Static Routing

Routing Protocols

Static Routing

Reach Remote Networks

A router can learn about remote networks in one of two ways:

- Manually - Remote networks are manually entered into the route table using static routes.
- Dynamically - Remote routes are automatically learned using a dynamic routing protocol.

Why Use Static Routing?

Static routing provides some advantages over dynamic routing, including:

- Static routes are not advertised over the network, resulting in better security.
- Static routes use less bandwidth than dynamic routing protocols, no CPU cycles are used to calculate and communicate routes.
- The path a static route uses to send data is known.

Why Use Static Routing? (continued)

Static routing has the following disadvantages:

- Initial configuration and maintenance is time-consuming.
- Configuration is error-prone, especially in large networks.
- Administrator intervention is required to maintain changing route information.
- Does not scale well with growing networks; maintenance becomes cumbersome.
- Requires complete knowledge of the whole network for proper implementation.

Static Routing

When to Use Static Routes

Static routing has three primary uses:

- Providing ease of routing table maintenance in smaller networks that are not expected to grow significantly.
- Routing to and from stub networks. A stub network is a network accessed by a single route, and the router has no other neighbors.
- Using a single default route to represent a path to any network that does not have a more specific match with another route in the routing table. Default routes are used to send traffic to any destination beyond the next upstream router.

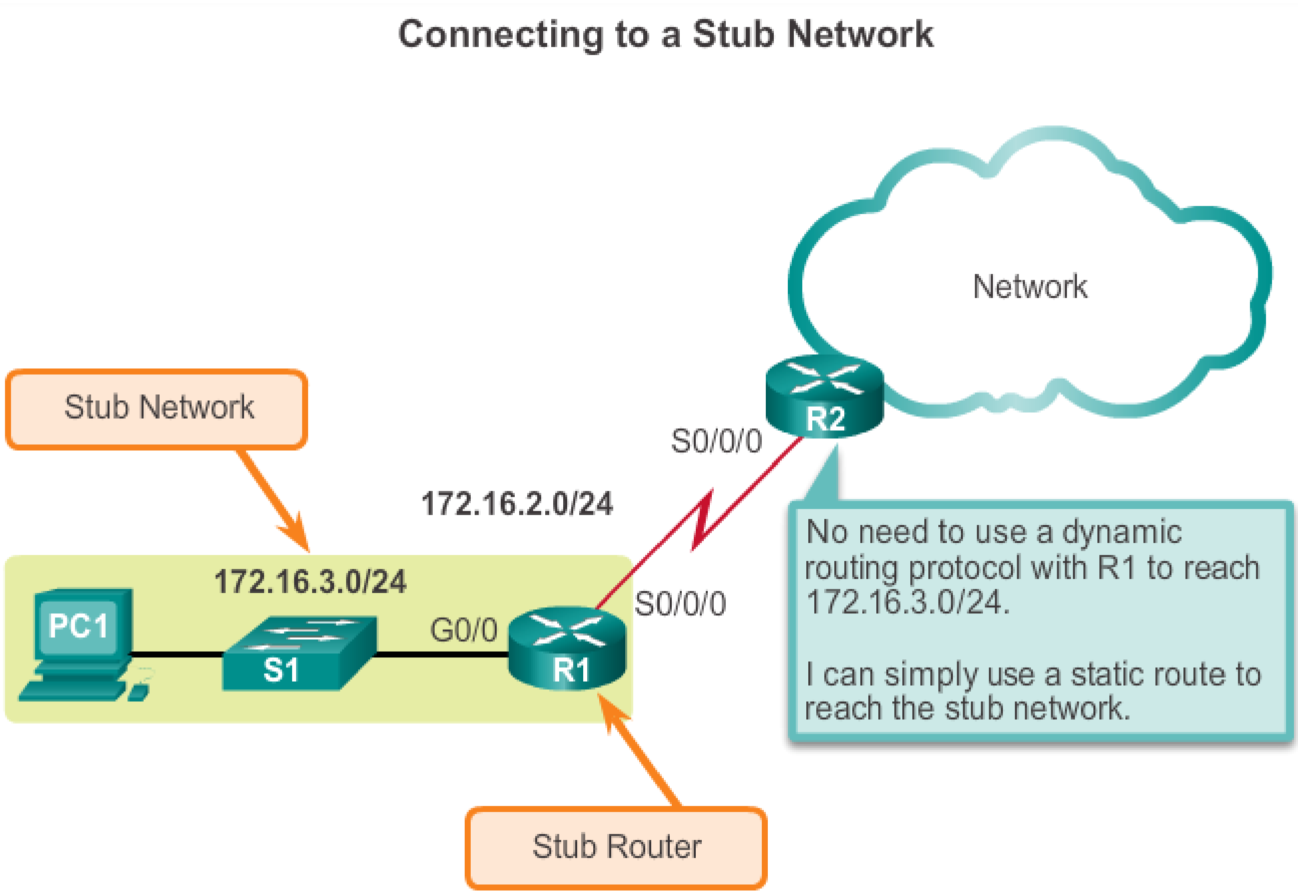
Types of Static Routes

Static Route Applications

Static Routes are often used to:

- Connect to a specific network
- Provide a Gateway of Last Resort for a stub network
- Reduce the number of routes advertised by summarizing several contiguous networks as one static route
- Create a backup route in case a primary route link fails

Types of Static Routes
Standard Static Route

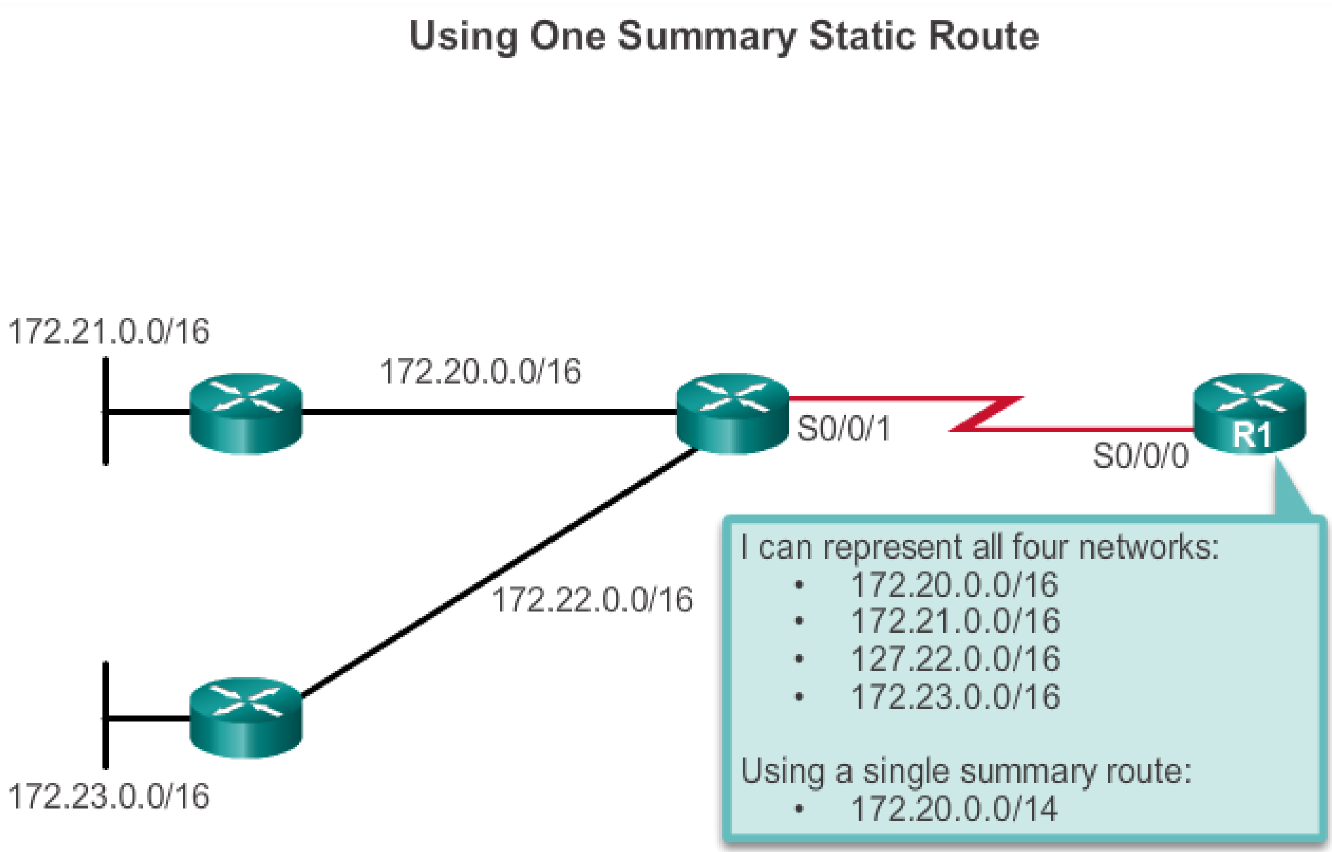


Types of Static Routes
Default Static Route

- A default static route is a route that matches all packets.
- A default route identifies the gateway IP address to which the router sends all IP packets that it does not have a learned or static route.
- A default static route is simply a static route with 0.0.0.0/0 as the destination IPv4 address.

Types of Static Routes

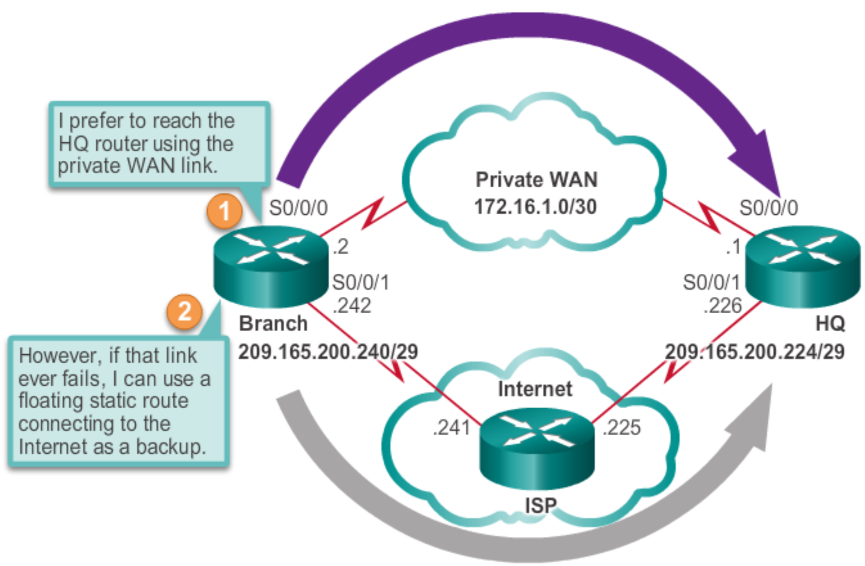
Summary Static Route



Types of Static Routes
Floating Static Route

- Floating static routes are static routes that are used to provide a backup path to a primary static or dynamic route, in the event of a link failure.
- The floating static route is only used when the primary route is not available.
- In order to accomplish this, the floating static route is configured with a higher administrative distance than the primary route.

Configuring a Backup Route



ip route Command

ip route Command Syntax

```
Router(config)#ip route network-address subnet-mask
{ip-address | exit-intf}
```

Parameter	Description
network-address	Destination network address of the remote network to be added to the routing table.
subnet-mask	• Subnet mask of the remote network to be added to the routing table. • The subnet mask can be modified to summarize a group of networks.
ip-address	• Commonly referred to as the next-hop router's IP address. • Typically used when connecting to a broadcast media (i.e., Ethernet). • Commonly creates a recursive lookup.
exit-intf	• Use the outgoing interface to forward packets to the destination network. • Also referred to as a directly attached static route. • Typically used when connecting in a point-to-point configuration.

Configure IPv4 Static Routes
Next-Hop Options

The next hop can be identified by an IP address, exit interface, or both. How the destination is specified creates one of the three following route types:

- Next-hop route - Only the next-hop IP address is specified.
- Directly connected static route - Only the router exit interface is specified.
- Fully specified static route - The next-hop IP address and exit interface are specified.

Configure IPv4 Static Routes

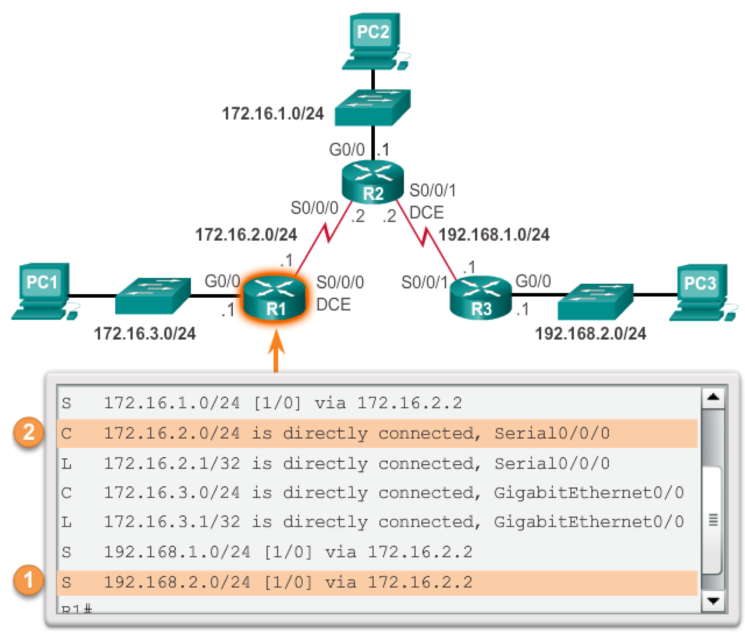
Configure a Next-Hop Static Route

When a packet is destined for the 192.168.2.0/24 network, R1:

1. Looks for a match in the routing table and finds that it has to forward the packets to the next-hop IPv4 address 172.16.2.2.

2. R1 must now determine how to reach 172.16.2.2; therefore, it searches a second time for a 172.16.2.2 match.

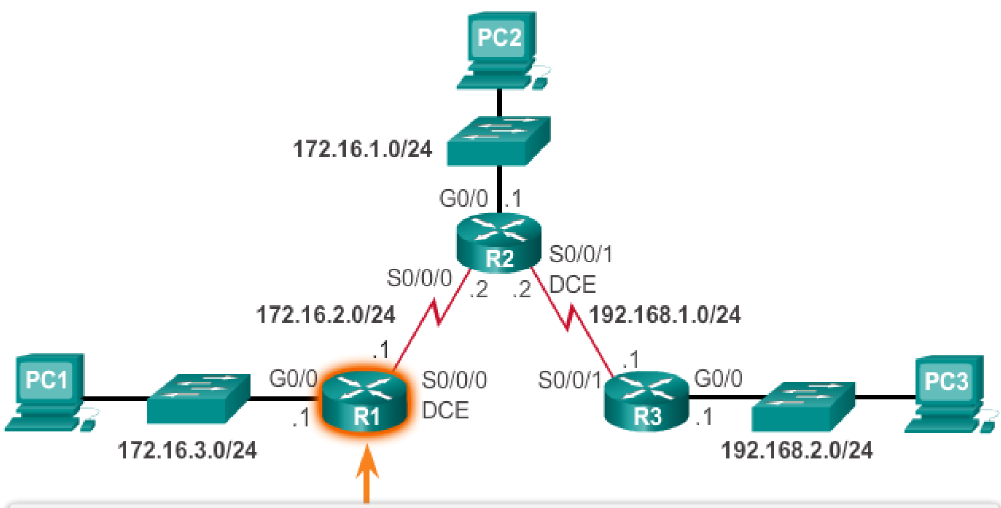
Verify the Routing Table of R1



Configure IPv4 Static Routes

Configure Directly Connected Static Route

Configure Directly Attached Static Routes on R1




```
R1(config)#ip route 172.16.1.0 255.255.255.0 s0/0/0
R1(config)#ip route 192.168.1.0 255.255.255.0 s0/0/0
R1(config)#ip route 192.168.2.0 255.255.255.0 s0/0/0
R1(config)#
```

```
S        172.16.1.0/24 is directly connected, Serial0/0/0
C        172.16.2.0/24 is directly connected, Serial0/0/0
L        172.16.2.1/32 is directly connected, Serial0/0/0
C        172.16.3.0/24 is directly connected, GigabitEthernet0/0
L        172.16.3.1/32 is directly connected, GigabitEthernet0/0
S     192.168.1.0/24 is directly connected, Serial0/0/0
S     192.168.2.0/24 is directly connected, Serial0/0/0
R1#
```

Configure IPv4 Static Routes
Configure a Fully Specified Static Route

- In a fully specified static route, both the output interface and the next-hop IP address are specified.
- This is another type of static route that is used in older IOS's, prior to CEF.
- This form of static route is used when the output interface is a multi-access interface and it is necessary to explicitly identify the next hop.
- The next hop must be directly connected to the specified exit interface.

Configure IPv4 Static Routes

Verify a Static Route

Along with **`ping`** and **`traceroute`**, useful commands to verify static routes include:

- **`show ip route`**
- **`show ip route static`**
- **`show ip route`** `network`

Configure IPv4 Default Routes
Default Static Route

Default Static Route Syntax

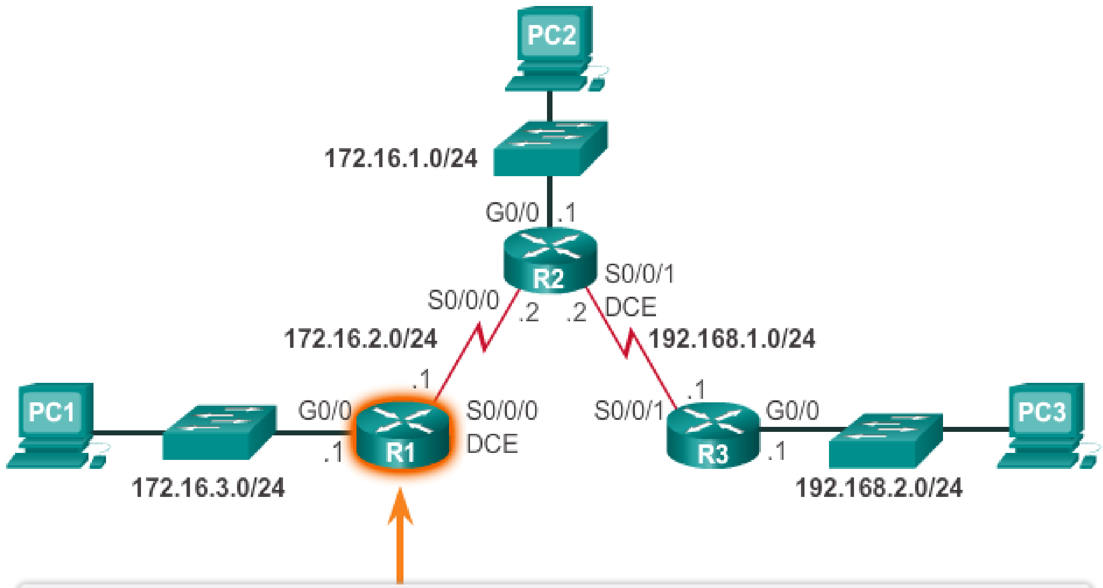
```
Router(config)#ip route 0.0.0.0 0.0.0.0 {ip-address | exit-intf}
```

Parameter	Description
0.0.0.0	Matches any network address.
0.0.0.0	Matches any subnet mask.
ip-address	• Commonly referred to as the next-hop router's IP address. • Typically used when connecting to a broadcast media (i.e., Ethernet). • Commonly creates a recursive lookup.
exit-intf	• Use the outgoing interface to forward packets to the destination network. • Also referred to as a directly attached static route. • Typically used when connecting in a point-to-point configuration.

Configure IPv4 Default Routes

Configure a Default Static Route

Configuring a Default Static Route

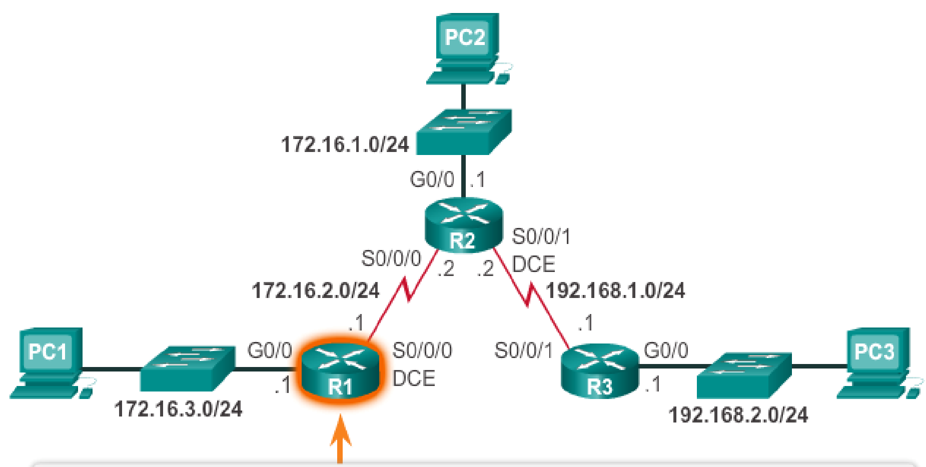



```
R1(config)# ip route 0.0.0.0 0.0.0.0 172.16.2.2
R1(config)#
```

Configure IPv4 Default Routes

Verify a Default Static Route

Verifying the Routing Table of R1

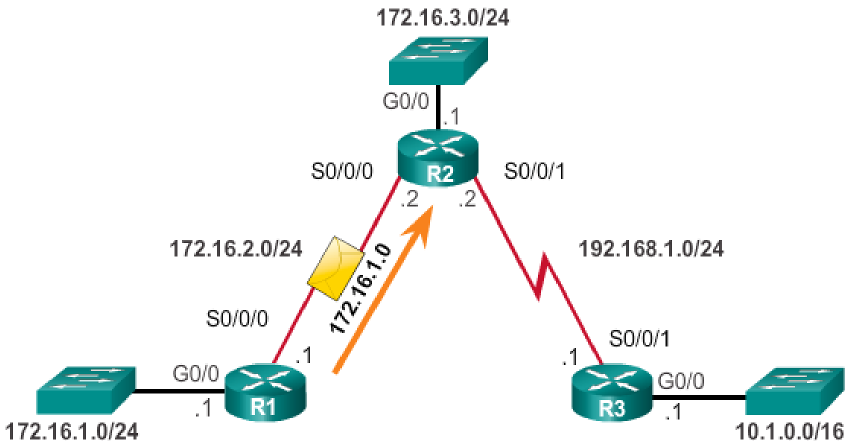


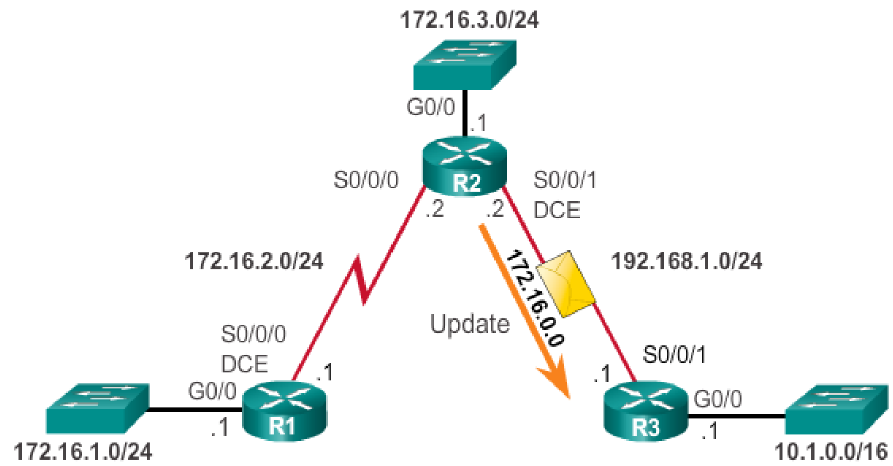

```
R1#show ip route static
Codes: L - local, C - connected, S - static, R - RIP,
       M - mobile, B - BGP, D - EIGRP,
       EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA extern
       N2 - OSPF NSSA extern
       E1 - OSPF external ty
       E2 - OSPF external ty
       su - IS-IS summary, L
```

```
          * - candidate default, U - per-user static route
          o - ODR, P - periodic downloaded static route,
          H - NHRP, l - LISP, + - replicated route,
          % - next hop override

Gateway of last resort is 172.16.2.2 to network 0.0.0.0

S*     0.0.0.0/0 [1/0] via 172.16.2.2
R1#
```

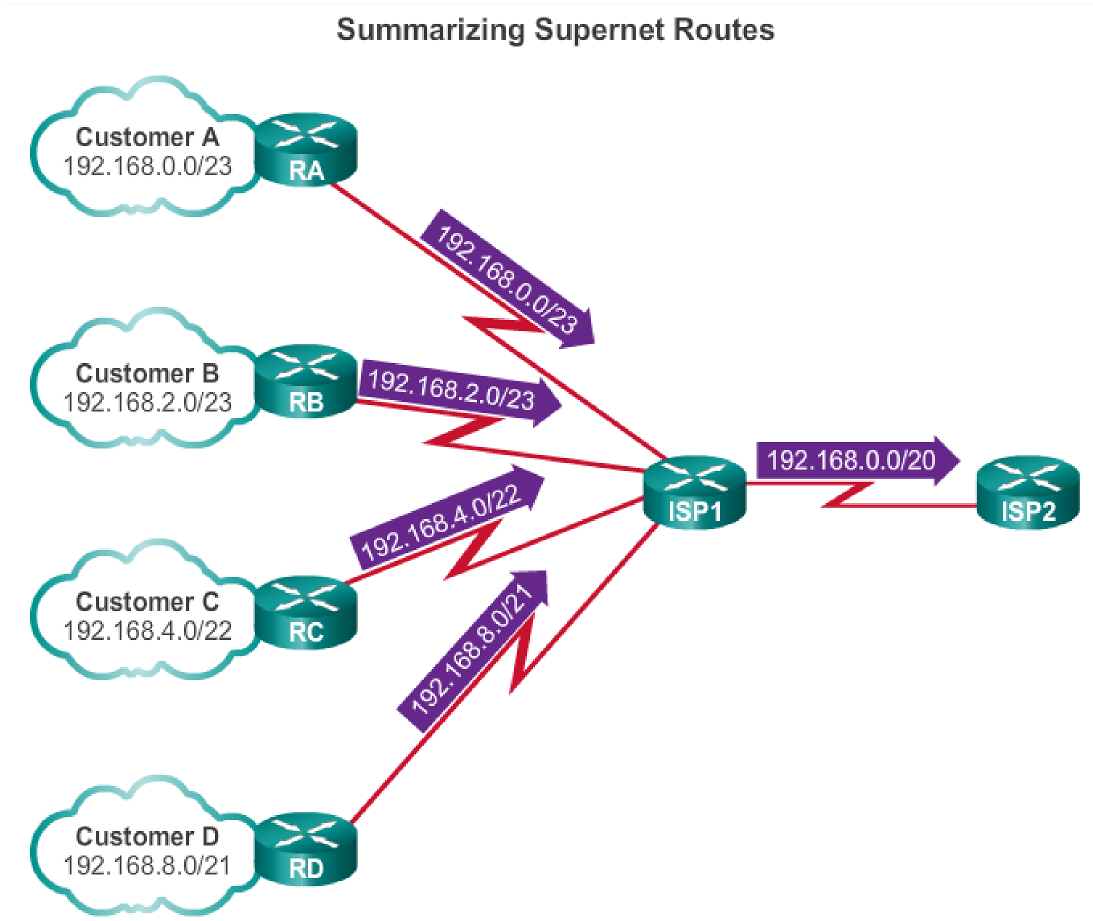
Classful Addressing

Classful Routing Protocol Example





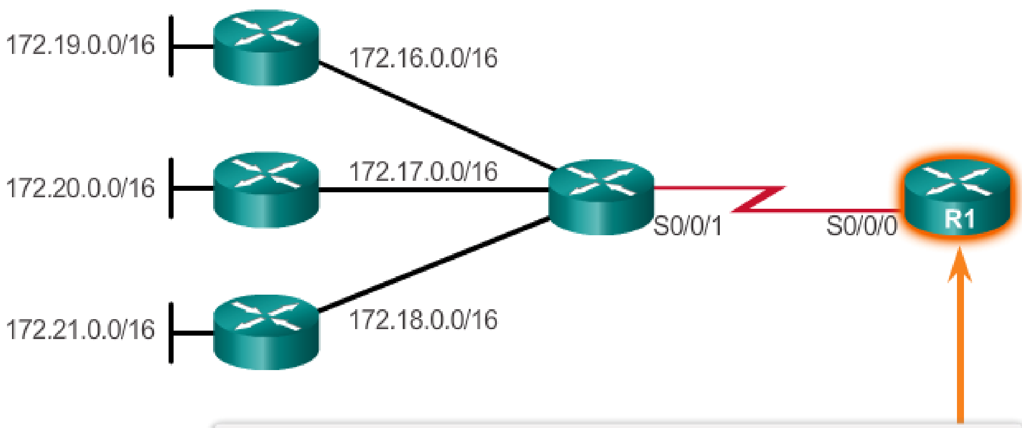
CIDR and Route Summarization



CIDR

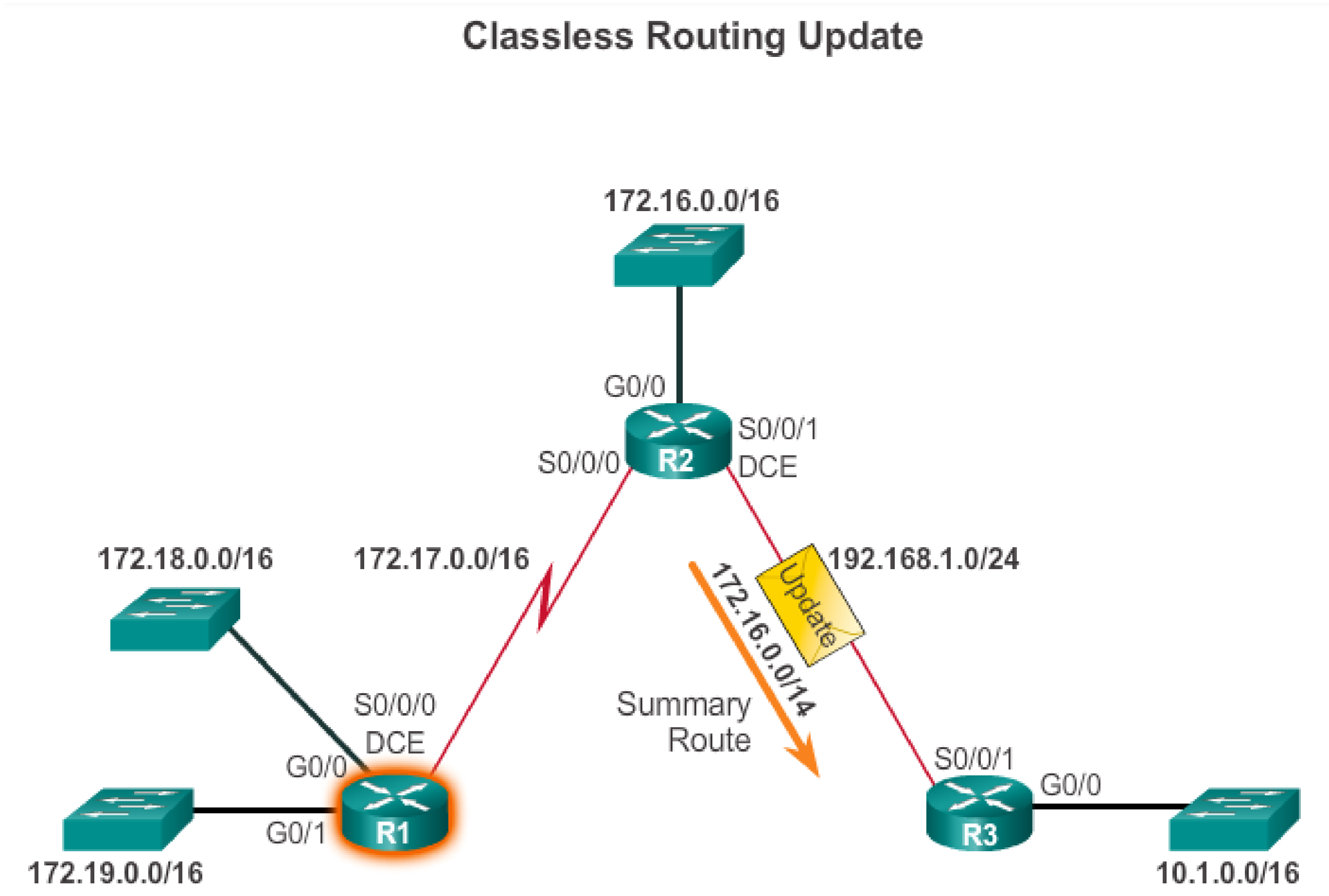
Static Routing CIDR Example

One Summary Static Route




```
R1(config)#no ip route 172.16.0.0 255.255.0.0 s0/0/0
R1(config)#no ip route 172.17.0.0 255.255.0.0 s0/0/0
R1(config)#no ip route 172.18.0.0 255.255.0.0 s0/0/0
R1(config)#no ip route 172.19.0.0 255.255.0.0 s0/0/0
R1(config)#no ip route 172.20.0.0 255.255.0.0 s0/0/0
R1(config)#no ip route 172.21.0.0 255.255.0.0 s0/0/0
R1(config)#
R1(config)#ip route 172.16.0.0 255.248.0.0 s0/0/0
R1(config)#
```

CIDR
Classless Routing Protocol Example



Configure IPv4 Summary Routes

Route Summarization

- Route summarization, also known as route aggregation, is the process of advertising a contiguous set of addresses as a single address with a less-specific, shorter subnet mask.
- CIDR is a form of route summarization and is synonymous with the term supernetting.
- CIDR ignores the limitation of classful boundaries, and allows summarization with masks that are smaller than that of the default classful mask.
- This type of summarization helps reduce the number of entries in routing updates and lowers the number of entries in local routing tables.

Configure IPv4 Summary Routes

Calculate a Summary Route

Calculating a Route Summary

Step 1: List networks in binary format.

172.20.0.0	**10101100 . 000101**00 . 00000000 . 00000000
172.21.0.0	**10101100 . 000101**01 . 00000000 . 00000000
172.22.0.0	**10101100 . 000101**10 . 00000000 . 00000000
172.23.0.0	**10101100 . 000101**11 . 00000000 . 00000000

Step 2: Count the number of far-left matching bits to determine the mask.

Answer: 14 matching bits = /14 or 255.252.0.0

Step 3: Copy the matching bits and add zero bits to determine the network address.

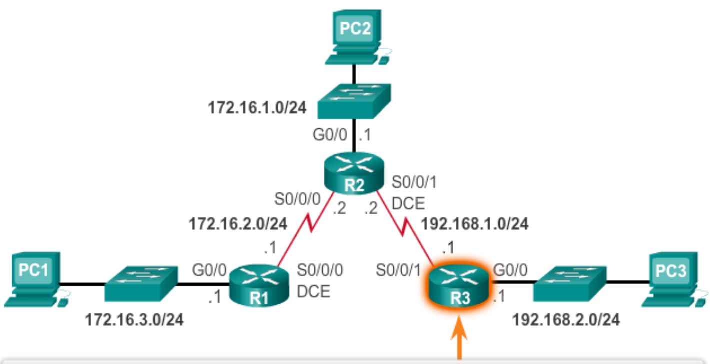
10101100 . 00010100 . 00000000 . 00000000

Copy — Add zero bits

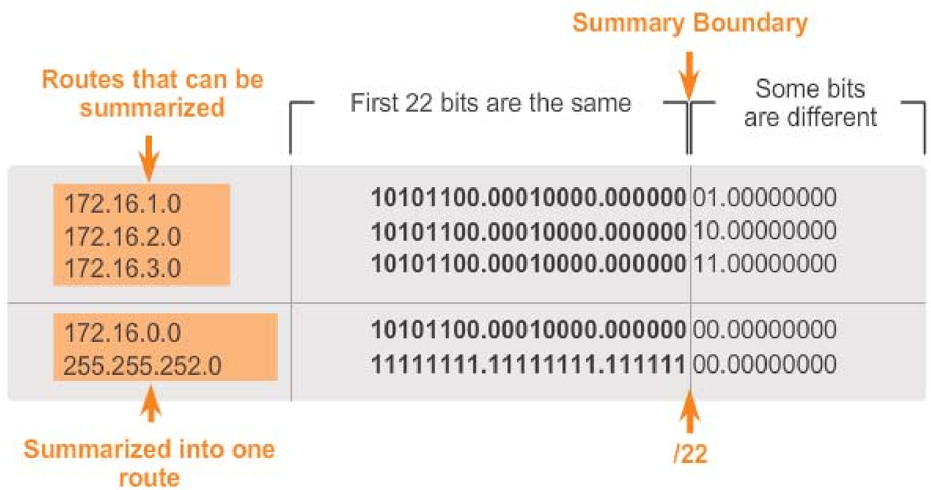
Answer: 172.20.0.0

Configure IPv4 Summary Routes
Summary Static Route Example

Verify the Routing Table




```
R3# show ip route static | begin Gateway
Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 3 subnets
S       172.16.1.0 [1/0] via 192.168.1.2
S       172.16.2.0 [1/0] via 192.168.1.2
S       172.16.3.0 [1/0] via 192.168.1.2
```



172.16.0.0	255.255.252.0

Configure Floating Static Routes

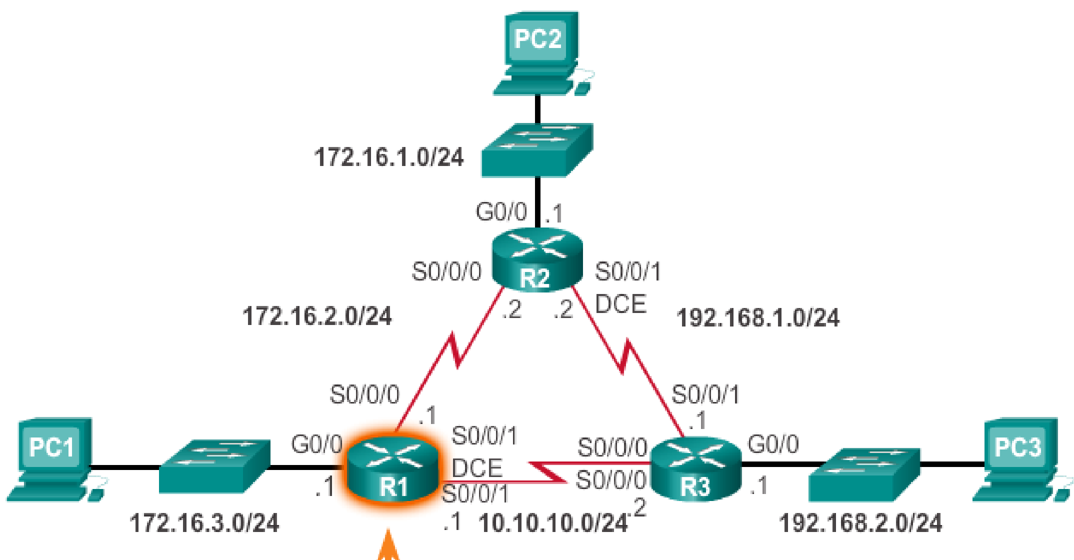
Floating Static Routes

- Floating static routes are static routes that have an administrative distance greater than the administrative distance of another static route or dynamic routes.
- The administrative distance of a static route can be increased to make the route less desirable than that of another static route or a route learned through a dynamic routing protocol.
- In this way, the static route “floats” and is not used when the route with the better administrative distance is active.
- However, if the preferred route is lost, the floating static route can take over, and traffic can be sent through this alternate route.

Configure Floating Static Routes

Configure a Floating Static Route

Configuring a Floating Static Route to R3




```
R1(config)# ip route 0.0.0.0 0.0.0.0 172.16.2.2
R1(config)# ip route 0.0.0.0 0.0.0.0 10.10.10.2 5
R1(config)#
```

Configure Floating Static Routes

Test the Floating Static Route

- Use a **`show ip route`** command to verify that the routing table is using the default static route.
- Use a **`traceroute`** command to follow the traffic flow out the primary route.
- Disconnect the primary link or shutdown the primary exit interface.
- Use a **`show ip route`** command to verify that the routing table is using the floating static route.
- Use a **`traceroute`** command to follow the traffic flow out the backup route.

Routing Dynamically

Routing Protocols

The Evolution of Dynamic Routing Protocols

- Dynamic routing protocols used in networks since the late 1980s
- Newer versions support the communication based on IPv6

Routing Protocols Classification

	Interior Gateway Protocols				Exterior Gateway Protocols
	Distance Vector		Link-State		Path Vector
IPv4	RIPv2	EIGRP	OSPFv2	IS-IS	BGP-4
IPv6	RIPng	EIGRP for IPv6	OSPFv3	IS-IS for IPv6	BGP-MP

Dynamic Routing Protocol Operation

Purpose of Dynamic Routing Protocols

- Routing Protocols
  - Used to facilitate the exchange of routing information between routers
- Purpose of dynamic routing protocols includes:
  - Discovery of remote networks
  - Maintaining up-to-date routing information
  - Choosing the best path to destination networks
  - Ability to find a new best path if the current path is no longer available

Dynamic Routing Protocol Operation

Purpose of Dynamic Routing Protocols

Main components of dynamic routing protocols include:

- **Data structures -** Routing protocols typically use tables or databases for its operations. This information is kept in RAM.
- **Routing protocol messages -** Routing protocols use various types of messages to discover neighboring routers, exchange routing information, and other tasks to learn and maintain accurate information about the network.
- **Algorithm -** Routing protocols use algorithms for facilitating routing information for best path determination.

Dynamic Routing Protocol Operation

The Role of Dynamic Routing Protocols

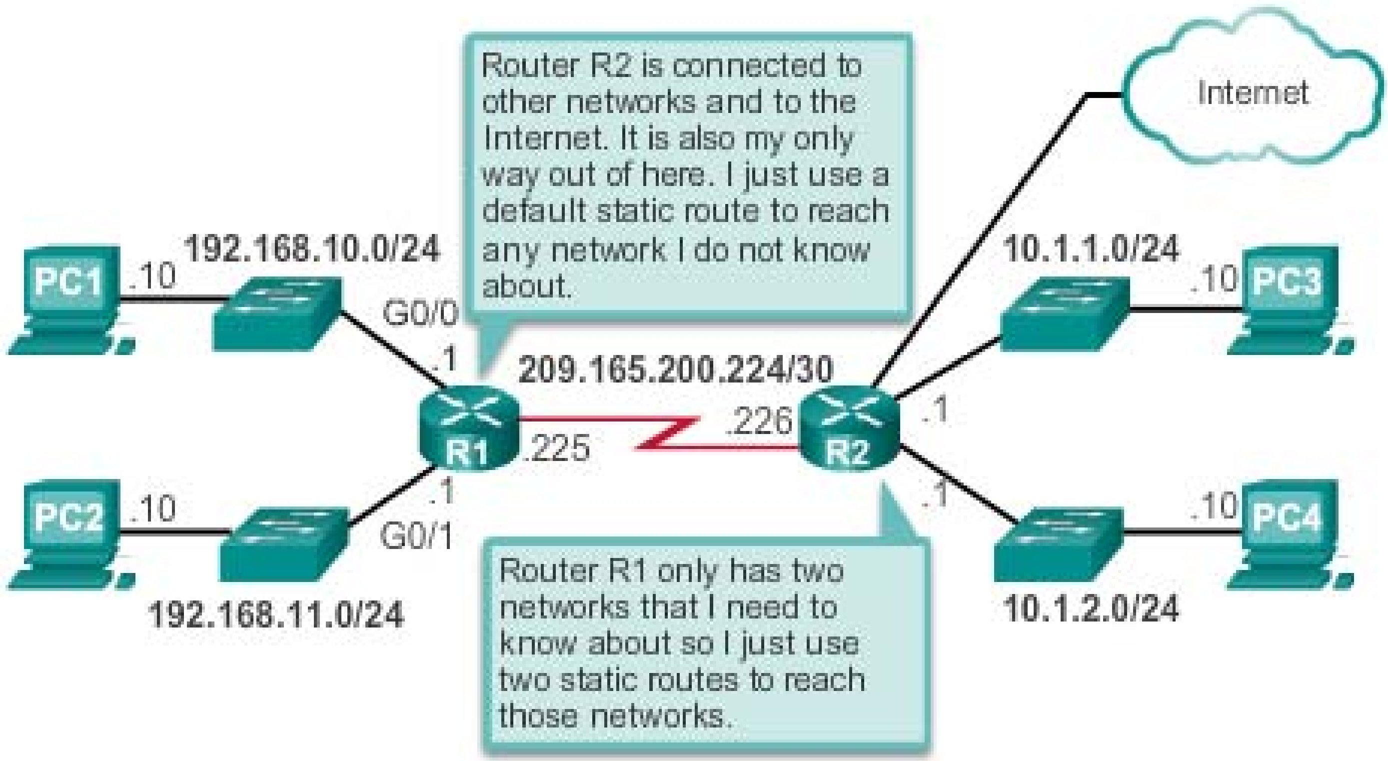
- Advantages of dynamic routing
  - Automatically share information about remote networks
  - Determine the best path to each network and add this information to their routing tables
  - Compared to static routing, dynamic routing protocols require less administrative overhead
  - Help the network administrator manage the time-consuming process of configuring and maintaining static routes
- Disadvantages of dynamic routing
  - Dedicate part of a routers resources for protocol operation, including CPU time and network link bandwidth
- Times when static routing is more appropriate

Dynamic verses Static Routing

Using Static Routing

- Networks typically use a combination of both static and dynamic routing
- Static routing has several primary uses
  - Providing ease of routing table maintenance in smaller networks that are not expected to grow significantly
  - Routing to and from a stub network
    - a network with only one default route out and no knowledge of any remote networks
  - Accessing a single default router
    - used to represent a path to any network that does not have a match in the routing table

Dynamic verses Static Routing
Using Static Routing



Dynamic verses Static Routing
Static Routing Scorecard

Static Routing Advantages and Disadvantages

Advantages	Disadvantages
Easy to implement in a small network.	Suitable only for simple topologies or for special purposes such as a default static route. Configuration complexity increases dramatically as network grows.
Very secure. No advertisements are sent as compared to dynamic routing protocols.	
Route to destination is always the same.	Manual intervention required to re-route traffic.
No routing algorithm or update mechanism required; therefore, extra resources (CPU or RAM) are not required.	

Dynamic verses Static Routing
Dynamic Routing Scorecard

Dynamic Routing Advantages and Disadvantages

Advantages	Disadvantages
Suitable in all topologies where multiple routers are required.	Can be more complex to implement.
Generally independent of the network size.	Less secure. Additional configuration settings are required to secure.
Automatically adapts topology to reroute traffic if possible.	Route depends on the current topology.
	Requires additional CPU, RAM, and link bandwidth.

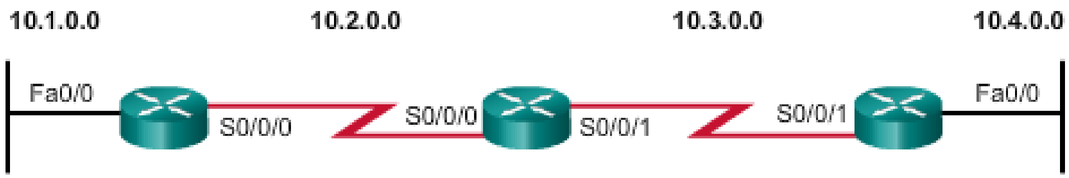
Dynamic Routing Protocol Operation

In general, the operations of a dynamic routing protocol can be described as follows:

1. The router sends and receives routing messages on its interfaces.
2. The router shares routing messages and routing information with other routers that are using the same routing protocol.
3. Routers exchange routing information to learn about remote networks.
4. When a router detects a topology change the routing protocol can advertise this change to other routers.

Routing Protocol Operating Fundamentals
Cold Start

Directly Connected Networks Detected



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0

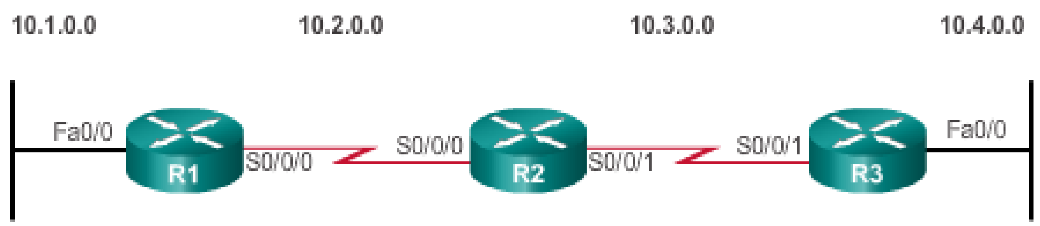
Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0

Routers running RIPv2

- R1 adds the 10.1.0.0 network available through interface FastEthernet 0/0 and 10.2.0.0 is available through interface Serial 0/0/0.
- R2 adds the 10.2.0.0 network available through interface Serial 0/0/0 and 10.3.0.0 is available through interface Serial 0/0/1.
- R3 adds the 10.3.0.0 network available through interface Serial 0/0/1 and 10.4.0.0 is available through interface FastEthernet 0/0.

Routing Protocol Operating Fundamentals
Network Discovery

Initial Exchange



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/0	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

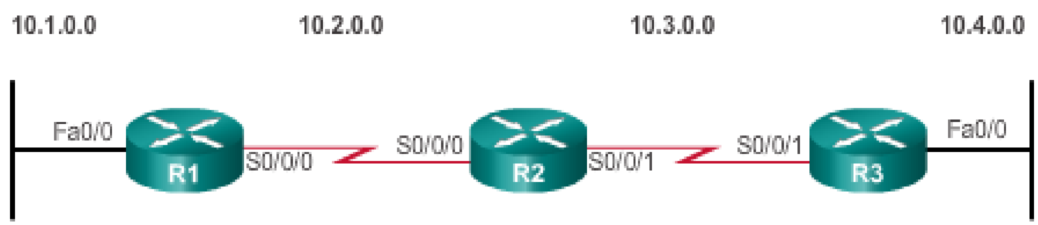
Routers running RIPv2

R1:

- Sends an update about network 10.1.0.0 out the Serial0/0/0 interface
- Sends an update about network 10.2.0.0 out the FastEthernet0/0 interface
- Receives update from R2 about network 10.3.0.0 with a metric of 1
- Stores network 10.3.0.0 in the routing table with a metric of 1

Network Discovery

Initial Exchange



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/0	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

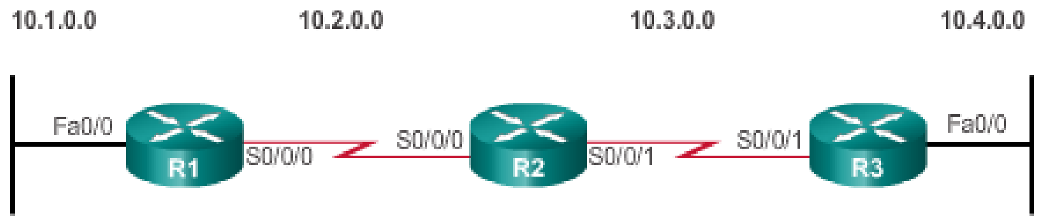
Routers running RIPv2

R2:

- Sends an update about network 10.3.0.0 out the Serial 0/0/0 interface
- Sends an update about network 10.2.0.0 out the Serial 0/0/1 interface
- Receives an update from R1 about network 10.1.0.0 with a metric of 1
- Stores network 10.1.0.0 in the routing table with a metric of 1
- Receives an update from R3 about network 10.4.0.0 with a metric of 1
- Stores network 10.4.0.0 in the routing table with a metric of 1

Routing Protocol Operating Fundamentals
Network Discovery

Initial Exchange



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

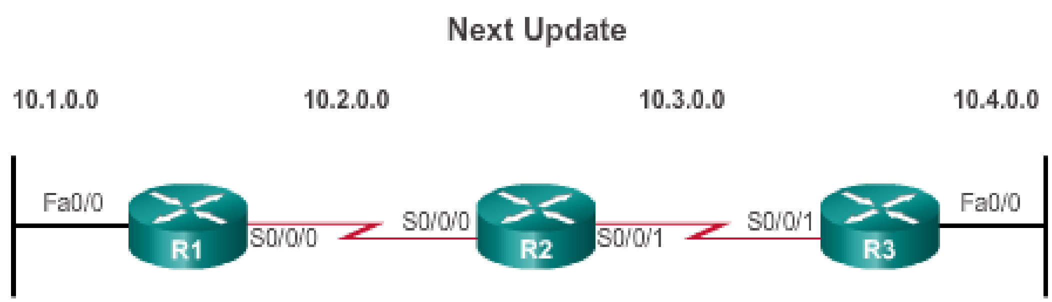
Network	Interface	Hop
10.3.0.0	S0/0/0	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

Routers running RIPv2

R3:

- Sends an update about network 10.4.0.0 out the Serial 0/0/1 interface
- Sends an update about network 10.3.0.0 out the FastEthernet0/0
- Receives an update from R2 about network 10.2.0.0 with a metric of 1
- Stores network 10.2.0.0 in the routing table with a metric of 1

Exchanging the Routing Information



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1
10.1.0.0	S0/0/1	2

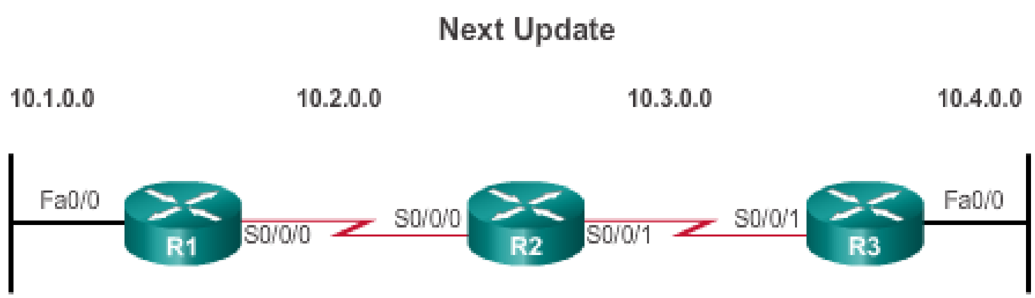
Routers running RIPv2

R1:

- Sends an update about network 10. 1. 0. 0 out the Serial 0/0/0 interface
- Sends an update about networks 10. 2. 0. 0 and 10. 3. 0. 0 out the FastEthernet0/0 interface
- Receives an update from R2 about network 10. 4. 0. 0 with a metric of 2
- Stores network 10. 4. 0. 0 in the routing table with a metric of 2
- Same update from R2 contains information about network 10. 3. 0. 0 with a metric of 1. There is no change; therefore, the routing information remains the same

Routing Protocol Operating Fundamentals

Exchanging the Routing Information



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

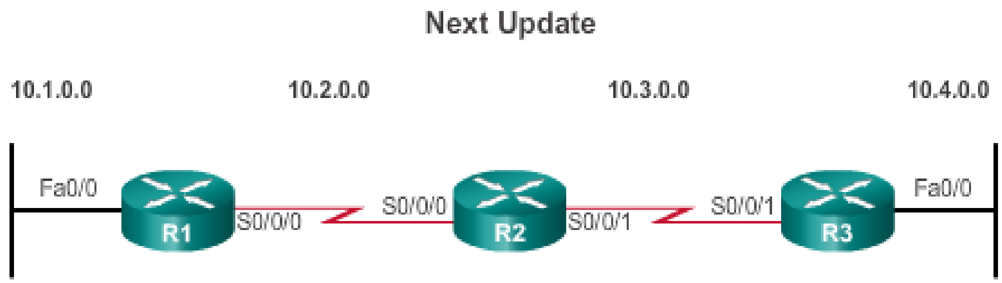
Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1
10.1.0.0	S0/0/1	2

Routers running RIPv2

R2:

- Sends an update about networks 10. 3. 0. 0 and 10. 4. 0. 0 out of Serial 0/0/0 interface
- Sends an update about networks 10. 1. 0. 0 and 10. 2. 0. 0 out of Serial 0/0/1 interface
- Receives an update from R1 about network 10. 1. 0. 0. There is no change; therefore, the routing information remains the same.
- Receives an update from R3 about network 10. 4. 0. 0. There is no change; therefore, the routing information remains the same.

Exchanging the Routing Information



Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

Network	Interface	Hop
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/1	0
10.1.0.0	S0/0/0	1
10.4.0.0	S0/0/1	1

Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1
10.1.0.0	S0/0/1	2

Routers running RIPv2

R3:

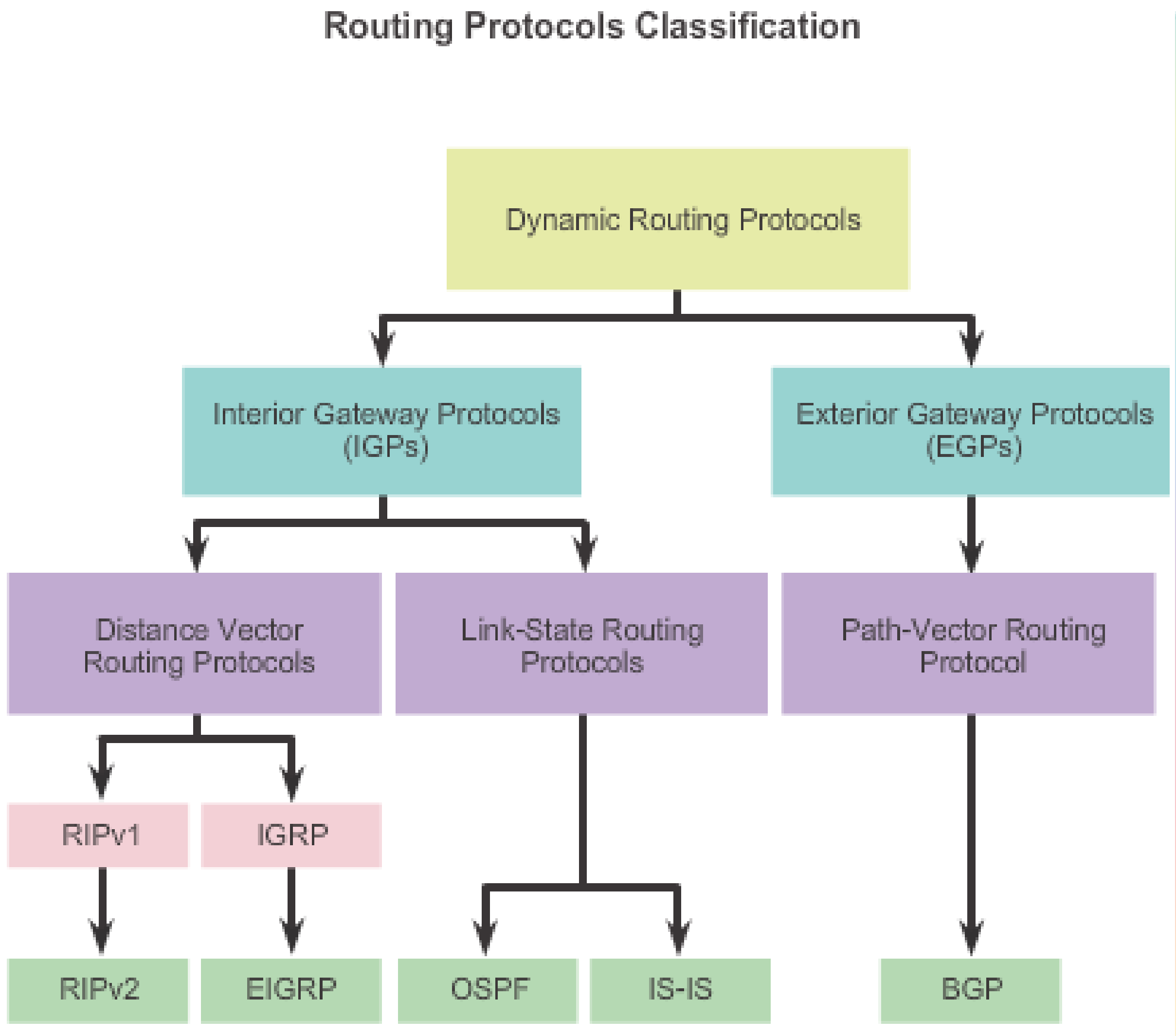
- Sends an update about network 10. 4. 0. 0 out the Serial 0/0/1 interface
- Sends an update about networks 10. 2. 0. 0 and 10. 3. 0. 0 out the FastEthernet0/0 interface
- Receives an update from R2 about network 10. 1. 0. 0 with a metric of 2
- Stores network 10. 1. 0. 0 in the routing table with a metric of 2
- Same update from R2 contains information about network 10. 2. 0. 0 with a metric of 1. There is no change; therefore, the routing information remains the same.

Routing Protocol Operating Fundamentals
Achieving Convergence

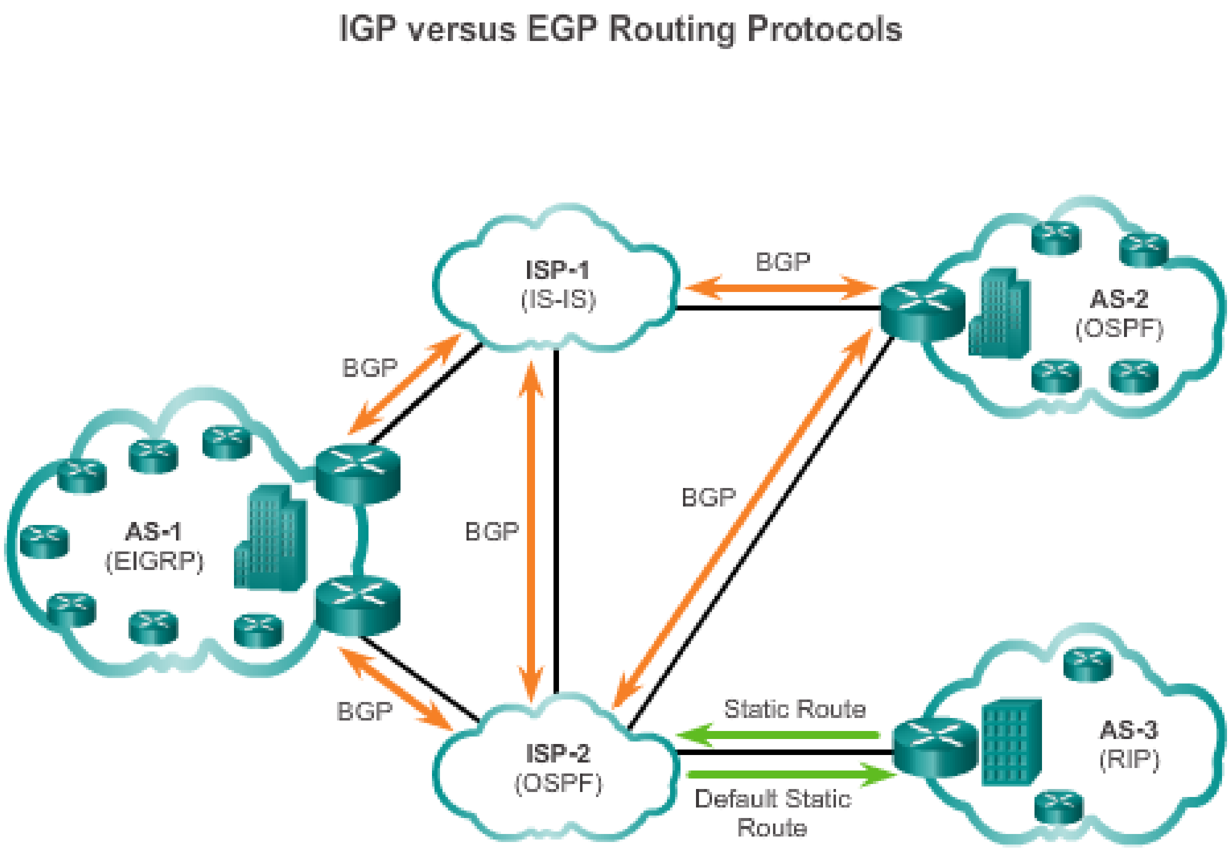
- Network converged when all routers have complete and accurate information about the entire network.
- Convergence time is the time it takes routers to share information, calculate best paths, and update their routing tables.
- A network is not completely operable until the network has converged.
- Convergence properties include the speed of propagation of routing information and the calculation of optimal paths. The speed of propagation refers to the amount of time it takes for routers within the network to forward routing information.
- Generally, older protocols, such as RIP, are slow to converge, whereas modern protocols, such as EIGRP and OSPF, converge more quickly.

Types of Routing Protocols

Classifying Routing Protocols



Types of Routing Protocols
IGP and EGP Routing Protocols



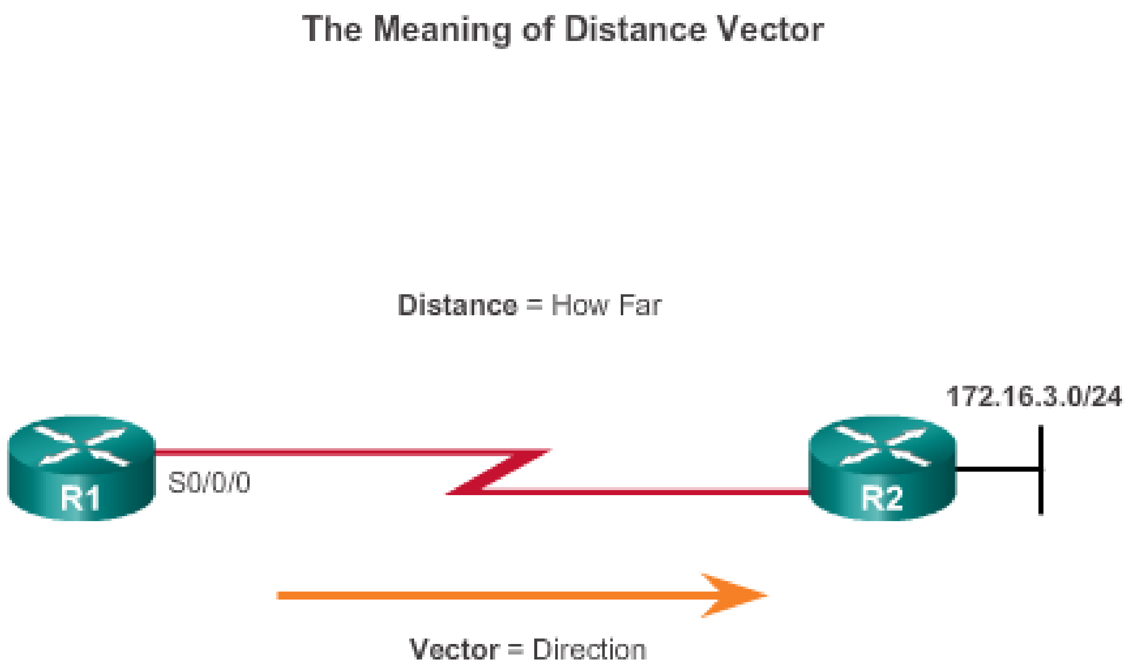
Interior Gateway Protocols (IGP) -

- Used for routing within an AS
- Include RIP, EIGRP, OSPF, and IS-IS

Exterior Gateway Protocols (EGP) -

- Used for routing between AS
- Official routing protocol used by the Internet

Types of Routing Protocols
Distance Vector Routing Protocols



For R1, 172.16.3.0/24 is one hop away (distance) it can be reached through R2 (vector)

Distance vector IPv4 IGPs:

- **RIPv1** - First generation legacy protocol
- **RIPv2** - Simple distance vector routing protocol
- **IGRP** - First generation Cisco proprietary protocol (obsolete)
- **EIGRP** - Advanced version of distance vector routing

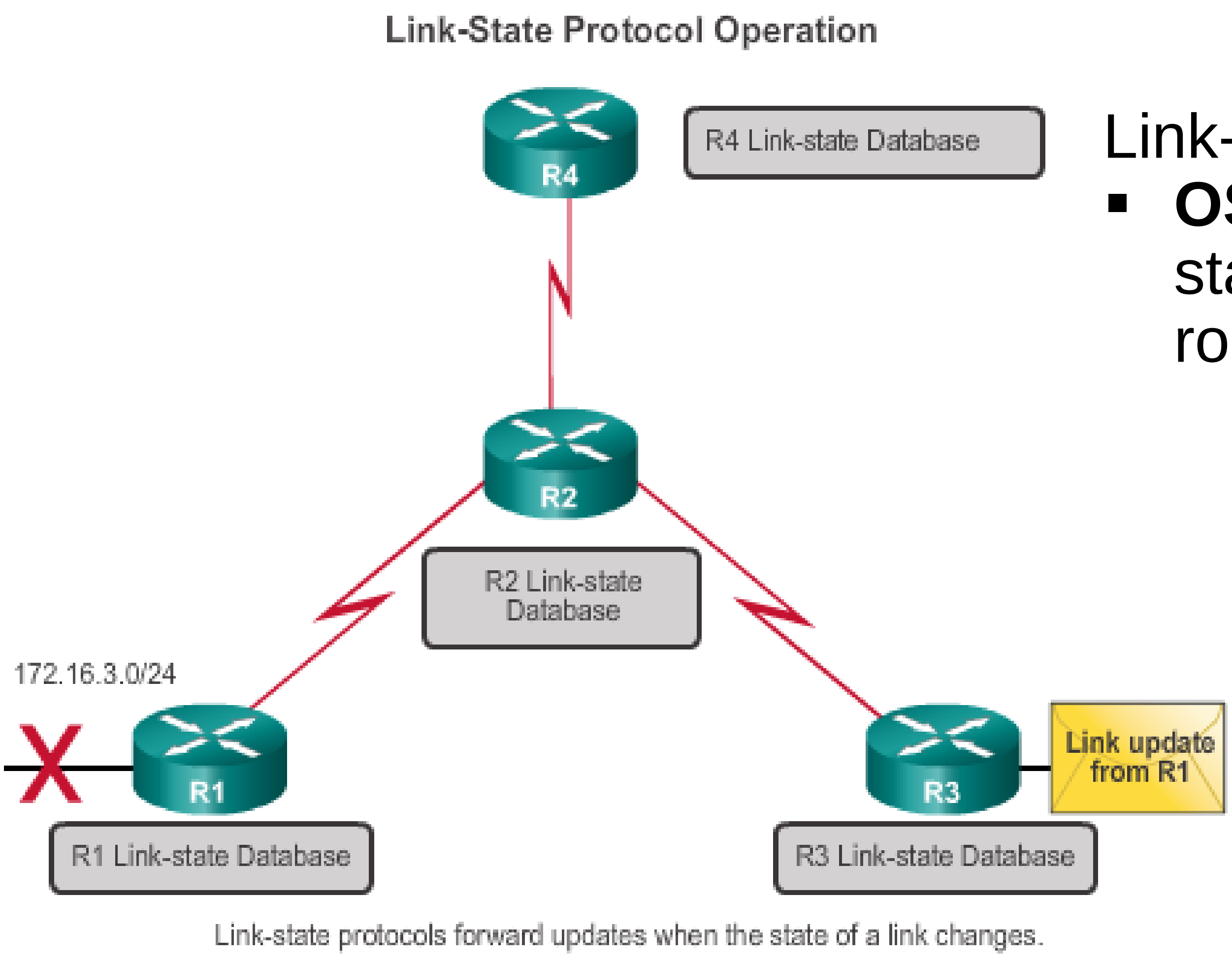
Types of Routing Protocols

Distance Vector or Link-State Routing Protocols

Distance vector protocols use routers as sign posts along the path to the final destination.

A link-state routing protocol is like having a complete map of the network topology. The sign posts along the way from source to destination are not necessary, because all link-state routers are using an identical map of the network. A link-state router uses the link-state information to create a topology map and to select the best path to all destination networks in the topology.

Types of Routing Protocols
Link-State Routing Protocols



Link-state IPv4 IGPs:

- **OSPF** - Popular standards based routing protocol

Types of Routing Protocols
Classful Routing Protocols

- Classful routing protocols do not send subnet mask information in their routing updates
  - Only RIPv1 and IGRP are classful
  - Created when network addresses were allocated based on classes (class A, B, or C)
  - Cannot provide variable length subnet masks (VLSMs) and classless interdomain routing (CIDR)
  - Create problems in discontiguous networks

Types of Routing Protocols
Classless Routing Protocols

- Classless routing protocols include subnet mask information in the routing updates
  - RIPv2, EIGRP, OSPF, and IS_IS
  - Support VLSM and CIDR
  - IPv6 routing protocols

Types of Routing Protocols

Routing Protocol Characteristics

	Distance Vector				Link State	
	RIPv1	RIPv2	IGRP	EIGRP	OSPF	IS-IS
Speed Convergence	Slow	Slow	Slow	Fast	Fast	Fast
Scalability - Size of Network	Small	Small	Small	Large	Large	Large
Use of VLSM	No	Yes	No	Yes	Yes	Yes
Resource Usage	Low	Low	Low	Medium	High	High
Implemenation and Maintenance	Simple	Simple	Simple	Complex	Complex	Complex

Types of Routing Protocols
Routing Protocol Metrics

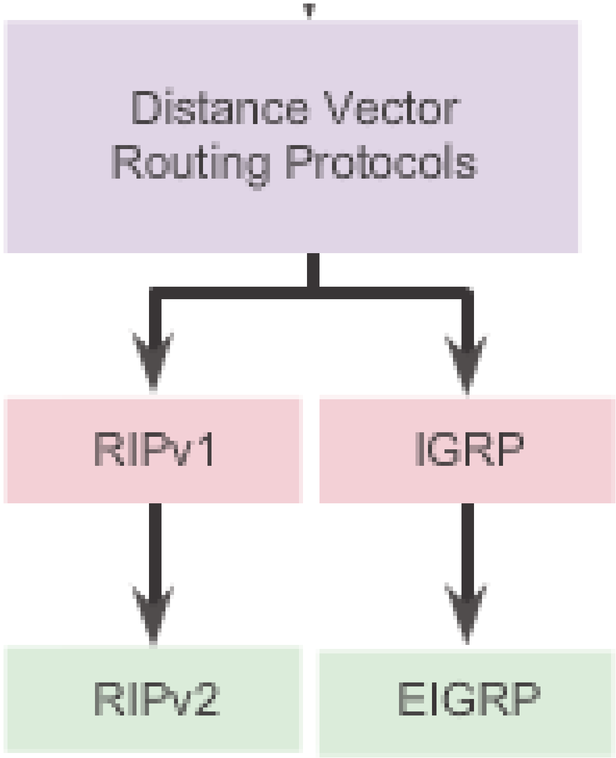
A metric is a measurable value that is assigned by the routing protocol to different routes based on the usefulness of that route

- Used to determine the overall “cost” of a path from source to destination
- Routing protocols determine the best path based on the route with the lowest cost

Distance Vector Technologies

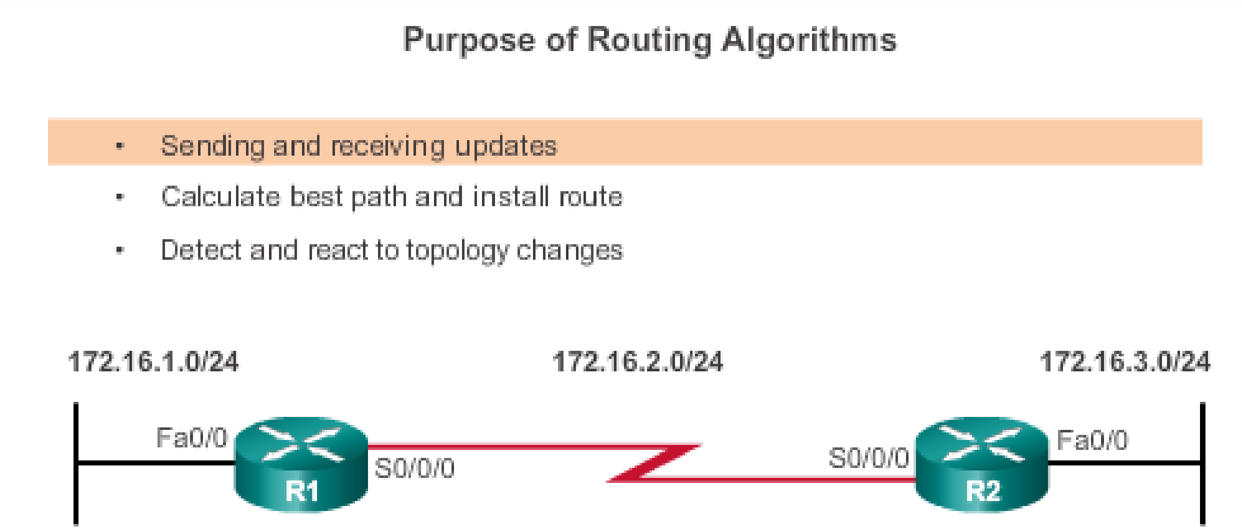
Distance vector routing protocols

- Share updates between neighbors
- Not aware of the network topology
- Some send periodic updates to broadcast IP 255.255.255.255 even if topology has not changed
- Updates consume bandwidth and network device CPU resources
- RIPv2 and EIGRP use multicast addresses
- EIGRP will only send an update when topology has changed



Distance Vector Routing Protocol Operation

Distance Vector Algorithm



RIP uses the Bellman-Ford algorithm as its routing algorithm

IGRP and EIGRP use the Diffusing Update Algorithm (DUAL) routing algorithm developed by Cisco

Types of Distance Vector Routing Protocols
Routing Information Protocol

RIPv1 versus RIPv2

Routing updates broadcasted every 30 seconds

Characteristics and Features	RIPv1	RIPv2
Metric	Both use hop count as a simple metric. The maximum number of hops is 15.	
Updates Forwarded to Address	255.255.255.255	224.0.0.9
Supports VLSM	✗	✓
Supports CIDR	✗	✓
Supports Summarization	✗	✓
Supports Authentication	✗	✓

Updates use UDP port 520

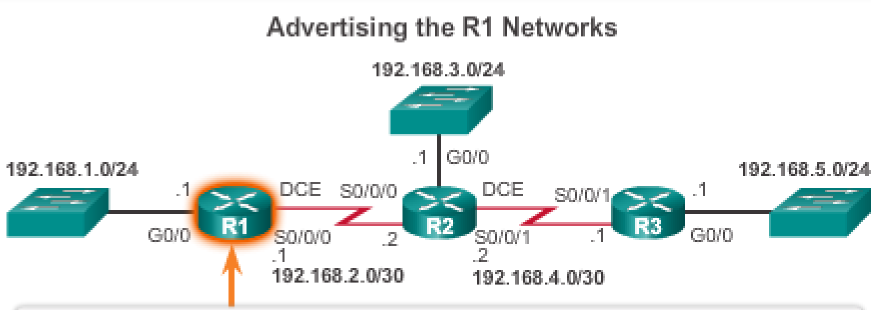
RIPng is based on RIPv2 with a 15 hop limitation and the administrative distance of 120

RIP Routing

Configuring the RIP Protocol

Router RIP Configuration Mode
Advertising Networks

```
R1# conf t
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# router rip
R1(config-router)#
```




```
R1(config)#router rip
R1(config-router)#network 192.168.1.0
R1(config-router)#network 192.168.2.0
R1(config-router)#
```

Configuring the RIP Protocol

Examining Default RIP Settings

Verifying RIP Settings on R1

```
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Sending updates every 30 seconds, next due in 16 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Redistributing: rip

  Default version control: send version 1, receive any version
    Interface             Send  Recv  Triggered RIP  Key-chain
    GigabitEthernet0/0    1     1 2
    Serial0/0/0           1     1 2

  Automatic network summarization is in effect
  Maximum path: 4
  Routing for Networks:
    192.168.1.0
    192.168.2.0

  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.2.2          120      00:00:15
  Distance: (default is 120)

R1#
```

Verifying RIP Routes on R1

```
R1# show ip route | begin Gateway
Gateway of last resort is not set

      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, GigabitEthernet0/0
L        192.168.1.1/32 is directly connected, GigabitEthernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/24 is directly connected, Serial0/0/0
L        192.168.2.1/32 is directly connected, Serial0/0/0
R     192.168.3.0/24 [120/1] via 192.168.2.2, 00:00:24, Serial0/0/0
R     192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:24, Serial0/0/0
R     192.168.5.0/24 [120/2] via 192.168.2.2, 00:00:24, Serial0/0/0
R1#
```

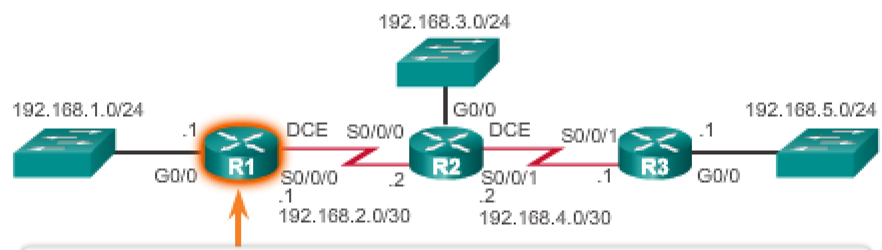
Configuring the RIP Protocol

Enabling RIPv2

Verifying RIP Settings on R1

```
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not
set
  Incoming update filter list for all interfaces is not
set
  Sending updates every 30 seconds, next due in 16 seconds
  Invalid after 180 seconds, hold down 180, flushed after
240
  Redistributing: rip
  Default version control: send version 1, receive any
version
    Interface           Send  Recv  Triggered RIP  Key-chain
    GigabitEthernet0/0    1     1 2
    Serial0/0/0           1     1 2
  Automatic network summarization is in effect
  Maximum path: 4
  Routing for Networks:
    192.168.1.0
    192.168.2.0
  Routing Information Sources:
    Gateway         Distance      Last Update
```

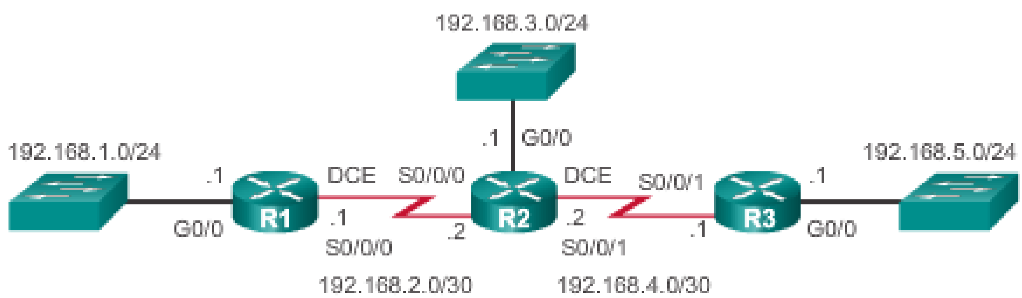
Enable and Verify RIPv2 on R1




```
R1(config)# router rip
R1(config-router)# version 2
R1(config-router)# ^Z
R1#
R1# show ip protocols | section Default
  Default version control: send version 2, receive version 2
    Interface           Send   Recv   Triggered RIP   Key-chain
    GigabitEthernet0/0    2      2
    Serial0/0/0           2      2
R1#
```

Configuring the RIP Protocol
Configuring Passive Interfaces

Configuring Passive Interfaces on R1



Sending out unneeded updates on a LAN impacts the network in three ways:

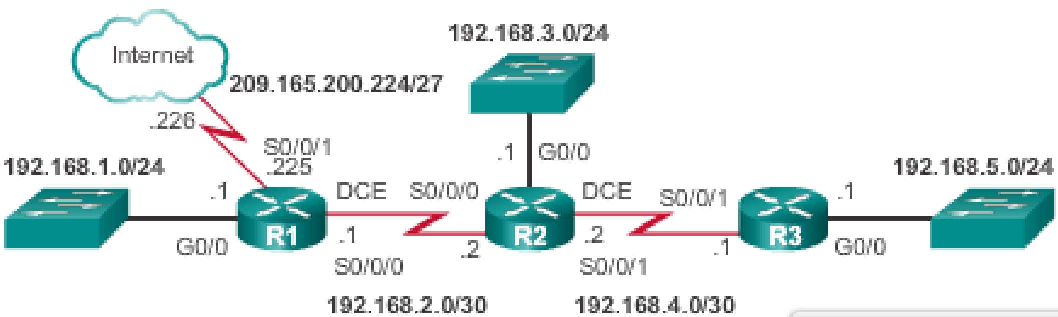
- **Wasted Bandwidth**
- **Wasted Resources**
- **Security Risk**

```
R1(config)# router rip
R1(config-router)# passive-interface g0/0
R1(config-router)# end
R1#
R1# show ip protocols | begin Default
  Default version control: send version 2, receive version 2
    Interface             Send  Recv  Triggered RIP  Key-chain
    Serial0/0/0           2     2
  Automatic network summarization is not in effect
  Maximum path: 4
  Routing for Networks:
    192.168.1.0
    192.168.2.0
  Passive Interface(s):
    GigabitEthernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.2.2          120      00:00:06
  Distance: (default is 120)

R1#
```

Configuring the RIP Protocol

Propagating a Default Route

Propagating a Default Route on R1

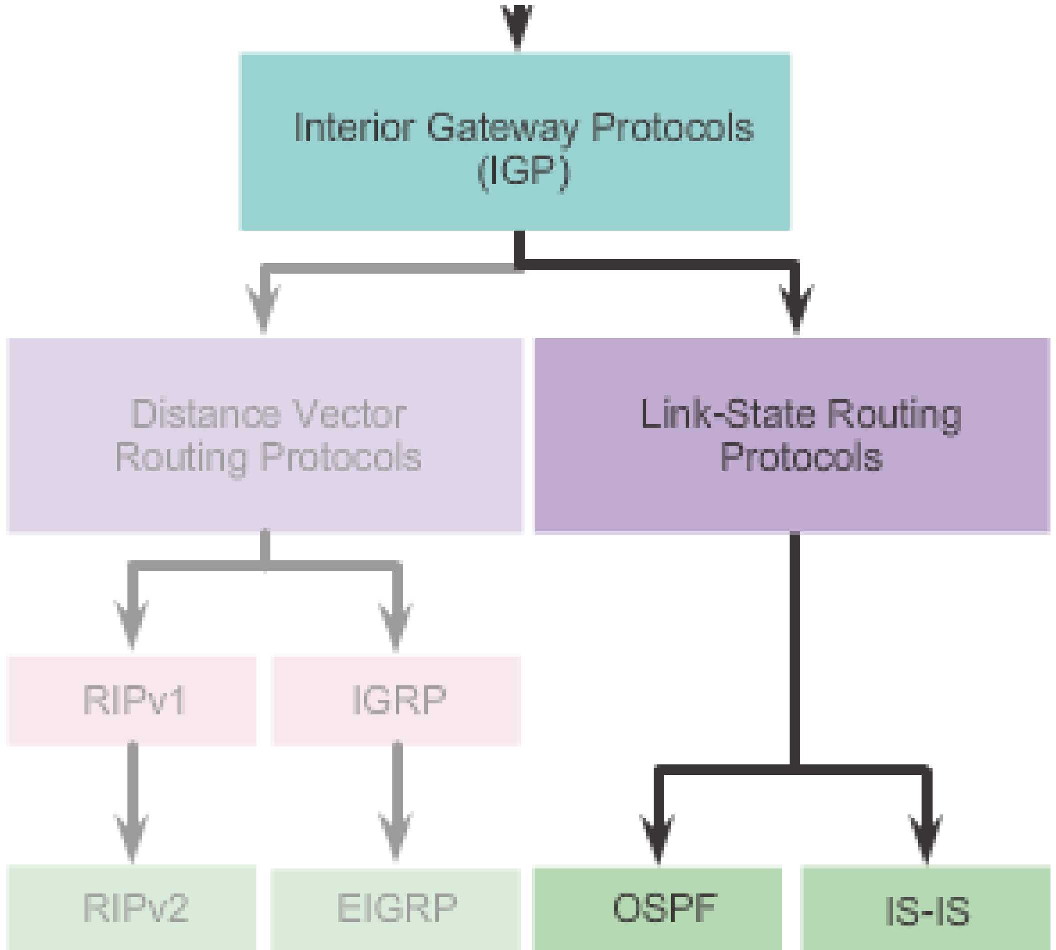



```
R1(config)# ip route 0.0.0.0 0.0.0.0 S0/0/1 209.165.200.226
R1(config)# router rip
R1(config-router)# default-information originate
R1(config-router)# ^Z
R1#
*Mar 10 23:33:51.801: %SYS-5-CONFIG_I: Configured from
console by console
R1# show ip route | begin Gateway
Gateway of last resort is 209.165.200.226 to network
0.0.0.0

S*    0.0.0.0/0 [1/0] via 209.165.200.226, Serial0/0/1
      192.168.1.0/24 is variably subnetted, 2 subnets, 2
masks
C        192.168.1.0/24 is directly connected,
GigabitEthernet0/0
L        192.168.1.1/32 is directly connected,
GigabitEthernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2
masks
C        192.168.2.0/24 is directly connected, Serial0/0/0
L        192.168.2.1/32 is directly connected, Serial0/0/0
R     192.168.3.0/24 [120/1] via 192.168.2.2, 00:00:08,
```

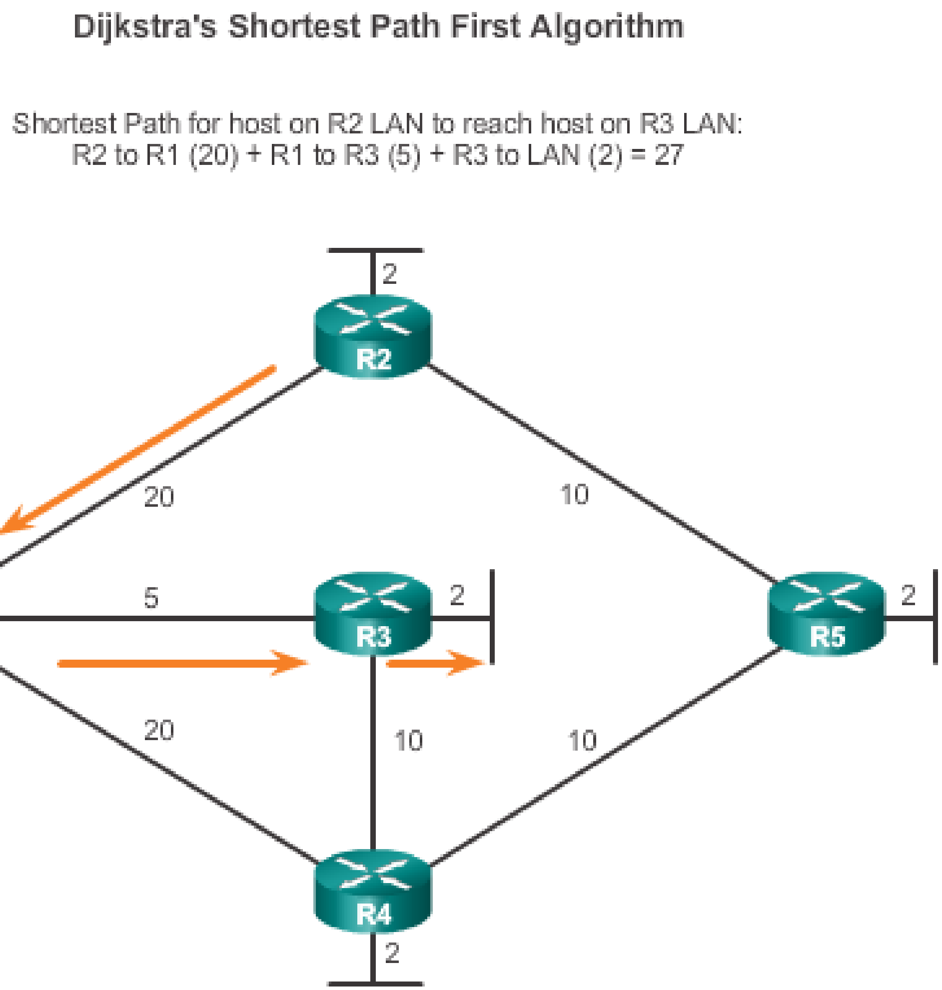
Link-State Dynamic Routing

Link-State Routing Protocol Operation

Shortest Path First Protocols



Link-State Routing Protocol Operation
Dijkstra's Algorithm



Link-State Updates

Link-State Routing Process

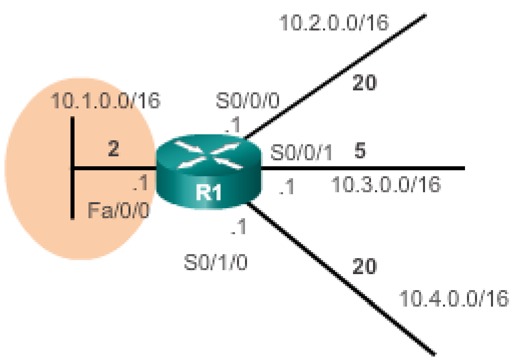
Link-State Routing Process

- Each router learns about each of its own directly connected networks.
- Each router is responsible for "saying hello" to its neighbors on directly connected networks.
- Each router builds a Link State Packet (LSP) containing the state of each directly connected link.
- Each router floods the LSP to all neighbors who then store all LSP's received in a database.
- Each router uses the database to construct a complete map of the topology and computers the best path to each destination networks.

Link and Link-State

The first step in the link-state routing process is that each router learns about its own links, its own directly connected networks.

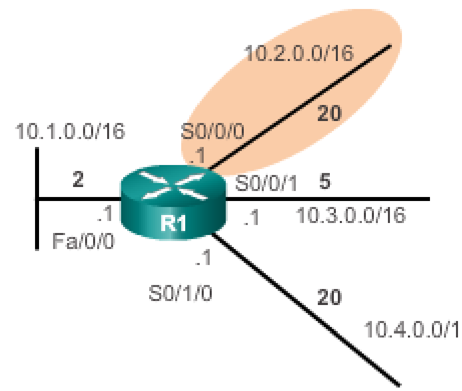
Link-State of Interface Fa0/0



Link 1

- Network: **10.1.0.0/16**
- IP address: **10.1.0.1**
- Type of network: **Ethernet**
- Cost of that link: **2**
- Neighbors: **None**

Link-State of Interface S0/0/0

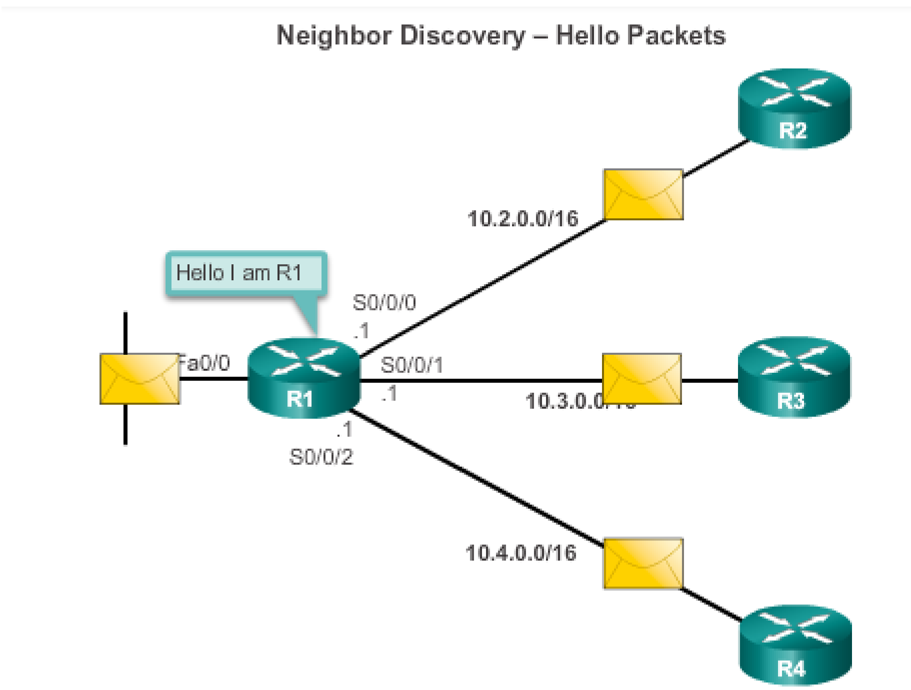


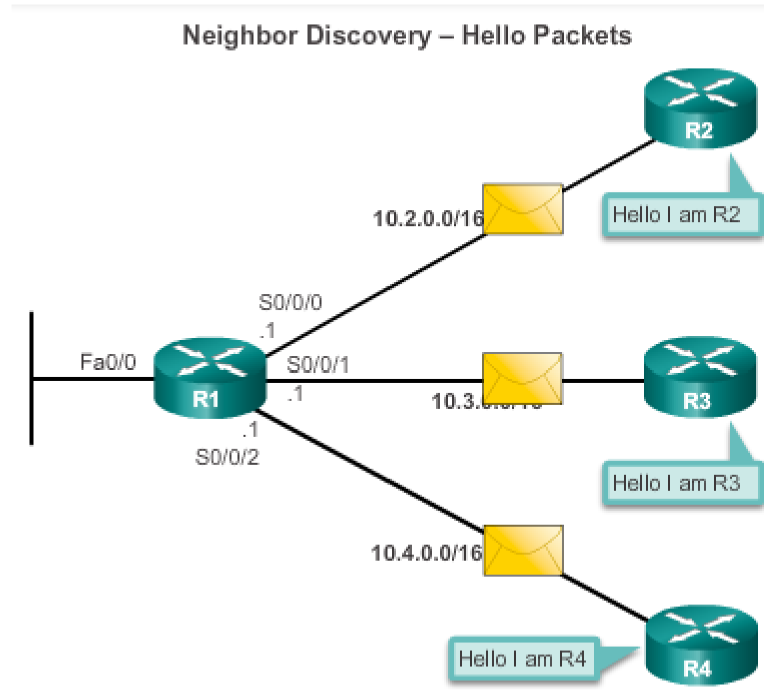
Link 2

- Network: **10.2.0.0/16**
- IP address: **10.2.0.1**
- Type of network: **Serial**
- Cost of that link: **20**
- Neighbors: **R2**

Link-State Updates
Say Hello

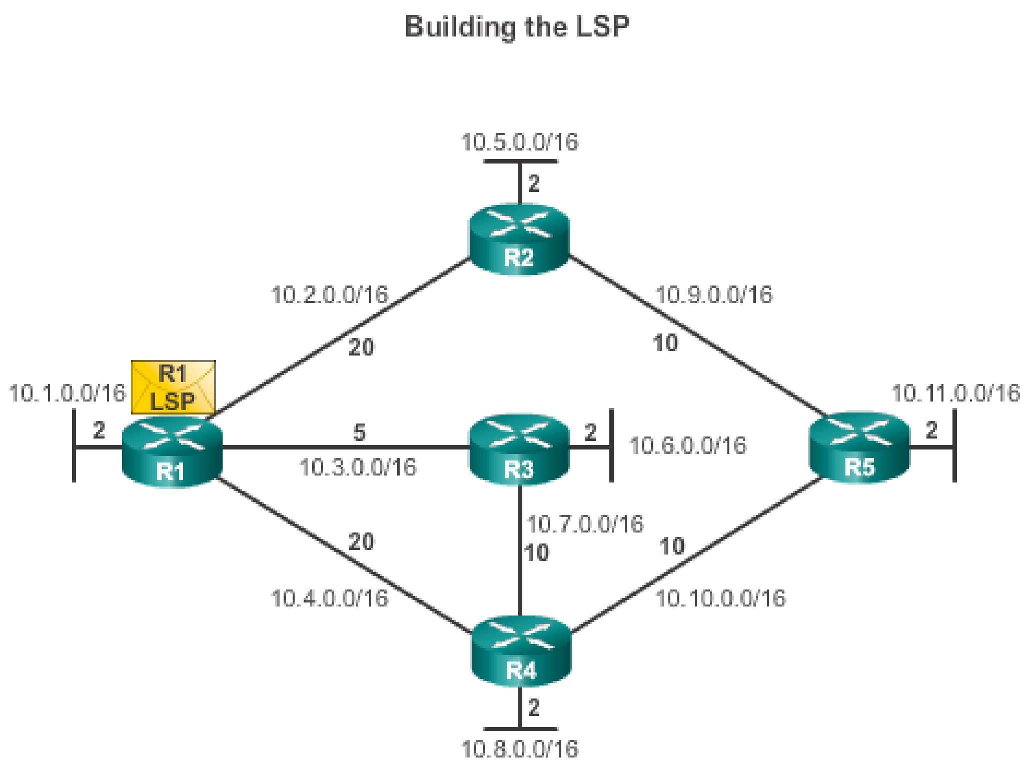
The second step in the link-state routing process is that each router is responsible for meeting its neighbors on directly connected networks.





Link-State Updates
LSP

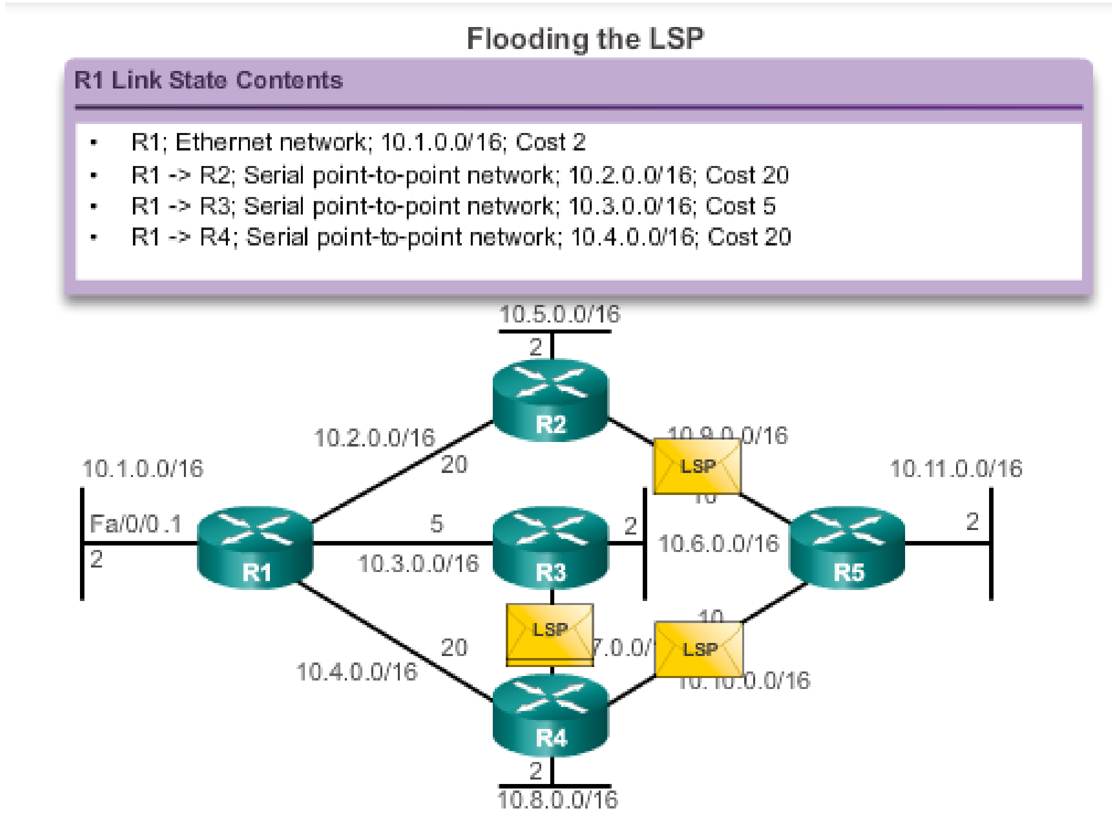
The third step in the link-state routing process is that each router builds a link-state packet (LSP) containing the state of each directly connected link.



1. R1; Ethernet network 10.1.0.0/16; Cost 2
2. R1 -> R2; Serial point-to-point network; 10.2.0.0/16; Cost 20
3. R1 -> R3; Serial point-to-point network; 10.3.0.0/16; Cost 5
4. R1 -> R4; Serial point-to-point network; 10.4.0.0/16; Cost 20

Link-State Updates
Flooding the LSP

The fourth step in the link-state routing process is that each router floods the LSP to all neighbors, who then store all LSPs received in a database.



Link-State Updates
Building the Link-State Database

The final step in the link-state routing process is that each router uses the database to construct a complete map of the topology and computes the best path to each destination network.

Contents of the Link-State Database

R1 Link-State Database

R1 Link-states:
- Connected to network 10.1.0.0/16, cost = 2
- Connected to R2 on network 10.2.0.0/16, cost = 20
- Connected to R3 on network 10.3.0.0/16, cost = 5
- Connected to R4 on network 10.4.0.0/16, cost = 20

R2 Link-states:
- Connected to network 10.5.0.0/16, cost = 2
- Connected to R1 on network 10.2.0.0/16, cost = 20
- Connected to R5 on network 10.9.0.0/16, cost = 10

R3 Link-states:
- Connected to network 10.6.0.0/16, cost = 2
- Connected to R1 on network 10.3.0.0/16, cost = 5
- Connected to R4 on network 10.7.0.0/16, cost = 10

R4 Link-states:
- Connected to network 10.8.0.0/16, cost = 2
- Connected to R1 on network 10.4.0.0/16, cost = 20
- Connected to R3 on network 10.7.0.0/16, cost = 10
- Connected to R5 on network 10.10.0.0/16, cost = 10

R5 Link-states:
- Connected to network 10.11.0.0/16, cost = 2
- Connected to R2 on network 10.9.0.0/16, cost = 10
- Connected to R4 on network 10.10.0.0/16, cost = 10

Building the SPF Tree

Identify the Directly Connected Networks

R1 Link-State Database	SPF Tree

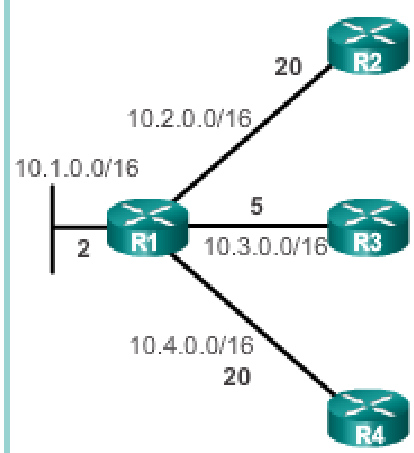
R1 Link-states:
- Connected to network 10.1.0.0/16, cost = 2
- Connected to R2 on network 10.2.0.0/16, cost = 20
- Connected to R3 on network 10.3.0.0/16, cost = 5
- Connected to R4 on network 10.4.0.0/16, cost = 20

R2 Link-states:
- Connected to network 10.5.0.0/16, cost = 2
- Connected to R1 on network 10.2.0.0/16, cost = 20
- Connected to R5 on network 10.9.0.0/16, cost = 10

R3 Link-states:
- Connected to network 10.6.0.0/16, cost = 2
- Connected to R1 on network 10.3.0.0/16, cost = 5
- Connected to R4 on network 10.7.0.0/16, cost = 10

R4 Link-states:
- Connected to network 10.8.0.0/16, cost = 2
- Connected to R1 on network 10.4.0.0/16, cost = 20
- Connected to R3 on network 10.7.0.0/16, cost = 10
- Connected to R5 on network 10.10.0.0/16, cost = 10

R5 Link-states:
- Connected to network 10.11.0.0/16, cost = 2
- Connected to R2 on network 10.9.0.0/16, cost = 10
- Connected to R4 on network 10.10.0.0/16, cost = 10

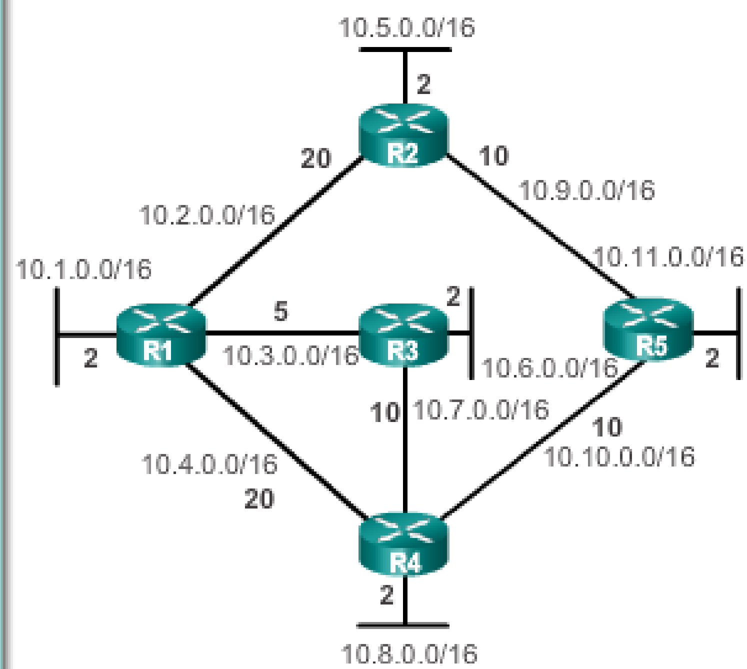


Link-State Updates

Building the SPF Tree

Resulting SPF Tree of R1

Destination	Shortest Path	Cost
10.5.0.0/16	R1 → R2	22
10.6.0.0/16	R1 → R3	7
10.7.0.0/16	R1 → R3	15
10.8.0.0/16	R1 → R3 → R4	17
10.9.0.0/16	R1 → R2	30
10.10.0.0/16	R1 → R3 → R4	25
10.11.0.0/16	R1 → R3→ R4→ R5	27



Link-State Updates

Adding OSPF Routes to the Routing Table

Populate the Routing Table

Destination	Shortest Path	Cost
10.5.0.0/16	R1 → R2	22
10.6.0.0/16	R1 → R3	7
10.7.0.0/16	R1 → R3	15
10.8.0.0/16	R1 → R3 → R4	17
10.9.0.0/16	R1 → R2	30
10.10.0.0/16	R1 → R3 → R4	25
10.11.0.0/16	R1 → R3 → R4 → R5	27

R1 Routing Table

Directly Connected Networks

- 10.1.0.0/16 Directly Connected Network
- 10.2.0.0/16 Directly Connected Network
- 10.3.0.0/16 Directly Connected Network
- 10.4.0.0/16 Directly Connected Network

Remote Networks

- 10.5.0.0/16 via R2 serial 0/0/0,cost=22
- 10.6.0.0/16 via R3 serial 0/0/1,cost=7
- 10.7.0.0/16 via R3 serial 0/0/1,cost=15
- 10.8.0.0/16 via R3 serial 0/0/1,cost=17
- 10.9.0.0/16 via R2 serial 0/0/0,cost=30
- 10.10.0.0/16 via R3 serial 0/0/1,cost=25
- 10.11.0.0/16 via R3 serial 0/0/1,cost=27

Why Use Link-State Routing Protocols

Why Use Link-State Protocols?

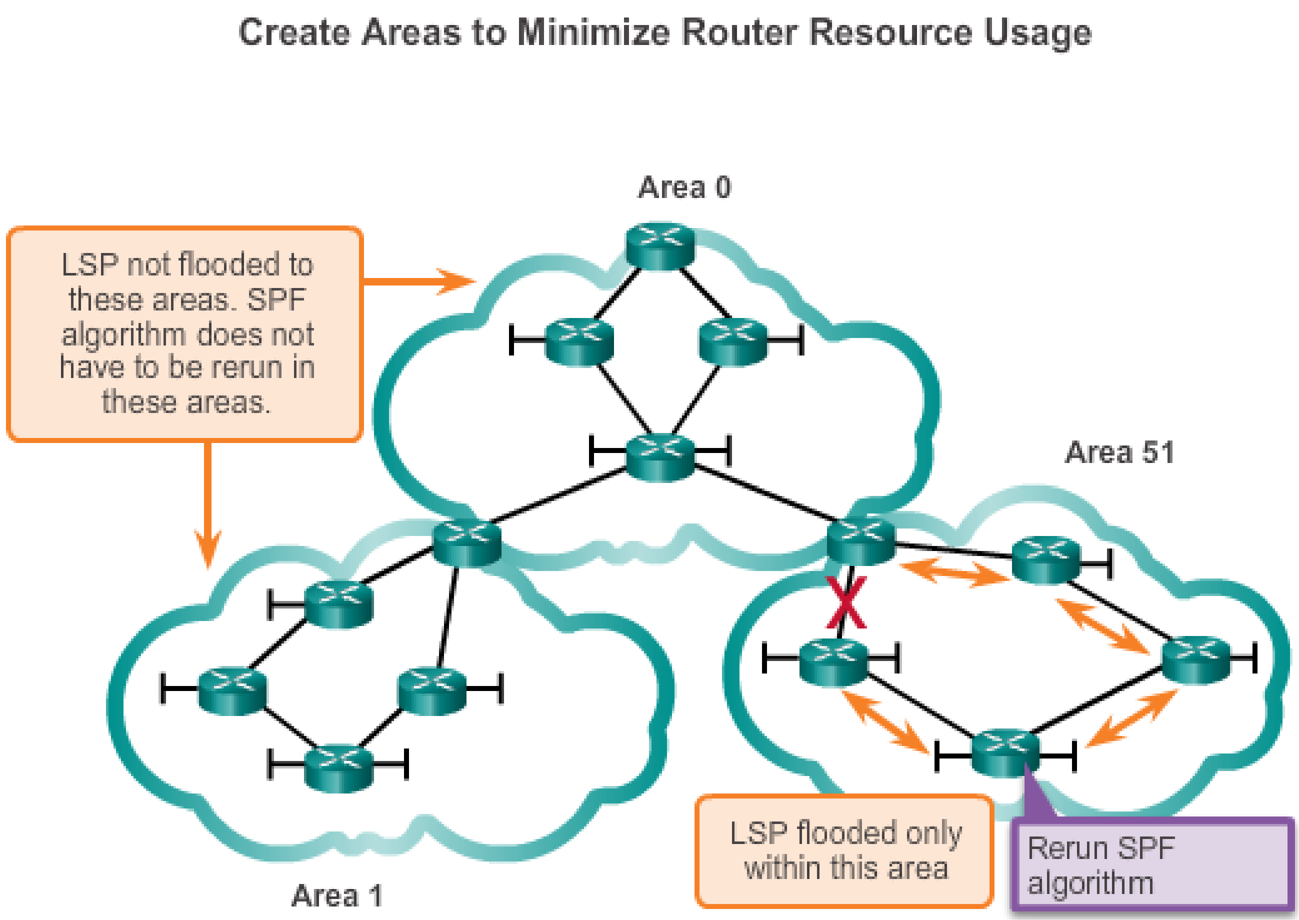
Advantages of Link-State Routing Protocols

- Each router builds its own topological map of the network to determine the shortest path.
- Immediate flooding of LSPs achieves faster convergence.
- LSPs are sent only when there is a change in the topology and contain only the information regarding that change.
- Hierarchical design used when implementing multiple areas.

Disadvantages compared to distance vector routing protocols:

- Memory Requirements
- Processing Requirements
- Bandwidth Requirements

Why Use Link-State Routing Protocols
Disadvantages of Link-State Protocols



The Routing Table

Parts of an IPv4 Route Entry
Routing Table Entries

Routing Table of R1

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0

S* 0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
                     is directly connected, Serial0/0/1
   172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
C     172.16.1.0/24 is directly connected, GigabitEthernet0/0
L     172.16.1.1/32 is directly connected, GigabitEthernet0/0
R     172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
R     172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R     172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R  192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03, Serial0/0/0
   209.165.200.0/24 is variably subnetted, 5 subnets, 2 masks
C     209.165.200.224/30 is directly connected, Serial0/0/0
L     209.165.200.225/32 is directly connected, Serial0/0/0
R     209.165.200.228/30 [120/1] via 209.165.200.226, 00:00:12,
                Serial0/0/0
C     209.165.200.232/30 is directly connected, Serial0/0/1
L     209.165.200.233/30 is directly connected, Serial0/0/1
R1#
```

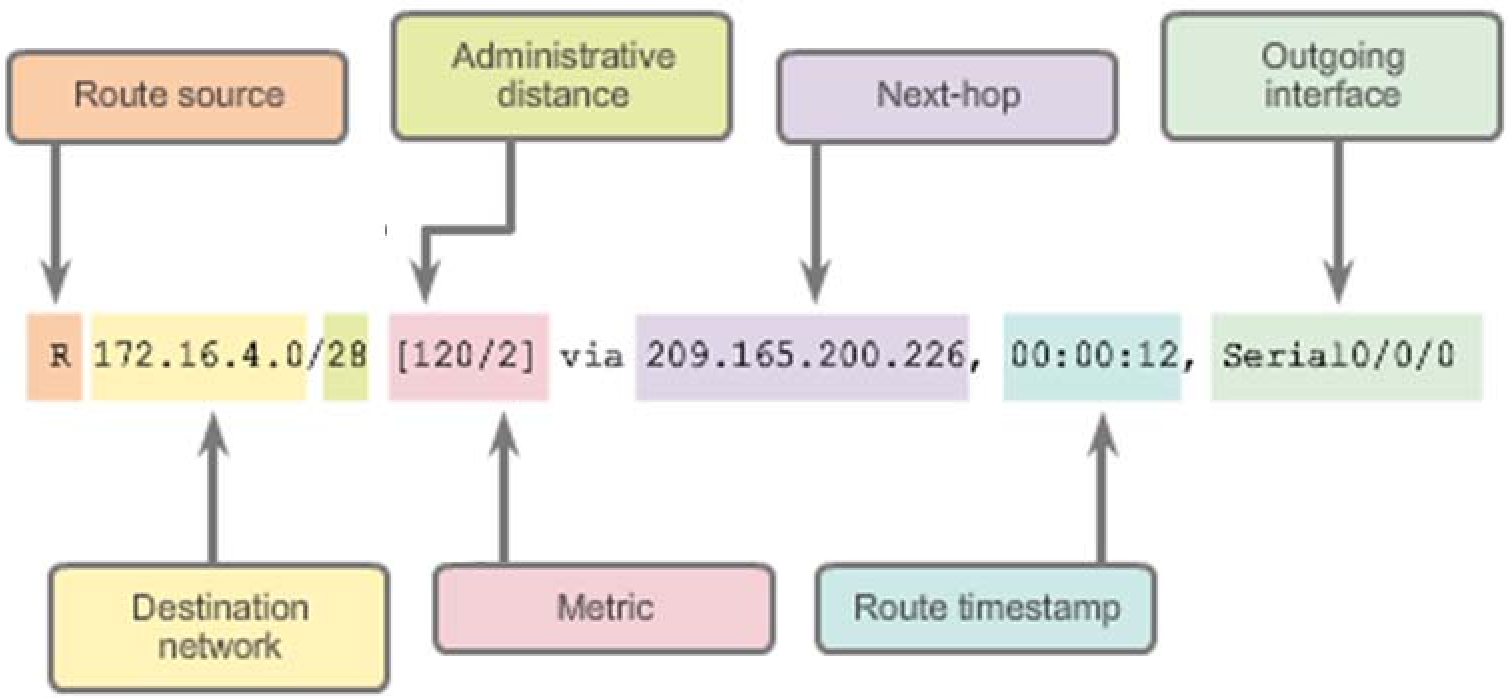
Directly Connected Entries

Directly Connected Interfaces of R1

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0

S* 0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
                is directly connected, Serial0/0/1
   172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
C     172.16.1.0/24 is directly connected, GigabitEthernet0/0
L     172.16.1.1/32 is directly connected, GigabitEthernet0/0
R     172.16.2.0/24 [120/1] via 209.165.200.226,00:00:12, Serial0/0/0
R     172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R     172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12, Serial0/0/0
R     192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03, Serial0/0/0
   209.165.200.0/24 is variably subnetted, 5 subnets, 2 masks
C     209.165.200.224/30 is directly connected, Serial0/0/0
L     209.165.200.225/32 is directly connected, Serial0/0/0
R     209.165.200.228/30 [120/1] via 209.165.200.226, 00:00:12, Serial0/0/0
C     209.165.200.232/30 is directly connected, Serial0/0/1
L     209.165.200.233/32 is directly connected, Serial0/0/1
R1#
```

Parts of an IPv4 Route Entry

Remote Network Entries



Dynamically Learned IPv4 Routes
Routing Table Terms

Routes are discussed in terms of:

- Ultimate route
- Level 1 route
- Level 1 parent route
- Level 2 child routes

Routing Table of R1

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
                is directly connected, Serial0/0/1
      172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
C        172.16.1.0/24 is directly connected, GigabitEthernet0/0
L        172.16.1.1/32 is directly connected, GigabitEthernet0/0
R        172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12,
         Serial0/0/0
R        172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12,
         Serial0/0/0
R        172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12,
         Serial0/0/0
R     192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03,
      Serial0/0/0
      209.165.200.0/24 is variably subnetted, 5 subnets, 2 masks
C        209.165.200.224/30 is directly connected, Serial0/0/0
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R        209.165.200.228/30 [120/1] via 209.165.200.226, 00:00:12,
         Serial0/0/0
C        209.165.200.232/30 is directly connected, Serial0/0/1
L        209.165.200.233/32 is directly connected, Serial0/0/1
R1#
```

Dynamically Learned IPv4 Routes
Ultimate Route

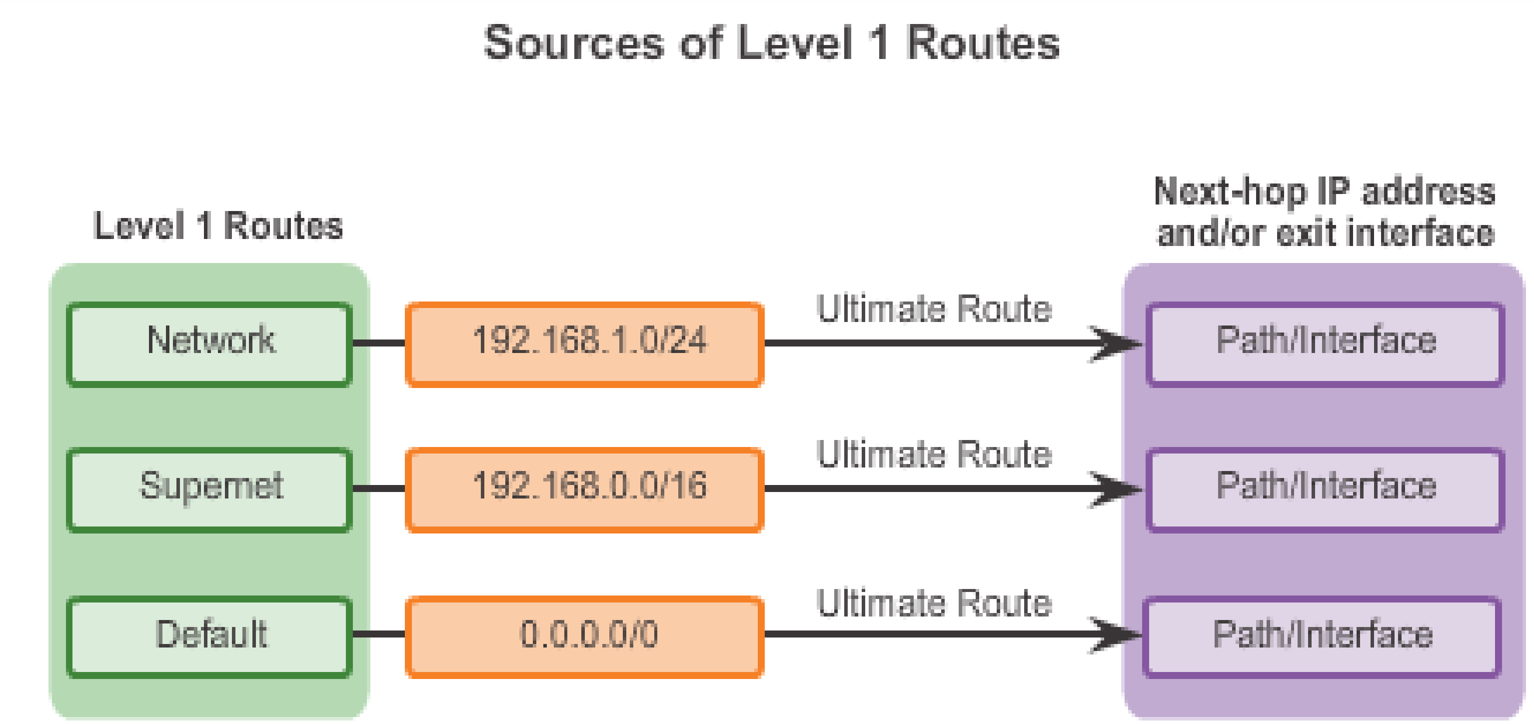
An ultimate route is a routing table entry that contains either a next-hop IP address or an exit interface. Directly connected, dynamically learned are ultimate routes.

Ultimate Routes of R1

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
                is directly connected, Serial0/0/1
      172.16.0.0/16 is variably subnetted, 5 subnets, 3 masks
C        172.16.1.0/24 is directly connected, GigabitEthernet0/0
L        172.16.1.1/32 is directly connected, GigabitEthernet0/0
R        172.16.2.0/24 [120/1] via 209.165.200.226, 00:00:12,
         Serial0/0/0
R        172.16.3.0/24 [120/2] via 209.165.200.226, 00:00:12,
          Serial0/0/0
R        172.16.4.0/28 [120/2] via 209.165.200.226, 00:00:12,
         Serial0/0/0
R     192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03,
      Serial0/0/0
      209.165.200.0/24 is variably subnetted, 5 subnets, 2 masks
C        209.165.200.224/30 is directly connected, Serial0/0/0
L        209.165.200.225/32 is directly connected, Serial0/0/0
R        209.165.200.228/30 [120/1] via 209.165.200.226, 00:00:12,
         Serial0/0/0
C        209.165.200.232/30 is directly connected, Serial0/0/1
L        209.165.200.233/32 is directly connected, Serial0/0/1
R1#
```

Dynamically Learned IPv4 Routes
Level 1 Route



Dynamically Learned IPv4 Routes
Level 1 Parent Route

Level 1 Parent Routes of R1

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network
0.0.0.0

S*    0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
                is directly connected, Serial0/0/1
      172.16.0.0/16 is variably subnetted, 5 subnets, 3
masks
C        172.16.1.0/24 is directly connected,
GigabitEthernet0/0
L        172.16.1.1/32 is directly connected,
GigabitEthernet0/0
R        172.16.2.0/24 [120/1] via 209.165.200.226,
00:00:12, Serial0/0/0
R        172.16.3.0/24 [120/2] via 209.165.200.226,
00:00:12, Serial0/0/0
R        172.16.4.0/28 [120/2] via 209.165.200.226,
00:00:12, Serial0/0/0
R     192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03,
Serial0/0/0
      209.165.200.0/24 is variably subnetted, 5 subnets, 2
masks
C        209.165.200.224/30 is directly connected,
Serial0/0/0
```

Dynamically Learned IPv4 Routes
Level 2 Child Route

Example of Level 2 Child Routes

```
R1#show ip route | begin Gateway
Gateway of last resort is 209.165.200.234 to network
0.0.0.0

S*    0.0.0.0/0 [1/0] via 209.165.200.234, Serial0/0/1
                is directly connected, Serial0/0/1
      172.16.0.0/16 is variably subnetted, 5 subnets, 3
masks
C        172.16.1.0/24 is directly connected,
GigabitEthernet0/0
L        172.16.1.1/32 is directly connected,
GigabitEthernet0/0
R        172.16.2.0/24 [120/1] via 209.165.200.226,
00:00:12, Serial0/0/0
R        172.16.3.0/24 [120/2] via 209.165.200.226,
00:00:12, Serial0/0/0
R        172.16.4.0/28 [120/2] via 209.165.200.226,
00:00:12, Serial0/0/0
R     192.168.0.0/16 [120/2] via 209.165.200.226, 00:00:03,
Serial0/0/0
      209.165.200.0/24 is variably subnetted, 5 subnets, 2
masks
C        209.165.200.224/30 is directly connected,
Serial0/0/0
```

The IPv4 Route Lookup Process
Best Route = Longest Match

Matches for Packet Destined to 172.16.0.10

IP Packet Destination	172.16.0.10	10101100.00010000.00000000.00001010

Route 1	172.16.0.0/12	10101100.00010000.00000000.00000000
Route 2	172.16.0.0/18	10101100.00010000.00000000.00000000
Route 3	172.16.0.0/26	10101100.00010000.00000000.00000000

Longest Match to IP Packet Destination

Single-Area OSPF

Routing Protocols

Open Shortest Path First

Evolution of OSPF

Interior Gateway Protocols

	Interior Gateway Protocols				Exterior Gateway Protocols
	Distance Vector		Link-State		Path Vector
IPv4	RIPv2	EIGRP	OSPFv2	IS-IS	BGP-4
IPv6	RIPng	EIGRP for IPv6	OSPFv3	IS-IS for IPv6	BGP-MP

1988

1989 updated in 2008

Open Shortest Path First
Features of OSPF

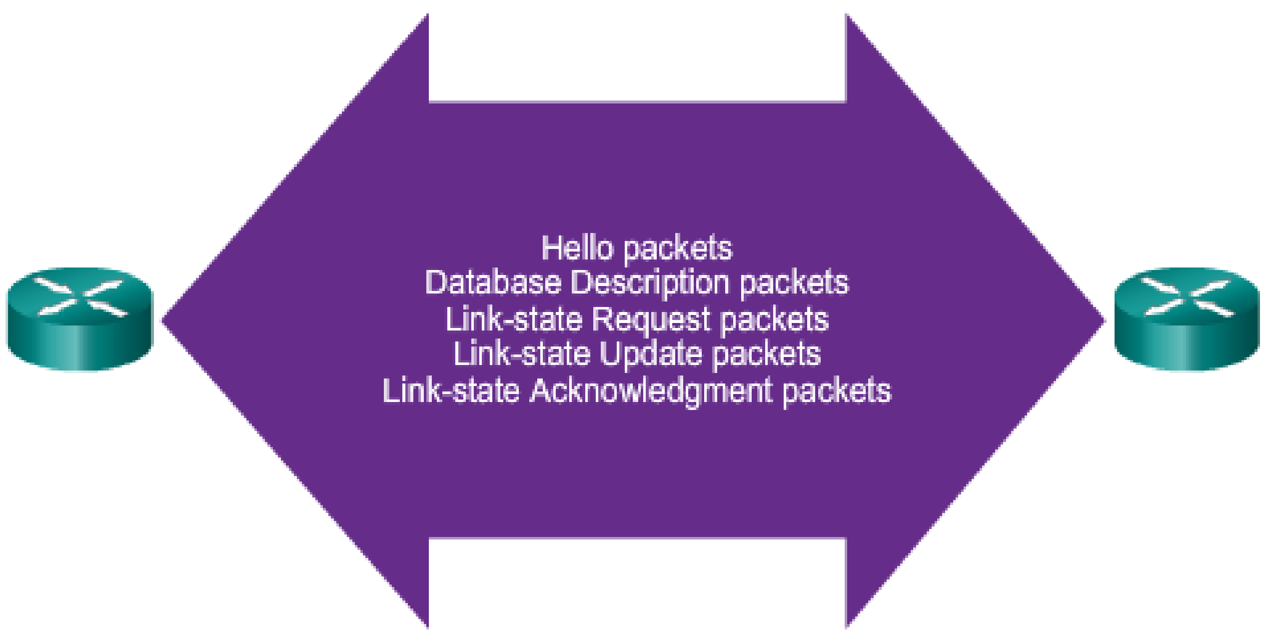
Components of OSPF

OSPF Data Structures

Database	Table	Description
Adjacency Database	Neighbor Table	• List of all neighbor routers to which a router has established bidirectional communication. • This table is unique for each router. • Can be viewed using the **`show ip ospf neighbor`** command.
Link-state Database (LSDB)	Topology Table	• Lists information about all other routers in the network. • The database shows the network topology. • All routers within an area have identical LSDB. • Can be viewed using the **`show ip ospf database`** command.
Forwarding Database	Routing Table	• List of routes generated when an algorithm is run on the link-state database. • Each router's routing table is unique and contains information on how and where to send packets to other routers. • Can be viewed using the **`show ip route`** command.

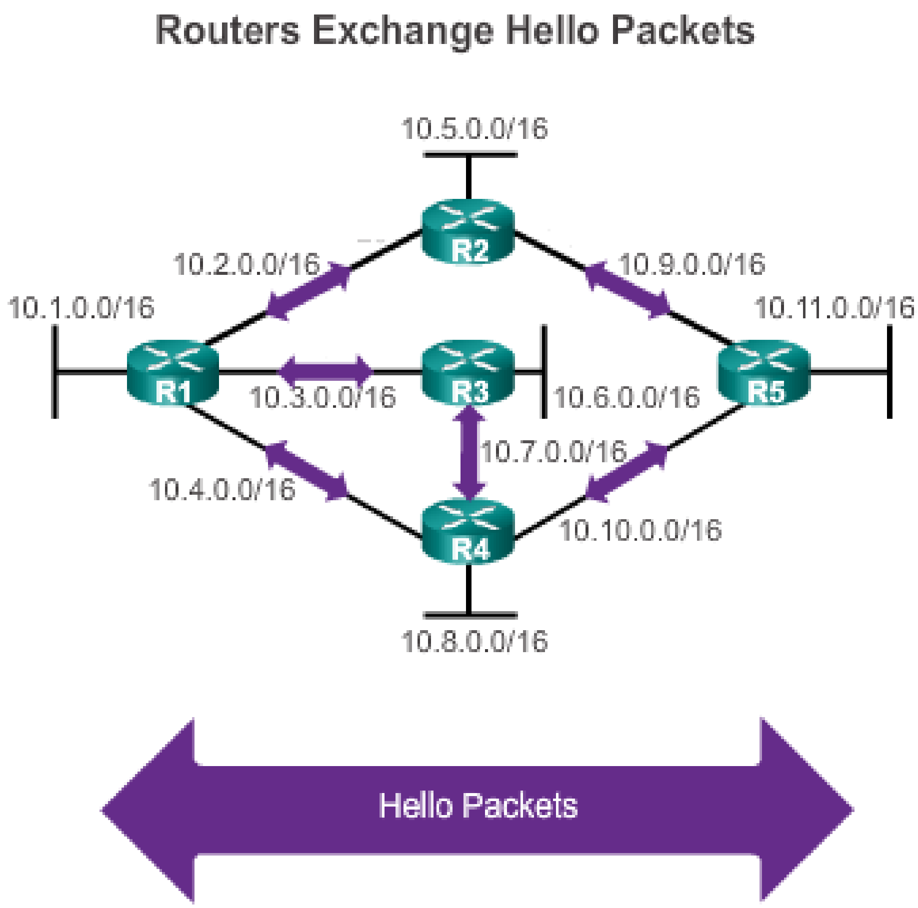
Open Shortest Path First
Components of OSPF

OSPF Routers Exchange Packets - These packets are used to discover neighboring routers and also to exchange routing information to maintain accurate information about the network.



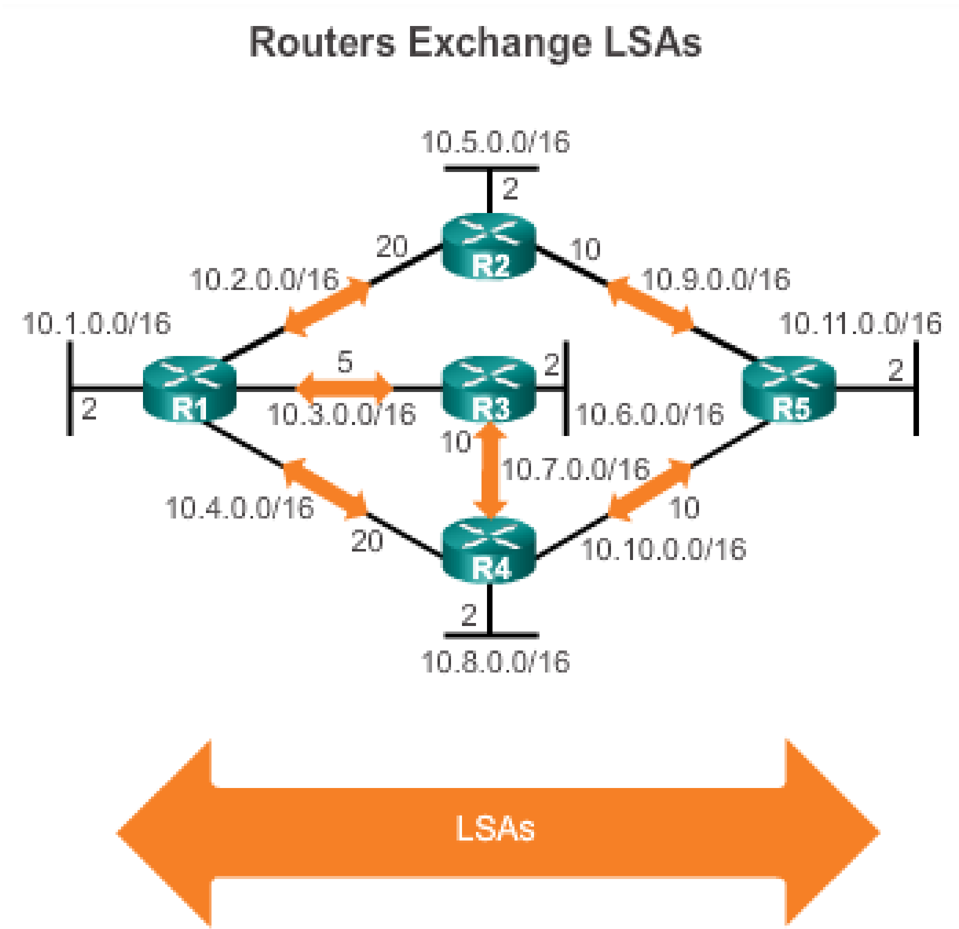
Open Shortest Path First

Link-State Operation



If a neighbor is present, the OSPF-enabled router attempts to establish a neighbor adjacency with that neighbor

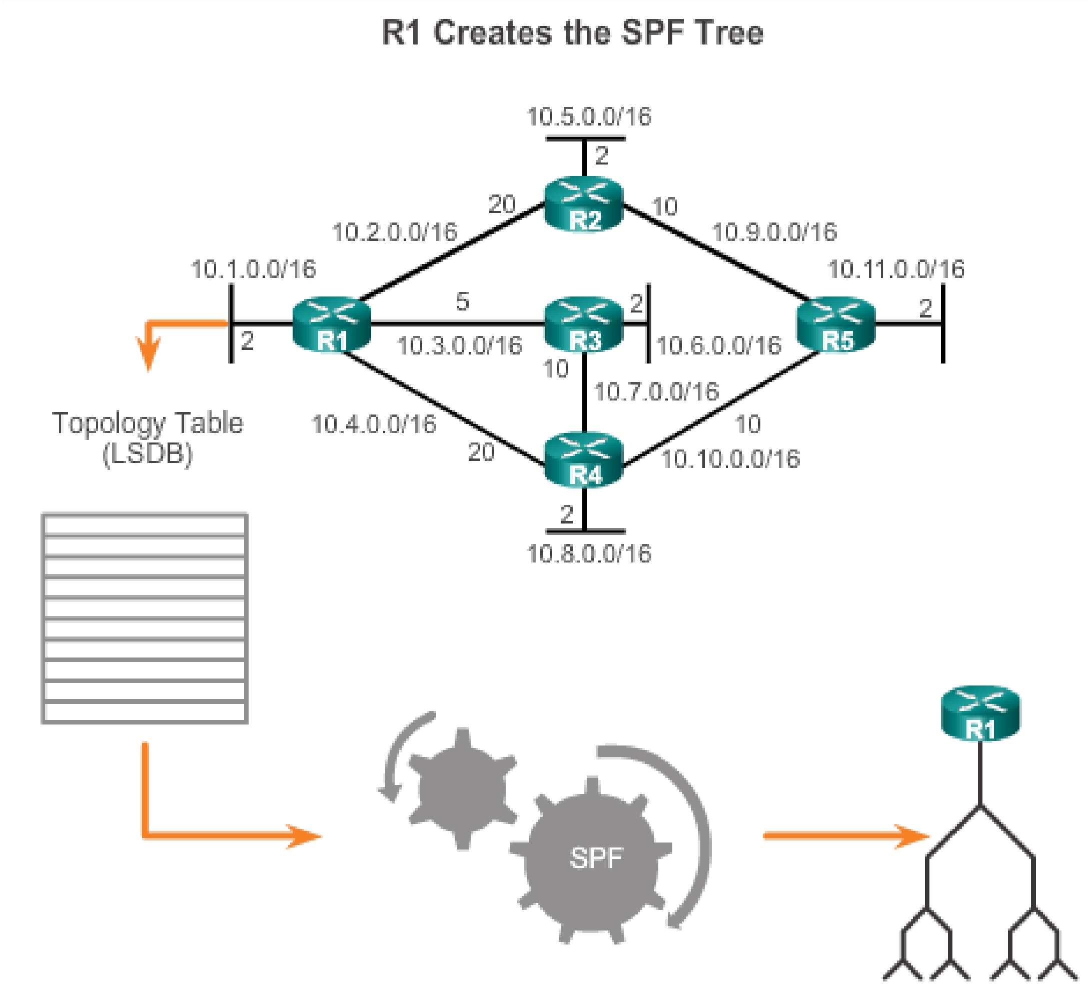
Open Shortest Path First
Link-State Operation



- LSAs contain the state and cost of each directly connected link.
- Routers flood their LSAs to adjacent neighbors.
- Adjacent neighbors receiving the LSA immediately flood the LSA to other directly connected neighbors, until all routers in the area have all LSAs.

Open Shortest Path First

Link-State Operation

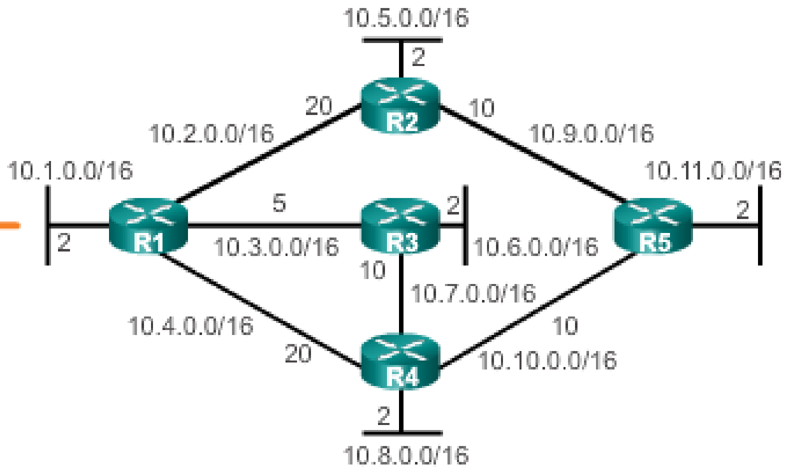


- Build the topology table based on the received LSAs.
- This database eventually holds all the information about the topology of the network.
- Execute the SPF Algorithm.

Open Shortest Path First

Link-State Operation

Content of the R1 SPF Tree



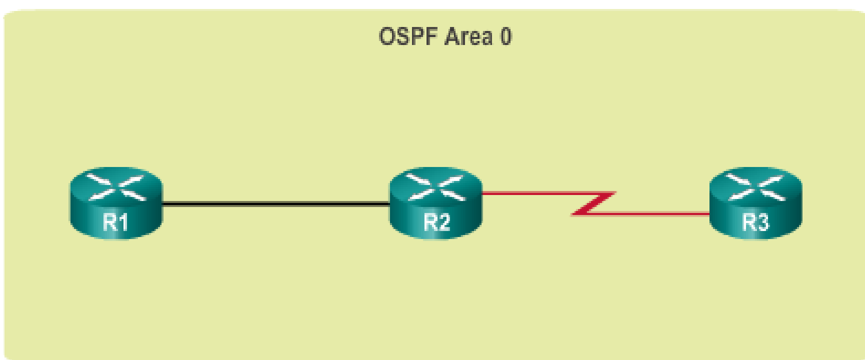
Destination	Shortest Path	Cost
10.5.0.0/16	R1 → R2	22
10.6.0.0/16	R1 → R3	7
10.7.0.0/16	R1 → R3	15
10.8.0.0/16	R1 → R3 → R4	17
10.9.0.0/16	R1 → R2	30
10.10.0.0/16	R1 → R3 → R4	25
10.11.0.0/16	R1 → R3 → R4 → R5	27

From the SPF tree, the best paths are inserted into the routing table.

Open Shortest Path First

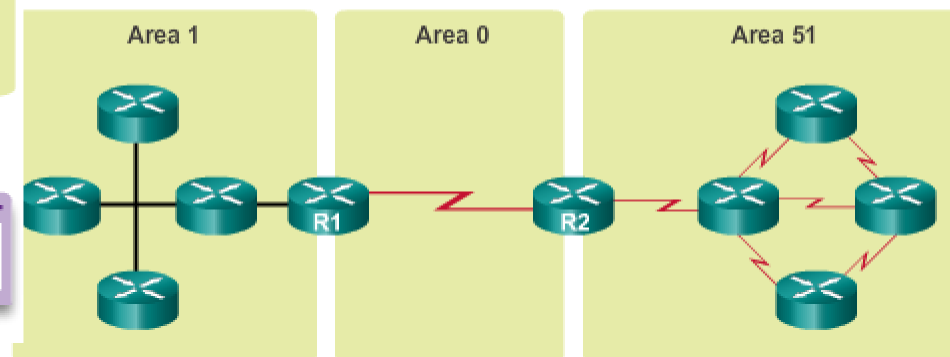
Single-area and Multiarea OSPF

Single-Area OSPF



- Area 0 is also called the backbone area.
- Single-area OSPF is useful in smaller networks with few routers.

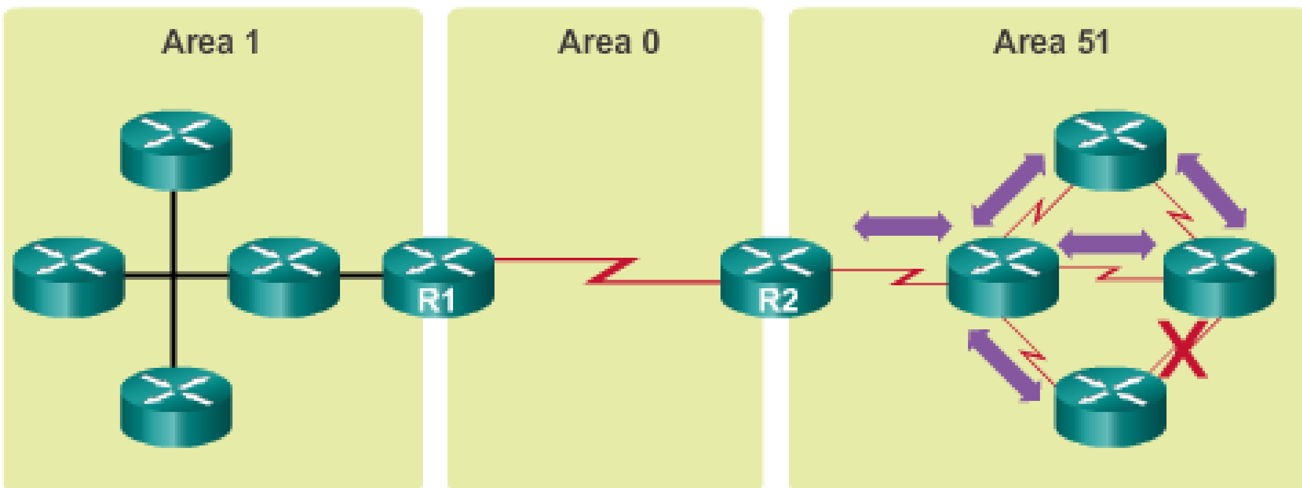
Multiarea OSPF



- Implemented using a two-layer area hierarchy as all areas must connect to the backbone area (area 0).
- Interconnecting routers are called Area Border Routers (ABR).
- Useful in larger network deployments to reduce processing and memory overhead.

Open Shortest Path First
Single-area and Multiarea OSPF

Link Change Impacts Local Area Only



- Link failure affects the local area only (area 51).
- The ABR (R2) isolates the fault to area 51 only.
- Routers in areas 0 and 1 do not need the run the SPF algorithm.

OSPF Messages

Encapsulating OSPF Messages

OSPF IPv4 Header Fields

Data Link Frame Header	IP Packet Header	OSPF Packet Header	OSPF Packet Type-Specific Database

Data Link Frame (Ethernet Fields shown here)
MAC Destination Address = Multicast: 01-00-5E-00-00-05 or 01-00-5E-00-00-06
MAC Source Address = Address of sending interface

IP Packet
IP Source Address = Address of sending interface
IP Destination Address = Multicast: 224.0.0.5 or 224.0.0.6
Protocol field = 89 for OSPF

OSPF Packet Header
Type code for OSPF Packet type
Router ID and Area Id

OSPF Packet types
0x01 Hello
0x02 Database Description (DD)
0X03 Link State Request
0X04 Link State Update
0X05 Link State Acknowledgment

OSPF Messages

Types of OSPF Packets

OSPF Packet Descriptions

Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them
2	Database Description (DBD)	Checks for database synchronization between routers
3	Link-State Request (LSR)	Requests specific link-state records from router to router
4	Link-State Update (LSU)	Sends specifically requested link-state records
5	Link-State Acknowledgment (LSAck)	Acknowledges the other packet types

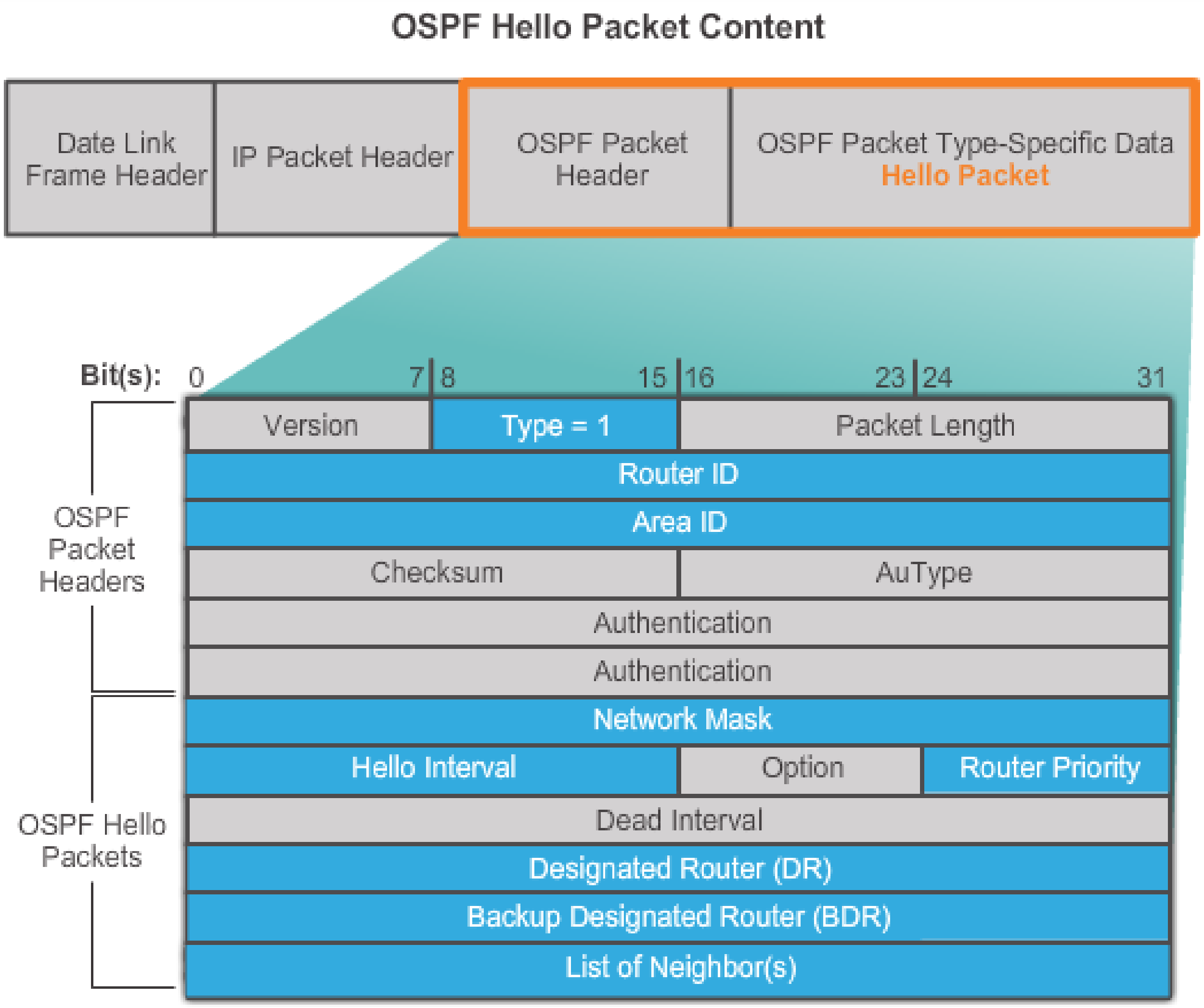
OSPF Messages
Hello Packet

OSPF Type 1 packet = Hello packet

- Discover OSPF neighbors and establish neighbor adjacencies
- Advertise parameters on which two routers must agree to become neighbors
- Elect the Designated Router (DR) and Backup Designated Router (BDR) on multiaccess networks like Ethernet.

OSPF Messages

Hello Packet



OSPF Messages
Hello Packet Intervals

OSPF Hello packets are transmitted

- To 224.0.0.5 in IPv4
- Every 10 seconds (default on multiaccess and point-to-point networks)
- Every 30 seconds (default on non-broadcast multiaccess [NBMA] networks)
- Dead interval is the period that the router waits to receive a Hello packet before declaring the neighbor down
- Router floods the LSDB with information about down neighbors out all OSPF enabled interfaces
- Cisco’s default is 4 times the Hello interval

OSPF Messages
Link-State Updates

LSUs Contain LSAs

Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them
2	DBD	Checks for database synchronization between router
3	LSR	Requests specific link-state records from router to router
4	LSU	Sends specifically requested link-state records
5	LSAck	Acknowledges the other packet types

- An LSU contains one or more LSAs.
- LSAs contain route information for destination networks.

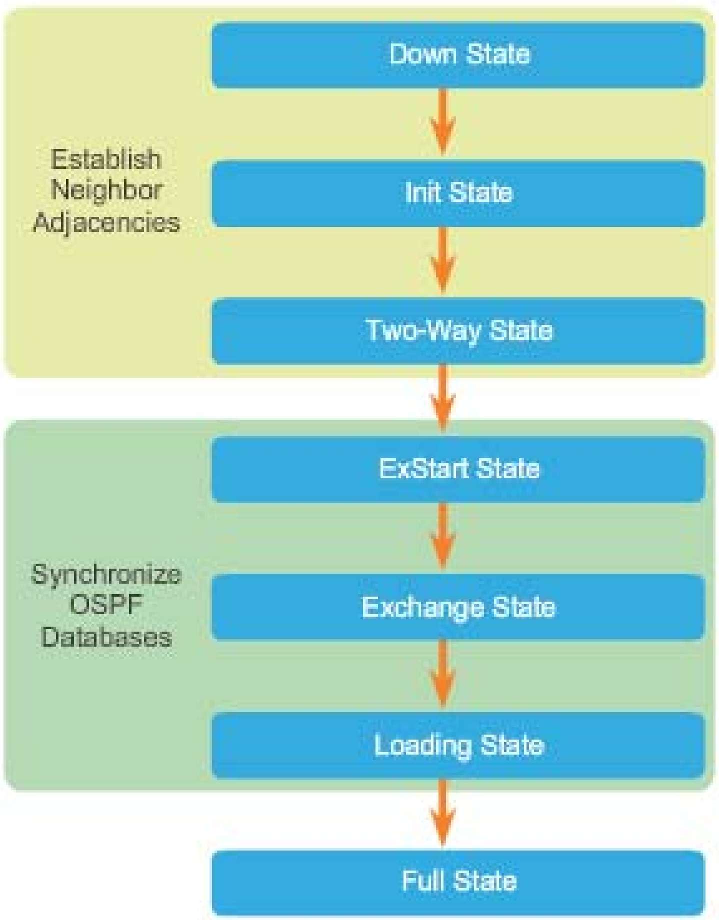
LSA Type	Description
1	Router LSAs
2	Network LSAs
3 or 4	Summary LSAs
5	Autonomous System External LSAs
6	Multicast OSPF LSAs
7	Defined for Not-So-Stubby Areas
8	External Attributes LSA for Border Gateway Protocol (BGP)
9,10,11	Opaque LSAs

OSPF Operation

OSPF Operational States

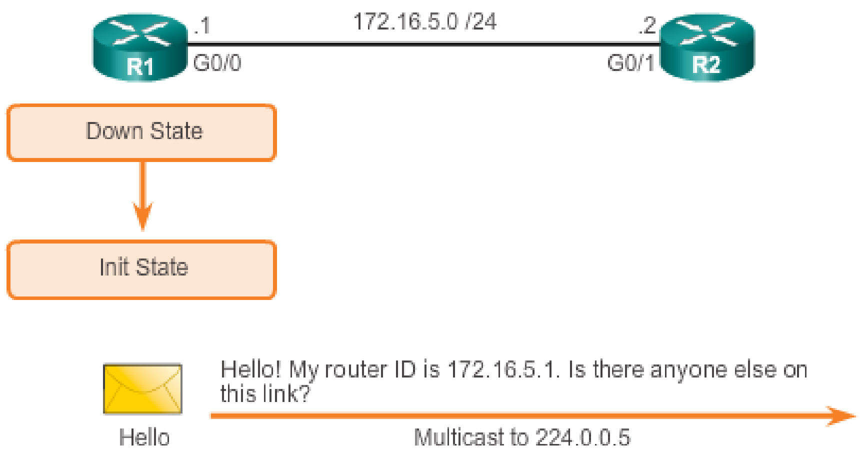
When an OSPF router is initially connected to a network, it attempts to:

- Create adjacencies with neighbors
- Exchange routing information
- Calculate the best routes
- Reach convergence
- OSPF progresses through several states while attempting to reach convergence.

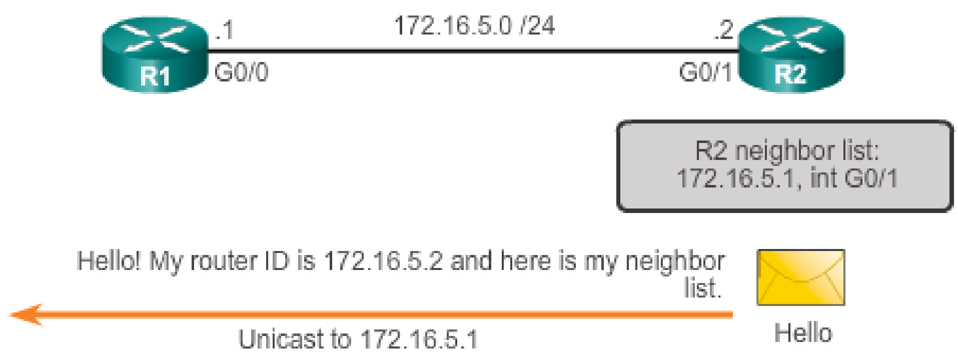


OSPF Operation
Establish Neighbor Adjacencies

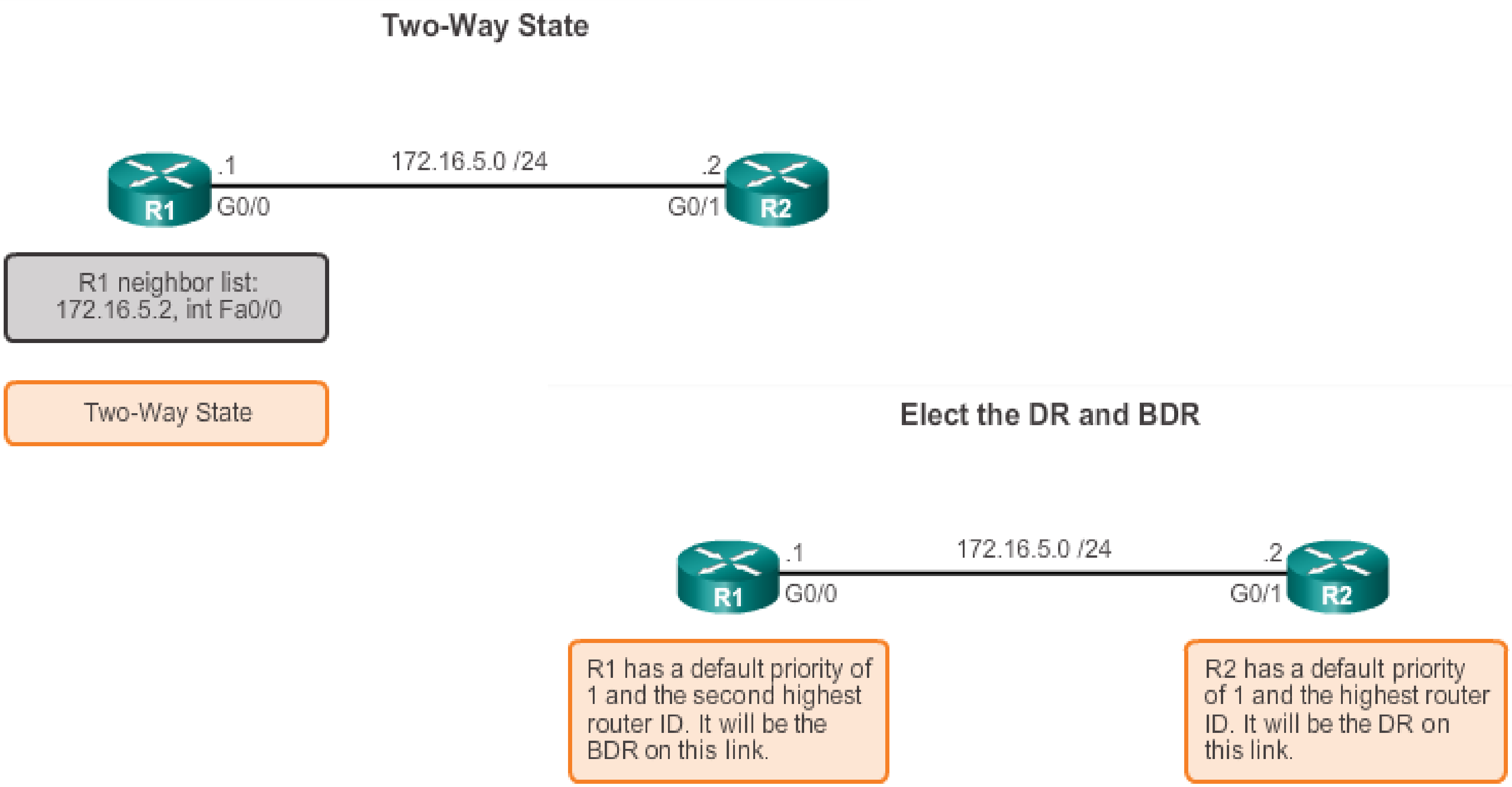
Down State to Init State



The Init State

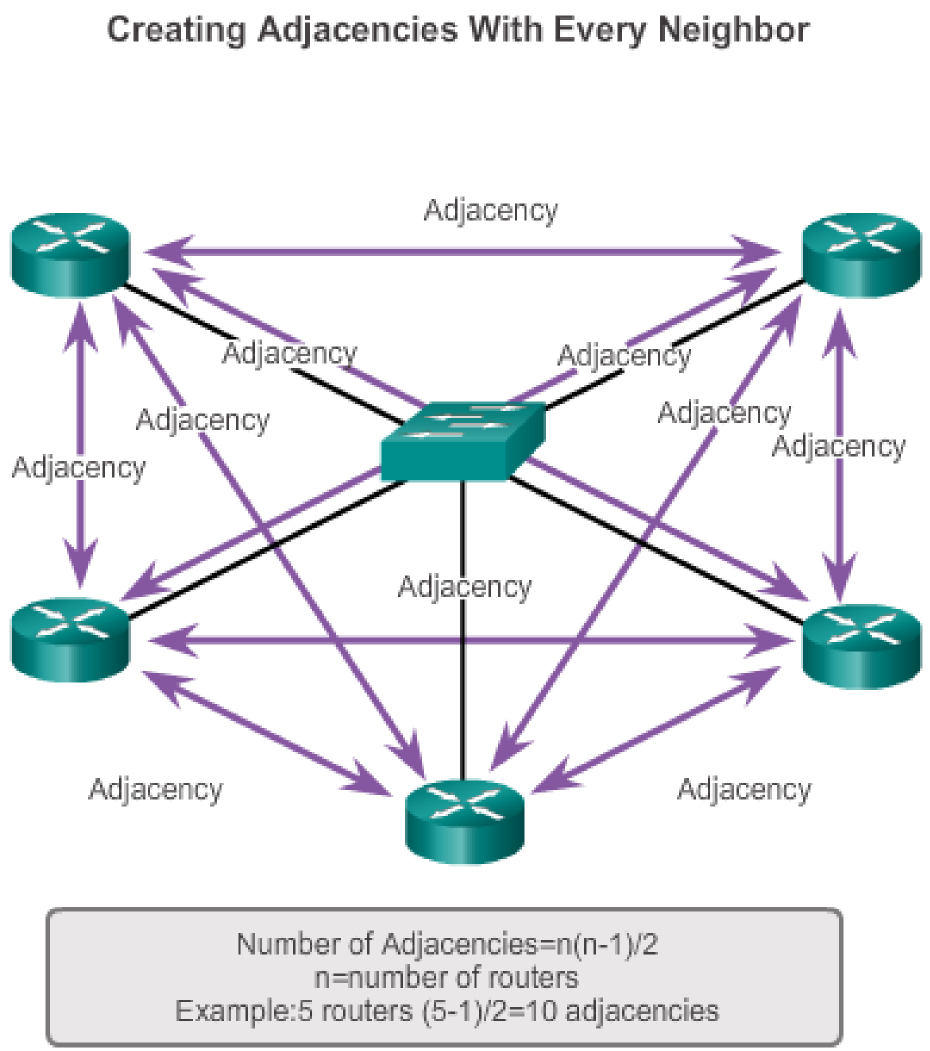


OSPF Operation
Establish Neighbor Adjacencies

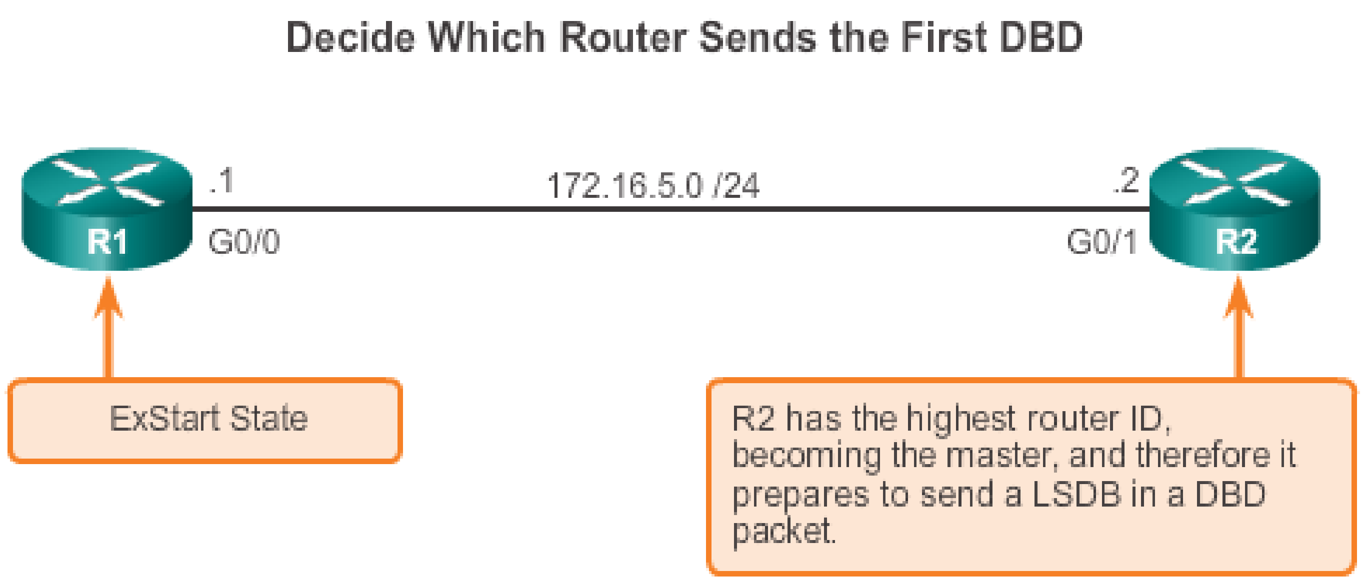


DR and BDR election only occurs on multi-access networks such as Ethernet LANs.

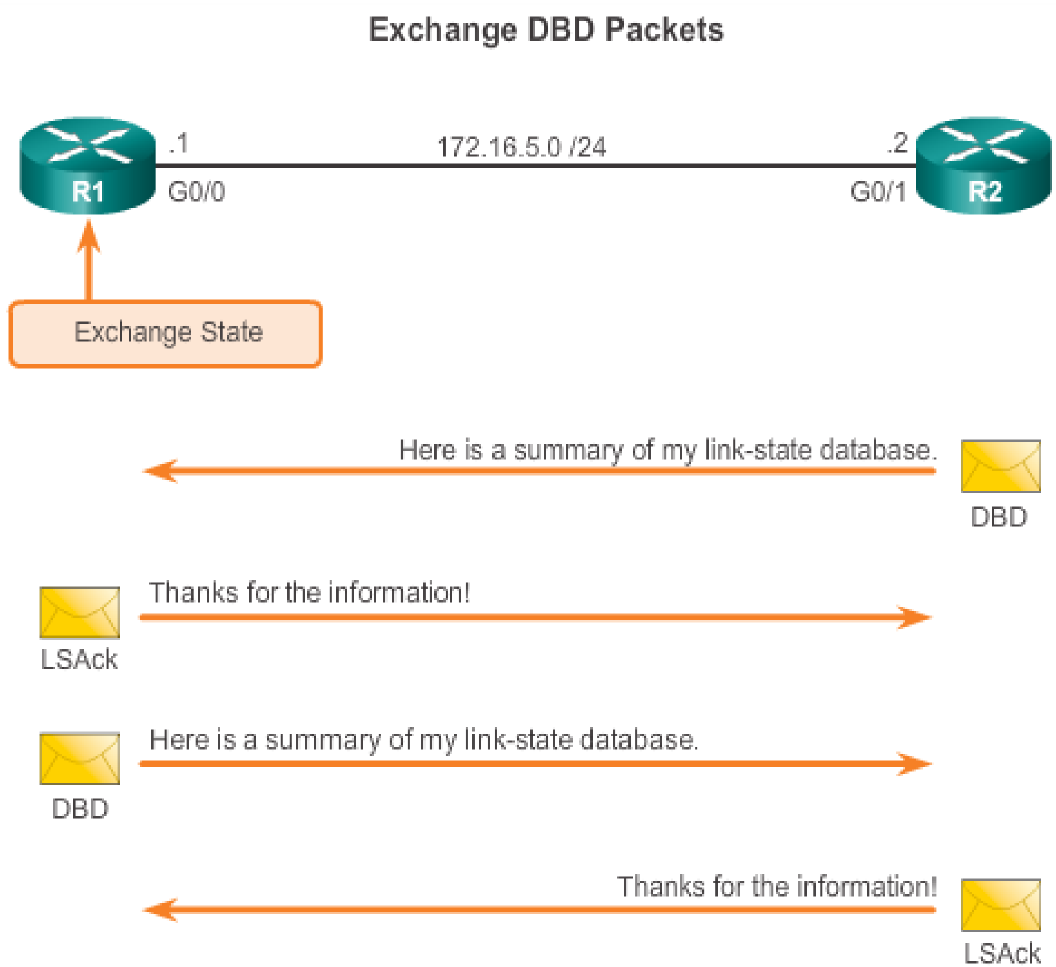
OSPF Operation
OSPF DR and BDR



OSPF Operation
Synchronizing OSPF Database



OSPF Operation
Synchronizing OSPF Database



8.2 Configuring Single-area OSPFv2

OSPF Router ID

OSPF Network Topology

Entering Router OSPF Configuration Mode on R1

```
R1(config)# router ospf 10
R1(config-router)# ?
Router configuration commands:
  auto-cost                Calculate OSPF interface cost
                           according to bandwidth
  network                  Enable routing on an IP network
  no                       Negate a command or set its defaults
  passive-interface        Suppress routing updates on an
                           interface
  priority                 OSPF topology priority
  router-id                router-id for this OSPF process
```

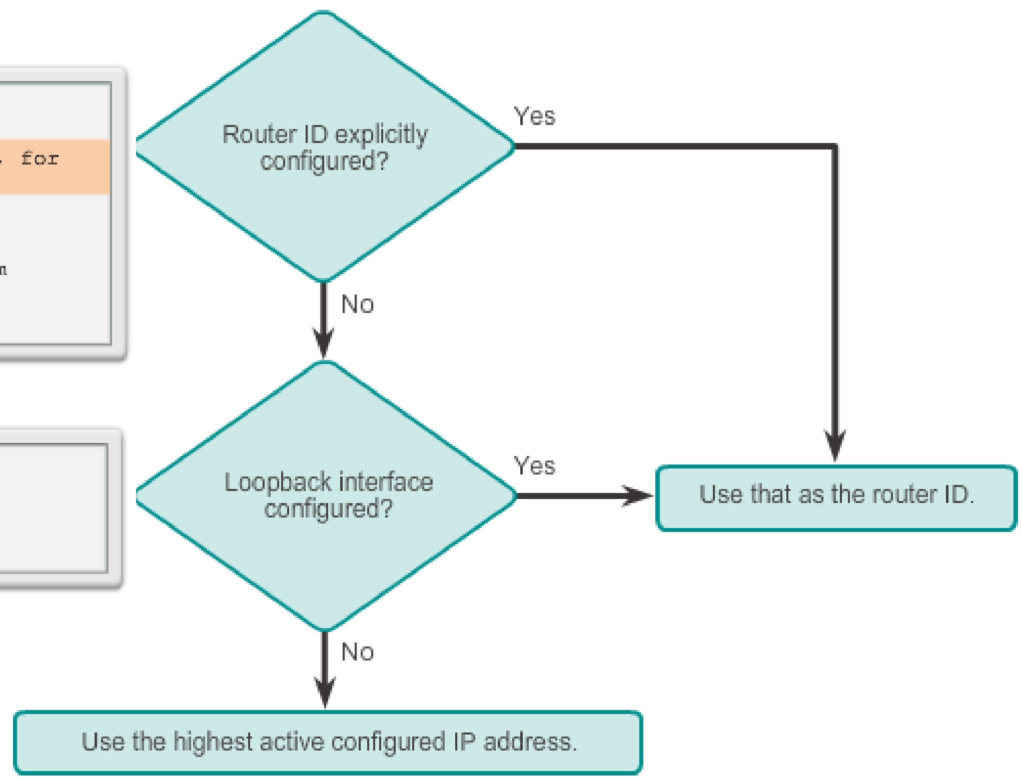
Note: Output has been altered to display only the commands that will be used in this chapter.

OSPF Router ID
Router IDs

```
R1(config)# router ospf 10
R1(config-router)# router-id 1.1.1.1
% OSPF: Reload or use "clear ip ospf process" command, for
this to take effect
R1(config-router)# end
R1#
*Mar 25 19:46:09.711: %SYS-5-CONFIG_I: Configured from
console by console
```

```
R1(config)# interface loopback 0
R1(config-if)# ip address 1.1.1.1 255.255.255.255
R1(config-if)# end
R1#
```

Router ID Order of Precedence



Clearing the OSPF Process

```
R1# clear ip ospf process
Reset ALL OSPF processes? [no]: y
R1#
*Mar 25 19:46:22.423: %OSPF-5-ADJCHG: Process 10, Nbr
3.3.3.3 on Serial0/0/1 from FULL to DOWN, Neighbor Down:
Interface down or detached
*Mar 25 19:46:22.423: %OSPF-5-ADJCHG: Process 10, Nbr
2.2.2.2 on Serial0/0/0 from FULL to DOWN, Neighbor Down:
Interface down or detached
```

Configure Single-area OSPFv2

The network Command

Assigning Interfaces to an OSPF Area

```
R1(config)# router ospf 10
R1(config-router)# network 172.16.1.0 0.0.0.255 area 0
R1(config-router)# network 172.16.3.0 0.0.0.3 area 0
R1(config-router)# network 192.168.10.4 0.0.0.3 area 0
R1(config-router)#
R1#
```

Assigning Interfaces to an OSPF Area with a Quad Zero

```
R1(config)# router ospf 10
R1(config-router)# network 172.16.1.1 0.0.0.0 area 0
R1(config-router)# network 172.16.3.1 0.0.0.0 area 0
R1(config-router)# network 192.168.10.5 0.0.0.0 area 0
R1(config-router)#
R1#
```

Configuring Passive Interfaces

Configuring a Passive Interface on R1

```
R1(config)# router ospf 10
R1(config-router)# passive-interface GigabitEthernet 0/0
R1(config-router)# end
R1#
```

Use the **passive-interface** router configuration mode command to prevent the transmission of routing messages through a router interface, but still allow that network to be advertised to other routers.

OSPF Cost

OSPF Metric = Cost

Cost = ***reference bandwidth*** / ***interface bandwidth***

(default reference bandwidth is 10^8)

Cost = <u>100,000,000 bps</u> / ***interface bandwidth in bps***

Default Cisco OSPF Cost Values

Interface Type	Reference Bandwidth in bps		Default Bandwidth in bps	Cost
Gigabit Ethernet 10 Gbps	100,000,000	÷	10,000,000,000	1
Gigabit Ethernet 1 Gbps	100,000,000	÷	1,000,000,000	1
Fast Ethernet 100 Mbps	100,000,000	÷	100,000,000	1
Ethernet 10 Mbps	100,000,000	÷	10,000,000	10
Serial 1.544 Mbps	100,000,000	÷	1,544,000	64
Serial 128 kbps	100,000,000	÷	128,000	781
Serial 64 kbps	100,000,000	÷	64,000	1562

Same Cos
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OSPF Cost

OSPF Accumulates Costs

Cost of an OSPF route is the accumulated value from one router to the destination network

```
R1# show ip route | include 172.16.2.0
O        172.16.2.0/24 [110/65] via 172.16.3.2, 03:39:07,
         Serial0/0/0
R1#
R1# show ip route 172.16.2.0
Routing entry for 172.16.2.0/24
  Known via "ospf 10", distance 110, metric 65, type intra
  area
  Last update from 172.16.3.2 on Serial0/0/0, 03:39:15 ago
  Routing Descriptor Blocks:
  * 172.16.3.2, from 2.2.2.2, 03:39:15 ago, via Serial0/0/0
      Route metric is 65, traffic share count is 1
R1#
```

OSPF Cost
Adjusting the Reference Bandwidth

- Use the **command - auto-cost reference-bandwidth**
- Must be configured on every router in the OSPF domain
- Notice that the value is expressed in Mb/s:

  Gigabit Ethernet - auto-cost reference-bandwidth 1000

  10 Gigabit Ethernet - auto-cost reference-bandwidth 10000

Verifying the S0/0/0 Link Cost

```
R1# show ip ospf interface serial 0/0/0
Serial0/0/0 is up, line protocol is up
 Internet Address 172.16.3.1/30,Area 0,Attached via Network Statement
 Process ID 10,Router ID 1.1.1.1,Network Type POINT_TO_POINT,Cost:647
 Topology-MTID    Cost    Disabled    Shutdown      Topol
       0           647       no          no          B
 Transmit Delay is 1 sec, State POINT_TO_POINT
 Timer intervals configured, Hello 10, Dead 40, Wait 40,
   oob-resync timeout 40
   Hello due in 00:00:01
 Supports Link-local Signaling (LLS)
 Cisco NSF helper support enabled
 IETF NSF helper support enabled
 Index 3/3, flood queue length 0
 Next 0x0(0)/0x0(0)
 Last flood scan length is 1, maximum is 1
 Last flood scan time is 0 msec, maximum is 0 msec
 Neighbor Count is 1, Adjacent neighbor count is 1
   Adjacent with neighbor 2.2.2.2
 Suppress hello for 0 neighbor(s)
R1#
```

Verifying the Metric to the R2 LAN

```
R1# show ip route | include 172.16.2.0
O       172.16.2.0/24 [110/648] via 172.16.3.2, 00:06:03, Serial0/0/0
R1#
R1# show ip route 172.16.2.0
Routing entry for 172.16.2.0/24
  Known via "ospf 10", distance 110, metric 648, type intra area
  Last update from 172.16.3.2 on Serial0/0/0, 00:06:17 ago
  Routing Descriptor Blocks:
  * 172.16.3.2, from 2.2.2.2, 00:06:17 ago, via Serial0/0/0
      Route metric is 648, traffic share count is 1
R1#
R1#
```

OSPF Cost

Default Interface Bandwidths

On Cisco routers, the default bandwidth on most serial interfaces is set to 1.544 Mb/s

Verifying the Default Bandwidth Settings of R1 Serial 0/0/0

```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: Link to R2
  Internet address is 172.16.3.1/30
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
  Last input 00:00:05, output 00:00:03, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total
```

OSPF Cost

Adjusting the Interface Bandwidths

Adjusting the R1 Serial 0/0/1 Interface

```
R1(config)# int s0/0/1
R1(config-if)# bandwidth 64
R1(config-if)# end
R1#
*Mar 27 10:10:07.735: %SYS-5-CONFIG_I: Configured from console by c
R1#
R1# show interfaces serial 0/0/1 | include BW
  MTU 1500 bytes, BW 64 Kbit/sec, DLY 20000 usec,
R1#
R1# show ip ospf interface serial 0/0/1 | include Cost:
  Process ID 10, Router ID 1.1.1.1, Network Type
  POINT_TO_POINT, Cost: 15625
R1#
```

Manually Setting the OSPF Cost

Both the **bandwidth** interface command and the **ip ospf cost** interface command achieve the same result, which is to provide an accurate value for use by OSPF in determining the best route.

```
R1(config)# int s0/0/1
R1(config-if)# no bandwidth 64
R1(config-if)# ip ospf cost 15625
R1(config-if)# end
R1#
R1# show interface serial 0/0/1 | include BW
    MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
R1#
R1# show ip ospf interface serial 0/0/1 | include Cost:
    Process ID 10, Router ID 1.1.1.1, Network Type POINT_TO_POINT,
    Cost: 15625
R1#
```

Verify OSPF

Verify OSPF Neighbors

Verify that the router has formed an adjacency with its neighboring routers

```
R1# show ip ospf neighbor

Neighbor ID   Pri   State    Dead Time  Address        Interface
3.3.3.3       0     FULL/-   00:00:37   192.168.10.6   Serial0/0/1
2.2.2.2       0     FULL/-   00:00:30   172.16.3.2     Serial0/0/0
R1#
```

Verify OSPF

Verify OSPF Protocol Settings

Verifying R1's OSPF Neighbors

```
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 10"
  Outgoing update filter list for all interfaces is not
  set
  Incoming update filter list for all interfaces is not
  set
  Router ID 1.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0
  nssa
  Maximum path: 4
  Routing for Networks:
    172.16.1.0 0.0.0.255 area 0
    172.16.3.0 0.0.0.3 area 0
    192.168.10.4 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    2.2.2.2              110      00:17:18
    3.3.3.3              110      00:14:49
  Distance: (default is 110)

R1#
```

Verify OSPF Interface Settings

Verifying R1's OSPF Interfaces

```
R1# show ip ospf interface brief
Interface    PID   Area     IP Address/Mask    Cost  State    Nbrs F/C
Se0/0/1      10    0        192.168.10.5/30    15625 P2P      1/1
Se0/0/0      10    0        172.16.3.1/30      647   P2P      1/1
Gi0/0        10    0        172.16.1.1/24      1     DR       0/0
R1#
```