Chapter 7: Routing Dynamically

Routing & Switching

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Chapter 7

7.1 Dynamic Routing Protocols

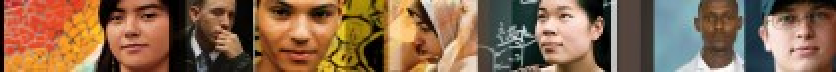
7.2 Distance Vector Dynamic Routing

7.3 RIP and RIPng Routing

7.4 Link-State Dynamic Routing

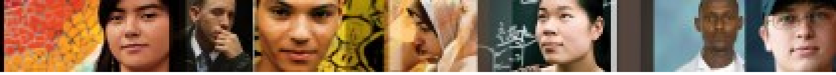
7.5 The Routing Table

7.6 Summary



Chapter 7: Objectives

- Explain the basic operation of dynamic routing protocols.
- Compare and contrast dynamic and static routing.
- Determine which networks are available during an initial network discovery phase.
- Define the different categories of routing protocols.
- Describe the process by which distance vector routing protocols learn about other networks.
- Identify the types of distance-vector routing protocols.
- Configure the RIP routing protocol.
- Configure the RIPng routing protocol.
- Explain the process by which link-state routing protocols learn about other networks.



Chapter 7: Objectives (cont.)

- Describe the information sent in a link-state update.
- Describe advantages and disadvantages of using link-state routing protocols.
- Identify protocols that use the link-state routing process. (OSPF, IS-IS)
- Determine the route source, administrative distance, and metric for a given route.
- Explain the concept of a parent/child relationship in a dynamically built routing table.
- Compare the IPv4 classless route lookup process and the IPv6 lookup process.
- Analyze a routing table to determine which route will be used to forward a packet.

Dynamic Routing Protocol Operation

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 are used to facilitate the exchange of routing information between routers.

The purpose of dynamic routing protocols includes:

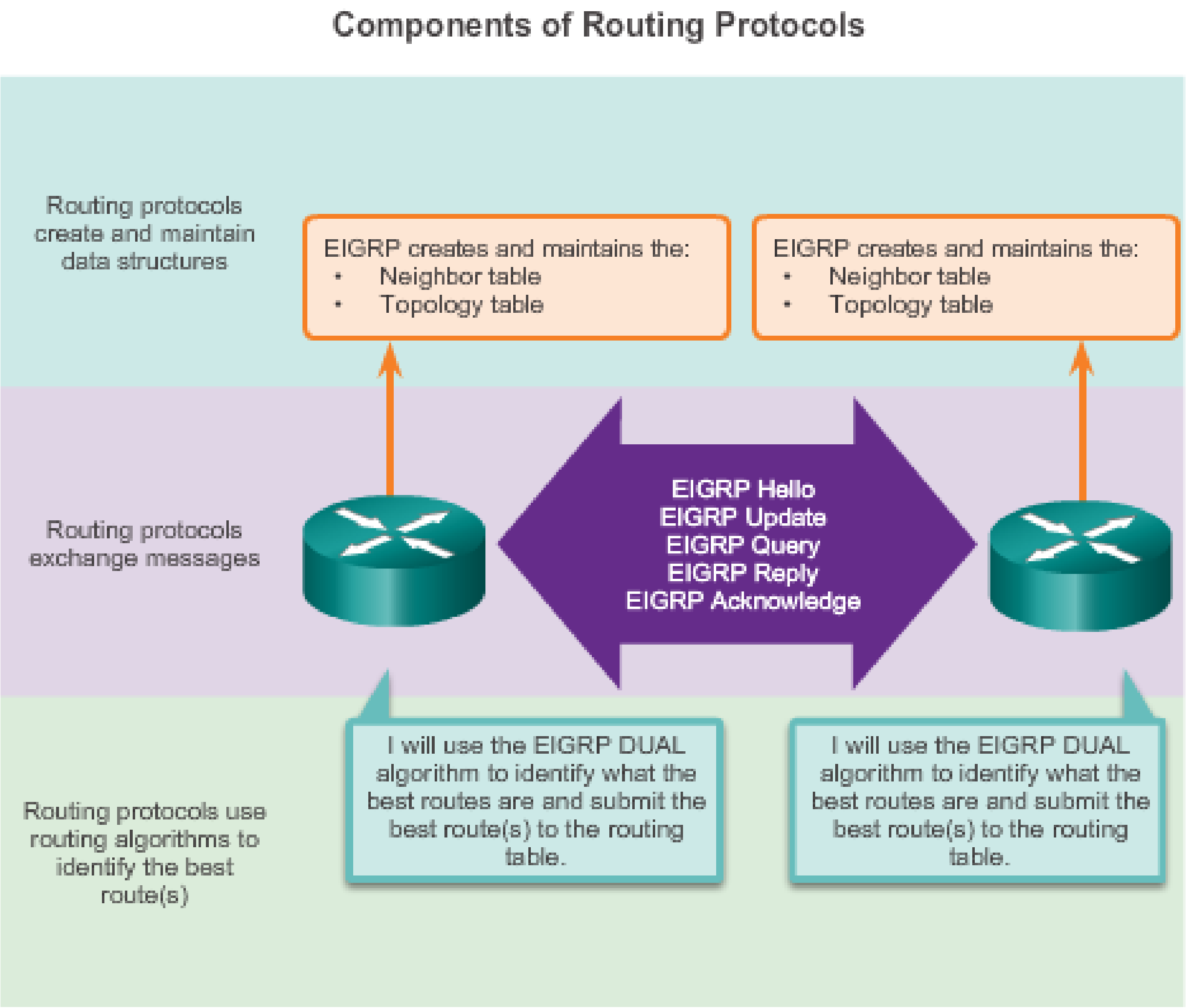
- Discovery of remote networks
- Maintaining up-to-date routing information
- Choosing the best path to destination networks
- Ability to find a new best path if the current path is no longer available

Purpose of Dynamic Routing Protocols (cont.)

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.

Purpose of Dynamic Routing Protocols (cont.)



Dynamic Routing Protocol Operation

The Role of Dynamic Routing Protocols

Advantages of dynamic routing include:

- 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 include:

- Part of a router's resources are dedicated for protocol operation, including CPU time and network link bandwidth
- Times when static routing is more appropriate

Dynamic verses Static Routing
Using Static Routing

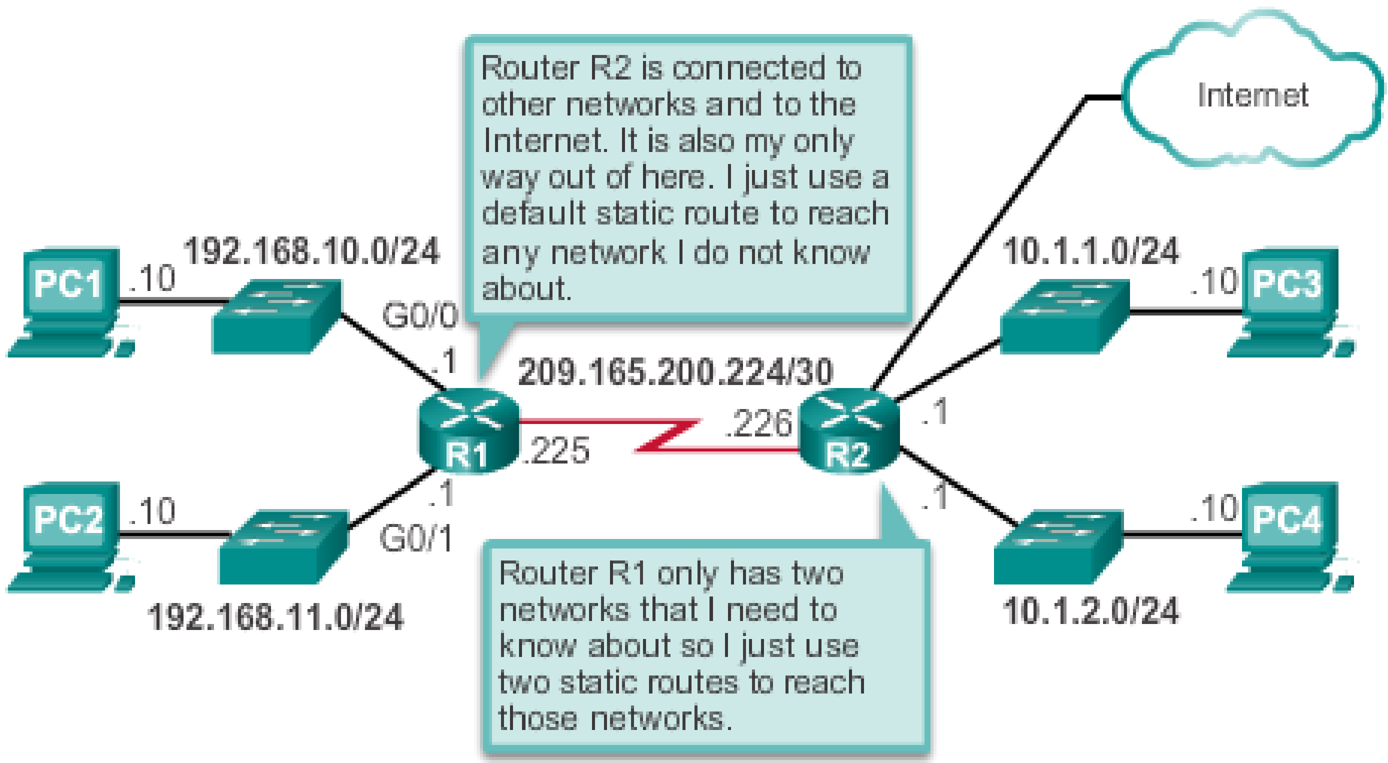
Networks typically use a combination of both static and dynamic routing.

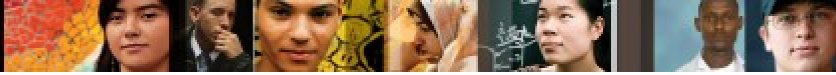
Static routing has several primary uses:

- 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. This is 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 (cont.)



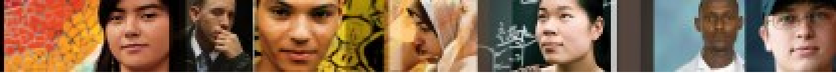


Dynamic verses Static Routing

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.

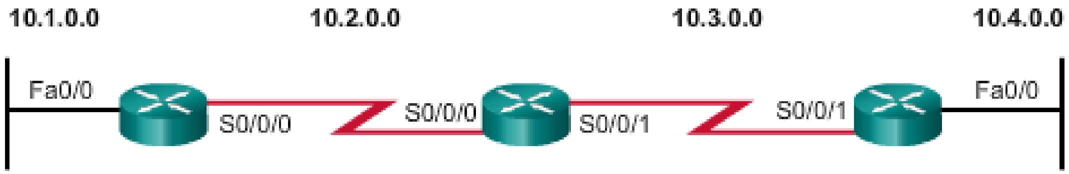
Dynamic Routing Protocol Operation

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

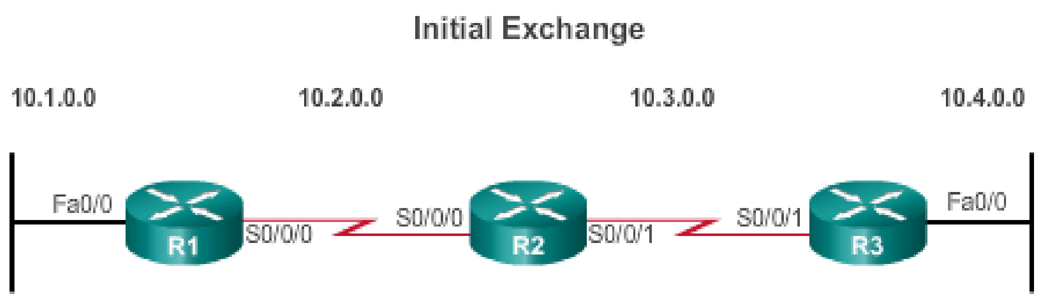
Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0

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



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

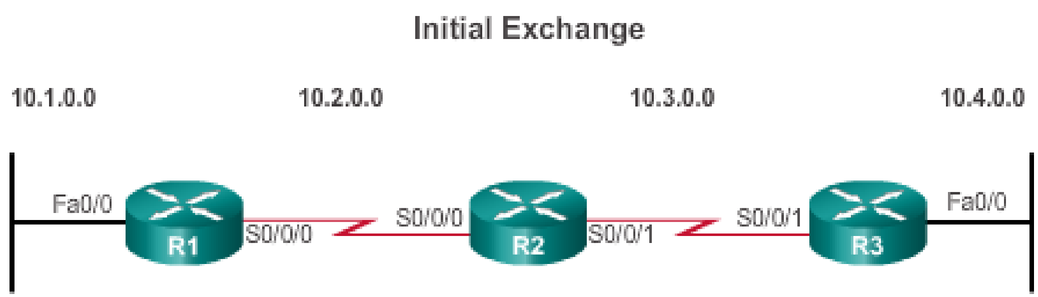
Network	Interface	Hop
10.3.0.0	S0/0/0	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

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

Routing Protocol Operating Fundamentals
Network Discovery (cont.)



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

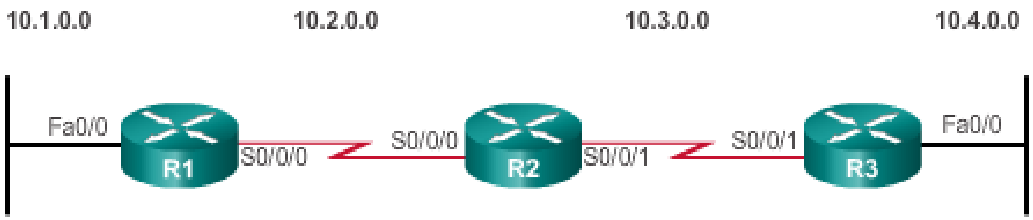
Routers running RIPv2

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 (cont.)

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

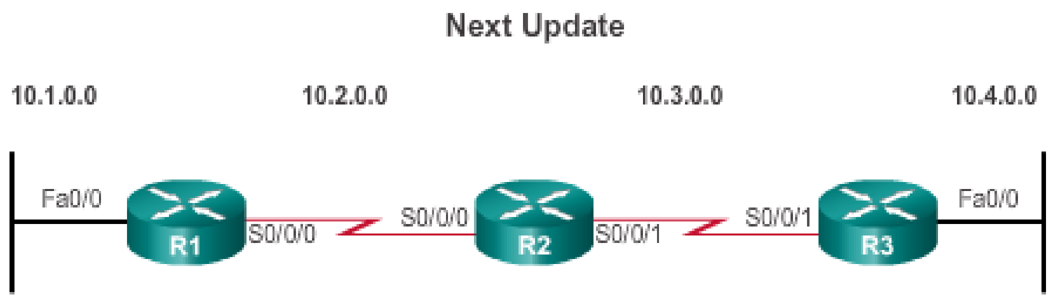
Network	Interface	Hop
10.3.0.0	S0/0/0	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1

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

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

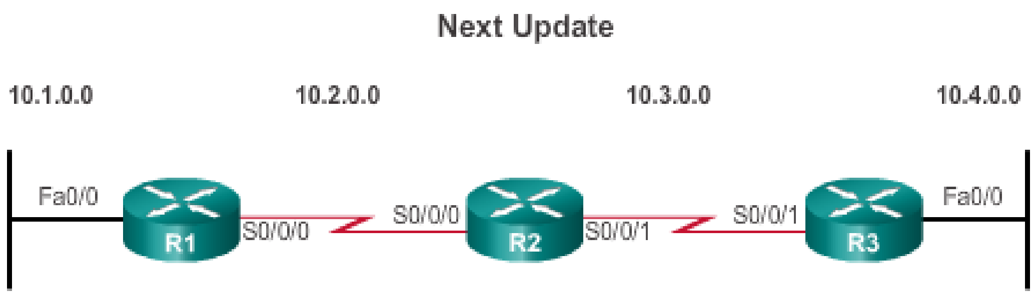
Network	Interface	Hop
10.3.0.0	S0/0/1	0
10.4.0.0	Fa0/0	0
10.2.0.0	S0/0/1	1
10.1.0.0	S0/0/1	2

Routers running RIPv2

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

Exchanging the Routing Information (cont.)



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

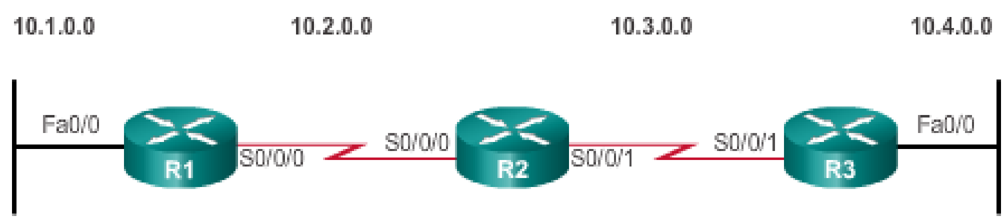
Routers running RIPv2

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 (cont.)

Next Update



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.

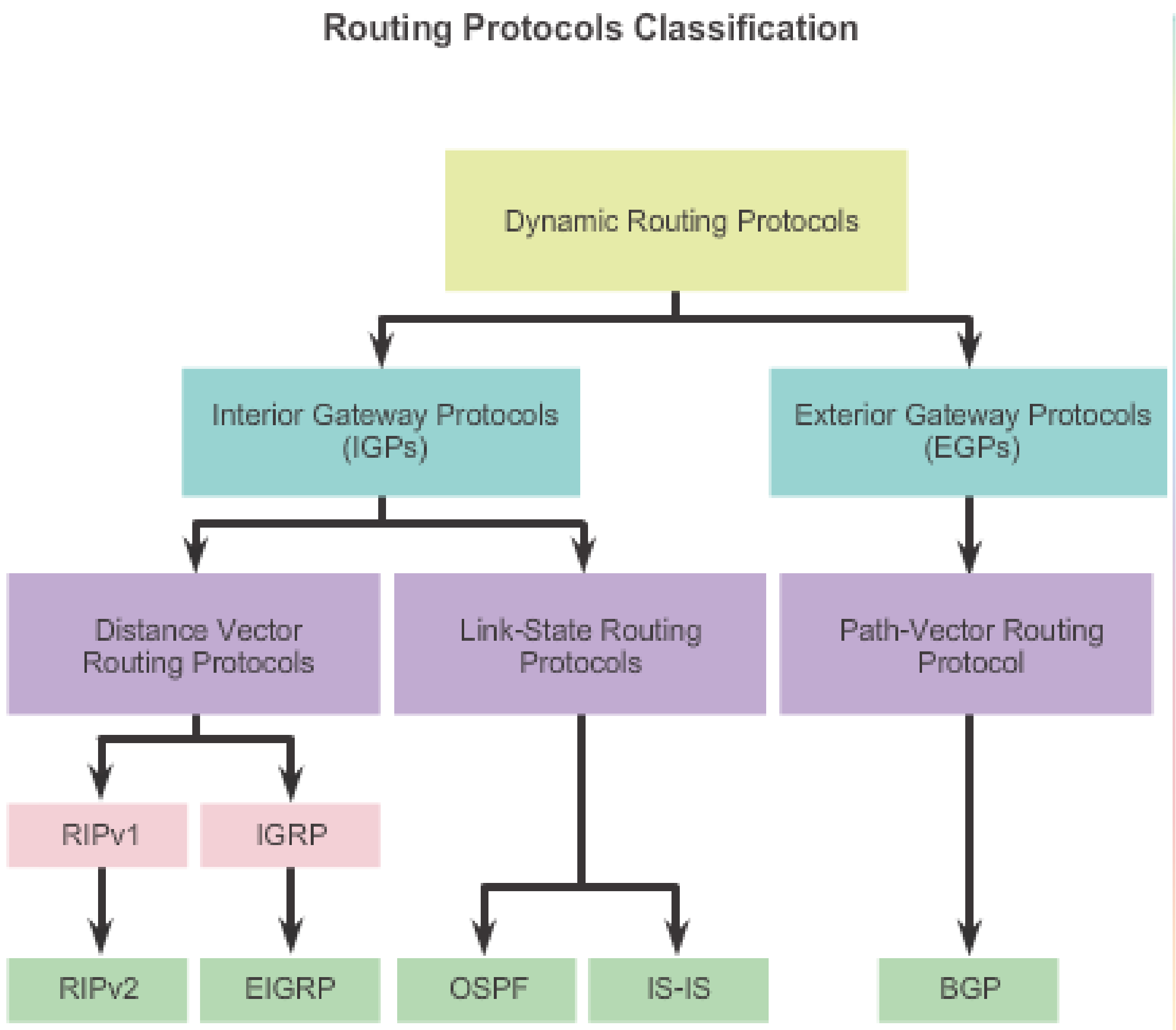
Routing Protocol Operating Fundamentals
Achieving Convergence

The network is converged when all routers have complete and accurate information about the entire network:

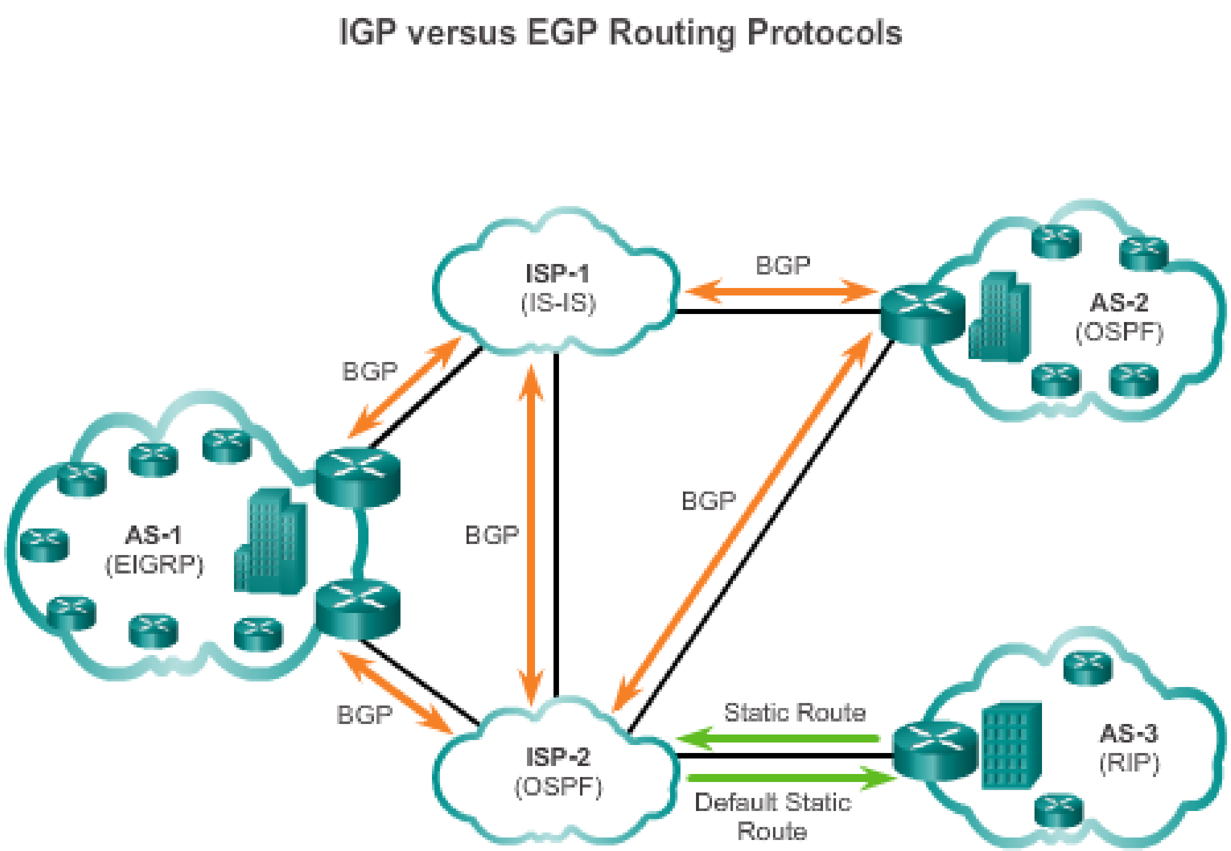
- Convergence time is the time it takes routers to share information, calculate best paths, and update their routing tables.
- A network is not completely operable until the network has converged.
- Convergence properties include the speed of propagation of routing information and the calculation of 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



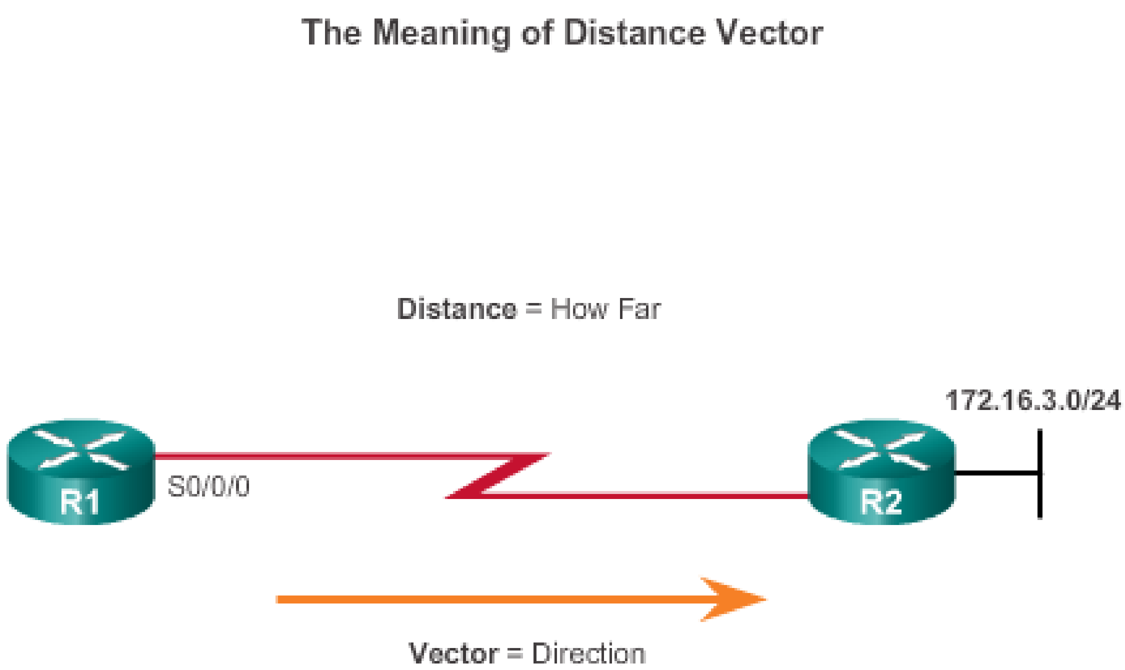
Types of Routing Protocols
IGP and EGP Routing Protocols



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



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

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

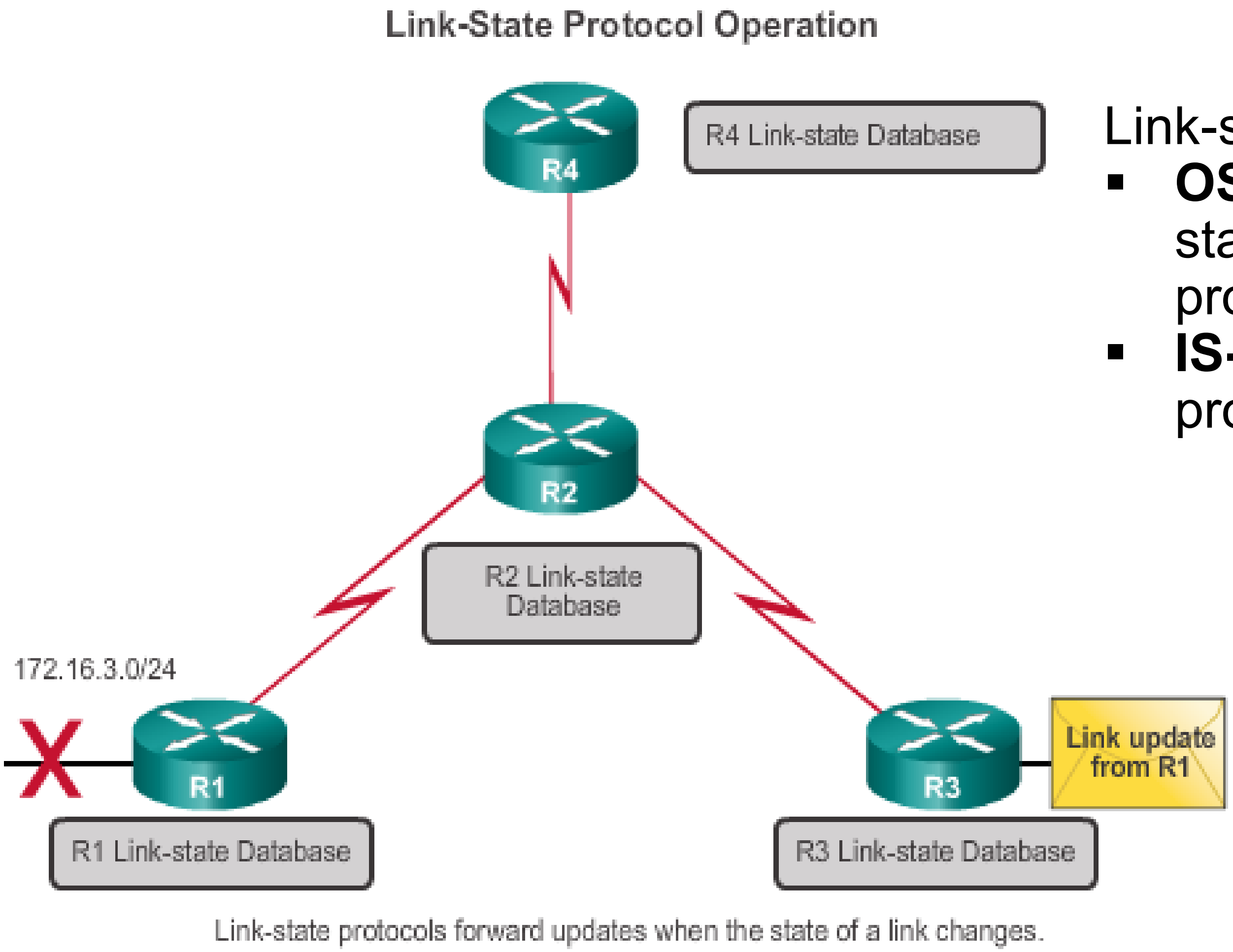
Types of Routing Protocols

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
- **IS-IS** - Popular in provider networks.

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:

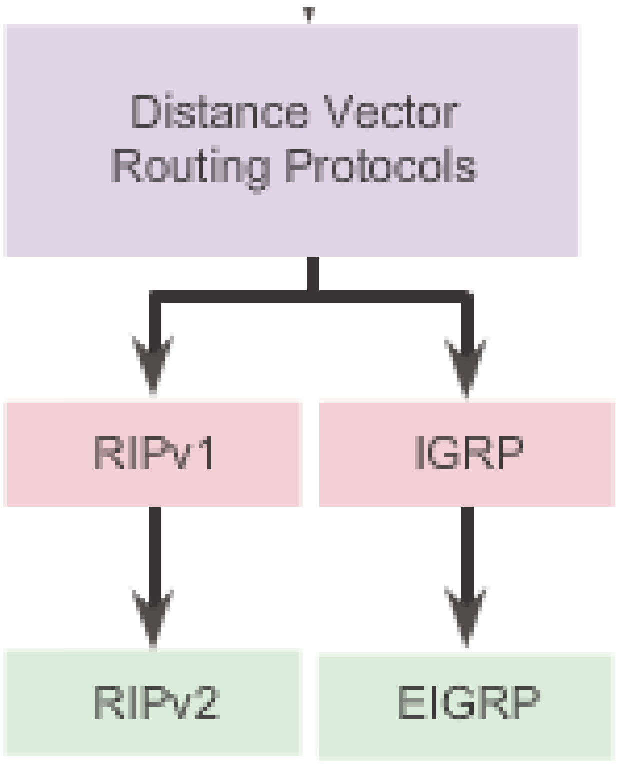
- Used to determine the overall "cost" of a path from source to destination.
- Routing protocols determine the best path based on the route with the lowest cost.

Distance Vector Routing Protocol Operation

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



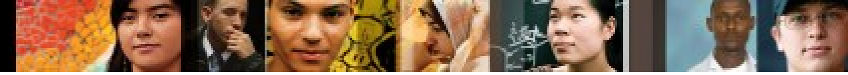
Distance Vector Algorithm

Purpose of Routing Algorithms

- Sending and receiving updates
- Calculate best path and install route
- Detect and react to topology changes

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

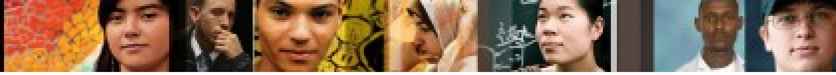
RIPv1 versus RIPv2

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



Types of Distance Vector Routing Protocols

Enhanced Interior-Gateway Routing Protocol

IGRP versus EIGRP

Characteristics and Features	IGRP	EIGRP
Metric	Both use a composite metric consisting of bandwidth and delay. Reliability and load can also be included in the metric calculation.	
Updates Forwarded to Address	255.255.255.255	224.0.0.10
Supports VLSM	✗	✓
Supports CIDR	✗	✓
Supports Summarization	✗	✓
Supports Authentication	✗	✓

EIGRP:

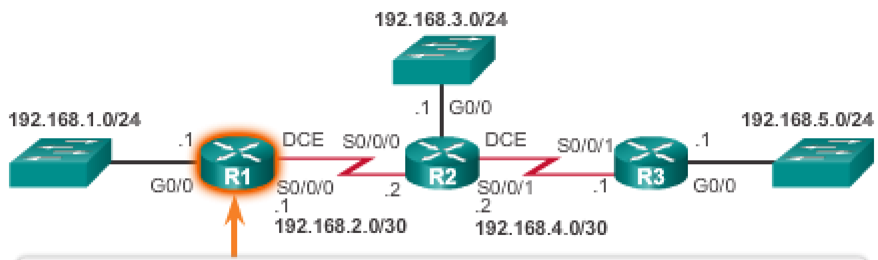
- Is bounded triggered updates
- Uses a Hello keepalives mechanism
- Maintains a topology table
- Supports rapid convergence
- Is a multiple network layer protocol support

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)#
```

Advertising the R1 Networks




```
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#
```

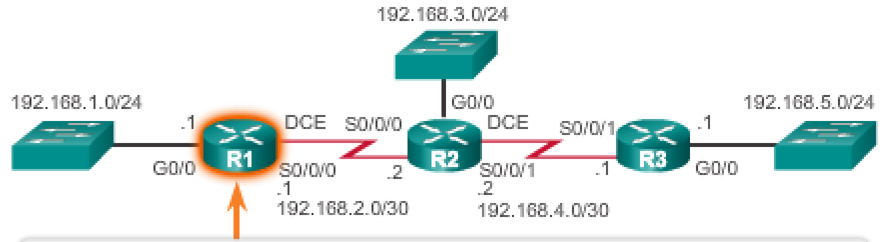
Configuring the RIP Protocol
Enabling RIPv2

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#
```

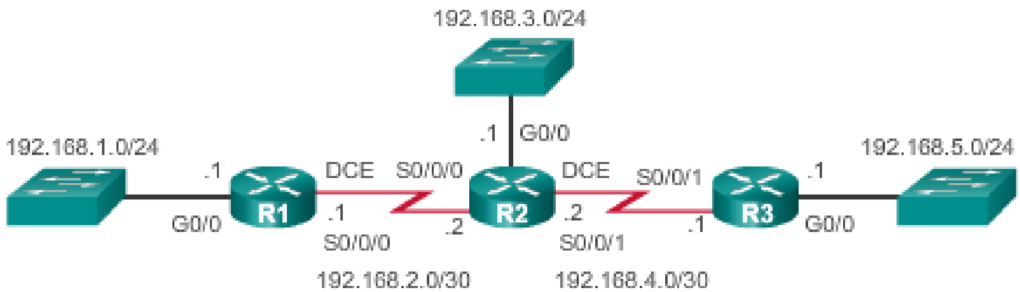
Configuring the RIP Protocol

Disabling Auto Summarization

- Similarly to RIPv1, RIPv2 automatically summarizes networks at major network boundaries by default.
- To modify the default RIPv2 behavior of automatic summarization, use the **`no auto-summary`** router configuration mode command.
- This command has no effect when using RIPv1.
- When automatic summarization has been disabled, RIPv2 no longer summarizes networks to their classful address at boundary routers. RIPv2 now includes all subnets and their appropriate masks in its routing updates.
- The **`show ip protocols`** now states that automatic network summarization is not in effect.

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

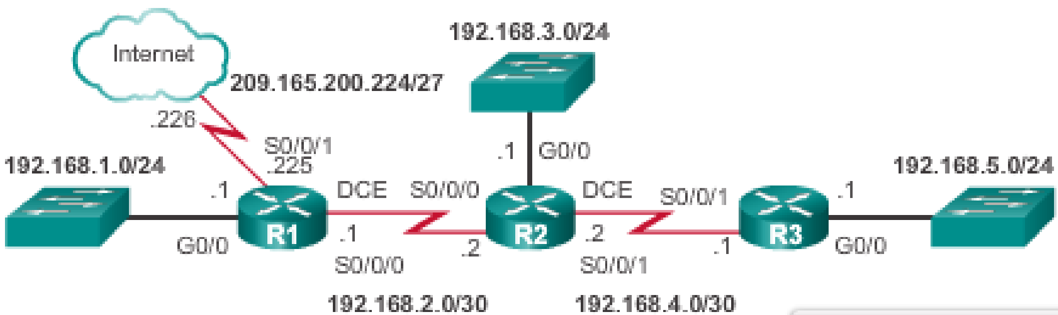
```
R1(config)# router rip
R1(config-router)# passive-interface g0/0
R1(config-router)# end
R1#
R1# show ip protocols | begin Default
  Default version control: send version 2, receive version 2
    Interface             Send  Recv  Triggered RIP  Key-chain
    Serial0/0/0           2     2
  Automatic 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

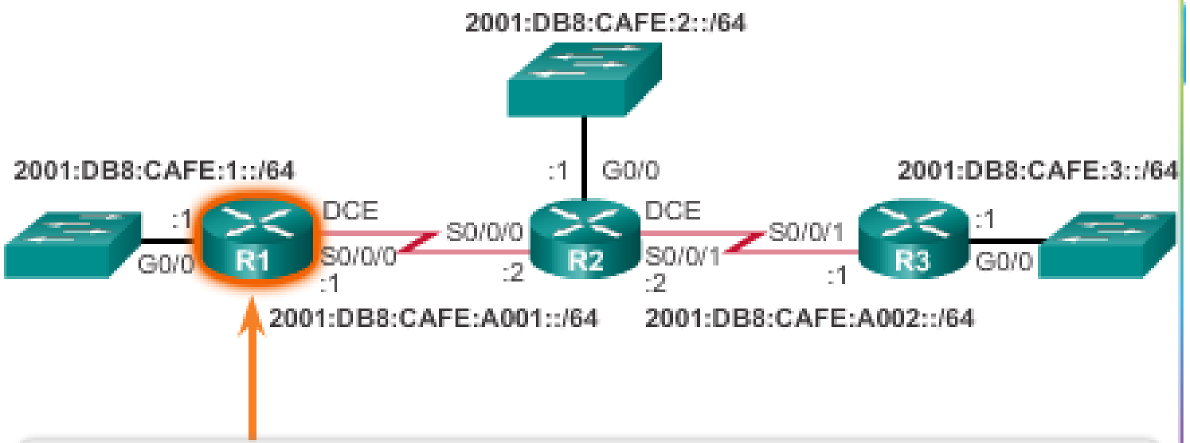



```
R1(config)# ip route 0.0.0.0 0.0.0.0 S0/0/1 209.165.200.226
R1(config)# router rip
R1(config-router)# default-information originate
R1(config-router)# ^Z
R1#
*Mar 10 23:33:51.801: %SYS-5-CONFIG_I: Configured from
console by console
R1# show ip route | begin Gateway
Gateway of last resort is 209.165.200.226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

Configuring the RIPng Protocol
Advertising IPv6 Networks

Enabling RIPng on IPv6 the R1 Interfaces




```
R1(config)# ipv6 unicast-routing
R1(config)#
R1(config)# interface gigabitethernet 0/0
R1(config-if)# ipv6 rip RIP-AS enable
R1(config-if)# exit
R1(config)#
R1(config)# interface serial 0/0/0
R1(config-if)# ipv6 rip RIP-AS enable
R1(config-if)# no shutdown
R1(config-if)#
```

Configuring the RIPng Protocol

Examining the RIPng Configuration

Verifying RIP Settings on R1

```
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "rip RIP-AS"
  Interfaces:
    Serial0/0/0
    GigabitEthernet0/0
  Redistribution:
    None
R1#
```

Verifying Routes on R1

```
R1# show ipv6 route
IPv6 Routing Table - default - 8 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user
Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP,
       EX - EIGRP external, ND - ND Default,
       NDp - ND Prefix, DCE - Destination, NDr - Redirect,
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1,
       OE2 - OSPF ext 2, ON1 - OSPF NSSA ext 1,
       ON2 - OSPF NSSA ext 2
C   2001:DB8:CAFE:1::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:CAFE:1::1/128 [0/0]
     via GigabitEthernet0/0, receive
R   2001:DB8:CAFE:2::/64 [120/2]
     via FE80::FE99:47FF:FE71:78A0, Serial0/0/0
R   2001:DB8:CAFE:3::/64 [120/3]
     via FE80::FE99:47FF:FE71:78A0, Serial0/0/0
C   2001:DB8:CAFE:A001::/64 [0/0]
     via Serial0/0/0, directly connected
L   2001:DB8:CAFE:A001::1/128 [0/0]
     via Serial0/0/0, receive
R   2001:DB8:CAFE:A002::/64 [120/2]
```

Configuring the RIPng Protocol

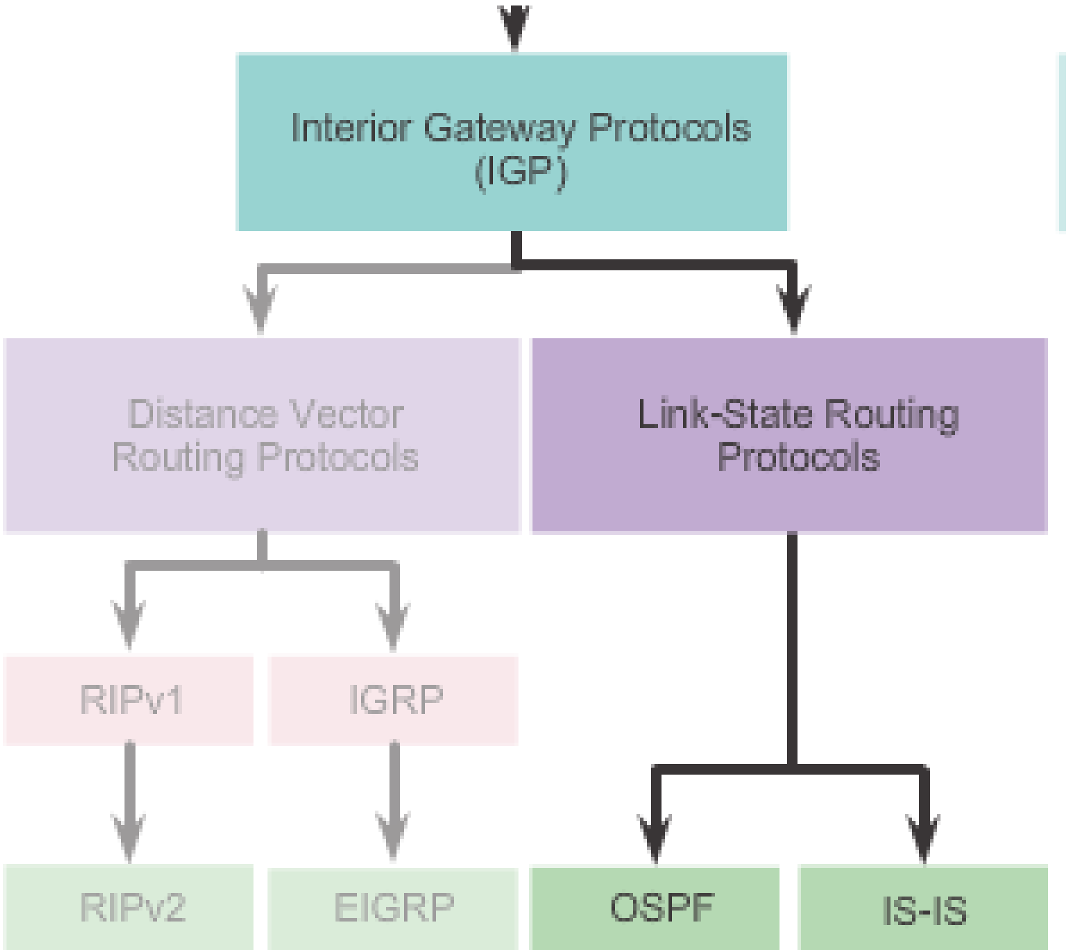
Examining the RIPng Configuration (cont.)

Verifying RIPng Routes on R1

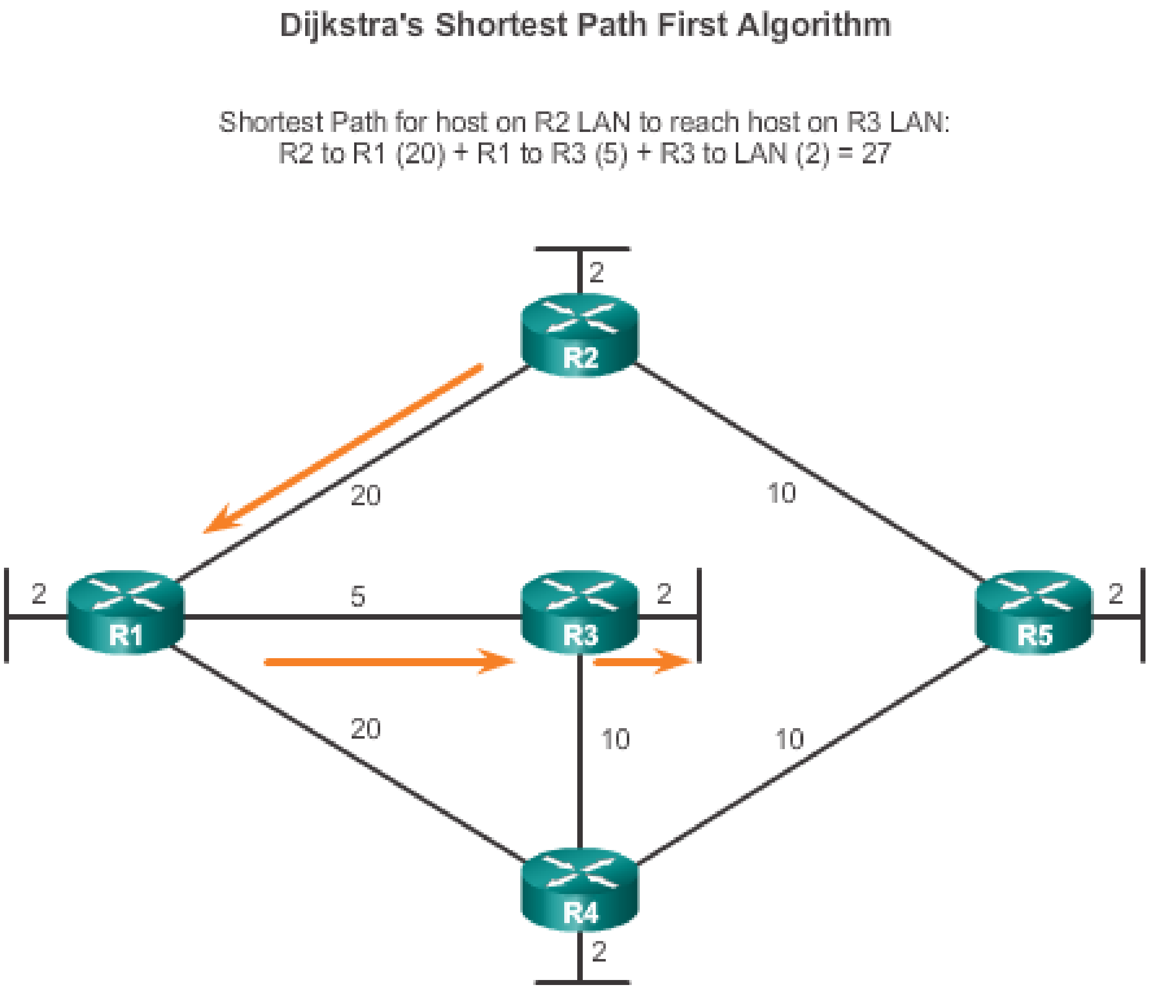
```
R1# show ipv6 route rip
IPv6 Routing Table - default - 8 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user
Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP,
       EX - EIGRP external, ND - ND Default,
       NDp - ND Prefix, DCE - Destination, NDr - Redirect,
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1,
       OE2 - OSPF ext 2, ON1 - OSPF NSSA ext 1,
       ON2 - OSPF NSSA ext 2
R   2001:DB8:CAFE:2::/64 [120/2]
     via FE80::FE99:47FF:FE71:78A0, Serial0/0/0
R   2001:DB8:CAFE:3::/64 [120/3]
     via FE80::FE99:47FF:FE71:78A0, Serial0/0/0
R   2001:DB8:CAFE:A002::/64 [120/2]
     via FE80::FE99:47FF:FE71:78A0, Serial0/0/0
R1#
```

Link-State Routing Protocol Operation

Shortest Path First Protocols



Dijkstra's Algorithm



Link-State Updates

Link-State Routing Process

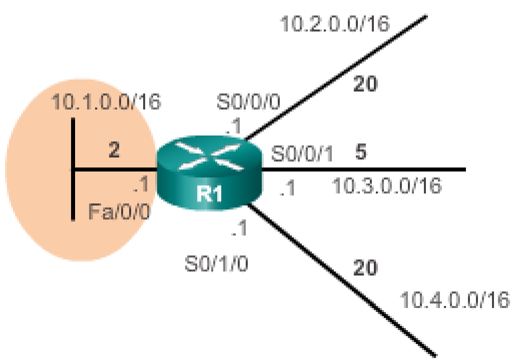
Link-State Routing Process

- 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 and its own directly connected networks.

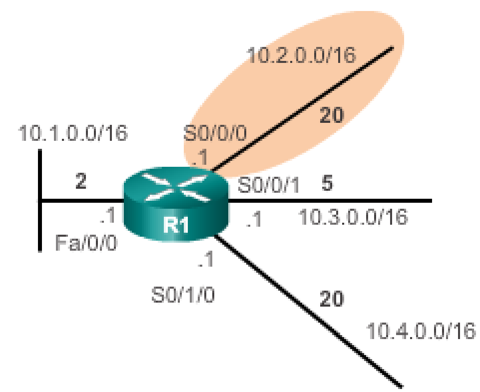
Link-State of Interface Fa0/0



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

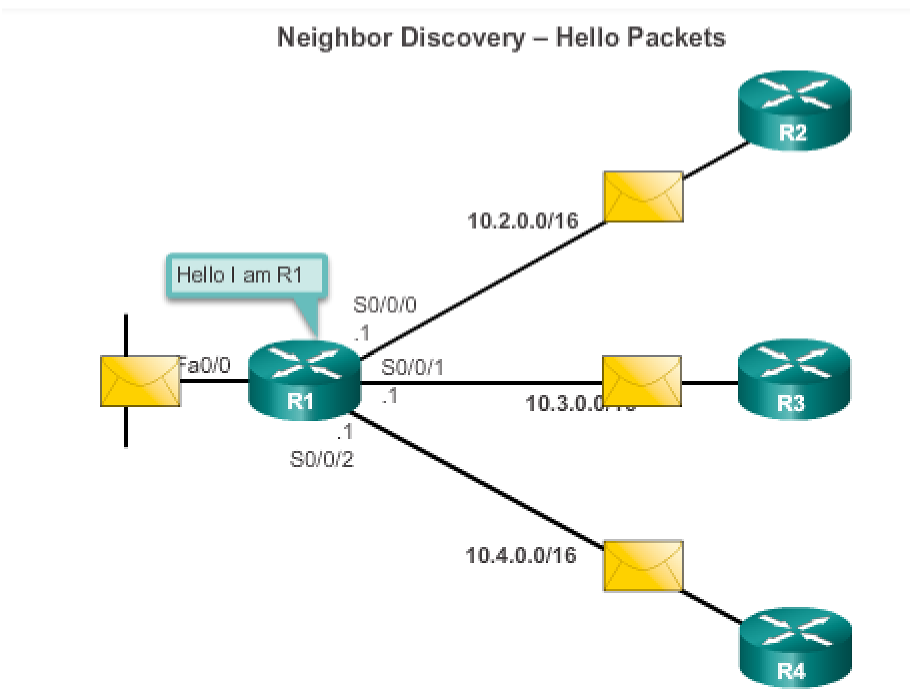


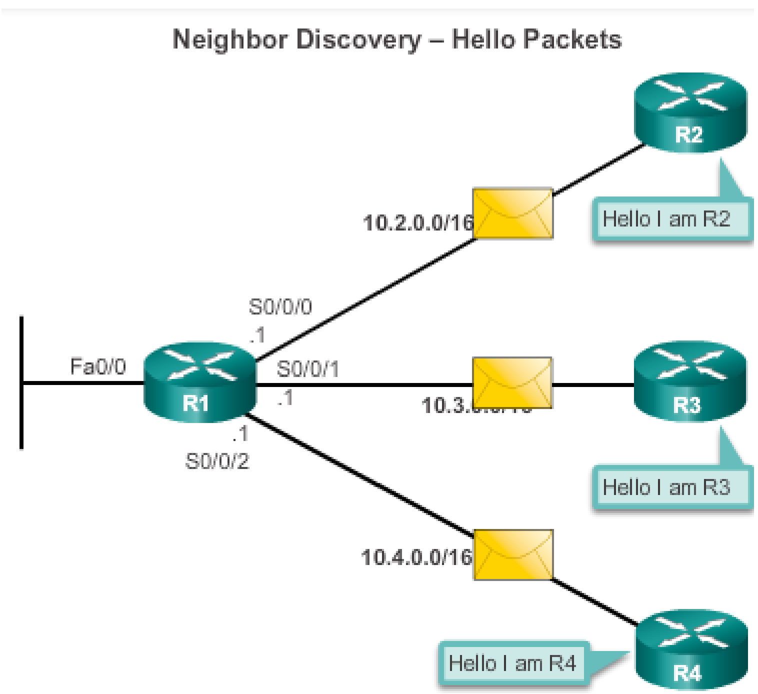
Link 2

- 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.

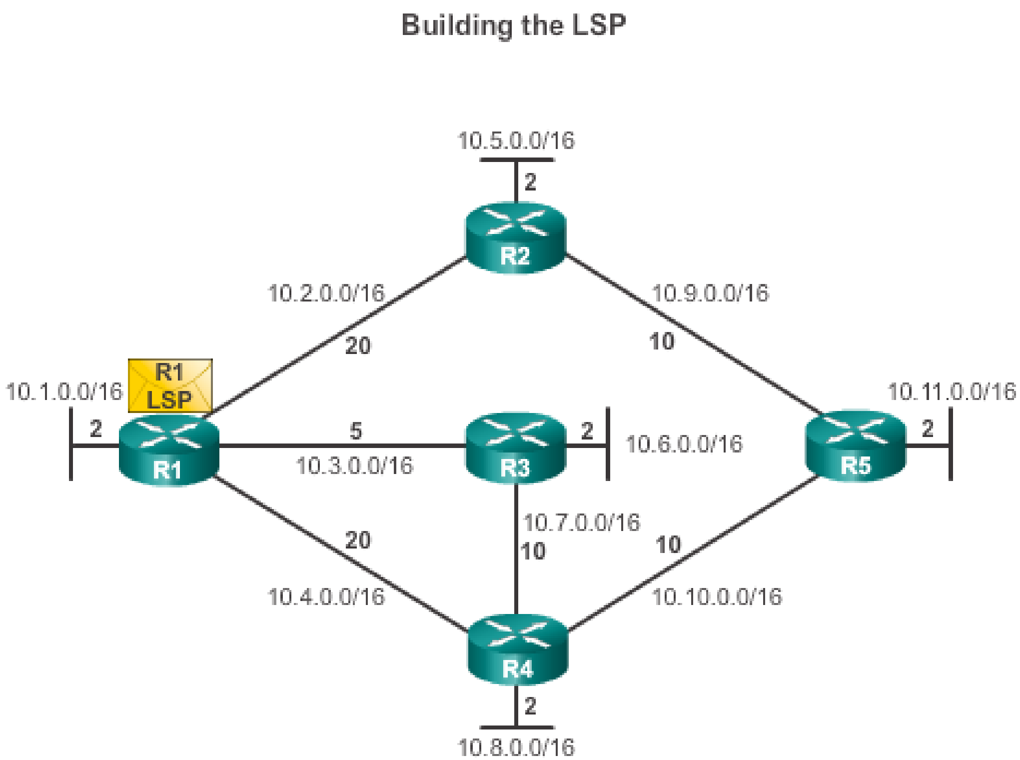




Link-State Updates

Say Hello

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; 10.7.0.0/16; Cost 5
4. R1 -> R4; Serial point-to-point network; 10.4.0.0/16; Cost 20

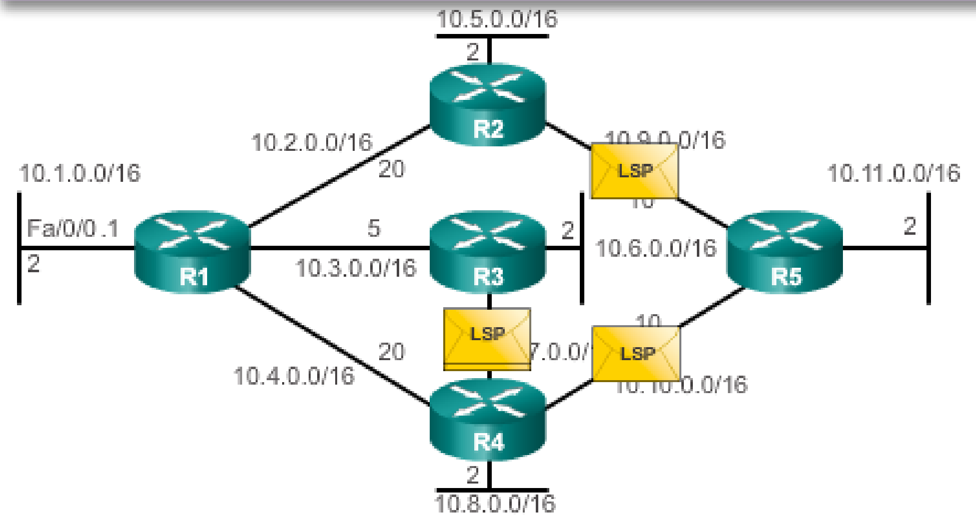
Flooding the LSP

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.

Flooding the LSP

R1 Link State Contents

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



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

Link-State Updates
Building the SPF Tree

Identify the Directly Connected Networks

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

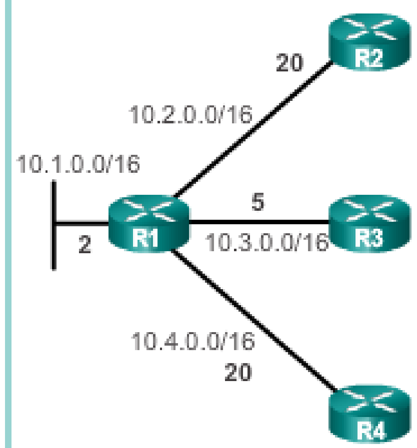
R2 Link-states:
- Connected to network 10.5.0.0/16, cost = 2
- Connected to R1 on network 10.2.0.0/16, cost = 20
- Connected to R5 on network 10.9.0.0/16, cost = 10

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

SPF Tree

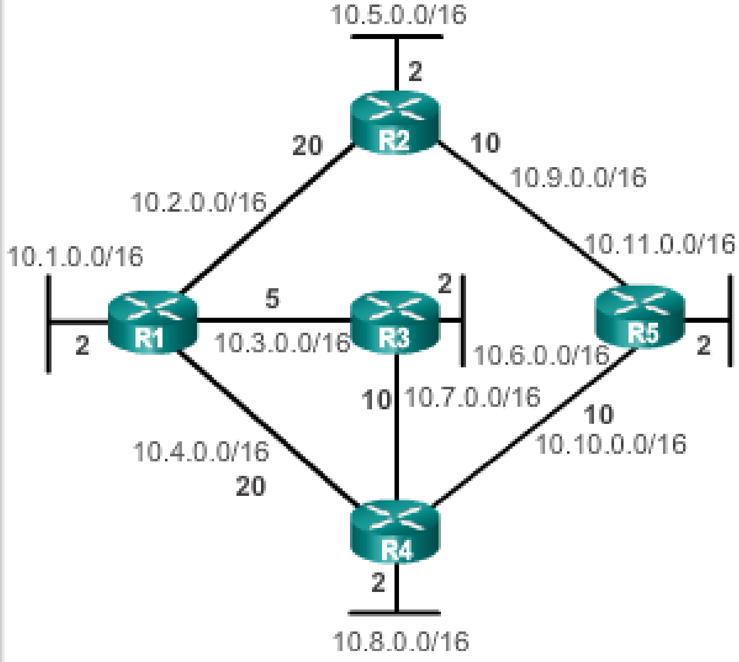


Link-State Updates

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



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 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.

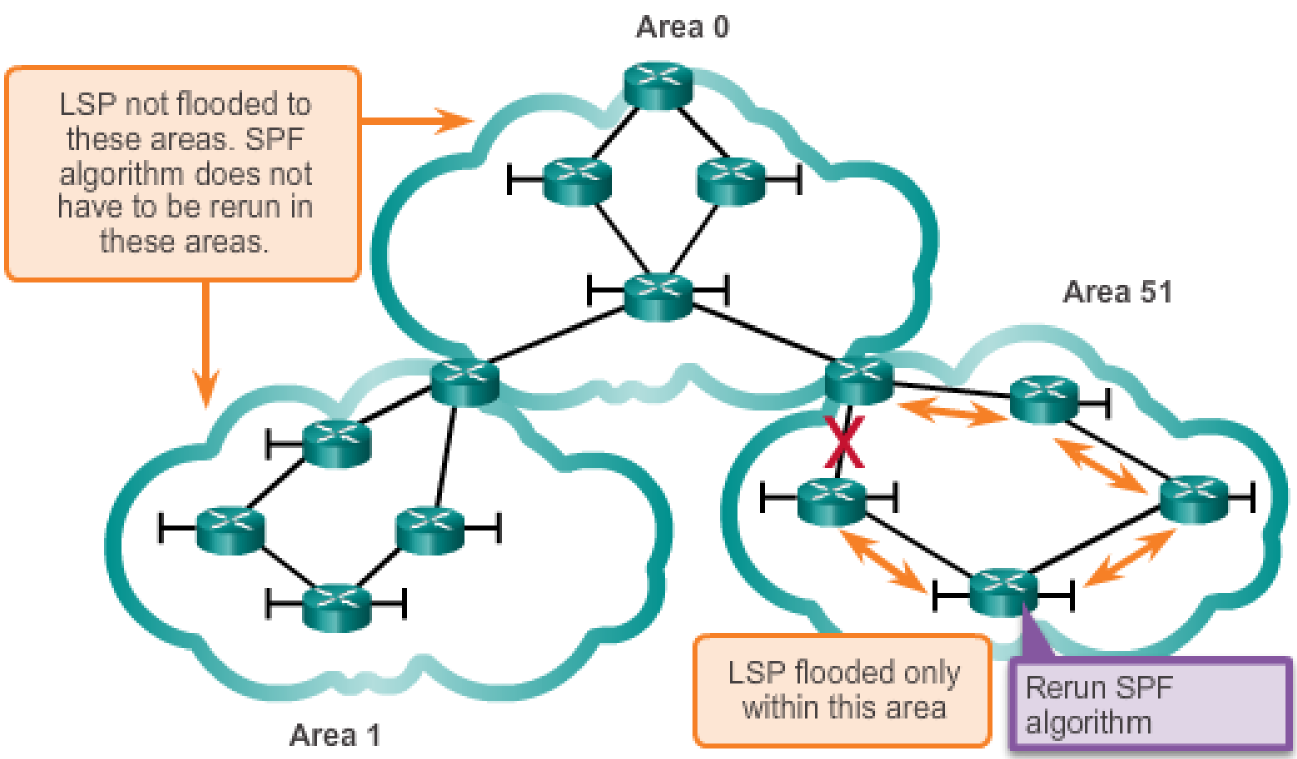
Why Use Link-State Protocols?

Disadvantages of Link-State Routing Protocols

- Maintaining a link-state database and SPF tree requires additional memory.
- Calculating the SPF algorithm also requires additional CPU processing.
- Bandwidth can be adversely affected by link-state packet flooding.

Disadvantages of Link-State Protocols

Create Areas to Minimize Router Resource Usage



Why Use Link-State Routing Protocols

Protocols that Use Link-State

There are only two link-state routing protocols:

- Open Shortest Path First (OSPF) most popular
  - began in 1987
  - two current versions
  - OSPFv2 - OSPF for IPv4 networks
  - OSPFv3 - OSPF for IPv6 networks
- IS-IS was designed by International Organization for Standardization (ISO)

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#
```

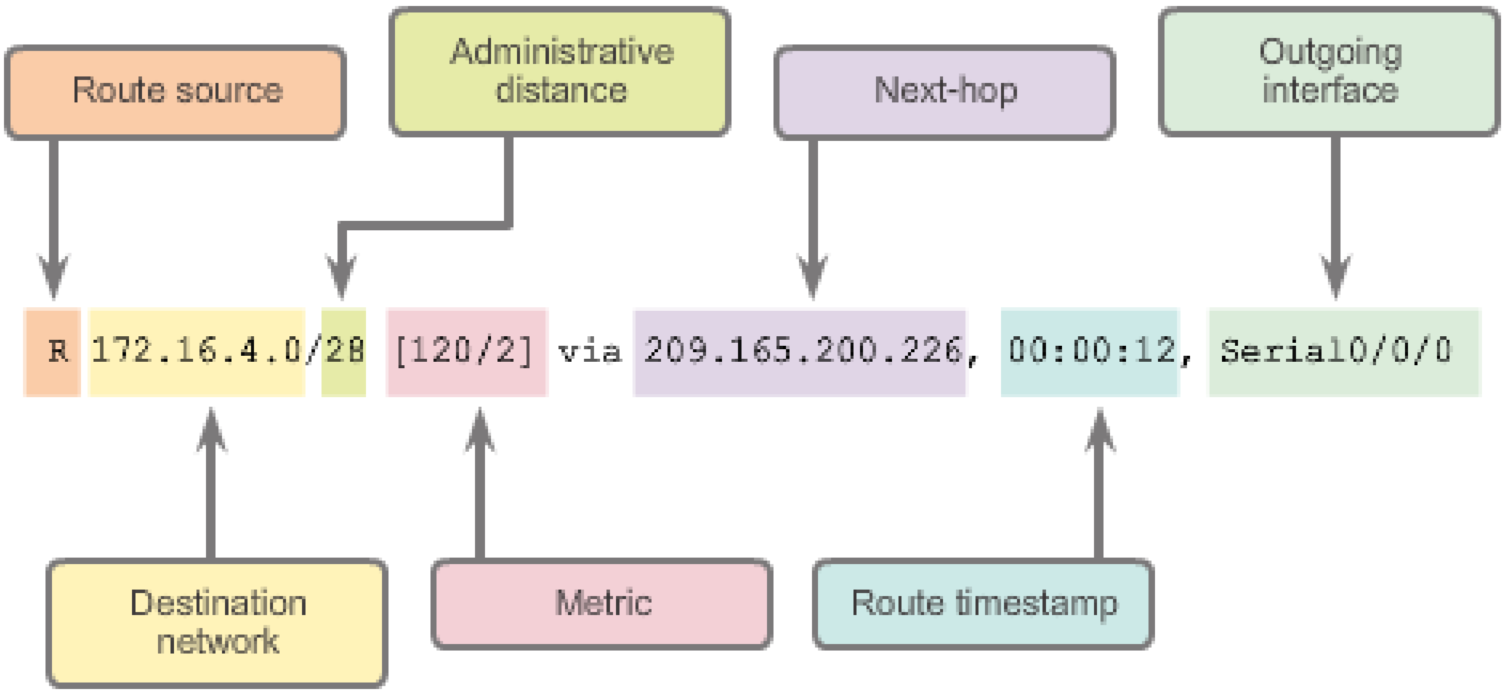
Parts of an IPv4 Route Entry
Directly Connected Entries

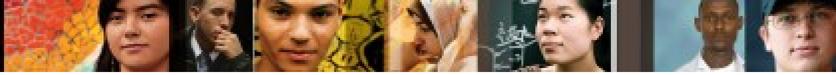
Directly Connected Interfaces of R1

```
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
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

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, and link local routes are ultimate routes.

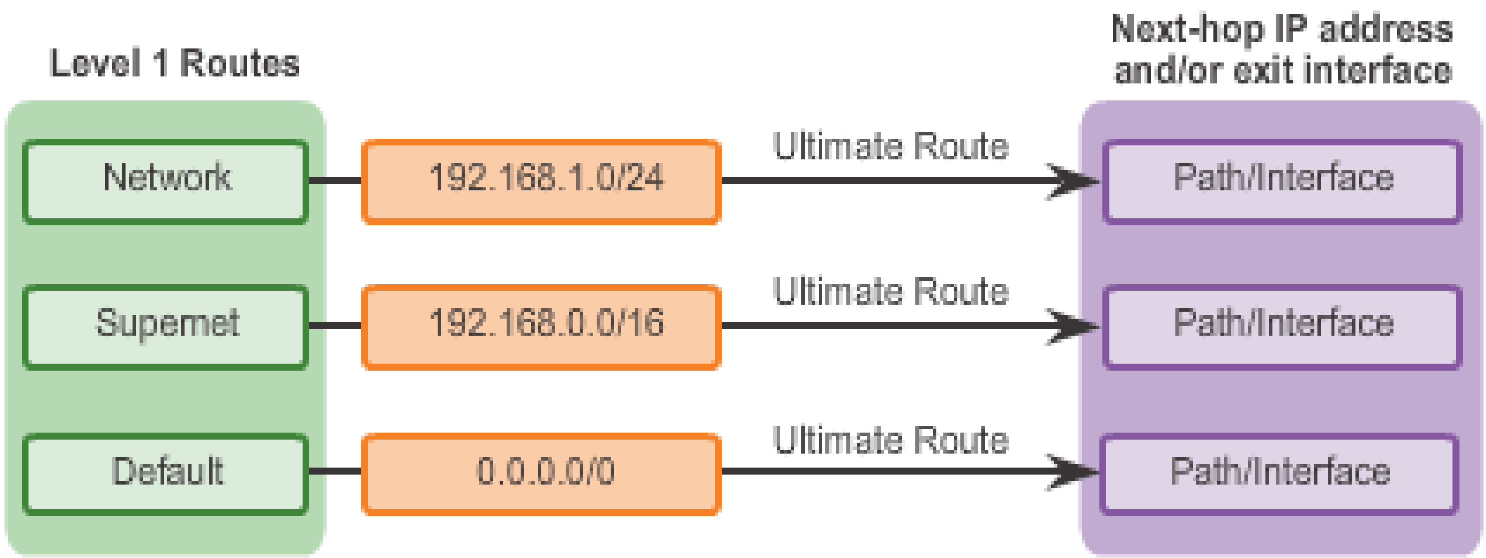
Ultimate Routes of R1

```
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

Sources of Level 1 Routes



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 Routing Table

Route Lookup Process

1. If the best match is a level 1 ultimate route, then this route is used to forward the packet.
2. If the best match is a level 1 parent route, proceed to the next step.
3. The router examines child routes (the subnet routes) of the parent route for a best match.
4. If there is a match with a level 2 child route, that subnet is used to forward the packet.
5. If there is not a match with any of the level 2 child routes, proceed to the next step.

The Routing Table

Route Lookup Process (cont.)

6. The router continues searching level 1 supernet routes in the routing table for a match, including the default route, if there is one.
7. If there is now a lesser match with a level 1 supernet or default routes, the router uses that route to forward the packet.
8. If there is not a match with any route in the routing table, the router drops the packet.

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

The IPv4 Route Lookup Process

IPv6 Routing Table Entries

- Components of the IPv6 routing table are very similar to the IPv4 routing table (directly connected interfaces, static routes, and dynamically learned routes).
- IPv6 is classless by design, all routes are effectively level 1 ultimate routes. There is no level 1 parent of level 2 child routes.

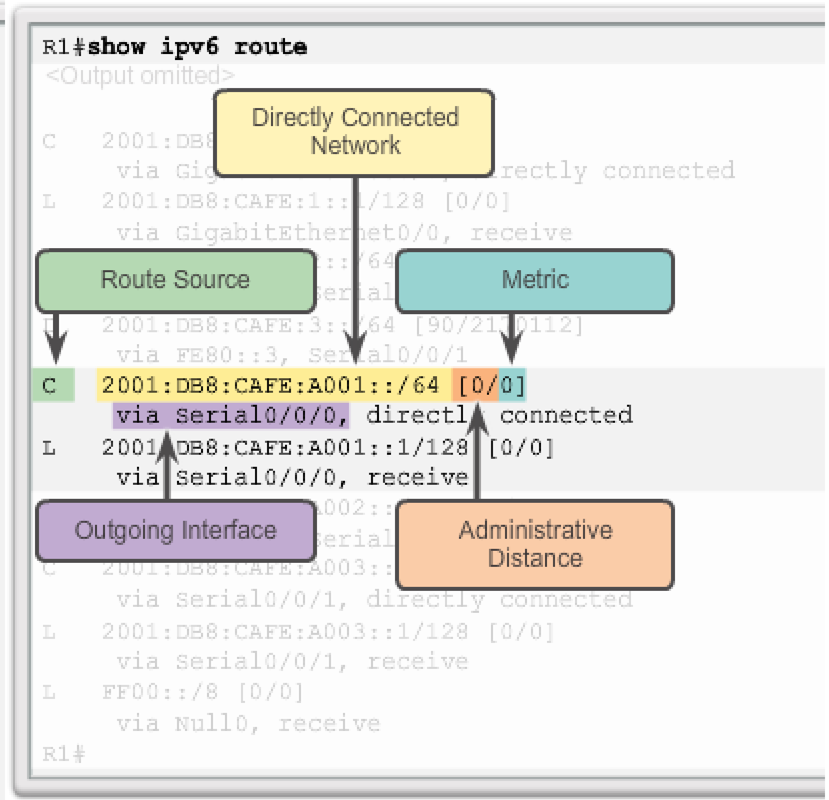
Directly Connected Entries

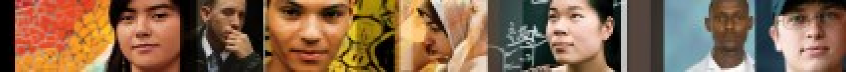
IPv6 Routing Table of R1

```
R1#show ipv6 route
<Output omitted>

C    2001:DB8:CAFE:1::/64 [0/0]
      via GigabitEthernet0/0, directly connected
L    2001:DB8:CAFE:1::1/128 [0/0]
      via GigabitEthernet0/0, receive
D    2001:DB8:CAFE:2::/64 [90/3524096]
      via FE80::3, Serial0/0/1
D    2001:DB8:CAFE:3::/64 [90/2170112]
      via FE80::3, Serial0/0/1
C    2001:DB8:CAFE:A001::/64 [0/0]
      via Serial0/0/0, directly connected
L    2001:DB8:CAFE:A001::1/128 [0/0]
      via Serial0/0/0, receive
D    2001:DB8:CAFE:A002::/64 [90/3523840]
      via FE80::3, Serial0/0/1
C    2001:DB8:CAFE:A003::/64 [0/0]
      via Serial0/0/1, directly connected
L    2001:DB8:CAFE:A003::1/128 [0/0]
      via Serial0/0/1, receive
L    FF00::/8 [0/0]
      via Null0, receive
R1#
```

Directly Connected Routes on R1





Analyze an IPVv6 Routing Table

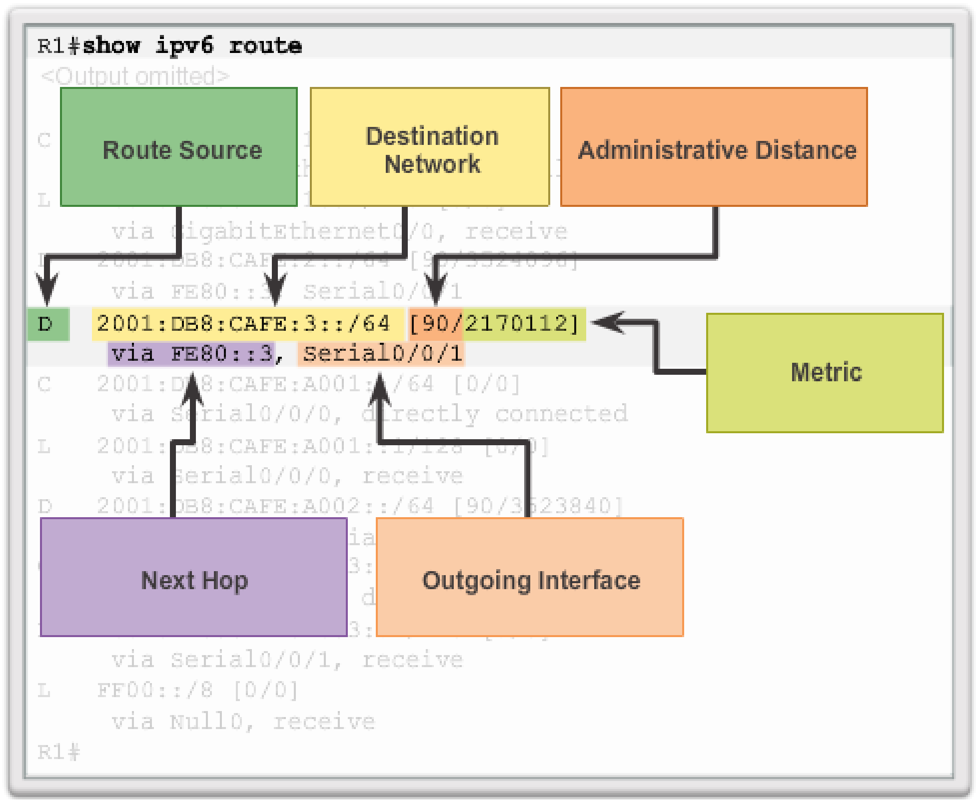
Remote IPv6 Network Entries

Remote Network Entries on R1

```
R1#show ipv6 route
<Output omitted>

C    2001:DB8:CAFE:1::/64 [0/0]
      via GigabitEthernet0/0, directly connected
L    2001:DB8:CAFE:1::1/128 [0/0]
      via GigabitEthernet0/0, receive
D    2001:DB8:CAFE:2::/64 [90/3524096]
      via FE80::3, Serial0/0/1
D    2001:DB8:CAFE:3::/64 [90/2170112]
      via FE80::3, Serial0/0/1
C    2001:DB8:CAFE:A001::/64 [0/0]
      via Serial0/0/0, directly connected
L    2001:DB8:CAFE:A001::1/128 [0/0]
      via Serial0/0/0, receive
D    2001:DB8:CAFE:A002::/64 [90/3523840]
      via FE80::3, Serial0/0/1
C    2001:DB8:CAFE:A003::/64 [0/0]
      via Serial0/0/1, directly connected
L    2001:DB8:CAFE:A003::1/128 [0/0]
      via Serial0/0/1, receive
L    FF00::/8 [0/0]
      via Null0, receive
R1#
```

Remote Network Entries on R1



Chapter 7: Summary

Dynamic routing protocols:

- Used by routers to automatically learn about remote networks from other routers
- Purpose includes: discovery of remote networks, maintaining up-to-date routing information, choosing the best path to destination networks, and ability to find a new best path if the current path is no longer available
- Best choice for large networks but static routing is better for stub networks.
- Function to inform other routers about changes
- Can be classified as either classful or classless, distance-vector or link-state, and an interior or an exterior gateway protocol

Chapter 7: Summary (cont.)

Dynamic routing protocols:

- A link-state routing protocol can create a complete view or topology of the network by gathering information from all of the other routers
- Metrics are used to determine the best path or shortest path to reach a destination network
- Different routing protocols may use different (hops, bandwidth, delay, reliability, and load)
- Show ip protocols command displays the IPv4 routing protocol settings currently configured on the router, for IPv6, use show ipv6 protocols

Chapter 7: Summary (cont.)

Dynamic routing protocols:

- Cisco routers use the administrative distance value to determine which routing source to use
- Each dynamic routing protocol has a unique administrative value, along with static routes and directly connected networks, lower is preferred the route
- Directly connected networks are preferred source, followed by static routes and then various dynamic routing protocols
- An OSPF link is an interface on a router, information about the state of the links is known as link-states
- Link-state routing protocols apply Dijkstra's algorithm to calculate the best path route which uses accumulated costs along each path, from source to destination, to determine the total cost of a route

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