. Basically, the switch receives the frame in port F0/1, finds the destination MAC (0200.3333.3333) in the MAC address table, sees the outgoing port of G0/1, so SW1 forwards the frame out its G0/1 port.

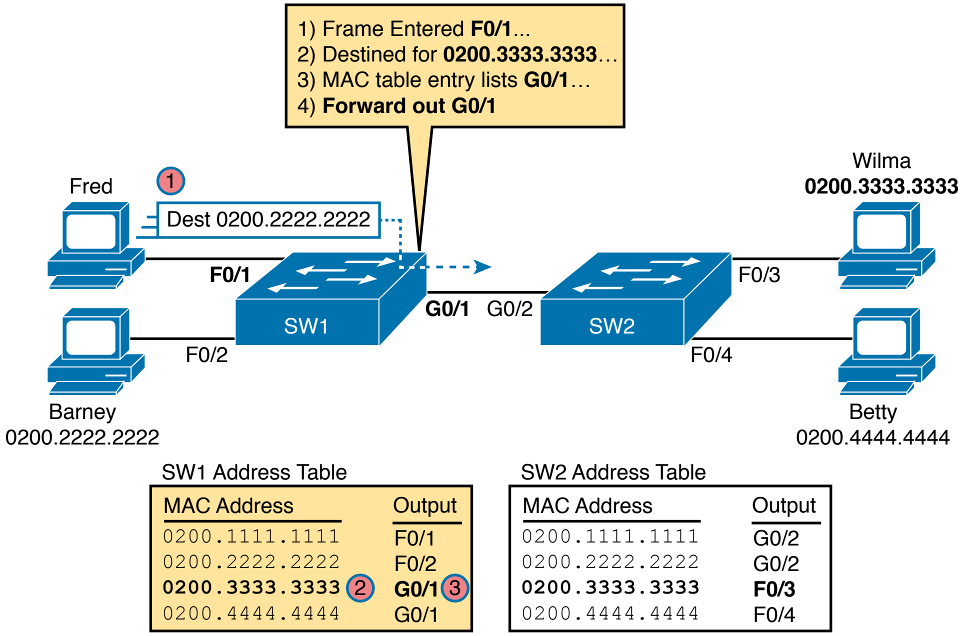


Figure 5-4 *Forwarding Decision with Two Switches: First Switch*

That same frame next arrives at switch SW2, entering SW2's G0/2 interface. As shown in Figure 5-5, SW2 uses the same logic steps, but using SW2's table. The MAC table lists the forwarding instructions for that switch only. In this case, switch SW2 forwards the frame out its F0/3 port, based on SW2's MAC address table.

Key Topic

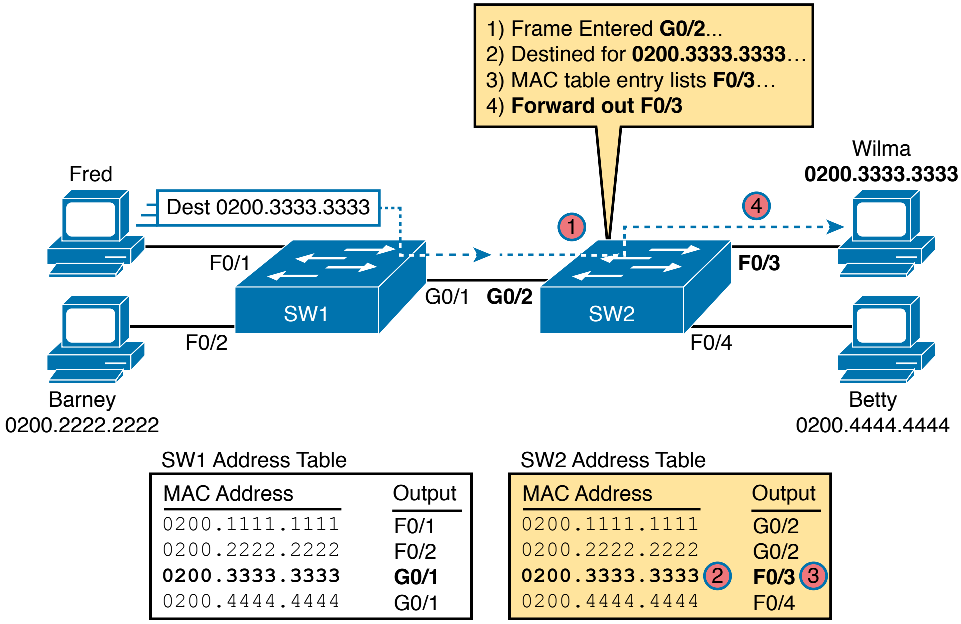


Figure 5-5 *Forwarding Decision with Two Switches: Second Switch*

NOTE The forwarding choice by a switch was formerly called a *forward-versus-filter* decision, because the switch also chooses to not forward (to filter) frames, not sending the frame out some ports.

The examples so far use switches that happen to have a MAC table with all the MAC addresses listed. As a result, the destination MAC address in the frame is known to the switch. The frames are called known unicast frames, or simply known unicasts, because the destination address is a unicast address, and the destination is known. As shown in these examples, switches forward known unicast frames out one port: the port as listed in the MAC table entry for that MAC address.

Learning MAC Addresses

Thankfully, the networking staff does not have to type in all those MAC table entries. Instead, each switch does its second main function: to learn the MAC addresses and interfaces to put into its address table. With a complete MAC address table, the switch can make accurate forwarding and filtering decisions as just discussed.

5

Switches build the address table by listening to incoming frames and examining the *source MAC address* in the frame. If a frame enters the switch and the source MAC address is not in the MAC address table, the switch creates an entry in the table. That table entry lists the interface from which the frame arrived. Switch learning logic is that simple.

Figure 5-6 depicts the same single-switch topology network as Figure 5-3, but before the switch has built any address table entries. The figure shows the first two frames sent in this network—first a frame from Fred, addressed to Barney, and then Barney's response, addressed to Fred.

Key Topic

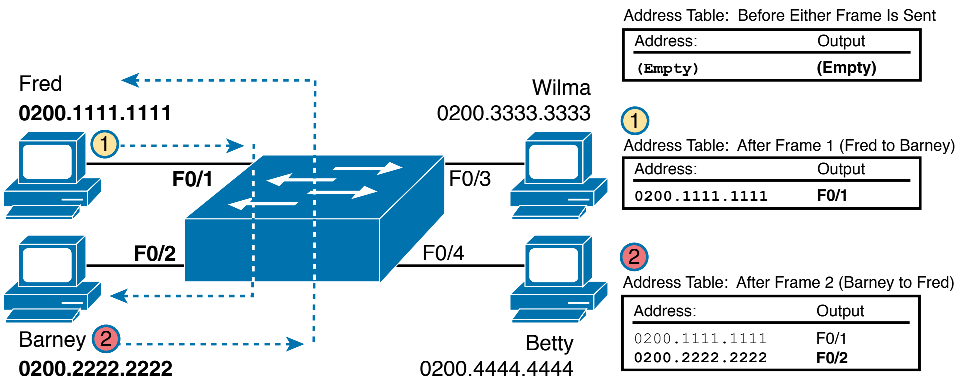


Figure 5-6 *Switch Learning: Empty Table and Adding Two Entries*

(Figure 5-6 depicts the MAC learning process only, and ignores the forwarding process and therefore ignores the destination MAC addresses.)

Focus on the learning process and how the MAC table grows at each step as shown on the right side of the figure. The switch begins with an empty MAC table, as shown in the upper-right part of the figure. Then Fred sends his first frame (labeled "1") to Barney, so the switch adds an entry for 0200.1111.1111, Fred's MAC address, associated with interface F0/1. Why F0/1? The frame sent by Fred entered the switch's F0/1 port. SW1's logic runs something like this: "The source is MAC 0200.1111.1111, the frame entered F0/1, so from my perspective, 0200.1111.1111 must be reachable out my port F0/1."

Continuing the example, when Barney replies in Step 2, the switch adds a second entry, this one for 0200.2222.2222, Barney's MAC address, along with interface F0/2. Why F0/2? The frame Barney sent entered the switch's F0/2 interface. Learning always occurs by looking at the source MAC address in the frame and adds the incoming interface as the associated port.

Flooding Unknown Unicast and Broadcast Frames

Now again turn your attention to the forwarding process, using the topology in Figure 5-5. What do you suppose the switch does with Fred's first frame, the one that occurred when there were no entries in the MAC address table? As it turns out, when there is no matching entry in the table, switches forward the frame out all interfaces (except the incoming interface) using a process called *flooding*. And the frame whose destination address is unknown to the switch is called an *unknown unicast frame*, or simply an *unknown unicast*.

Switches flood unknown unicast frames. Flooding means that the switch forwards copies of the frame out all ports, except the port on which the frame was received. The idea is simple: if you do not know where to send it, send it everywhere, to deliver the frame. And, by the way, that device will likely then send a reply—and then the switch can learn that device's MAC address and forward future frames out one port as a known unicast frame.

Switches also flood LAN broadcast frames (frames destined to the Ethernet broadcast address of FFFF.FFFF.FFFF) because this process helps deliver a copy of the frame to all devices in the LAN.

For example, Figure 5-7 shows the same first frame sent by Fred, when the switch's MAC table is empty. At step 1, Fred sends the frame. At step 2, the switch sends a copy of the frame out all three of the other interfaces.

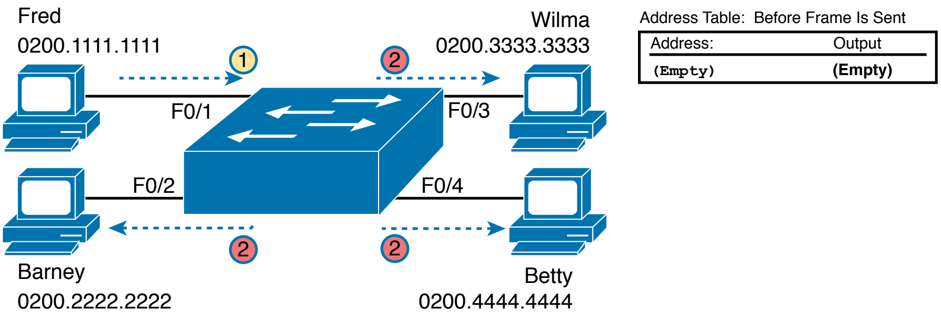


Figure 5-7 *Switch Flooding: Unknown Unicast Arrives, Floods Out Other Ports*

Avoiding Loops Using Spanning Tree Protocol

The third primary feature of LAN switches is loop prevention, as implemented by Spanning Tree Protocol (STP). Without STP, any flooded frames would loop for an indefinite period of time in Ethernet networks with physically redundant links. To prevent looping frames, STP blocks some ports from forwarding frames so that only one active path exists between any pair of LAN segments.

The result of STP is good: frames do not loop infinitely, which makes the LAN usable. However, STP has negative features as well, including the fact that it takes some work to balance traffic across the redundant alternate links.

A simple example makes the need for STP more obvious. Remember, switches flood unknown unicast frames and broadcast frames. Figure 5-8 shows an unknown unicast frame, sent by Larry to Bob, which loops forever because the network has redundancy but no STP. Note that the figure shows one direction of the looping frame only, just to reduce clutter, but a copy of the frame would also loop the other direction.

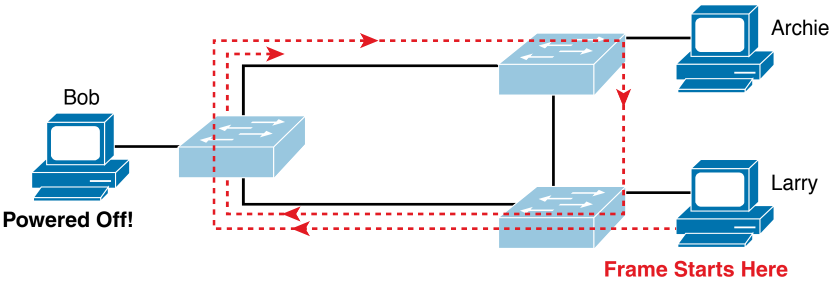


Figure 5-8 *Network with Redundant Links but Without STP: The Frame Loops Forever*

The flooding of this frame would result in the frame repeatedly rotating around the three switches, because none of the switches list Bob's MAC address in their address tables—so each switch floods the frame. And while the flooding process is a good mechanism for forwarding unknown unicasts and broadcasts, the continual flooding of traffic frames as in the figure can completely congest the LAN to the point of making it unusable.

A topology like Figure 5-8, with redundant links, is good, but we need to prevent the bad effect of those looping frames. To avoid Layer 2 loops, all switches need to use STP. STP causes each interface on a switch to settle into either a blocking state or a forwarding state. *Blocking* means that the interface cannot forward or receive data frames, while *forwarding* means that the interface can send and receive data frames. If a correct subset of the interfaces is blocked, only a single currently active logical path exists between each pair of LANs.

NOTE STP behaves identically for a transparent bridge and a switch. Therefore, the terms *bridge*, *switch*, and *bridging device* all are used interchangeably when discussing STP.

Chapter 9 of this book, "Spanning Tree Protocol Concepts," examines STP in depth, including how STP prevents loops.

LAN Switching Summary

Switches use Layer 2 logic, examining the Ethernet data-link header to choose how to process frames. In particular, switches make decisions to forward and filter frames, learn MAC addresses, and use STP to avoid loops, as follows:

Step 1. Switches forward frames based on the destination MAC address:

A. If the destination MAC address is a broadcast, multicast, or unknown destination unicast (a unicast not listed in the MAC table), the switch floods the frame.

B. If the destination MAC address is a known unicast address (a unicast address found in the MAC table):

i. If the outgoing interface listed in the MAC address table is different from the interface in which the frame was received, the switch forwards the frame out the outgoing interface.

ii. If the outgoing interface is the same as the interface in which the frame was received, the switch filters the frame, meaning that the switch simply ignores the frame and does not forward it.

Step 2. Switches use the following logic to learn MAC address table entries:

A. For each received frame, examine the source MAC address and note the interface from which the frame was received.

B. If it is not already in the table, add the MAC address and interface it was learned on.

Step 3. Switches use STP to prevent loops by causing some interfaces to block, meaning that they do not send or receive frames.

Verifying and Analyzing Ethernet Switching

A Cisco Catalyst switch comes from the factory ready to switch frames. All you have to do is connect the power cable, plug in the Ethernet cables, and the switch starts switching incoming frames. Connect multiple switches together, and they are ready to forward frames between the switches as well. And the big reason behind this default behavior has to do with the default settings on the switches.

Cisco Catalyst switches come ready to get busy switching frames because of settings like these:

- The interfaces are enabled by default, ready to start working once a cable is connected.
- All interfaces are assigned to VLAN 1.
- 10/100 and 10/100/1000 interfaces use autonegotiation by default.
- The MAC learning, forwarding, flooding logic all works by default.
- STP is enabled by default.

This second section of the chapter examines how switches will work with these default settings, showing how to verify the Ethernet learning and forwarding process.

Demonstrating MAC Learning

To see a switch's MAC address table, use the **show mac address-table** command. With no additional parameters, this command lists all known MAC addresses in the MAC table, including some overhead static MAC addresses that you can ignore. To see all the dynamically learned MAC addresses only, instead use the **show mac address-table dynamic** command.

The examples in this chapter use almost no configuration, as if you just unboxed the switch when you first purchased it. For the examples, the switches have no configuration other than the **hostname** command to set a meaningful hostname. Note that to do this in lab, all I did was

Key Topic

- Use the **erase startup-config** EXEC command to erase the startup-config file
- Use the **delete vlan.dat** EXEC command to delete the VLAN configuration details
- Use the **reload** EXEC command to reload the switch (thereby using the empty startup-config, with no VLAN information configured)
- Configure the **hostname SW1** command to set the switch hostname

Once done, the switch starts forwarding and learning MAC addresses, as demonstrated in Example 5-1.

Key Topic

Example 5-1 **show mac address-table dynamic** *for Figure 5-7*

```
SW1# show mac address-table dynamic
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1    0200.1111.1111    DYNAMIC     Fa0/1
   1    0200.2222.2222    DYNAMIC     Fa0/2
   1    0200.3333.3333    DYNAMIC     Fa0/3
   1    0200.4444.4444    DYNAMIC     Fa0/4
Total Mac Addresses for this criterion: 4
SW1#
```

First, focus on two columns of the table: the MAC Address and Ports columns of the table. The values should look familiar: they match the earlier single-switch example, as repeated here as Figure 5-9. Note the four MAC addresses listed, along with their matching ports, as shown in the figure.

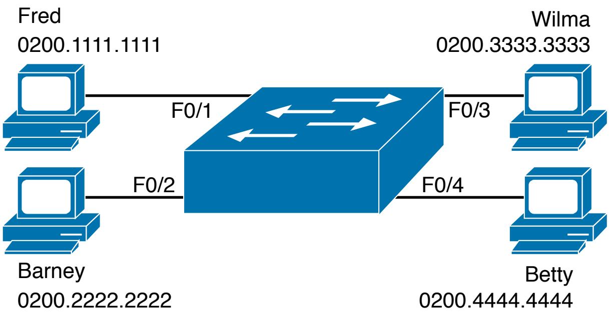


Figure 5-9 *Single Switch Topology Used in Verification Section*

Next, look at the Type field in the heading of the output table. The column tells us how the switch learned the MAC address as described earlier in this chapter; in this case, the switch learned all MAC addresses dynamically. You can also statically predefine MAC table entries using a couple of different features, including port security, and those would appear as Static in the Type column.

Finally, the VLAN column of the output gives us a chance to briefly discuss how VLANs impact switching logic. LAN switches forward Ethernet frames inside a VLAN. What that means is if a frame enters via a port in VLAN 1, then the switch will forward or flood that frame out other ports in VLAN 1 only, and not out any ports that happen to be assigned to another VLAN. Chapter 8, "Implementing Ethernet Virtual LANs," looks at all the details of how switches forward frames when using VLANs.

Switch Interfaces

The first example assumes that you installed the switch and cabling correctly, and that the switch interfaces work. Once you do the installation and connect to the Console, you can easily check the status of those interfaces with the **show interfaces status** command, as shown in Example 5-2.

Example 5-2 **show interfaces status** *on Switch SW1*

```
SW1# show interfaces status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/1                        connected    1          a-full  a-100 10/100BaseTX
Fa0/2                        connected    1          a-full  a-100 10/100BaseTX
Fa0/3                        connected    1          a-full  a-100 10/100BaseTX
Fa0/4                        connected    1          a-full  a-100 10/100BaseTX
Fa0/5                        notconnect   1            auto   auto 10/100BaseTX
Fa0/6                        notconnect   1            auto   auto 10/100BaseTX
Fa0/7                        notconnect   1            auto   auto 10/100BaseTX
Fa0/8                        notconnect   1            auto   auto 10/100BaseTX
Fa0/9                        notconnect   1            auto   auto 10/100BaseTX
Fa0/10                       notconnect   1            auto   auto 10/100BaseTX
Fa0/11                       notconnect   1            auto   auto 10/100BaseTX
```

```
Fa0/12                         notconnect   1            auto    auto 10/100BaseTX
Fa0/13                         notconnect   1            auto    auto 10/100BaseTX
Fa0/14                         notconnect   1            auto    auto 10/100BaseTX
Fa0/15                         notconnect   1            auto    auto 10/100BaseTX
Fa0/16                         notconnect   1            auto    auto 10/100BaseTX
Fa0/17                         notconnect   1            auto    auto 10/100BaseTX
Fa0/18                         notconnect   1            auto    auto 10/100BaseTX
Fa0/19                         notconnect   1            auto    auto 10/100BaseTX
Fa0/20                         notconnect   1            auto    auto 10/100BaseTX
Fa0/21                         notconnect   1            auto    auto 10/100BaseTX
Fa0/22                         notconnect   1            auto    auto 10/100BaseTX
Fa0/23                         notconnect   1            auto    auto 10/100BaseTX
Fa0/24                         notconnect   1            auto    auto 10/100BaseTX
Gi0/1                          notconnect   1            auto    auto 10/100/1000BaseTX
Gi0/2                          notconnect   1            auto    auto 10/100/1000BaseTX
SW1#
```


Focus on the port column for a moment. As a reminder, Cisco Catalyst switches name their ports based on the fastest specification supported, so in this case, the switch has 24 interfaces named FastEthernet, and two named GigabitEthernet. Many commands abbreviate those terms, this time as Fa for FastEthernet and Gi for GigabitEthernet. (The example happens to come from a Cisco Catalyst switch that has 24 10/100 ports and two 10/100/1000 ports.)

The Status column, of course, tells us the status or state of the port. In this case, the lab switch had cables and devices connected to ports F0/1–F0/4 only, with no other cables connected. As a result, those first four ports have a state of connected, meaning that the ports have a cable and are functional. The notconnect state means that the port is not yet functioning. It may mean that there is no cable installed, but other problems may exist as well. (The section "Analyzing Switch Interface Status and Statistics," in Chapter 7, "Configuring and Verifying Switch Interfaces," works through the details of what causes a switch interface to fail.)

NOTE You can see the status for a single interface in a couple of ways. For instance, for F0/1, the command **show interfaces f0/1 status** lists the status in a single line of output as in Example 5-2. The **show interfaces f0/1** command (without the **status** keyword) displays a detailed set of messages about the interface.

The **show interfaces** command has a large number of options. One particular option, the **counters** option, lists statistics about incoming and outgoing frames on the interfaces. In particular, it lists the number of unicast, multicast, and broadcast frames (both the in and out directions), and a total byte count for those frames. Example 5-3 shows an example, again for interface F0/1.

Example 5-3 **show interfaces f0/1 counters** *on Switch SW1*

```
SW1# show interfaces f0/1 counters

Port            InOctets    InUcastPkts    InMcastPkts    InBcastPkts
Fa0/1            1223303          10264            107             18

Port           OutOctets   OutUcastPkts   OutMcastPkts   OutBcastPkts
Fa0/1            3235055          13886          22940            437
```

Finding Entries in the MAC Address Table

With a single switch and only four hosts connected to it, you can just read the details of the MAC address table and find the information you want to see. However, in real networks, with lots of interconnected hosts and switches, just reading the output to find one MAC address can be hard to do. You might have hundreds of entries—page after page of output—with each MAC address looking like a random string of hex characters. (The book uses easy-to-recognize MAC addresses to make it easier to learn.)

Thankfully, Cisco IOS supplies several more options on the **show mac address-table** command to make it easier to find individual entries. First, if you know the MAC address, you can search for it—just type in the MAC address at the end of the command, as shown in Example 5-4. All you have to do is include the **address** keyword, followed by the actual MAC address. If the address exists, the output lists the address. Note that the output lists the exact same information in the exact same format, but it lists only the line for the matching MAC address.

Example 5-4 **show mac address-table dynamic** *with the* **address** *Keyword*

```
SW1# show mac address-table dynamic address 0200.1111.1111
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1    0200.1111.1111    DYNAMIC     Fa0/1
Total Mac Addresses for this criterion: 1
```

While this information is useful, often the engineer troubleshooting a problem does not know the MAC addresses of the devices connected to the network. Instead, the engineer has a topology diagram, knowing which switch ports connect to other switches and which connect to endpoint devices.

Sometimes you might be troubleshooting while looking at a network topology diagram and want to look at all the MAC addresses learned off a particular port. IOS supplies that option with the **show mac address-table dynamic interface** command. Example 5-5 shows one example, for switch SW1's F0/1 interface.

Example 5-5 **show mac address-table dynamic** *with the* **interface** *Keyword*

```
SW1# show mac address-table dynamic interface fastEthernet 0/1
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1    0200.1111.1111    DYNAMIC     Fa0/1
Total Mac Addresses for this criterion: 1
```

Finally, you may also want to find the MAC address table entries for one VLAN. You guessed it—you can add the **vlan** parameter, followed by the VLAN number. Example 5-6 shows two such examples from the same switch SW1 from Figure 5-7—one for VLAN 1, where all four devices reside, and one for a nonexistent VLAN 2.

Example 5-6 *The* **show mac address-table vlan** *Command*

```
SW1# show mac address-table dynamic vlan 1
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1    0200.1111.1111    DYNAMIC     Fa0/1
   1    0200.2222.2222    DYNAMIC     Fa0/2
   1    0200.3333.3333    DYNAMIC     Fa0/3
   1    0200.4444.4444    DYNAMIC     Fa0/4
Total Mac Addresses for this criterion: 4
SW1#
SW1# show mac address-table dynamic vlan 2
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
SW1#
```

Managing the MAC Address Table (Aging, Clearing)

This chapter closes with a few comments about how switches manage their MAC address tables. Switches do learn MAC addresses, but those MAC addresses do not remain in the table indefinitely. The switch will remove the entries due to age, due to the table filling, and you can remove entries using a command.

First, for aging out MAC table entries, switches remove entries that have not been used for a defined number of seconds (default of 300 seconds on many switches). To do that, switches look at every incoming frame and every source MAC address, and do something related to learning. If it is a new MAC address, the switch adds the correct entry to the table, of course. However, if that entry already exists, the switch still does something: it resets the inactivity timer back to 0 for that entry. Each entry's timer counts upward over time to measure how long the entry has been in the table. The switch times out (removes) any entries whose timer reaches the defined aging time.

Example 5-7 shows the aging timer setting for the entire switch. The aging time can be configured to a different time, globally and per-VLAN using the **mac address-table aging-time** *time-in-seconds* [**vlan** *vlan-number*] global configuration command. The example shows a case with all defaults, with the global setting of 300 seconds, and no per-VLAN overrides.

Example 5-7 *The MAC Address Default Aging Timer Displayed*

```
SW1# show mac address-table aging-time
Global Aging Time:  300
Vlan    Aging Time
----    ----------
SW1#

SW1# show mac address-table count

Mac Entries for Vlan 1:
---------------------------
Dynamic Address Count  : 4
Static  Address Count  : 0
Total Mac Addresses    : 4

Total Mac Address Space Available: 7299
```

Each switch also removes the oldest table entries, even if they are younger than the aging time setting, if the table fills. The MAC address table uses content-addressable memory (CAM), a physical memory that has great table lookup capabilities. However, the size of the table depends on the size of the CAM in a particular model of switch and based on some configurable settings in the switch. When a switch tries to add a new MAC table entry and finds the table full, the switch times out (removes) the oldest table entry to make space. For perspective, the end of Example 5-7 lists the size of a Cisco Catalyst switch's MAC table at about 8000 entries—the same four existing entries from the earlier examples, with space for 7299 more.

Finally, you can remove the dynamic entries from the MAC address table with the **clear mac address-table dynamic** command. Note that the **show** commands in this chapter can be executed from user and enable mode, but the **clear** command happens to be an enable mode command. The command also allows parameters to limit the types of entries cleared, as follows:

- By VLAN: **clear mac address-table dynamic vlan** *vlan-number*
- By Interface: **clear mac address-table dynamic interface** *interface-id*
- By MAC address: **clear mac address-table dynamic address** *mac-address*

MAC Address Tables with Multiple Switches

Finally, to complete the discussion, it helps to think about an example with multiple switches, just to emphasize how MAC learning, forwarding, and flooding happen independently on each LAN switch.

Consider the topology in Figure 5-10, and pay close attention to the port numbers. The ports were purposefully chosen so that neither switch used any of the same ports for this example. That is, switch SW2 does have a port F0/1 and F0/2, but I did not plug any devices into those ports when making this example. Also note that all ports are in VLAN 1, and as with the other examples in this chapter, all default configuration is used other than the hostname on the switches.

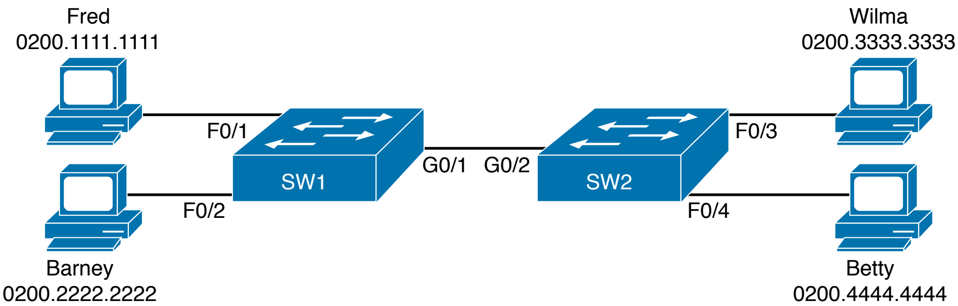


Figure 5-10 *Two-Switch Topology Example*

Think about a case in which both switches learn all four MAC addresses. For instance, that would happen if the hosts on the left communicate with the hosts on the right. SW1's MAC address table would list SW1's own port numbers (F0/1, F0/2, and G0/1) because SW1 uses that information to decide where SW1 should forward frames. Similarly, SW2's MAC table lists SW2's port numbers (F0/3, F0/4, G0/2 in this example). Example 5-8 shows the MAC address tables on both switches for that scenario.

Example 5-8 *The MAC Address Table on Two Switches*

```
SW1# show mac address-table dynamic
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1    0200.1111.1111    DYNAMIC     Fa0/1
   1    0200.2222.2222    DYNAMIC     Fa0/2
   1    0200.3333.3333    DYNAMIC     Gi0/1
   1    0200.4444.4444    DYNAMIC     Gi0/1
Total Mac Addresses for this criterion: 4
```

```
! The next output is from switch SW2
SW2# show mac address-table dynamic
   1    0200.1111.1111    DYNAMIC     Gi0/2
```

```
   1     0200.2222.2222    DYNAMIC     Gi0/2
   1     0200.3333.3333    DYNAMIC     Fa0/3
   1     0200.4444.4444    DYNAMIC     Fa0/4
Total Mac Addresses for this criterion: 4
```

Chapter Review

Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Table 5-2 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 5-2 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Repeat DIKTA questions		Book, PTP
Do labs		Book, Sim Lite, blog
Review command tables		Book

Review All the Key Topics

Key Topic

Table 5-3 Key Topics for Chapter 5

Key Topic Element	Description	Page Number
List	Three main functions of a LAN switch	109
Figure 5-3	Process to forward a known unicast frame	111
Figure 5-5	Process to forward a known unicast, second switch	112
Figure 5-6	Process to learn MAC addresses	113
List	Summary of switch forwarding logic	117
Example 5-1	The **show mac address-table dynamic** command	117

Do Labs

The Sim Lite software is a version of Pearson's full simulator learning product with a subset of the labs, included free with this book. The subset of labs mostly relate to this part of the book, so take the time to try some of the labs.

As always, also check the author's blog site pages for configuration exercises (Config Labs) at http://blog.certskills.com.

Key Terms You Should Know

broadcast frame, known unicast frame, Spanning Tree Protocol (STP), unknown unicast frame, MAC address table, forward, flood

Command References

Table 5-4 lists the verification commands used in this chapter. As an easy review exercise, cover the left column, read the right, and try to recall the command without looking. Then repeat the exercise, covering the right column, and try to recall what the command does.

Table 5-4 Chapter 5 EXEC Command Reference

Command	Mode/Purpose/Description
show mac address-table	Shows all MAC table entries of all types
show mac address-table dynamic	Shows all dynamically learned MAC table entries
show mac address-table dynamic vlan *vlan-id*	Shows all dynamically learned MAC table entries in that VLAN
show mac address-table dynamic address *mac-address*	Shows the dynamically learned MAC table entries with that MAC address
show mac address-table dynamic interface *interface-id*	Shows all dynamically learned MAC table entries associated with that interface
show mac address-table count	Shows the number of entries in the MAC table and the total number of remaining empty slots in the MAC table
show mac address-table aging-time	Shows the global and per-VLAN aging timeout for inactive MAC table entries
clear mac address-table dynamic	Empties the MAC table of all dynamic entries
show interfaces status	Lists one line per interface on the switch, with basic status and operating information for each
clear mac address-table dynamic [**vlan** *vlan-number*] [**interface** *interface-id*] [**address** *mac-address*]	Clears (removes) dynamic MAC table entries: either all (with no parameters), or a subset based on VLAN ID, interface ID, or a specific MAC address

Note that this chapter also includes reference to one configuration command, so it does not call for the use of a separate table. For review, the command is

mac address-table aging-time *time-in-seconds* [**vlan** *vlan-number*]

5

CHAPTER 6

Configuring Basic Switch Management

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.6 Configure and verify IPv4 addressing and subnetting

4.0 IP Services

4.6 Configure and verify DHCP client and relay

4.8 Configure network devices for remote access using SSH

5.0 Security Fundamentals

5.3 Configure device access control using local passwords

The work performed by a networking device can be divided into three broad categories. The first and most obvious, called the data plane, is the work a switch does to forward frames generated by the devices connected to the switch. In other words, the data plane is the main purpose of the switch. Second, the control plane refers to the configuration and processes that control and change the choices made by the switch's data plane. The network engineer can control which interfaces are enabled and disabled, which ports run at which speeds, how Spanning Tree blocks some ports to prevent loops, and so on.

The third category, the management plane, is the topic of this chapter. The management plane deals with managing the device itself, rather than controlling what the device is doing. In particular, this chapter looks at the most basic management features that can be configured in a Cisco switch. The first section of the chapter works through the configuration of different kinds of login security. The second section shows how to configure IPv4 settings on a switch so it can be remotely managed. The last (short) section then explains a few practical matters that can make your life in the lab a little easier.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 6-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Securing the Switch CLI	1–3
Enabling IP for Remote Access	4–5
Miscellaneous Settings Useful in Lab	6

1. Imagine that you have configured the **enable secret** command, followed by the **enable password** command, from the console. You log out of the switch and log back in at the console. Which command defines the password that you had to enter to access privileged mode?
   a. **enable password**
   b. **enable secret**
   c. Neither
   d. The **password** command, if it is configured
2. An engineer wants to set up simple password protection with no usernames for some switches in a lab, for the purpose of keeping curious coworkers from logging in to the lab switches from their desktop PCs. Which of the following commands would be a useful part of that configuration?
   a. A **login** vty mode subcommand
   b. A **password** *password* console subcommand
   c. A **login local** vty subcommand
   d. A **transport input ssh** vty subcommand
3. An engineer had formerly configured a Cisco 2960 switch to allow Telnet access so that the switch expected a password of **mypassword** from the Telnet user. The engineer then changed the configuration to support Secure Shell. Which of the following commands could have been part of the new configuration? (Choose two answers.)
   a. A **username** *name* **secret** *password* vty mode subcommand
   b. A **username** *name* **secret** *password* global configuration command
   c. A **login local** vty mode subcommand
   d. A **transport input ssh** global configuration command

4. An engineer's desktop PC connects to a switch at the main site. A router at the main site connects to each branch office through a serial link, with one small router and switch at each branch. Which of the following commands must be configured on the branch office switches, in the listed configuration mode, to allow the engineer to telnet to the branch office switches and supply only a password to login? (Choose three answers.)

- **a.** The **ip address** command in interface configuration mode
- **b.** The **ip address** command in global configuration mode
- **c.** The **ip default-gateway** command in VLAN configuration mode
- **d.** The **ip default-gateway** command in global configuration mode
- **e.** The **password** command in console line configuration mode
- **f.** The **password** command in vty line configuration mode

5. A Layer 2 switch configuration places all its physical ports into VLAN 2. The IP addressing plan shows that address 172.16.2.250 (with mask 255.255.255.0) is reserved for use by this new LAN switch and that 172.16.2.254 is already configured on the router connected to that same VLAN. The switch needs to support SSH connections into the switch from any subnet in the network. Which of the following commands are part of the required configuration in this case? (Choose two answers.)

- **a.** The **ip address 172.16.2.250 255.255.255.0** command in interface vlan 1 configuration mode.
- **b.** The **ip address 172.16.2.250 255.255.255.0** command in interface vlan 2 configuration mode.
- **c.** The **ip default-gateway 172.16.2.254** command in global configuration mode.
- **d.** The switch cannot support SSH because all its ports connect to VLAN 2, and the IP address must be configured on interface VLAN 1.

6. Which of the following line subcommands tells a switch to wait until a show command's output has completed before displaying log messages on the screen?

- **a.** **logging synchronous**
- **b.** **no ip domain-lookup**
- **c.** **exec-timeout 0 0**
- **d.** **history size 15**

Foundation Topics

Securing the Switch CLI

By default, a Cisco Catalyst switch allows anyone to connect to the console port, access user mode, and then move on to enable and configuration modes without any kind of security. That default makes sense, given that if you can get to the console port of the switch, you already have control over the switch physically. However, everyone needs to operate switches remotely, and the first step in that process is to secure the switch so that only the appropriate users can access the switch command-line interface (CLI).

This first topic in the chapter examines how to configure login security for a Cisco Catalyst switch. Securing the CLI includes protecting access to enable mode, because from enable mode, an attacker could reload the switch or change the configuration. Protecting user mode is also important, because attackers can see the status of the switch, learn about the network, and find new ways to attack the network.

Note that all remote access and management protocols require that the switch IP configuration be completed and working. A switch's IPv4 configuration has nothing to do with how a Layer 2 switch forwards Ethernet frames (as discussed in Chapter 5, "Analyzing Ethernet LAN Switching"). Instead, to support Telnet and Secure Shell (SSH) into a switch, the switch needs to be configured with an IP address. This chapter also shows how to configure a switch's IPv4 settings in the upcoming section "Enabling IPv4 for Remote Access."

In particular, this section covers the following login security topics:

- Securing user mode and privileged mode with simple passwords
- Securing user mode access with local usernames
- Securing user mode access with external authentication servers
- Securing remote access with Secure Shell (SSH)

Securing User Mode and Privileged Mode with Simple Passwords

By default, Cisco Catalyst switches allow full access from the console but no access via Telnet or SSH. Using default settings, a console user can move into user mode and then privileged mode with no passwords required; however, default settings prevent remote users from accessing even user mode.

The defaults work great for a brand new switch, but in production, you will want to secure access through the console as well as enable remote login via Telnet and/or SSH so you can sit at your desk and log in to all the switches in the LAN. Keep in mind, however, that you should not open the switch for just anyone to log in and change the configuration, so some type of secure login should be used.

Most people use a simple shared password for access to lab gear. This method uses a password only—with no username—with one password for console users and a different password for Telnet users. Console users must supply the *console password*, as configured in console line configuration mode. Telnet users must supply the *Telnet password*, also called the vty password, so called because the configuration sits in vty line configuration mode. Figure 6-1 summarizes these options for using shared passwords from the perspective of the user logging in to the switch.

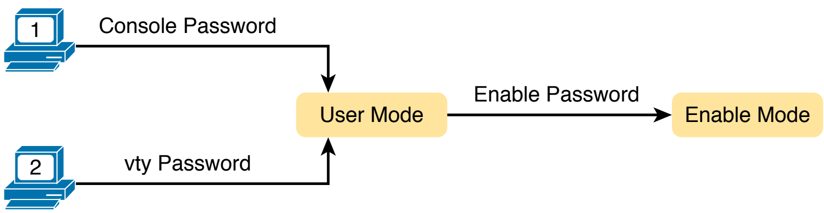


Figure 6-1 *Simple Password Security Concepts*

NOTE This section refers to several passwords as *shared* passwords. Users share these passwords in that all users must know and use that same password. In other words, each user does not have a unique username/password to use, but rather, all the appropriate staff knows and uses the same password.

In addition, Cisco switches protect enable mode (also called privileged mode) with yet another shared password called the *enable password*. From the perspective of the network engineer connecting to the CLI of the switch, once in user mode, the user types the **enable** EXEC command. This command prompts the user for this enable password; if the user types the correct password, IOS moves the user to enable mode.

Example 6-1 shows an example of the user experience of logging in to a switch from the console when the shared console password and the shared enable password have both been set. Note that before this example began, the user started the terminal emulator, physically connected a laptop to the console cable, and then pressed the Return key to make the switch respond as shown at the top of the example.

Example 6-1 *Console Login and Movement to Enable Mode*

```
(User now presses enter now to start the process. This line of text does not appear.)

User Access Verification

Password: faith
Switch> enable
Password: love
Switch#
```

Note that the example shows the password text as if typed (faith and love), along with the **enable** command that moves the user from user mode to enable mode. In reality, the switch hides the passwords when typed, to prevent someone from reading over your shoulder to see the passwords.

To configure the shared passwords for the console, Telnet, and for enable mode, you need to configure several commands. However, the parameters of the commands can be pretty intuitive. Figure 6-2 shows the configuration of all three of these passwords.

The configuration for these three passwords does not require a lot of work. First, the console and vty password configuration sets the password based on the context: console mode for the console (**line con 0**), and vty line configuration mode for the Telnet password (**line vty 0 15**). Then inside console mode and vty mode, respectively, the two commands in each mode are as follows:

password *password-value*: Defines the actual password used on the console or vty

login: Tells IOS to enable the use of a simple shared password (with no username) on this line (console or vty), so that the switch asks the user for a password

Answers to the "Do I Know This Already?" quiz:

1 B **2** A **3** B, C **4** A, D, F **5** B, C **6** A

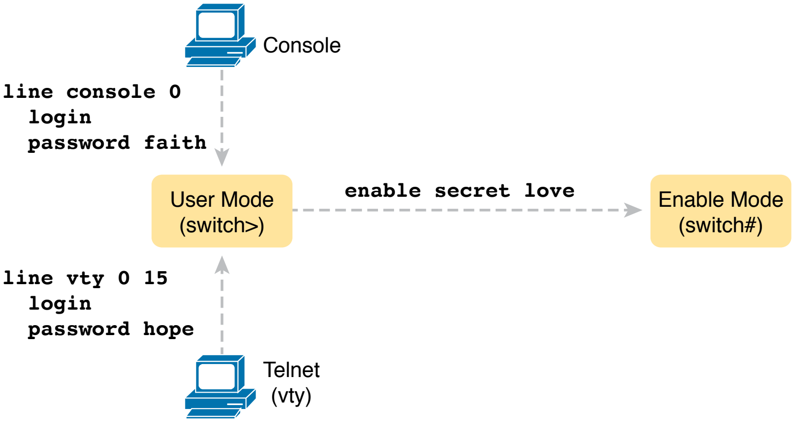


Figure 6-2 *Simple Password Security Configuration*

The configured enable password, shown on the right side of the figure, applies to all users, no matter whether they connect to user mode via the console, Telnet, or otherwise. The command to configure the enable password is a global configuration command: **enable secret** *password-value*.

NOTE Older IOS versions used the command **enable password** *password-value* to set the enable password, and that command still exists in IOS. However, the **enable secret** command is much more secure. In real networks, use **enable secret**. Chapter 5, "Securing Network Devices," in the *CCNA 200-301 Official Cert Guide, Volume 2*, explains more about the security levels of various password mechanisms, including a comparison of the **enable secret** and **enable password** commands.

To help you follow the process, and for easier study later, use the configuration checklist before the example. The configuration checklist collects the required and optional steps to configure a feature as described in this book. The configuration checklist for shared passwords for the console, Telnet, and enable passwords is

Config Checklist

Step 1. Configure the enable password with the **enable secret** *password-value* command.

Step 2. Configure the console password:

A. Use the **line con 0** command to enter console configuration mode.

B. Use the **password** *password-value* subcommand to set the value of the console password.

C. Use the **login** subcommand to enable console password security using a simple password.

Step 3. Configure the Telnet (vty) password:

A. Use the **line vty 0 15** command to enter vty configuration mode for all 16 vty lines (numbered 0 through 15).

B. Use the **password** *password-value* subcommand to set the value of the console password.

C. Use the **login** subcommand to enable console password security using a simple password.

Example 6-2 shows the configuration process as noted in the configuration checklist, along with setting the enable secret password. Note that the lines which begin with a **!** are comment lines; they are there to guide you through the configuration.

Key Topic

Example 6-2 *Configuring Basic Passwords*

```
! Enter global configuration mode, set the enable password, and also
! set the hostname (just because it makes sense to do so)
!
Switch# configure terminal
Switch(config)# enable secret love
!
! At Step 2 in the checklist, enter console configuration mode, set the
! password value to "faith" and enable simple passwords for the console.
! The exit command moves the user back to global config mode.
!
Switch#(config)# line console 0
Switch#(config-line)# password faith
Switch#(config-line)# login
Switch#(config-line)# exit
!
! The next few lines do basically the same configuration, except it is
! for the vty lines. Telnet users will use "hope" to login.
!
Switch#(config)# line vty 0 15
Switch#(config-line)# password hope
Switch#(config-line)# login
Switch#(config-line)# end
Switch#
```

Example 6-3 shows the resulting configuration in the switch per the **show running-config** command. The gray lines highlight the new configuration. Note that many unrelated lines of output have been deleted from the output to keep focused on the password configuration.

Example 6-3 *Resulting Running-Config File (Subset) Per Example 6-2 Configuration*

```
Switch# show running-config
!
Building configuration...
```

```
Current configuration: 1333 bytes
!
version 12.2
!
enable secret 5 $1$OwtI$A58c2XgqWyDNeDnv51mNR.
!
interface FastEthernet0/1
!
interface FastEthernet0/2
!
! Several lines have been omitted here - in particular, lines for
! FastEthernet interfaces 0/3 through 0/23.
!
interface FastEthernet0/24
!
interface GigabitEthernet0/1
!
interface GigabitEthernet0/2
!
line con 0
 password faith
 login
!
line vty 0 4
 password hope
 login
!
line vty 5 15
 password hope
 login
```


NOTE For historical reasons, the output of the **show running-config** command, in the last six lines of Example 6-3, separates the first five vty lines (0 through 4) from the rest (5 through 15).

Securing User Mode Access with Local Usernames and Passwords

Cisco switches support two other login security methods that both use per-user username/password pairs instead of a shared password with no username. One method, referred to as local usernames and passwords, configures the username/password pairs locally—that is, in the switch's configuration. Switches support this local username/password option for the console, for Telnet, and even for SSH, but do not replace the enable password used to reach enable mode.

The configuration to migrate from using the simple shared passwords to instead using local usernames/passwords requires only some small configuration changes, as shown in Figure 6-3.

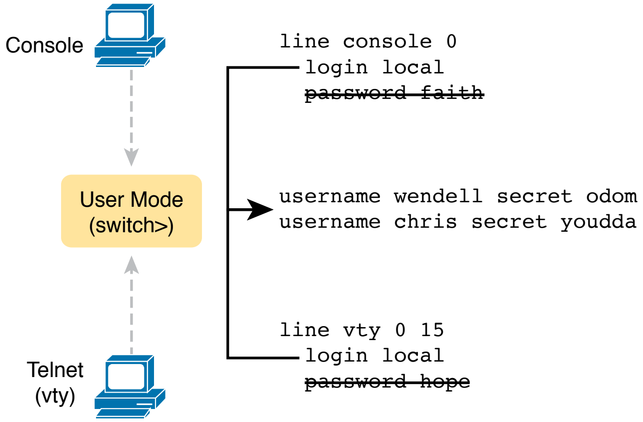


Figure 6-3 *Configuring Switches to Use Local Username Login Authentication*

Working through the configuration in the figure, first, the switch of course needs to know the list of username/password pairs. To create these, repeatedly use the **username** *name* **secret** *password* global configuration command. Then, to enable this different type of console or Telnet security, simply enable this login security method with the **login local** line. Basically, this command means "use the local list of usernames for login." You can also use the **no password** command (without even typing in the password) to clean up any remaining password subcommands from console or vty mode because these commands are not needed when using local usernames and passwords.

The following checklist details the commands to configure local username login, mainly as a method for easier study and review:

Config Checklist

Step 1. Use the **username** *name* **secret** *password* global configuration command to add one or more username/password pairs on the local switch.

Step 2. Configure the console to use locally configured username/password pairs:

- **A.** Use the **line con 0** command to enter console configuration mode.
- **B.** Use the **login local** subcommand to enable the console to prompt for both username and password, checked versus the list of local usernames/passwords.
- **C.** (Optional) Use the **no password** subcommand to remove any existing simple shared passwords, just for good housekeeping of the configuration file.

Step 3. Configure Telnet (vty) to use locally configured username/password pairs.

- **A.** Use the **line vty 0 15** command to enter vty configuration mode for all 16 vty lines (numbered 0 through 15).
- **B.** Use the **login local** subcommand to enable the switch to prompt for both username and password for all inbound Telnet users, checked versus the list of local usernames/passwords.
- **C.** (Optional) Use the **no password** subcommand to remove any existing simple shared passwords, just for good housekeeping of the configuration file.

When a Telnet user connects to the switch configured as shown in Figure 6-3, the user will be prompted first for a username and then for a password, as shown in Example 6-4. The username/password pair must be from the list of local usernames; otherwise, the login is rejected.

Example 6-4 *Telnet Login Process After Applying Configuration in Figure 6-3*

```
SW2# telnet 10.9.9.19
Trying 10.9.9.19 ... Open


User Access Verification

Username: wendell
Password:
SW1> enable
Password:
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)#^Z
SW1#
*Mar 1 02:00:56.229: %SYS-5-CONFIG_I: Configured from console by wendell on vty0
(10.9.9.19)
```

6

NOTE Example 6-4 does not show the password value as having been typed because Cisco switches do not display the typed password for security reasons.

Securing User Mode Access with External Authentication Servers

The end of Example 6-4 points out one of the many security improvements when requiring each user to log in with their own username. The end of the example shows the user entering configuration mode (**configure terminal**) and then immediately leaving (**end**). Note that when a user exits configuration mode, the switch generates a log message. If the user logged in with a username, the log message identifies that username; note the "wendell" in the log message.

However, using a username/password configured directly on the switch causes some administrative headaches. For instance, every switch and router needs the configuration for all users who might need to log in to the devices. Then, when any changes need to happen, like an occasional change to the passwords for good security practices, the configuration of all devices must be changed.

A better option would be to use tools like those used for many other IT login functions. Those tools allow for a central place to securely store all username/password pairs, with tools to make users change their passwords regularly, tools to revoke users when they leave their current jobs, and so on.

Cisco switches allow exactly that option using an external server called an authentication, authorization, and accounting (AAA) server. These servers hold the usernames/passwords. Typically, these servers allow users to do self-service and forced maintenance to their passwords. Many production networks use AAA servers for their switches and routers today.

The underlying login process requires some additional work on the part of the switch for each user login, but once set up, the username/password administration is much less. When using a AAA server for authentication, the switch (or router) simply sends a message to the AAA server asking whether the username and password are allowed, and the AAA server replies. Figure 6-4 shows an example, with the user first supplying a username/password, the switch asking the AAA server, and the server replying to the switch stating that the username/password is valid.

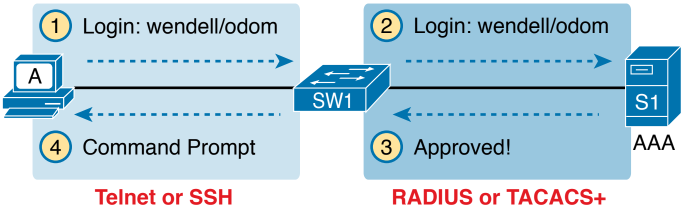


Figure 6-4 *Basic Authentication Process with an External AAA Server*

While the figure shows the general idea, note that the information flows with a couple of different protocols. On the left, the connection between the user and the switch or router uses Telnet or SSH. On the right, the switch and AAA server typically use either the RADIUS or TACACS+ protocol, both of which encrypt the passwords as they traverse the network.

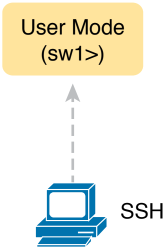
Securing Remote Access with Secure Shell

So far, this chapter has focused on the console and on Telnet, mostly ignoring SSH. Telnet has one serious disadvantage: all data in the Telnet session flows as clear text, including the password exchanges. So, anyone that can capture the messages between the user and the switch (in what is called a man-in-the-middle attack) can see the passwords. SSH encrypts all data transmitted between the SSH client and server, protecting the data and passwords.

SSH can use the same local login authentication method as Telnet, with the locally configured username and password. (SSH cannot rely on authentication methods that do not include a username, like shared passwords.) So, the configuration to support local usernames for Telnet, as shown previously in Figure 6-3, also enables local username authentication for incoming SSH connections.

Figure 6-5 shows one example configuration of what is required to support SSH. The figure repeats the local username configuration as shown earlier in Figure 6-3, as used for Telnet. Figure 6-5 shows three additional commands required to complete the configuration of SSH on the switch.

Key Topic



SSH-Specific Configuration

```
hostname sw1
ip domain-name example.com
! Next Command Uses FQDN "sw1.example.com"
crypto key generate rsa
```

Local Username Configuration (Like Telnet)

```
username wendell secret odom
username chris secret youdda
!
line vty 0 15
  login local
```

Figure 6-5 *Adding SSH Configuration to Local Username Configuration*

IOS uses the three SSH-specific configuration commands in the figure to create the SSH encryption keys. The SSH server uses the fully qualified domain name (FQDN) of the switch as input to create that key. The switch creates the FQDN from the hostname and domain name of the switch. Figure 6-5 begins by setting both values (just in case they are not already configured). Then the third command, the **crypto key generate rsa** command, generates the SSH encryption keys.

The configuration in Figure 6-5 relies on two default settings that the figure therefore conveniently ignored. IOS runs an SSH server by default. In addition, IOS allows SSH connections into the vty lines by default.

Seeing the configuration happen in configuration mode, step by step, can be particularly helpful with SSH configuration. Note in particular that in this example, the **crypto key** command prompts the user for the key modulus; you could also add the parameters **modulus** *modulus-value* to the end of the **crypto key** command to add this setting on the command. Example 6-5 shows the commands in Figure 6-5 being configured, with the encryption key as the final step.

Example 6-5 *SSH Configuration Process to Match Figure 6-5*

```
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
!
! Step 1 next. The hostname is already set, but it is repeated just
! to be obvious about the steps.
!
SW1(config)# hostname SW1
SW1(config)# ip domain-name example.com
SW1(config)# crypto key generate rsa
The name for the keys will be: SW1.example.com
Choose the size of the key modulus in the range of 360 to 2048 for your
  General Purpose Keys. Choosing a key modulus greater than 512 may take
  a few minutes.
```

```
How many bits in the modulus [512]: 1024
% Generating 1024 bit RSA keys, keys will be non-exportable...
[OK] (elapsed time was 4 seconds)
SW1(config)#
!
! Optionally, set the SSH version to version 2 (only) - preferred
!
SW1(config)# ip ssh version 2
!
! Next, configure the vty lines for local username support, just like
! with Telnet
!
SW1(config)# line vty 0 15
SW1(config-line)# login local
SW1(config-line)# exit
!
! Define the local usernames, just like with Telnet
!
SW1(config)# username wendell password odom
SW1(config)# username chris password youdaman
SW1(config)# ^Z
SW1#
```

Earlier, I mentioned that one useful default was that the switch defaults to support both SSH and Telnet on the vty lines. However, because Telnet is a security risk, you could disable Telnet to enforce a tighter security policy. (For that matter, you can disable SSH support and allow Telnet on the vty lines as well.)

To control which protocols a switch supports on its vty lines, use the **transport input** {**all** | **none** | **telnet** | **ssh**} vty subcommand in vty mode, with the following options:

transport input all or **transport input telnet ssh:** Support both Telnet and SSH

transport input none: Support neither

transport input telnet: Support only Telnet

transport input ssh: Support only SSH

To complete this section about SSH, the following configuration checklist details the steps for one method to configure a Cisco switch to support SSH using local usernames. (SSH support in IOS can be configured in several ways; this checklist shows one simple way to configure it.) The process shown here ends with a comment to configure local username support on vty lines, as was discussed earlier in the section titled "Securing User Mode Access with Local Usernames and Passwords."

Config Checklist

Step 1. Configure the switch to generate a matched public and private key pair to use for encryption:

A. If not already configured, use the **hostname** *name* in global configuration mode to configure a hostname for this switch.

B. If not already configured, use the **ip domain-name** *name* in global configuration mode to configure a domain name for the switch, completing the switch's FQDN.

C. Use the **crypto key generate rsa** command in global configuration mode (or the **crypto key generate rsa modulus** *modulus-value* command to avoid being prompted for the key modulus) to generate the keys. (Use at least a 768-bit key to support SSH version 2.)

Step 2. (Optional) Use the **ip ssh version 2** command in global configuration mode to override the default of supporting both versions 1 and 2, so that only SSHv2 connections are allowed.

Step 3. (Optional) If not already configured with the setting you want, configure the vty lines to accept SSH and whether to also allow Telnet:

A. Use the **transport input ssh** command in vty line configuration mode to allow SSH only.

B. Use the **transport input all** command (default) or **transport input telnet ssh** command in vty line configuration mode to allow both SSH and Telnet.

Step 4. Use various commands in vty line configuration mode to configure local username login authentication as discussed earlier in this chapter.

NOTE Cisco routers often default to **transport input none**, so you must add the **transport input** line subcommand to enable Telnet and/or SSH into a router.

Two key commands give some information about the status of SSH on the switch. First, the **show ip ssh** command lists status information about the SSH server itself. The **show ssh** command then lists information about each SSH client currently connected into the switch. Example 6-6 shows samples of each, with user wendell currently connected to the switch.

Example 6-6 *Displaying SSH Status*

```
SW1# show ip ssh
SSH Enabled - version 2.0
Authentication timeout: 120 secs; Authentication retries: 3

SW1# show ssh
Connection Version Mode  Encryption    Hmac             State            Username
0          2.0     IN    aes126-cbc    hmac-sha1        Session started  wendell
0          2.0     OUT   aes126-cbc    hmac-sha1        Session started  wendell
%No SSHv1 server connections running.
```

Enabling IPv4 for Remote Access

To allow Telnet or SSH access to the switch, and to allow other IP-based management protocols (for example, Simple Network Management Protocol, or SNMP) to function as intended, the switch needs an IP address, as well as a few other related settings. The IP address has nothing to do with how switches forward Ethernet frames; it simply exists to support overhead management traffic.

This next topic begins by explaining the IPv4 settings needed on a switch, followed by the configuration. Note that although switches can be configured with IPv6 addresses with commands similar to those shown in this chapter, this chapter focuses solely on IPv4. All references to IP in this chapter imply IPv4.

Host and Switch IP Settings

A switch needs the same kind of IP settings as a PC with a single Ethernet interface. For perspective, a PC has a CPU, with the operating system running on the CPU. It has an Ethernet network interface card (NIC). The OS configuration includes an IP address associated with the NIC, either configured or learned dynamically with DHCP.

A switch uses the same ideas, except that the switch needs to use a virtual NIC inside the switch. Like a PC, a switch has a real CPU, running an OS (called IOS). The switch obviously has lots of Ethernet ports, but instead of assigning its management IP address to any of those ports, the switch then uses a NIC-like concept called a switched virtual interface (SVI), or more commonly, a VLAN interface, that acts like the switch's own NIC. Then the settings on the switch look something like a host, with the switch configuration assigning IP settings, like an IP address, to this VLAN interface, as shown in Figure 6-6.

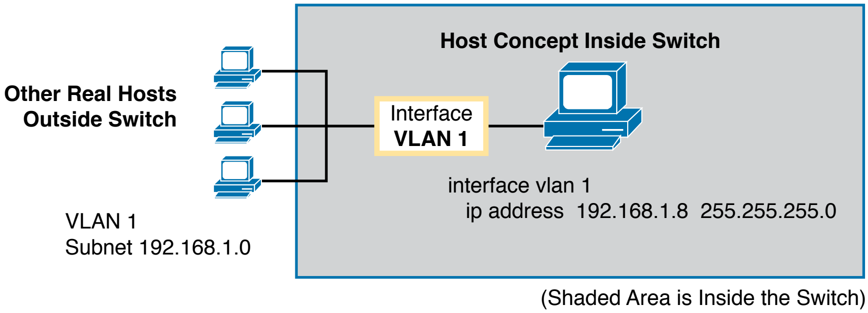


Figure 6-6 *Switch Virtual Interface (SVI) Concept Inside a Switch*

By using interface VLAN 1 for the IP configuration, the switch can then send and receive frames on any of the ports in VLAN 1. In a Cisco switch, by default, all ports are assigned to VLAN 1.

In most networks, switches configure many VLANs, so the network engineer has a choice of where to configure the IP address. That is, the management IP address does not have to be configured on the VLAN 1 interface (as configured with the **interface vlan 1** command seen in Figure 6-6).

A Layer 2 Cisco LAN switch needs only one IP address for management purposes. However, you can choose to use any VLAN to which the switch connects. The configuration then includes a VLAN interface for that VLAN number, with an appropriate IP address.

For example, Figure 6-7 shows a Layer 2 switch with some physical ports in two different VLANs (VLANs 1 and 2). The figure also shows the subnets used on those VLANs. The network engineer could choose to use either

- Interface VLAN 1, with an IP address in subnet 192.168.1.0
- Interface VLAN 2, with an IP address in subnet 192.168.2.0

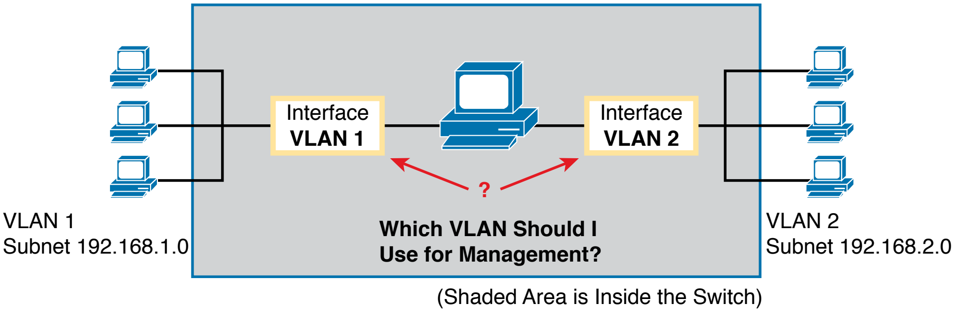


Figure 6-7 *Choosing One VLAN on Which to Configure a Switch IP Address*

Note that you should not try to use a VLAN interface for which there are no physical ports assigned to the same VLAN. If you do, the VLAN interface will not reach an up/up state, and the switch will not have the physical ability to communicate outside the switch.

NOTE Some Cisco switches can be configured to act as either a Layer 2 switch or a Layer 3 switch. When acting as a Layer 2 switch, a switch forwards Ethernet frames as discussed in depth in Chapter 5, "Analyzing Ethernet LAN Switching." Alternatively, a switch can also act as a *multilayer switch* or *Layer 3 switch*, which means the switch can do both Layer 2 switching and Layer 3 IP routing of IP packets, using the Layer 3 logic normally used by routers. This chapter assumes all switches are Layer 2 switches. Chapter 17, "IP Routing in the LAN," discusses Layer 3 switching in depth along with using multiple VLAN interfaces at the same time.

Configuring the IP address (and mask) on one VLAN interface allows the switch to send and receive IP packets with other hosts in a subnet that exists on that VLAN; however, the switch cannot communicate outside the local subnet without another configuration setting called the default gateway. The reason a switch needs a default gateway setting is the same reason that hosts need the same setting—because of how hosts think when sending IP packets. Specifically:

- To send IP packets to hosts in the same subnet, send them directly
- To send IP packets to hosts in a different subnet, send them to the local router; that is, the default gateway

Figure 6-8 shows the ideas. In this case, the switch (on the right) will use IP address 192.168.1.200 as configured on interface VLAN 1. However, to communicate with host A, on the far left of the figure, the switch must use Router R1 (the default gateway) to forward

IP packets to host A. To make that work, the switch needs to configure a default gateway setting, pointing to Router R1's IP address (192.168.1.1 in this case). Note that the switch and router both use the same mask, 255.255.255.0, which puts the addresses in the same subnet.

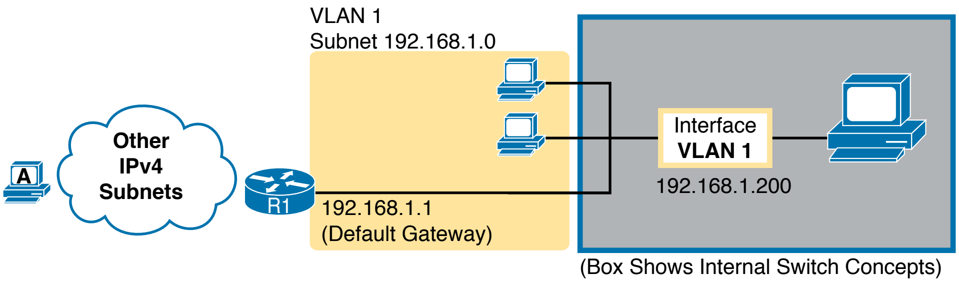


Figure 6-8 *The Need for a Default Gateway*

Configuring IPv4 on a Switch

A switch configures its IPv4 address and mask on this special NIC-like *VLAN interface*. The following steps list the commands used to configure IPv4 on a switch, assuming that the IP address is configured to be in VLAN 1, with Example 6-7 that follows showing an example configuration.

Config Checklist

Step 1. Use the **interface vlan 1** command in global configuration mode to enter interface VLAN 1 configuration mode.

Step 2. Use the **ip address** *ip-address mask* command in interface configuration mode to assign an IP address and mask.

Step 3. Use the **no shutdown** command in interface configuration mode to enable the VLAN 1 interface if it is not already enabled.

Step 4. Add the **ip default-gateway** *ip-address* command in global configuration mode to configure the default gateway.

Step 5. (Optional) Add the **ip name-server** *ip-address1 ip-address2 …* command in global configuration mode to configure the switch to use Domain Name System (DNS) to resolve names into their matching IP address.

Example 6-7 *Switch Static IP Address Configuration*

```
Emma# configure terminal
Emma(config)# interface vlan 1
Emma(config-if)# ip address 192.168.1.200 255.255.255.0
Emma(config-if)# no shutdown
00:25:07: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:25:08: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed
 state to up
Emma(config-if)# exit
Emma(config)# ip default-gateway 192.168.1.1
```

On a side note, this example shows a particularly important and common command: the [**no**] **shutdown** command. To administratively enable an interface on a switch, use the **no shutdown** interface subcommand; to disable an interface, use the **shutdown** interface subcommand. This command can be used on the physical Ethernet interfaces that the switch uses to switch Ethernet messages in addition to the VLAN interface shown here in this example.

Also, pause long enough to look at the messages that appear just below the **no shutdown** command in Example 6-7. Those messages are syslog messages generated by the switch stating that the switch did indeed enable the interface. Switches (and routers) generate syslog messages in response to a variety of events, and by default, those messages appear at the console. Chapter 9, "Device Management Protocols," in the *CCNA 200-301 Official Cert Guide, Volume 2*, discusses syslog messages in more detail.

Configuring a Switch to Learn Its IP Address with DHCP

The switch can also use Dynamic Host Configuration Protocol (DHCP) to dynamically learn its IPv4 settings. Basically, all you have to do is tell the switch to use DHCP on the interface and enable the interface. Assuming that DHCP works in this network, the switch will learn all its settings. The following list details the steps, again assuming the use of interface VLAN 1, with Example 6-8 that follows showing an example:

6

Config Checklist

Step 1. Enter VLAN 1 configuration mode using the **interface vlan 1** global configuration command, and enable the interface using the **no shutdown** command as necessary.

Step 2. Assign an IP address and mask using the **ip address dhcp** interface subcommand.

Example 6-8 *Switch Dynamic IP Address Configuration with DHCP*

```
Emma# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Emma(config)# interface vlan 1
Emma(config-if)# ip address dhcp
Emma(config-if)# no shutdown
Emma(config-if)# ^Z
Emma#
00:38:20: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:38:21: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed state to up
```

Verifying IPv4 on a Switch

The switch IPv4 configuration can be checked in several places. First, you can always look at the current configuration using the **show running-config** command. Second, you can look at the IP address and mask information using the **show interfaces vlan** *x* command, which shows detailed status information about the VLAN interface in VLAN *x*. Finally, if using DHCP, use the **show dhcp lease** command to see the (temporarily) leased IP address and other parameters. (Note that the switch does not store the DHCP-learned IP configuration in the running-config file.) Example 6-9 shows sample output from these commands to match the configuration in Example 6-8.

Example 6-9 *Verifying DHCP-Learned Information on a Switch*

```
Emma# show dhcp lease
Temp IP addr: 192.168.1.101   for peer on Interface: Vlan1
Temp sub net mask: 255.255.255.0
   DHCP Lease server: 192.168.1.1, state: 3 Bound
   DHCP transaction id: 1966
   Lease: 86400 secs,  Renewal: 43200 secs,  Rebind: 75600 secs
Temp default-gateway addr: 192.168.1.1
   Next timer fires after: 11:59:45
   Retry count: 0   Client-ID: cisco-0019.e86a.6fc0-Vl1
   Hostname: Emma
Emma# show interfaces vlan 1
Vlan1 is up, line protocol is up
  Hardware is EtherSVI, address is 0019.e86a.6fc0 (bia 0019.e86a.6fc0)
  Internet address is 192.168.1.101/24
  MTU 1500 bytes, BW 1000000 Kbit, DLY 10 usec,
     reliability 255/255, txload 1/255, rxload 1/255
! lines omitted for brevity
Emma# show ip default-gateway
192.168.1.1
```

The output of the **show interfaces vlan 1** command lists two very important details related to switch IP addressing. First, this **show** command lists the interface status of the VLAN 1 interface—in this case, "up and up." If the VLAN 1 interface is not up, the switch cannot use its IP address to send and receive management traffic. Notably, if you forget to issue the **no shutdown** command, the VLAN 1 interface remains in its default shutdown state and is listed as "administratively down" in the **show** command output.

Second, note that the output lists the interface's IP address on the third line. If you statically configure the IP address, as in Example 6-7, the IP address will always be listed; however, if you use DHCP and DHCP fails, the **show interfaces vlan** *x* command will not list an IP address here. When DHCP works, you can see the IP address with the **show interfaces vlan 1** command, but that output does not remind you whether the address is either statically configured or DHCP leased. So it does take a little extra effort to make sure you know whether the address is statically configured or DHCP-learned on the VLAN interface.

Miscellaneous Settings Useful in the Lab

This last short section of the chapter touches on a couple of commands that can help you be a little more productive when practicing in a lab.

History Buffer Commands

When you enter commands from the CLI, the switch saves the last several commands in the history buffer. Then, as mentioned in Chapter 4, "Using the Command-Line Interface," you can use the up-arrow key or press Ctrl+P to move back in the history buffer to retrieve a command you entered a few commands ago. This feature makes it very easy and fast to use a set of commands repeatedly. Table 6-2 lists some of the key commands related to the history buffer.

Table 6-2 Commands Related to the History Buffer

Command	Description
show history	An EXEC command that lists the commands currently held in the history buffer.
terminal history size *x*	From EXEC mode, this command allows a single user to set, just for this one login session, the size of his or her history buffer.
history size *x*	A configuration command that, from console or vty line configuration mode, sets the default number of commands saved in the history buffer for the users of the console or vty lines, respectively.

The logging synchronous, exec-timeout, and no ip domain-lookup Commands

These next three configuration commands have little in common, other than the fact that they can be useful settings to reduce your frustration when using the console of a switch or router.

The console automatically receives copies of all unsolicited syslog messages on a switch. The idea is that if the switch needs to tell the network administrator some important and possibly urgent information, the administrator might be at the console and might notice the message.

Unfortunately, IOS (by default) displays these syslog messages on the console's screen at any time—including right in the middle of a command you are entering, or in the middle of the output of a **show** command. Having a bunch of text show up unexpectedly can be a bit annoying.

You could simply disable the feature that sends these messages to the console and then re-enable the feature later using the **no logging console** and **logging console** global configuration commands. For example, when working from the console, if you want to temporarily not be bothered by log messages, you can disable the display of these messages with the **no logging console** global configuration command, and then when finished, enable them again.

However, IOS supplies a reasonable compromise, telling the switch to display syslog messages only at more convenient times, such as at the end of output from a **show** command. To do so, just configure the **logging synchronous** console line subcommand, which basically tells IOS to synchronize the syslog message display with the messages requested using **show** commands.

Another way to improve the user experience at the console is to control timeouts of the login session from the console or when using Telnet or SSH. By default, the switch automatically disconnects console and vty (Telnet and SSH) users after 5 minutes of inactivity. The **exec-timeout** *minutes seconds* line subcommand enables you to set the length of that inactivity timer. In the lab (but not in production), you might want to use the special value of 0 minutes and 0 seconds meaning "never time out."

Finally, IOS has an interesting combination of features that can make you wait for a minute or so when you mistype a command. First, IOS tries to use DNS name resolution on IP hostnames—a generally useful feature. If you mistype a command, however, IOS thinks you want to telnet to a host by that name. With all default settings in the switch, the switch tries to resolve the hostname, cannot find a DNS server, and takes about a minute to time out and give you control of the CLI again.

To avoid this problem, configure the **no ip domain-lookup** global configuration command, which disables IOS's attempt to resolve the hostname into an IP address.

Example 6-10 collects all these commands into a single example, as a template for some good settings to add in a lab switch to make you more productive.

Example 6-10 *Commands Often Used in the Lab to Increase Productivity*

```
no ip domain-lookup
!
line console 0
 exec-timeout 0 0
 logging synchronous
 history size 20
!
line vty 0 15
 exec-timeout 0 0
 logging synchronous
 history size 20
```

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element section titled "Step 2: Build Your Study Habits Around the Chapter" for more details. Table 6-3 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 6-3 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Repeat DIKTA questions		Book, PTP
Review config checklists		Book, website
Do labs		Sim Lite, blog
Review command tables		Book