# Chapter 5: Dynamic Routing

CCNA Routing and Switching

Scaling Networks v6.0

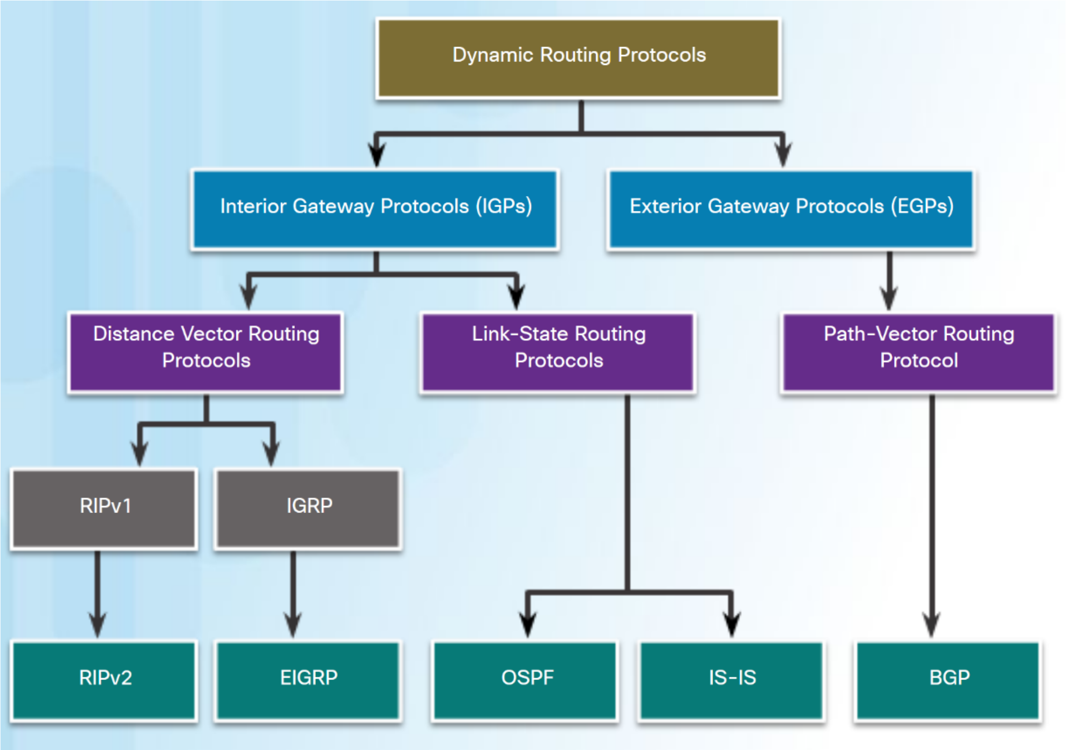
# Chapter 5 - Sections & Objectives

- 5.1 Dynamic Routing Protocols
  - Explain the features and characteristics of dynamic routing protocols.
    - Compare the different types of routing protocols.
- 5.2 Distance Vector Dynamic Routing
  - Explain how distance vector routing protocols operate.
    - Explain how dynamic routing protocols achieve convergence.
    - Describe the algorithm used by distance vector routing protocols to determine the best path.
    - Identify the types of distance-vector routing protocols.
- 5.3 Link-State Dynamic Routing
  - Explain how link-state protocols operate.
    - Describe the algorithm used by link-state routing protocols to determine the best path.
    - Explain how the link-state routing protocol uses information sent in a link-state update.
    - Explain the advantages and disadvantages of using link-state routing protocols.

# 5.1 Dynamic Routing Protocols

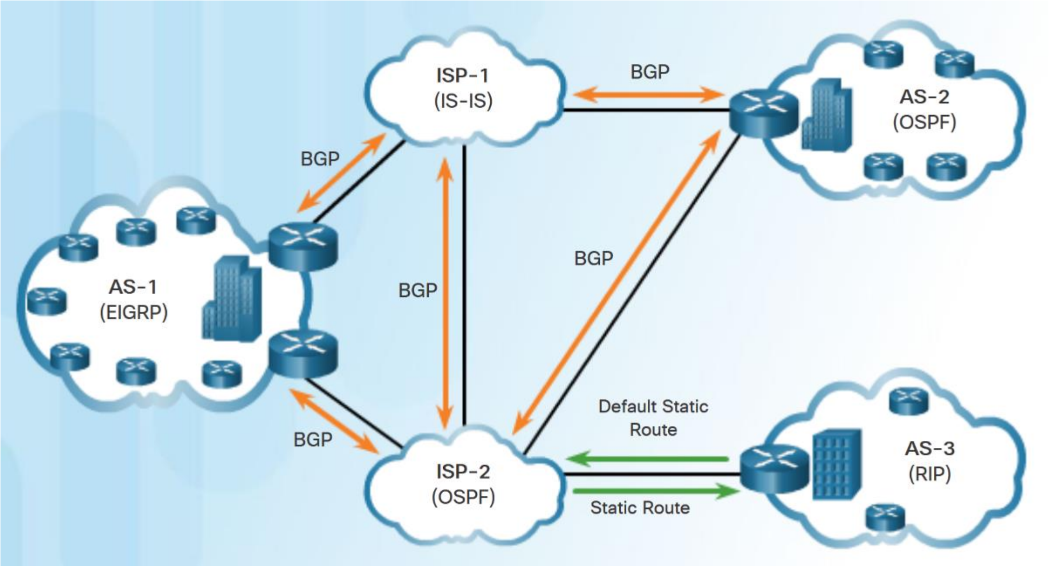
# Classifying Routing Protocols

- 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 current path is no longer available.



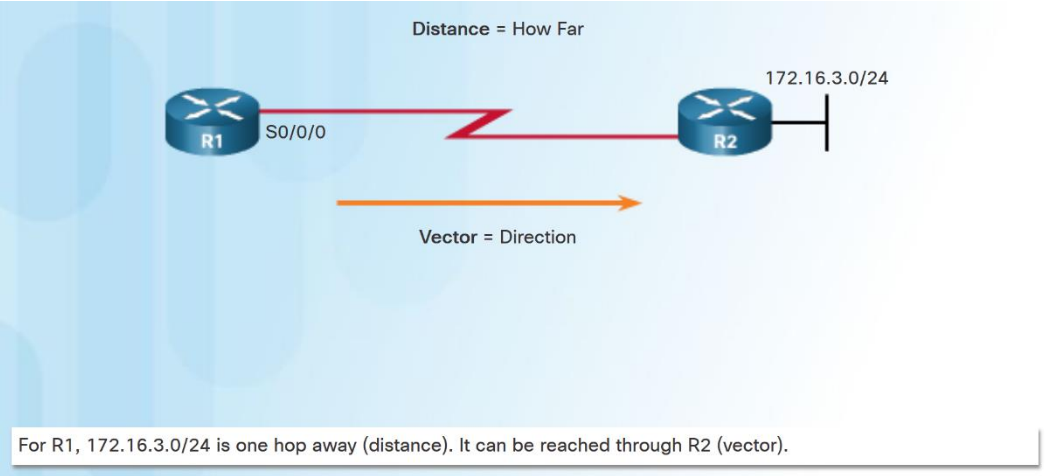
# IGP and EGP Routing Protocols

- Interior Gateway Protocols (IGP) - Used for routing within an Autonomous System (AS).
  - RIP, EIGRP, OSPF, and IS-IS.
- Exterior Gateway Protocols (EGP) - Used for routing between Autonomous Systems.
  - BGP



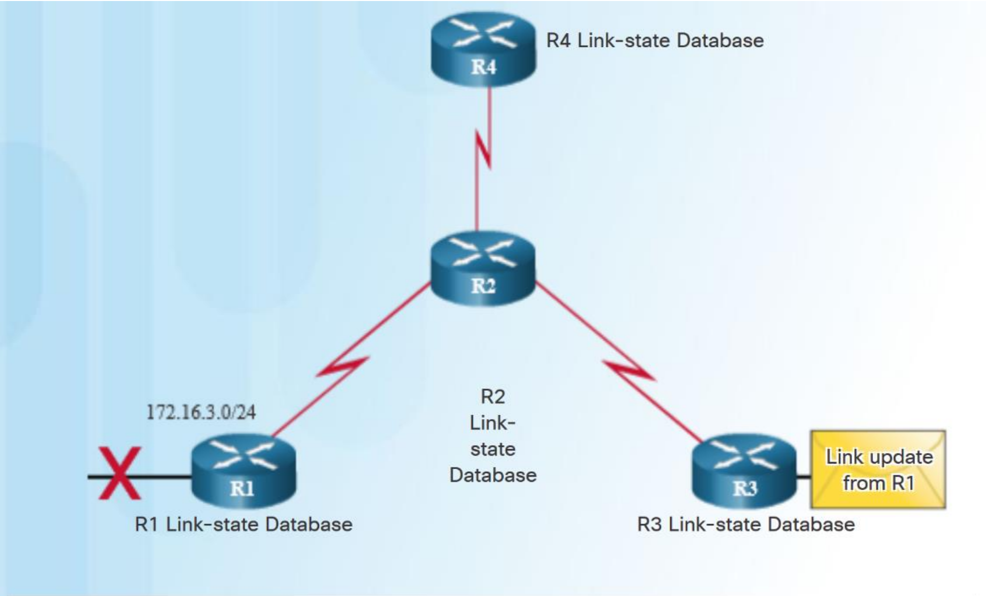

 

# Distance Vector Routing Protocols




- Distance vector means that routes are advertised by providing two characteristics:
  - Distance - Identifies how far it is to the destination network based on a metric such as hop count, cost, bandwidth, delay.
  - Vector - Specifies the direction of the next-hop router or exit interface to reach the destination.
- RIPv1 (legacy), RIPv2, IGRP  Cisco proprietary (obsolete), EIGRP.

# Link-State Routing Protocols

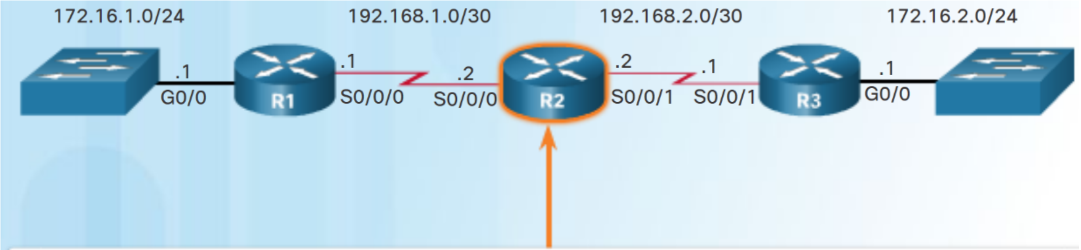



Link-state protocols forward updates when the state of a link changes.

- A link-State router uses the link-state information received from other routers:
  - to create a topology map.
  - to select the best path to all destination networks in the topology.
- Link-state routing protocols do not use periodic updates.
  - updates are only sent when there is a change in the topology
- OSPF and IS-IS

# Classful Routing Protocols

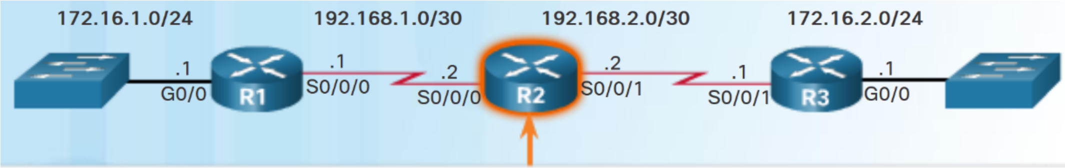
- Classless routing protocols include subnet mask information in the routing updates.
- Classful routing protocols do not send subnet mask information in routing updates.
- Classful routing protocols cannot support variable-length subnet masks (VLSMs) and classless interdomain routing (CIDR).
- Classful routing protocols also create problems in discontiguous networks.




```
R2# ping 172.16.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.1, timeout is 2
seconds:
U.U.U
Success rate is 0 percent (0/5)
R2#
R2# traceroute 172.16.1.1
Type escape sequence to abort.
Tracing the route to 172.16.1.1
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.1.1 4 msec
    192.168.2.1 4 msec
    192.168.1.1 4 msec
R2#
```

# Classless Routing Protocols

- Classless IPv4 routing protocols (RIPv2, EIGRP, OSPF, and IS-IS) all include the subnet mask information in routing updates.
- Classless routing protocols support VLSM and CIDR.
- IPv6 routing protocols are classless.



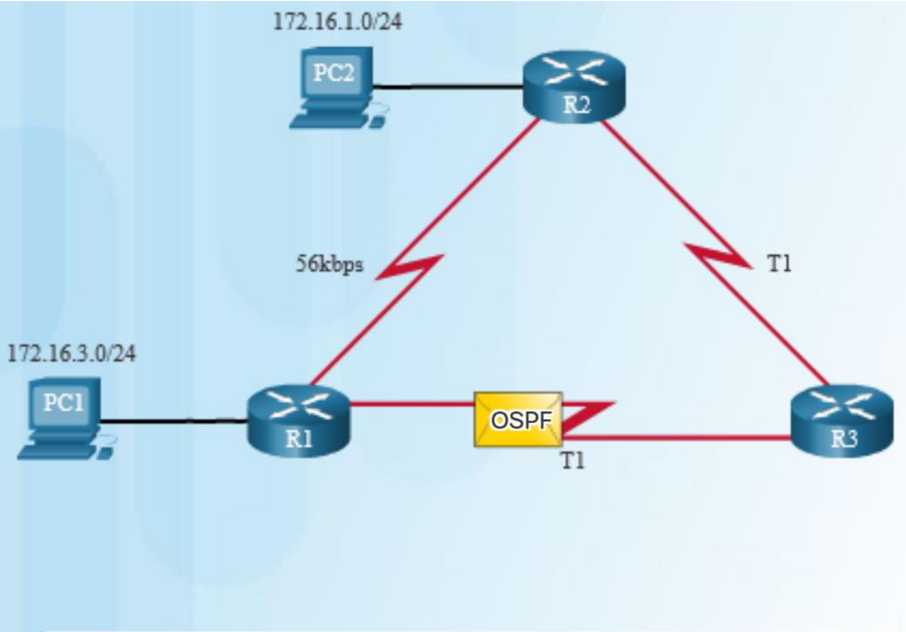

```
R2# ping 172.16.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 12/14/16 ms
R2#
R2# traceroute 172.16.1.1
Type escape sequence to abort.
Tracing the route to 172.16.1.1
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.1.1 4 msec 4 msec *
R2#
```

# Routing Protocol Characteristics

- Routing protocols can be compared based on the characteristics in the chart.

| | Distance Vector | | | | Link State | |
|---|---|---|---|---|---|---|
| | RIPv1 | RIPv2 | IGRP | EIGRP | OSPF | IS-IS |
| Speed of 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 |
| Implementation and Maintenance | Simple | Simple | Simple | Complex | Complex | Complex |

# Routing Protocol Metrics



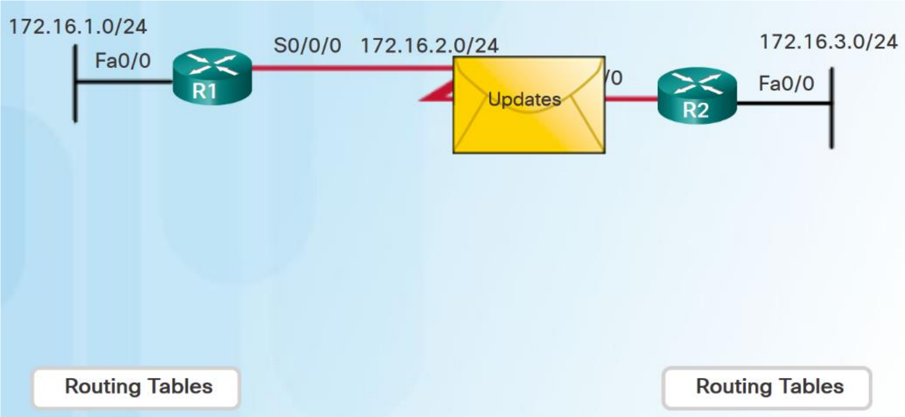

RIP chooses best path based on hop count.
OSPF chooses best path based on bandwidth.

- A metric is a measurable value that is assigned by the routing protocol to different routes based on the usefulness of that route.
- Routing metrics are used to determine the overall “cost” of a path from source to destination.
- Best path is  route with the lowest cost.
- Metrics used by various dynamic protocols:
  - RIP – Hop count
  - OSPF – Cost based on cumulative bandwidth
  - EIGRP - Bandwidth, delay, load, and reliability.

# 5.2 Distance Vector Dynamic Routing

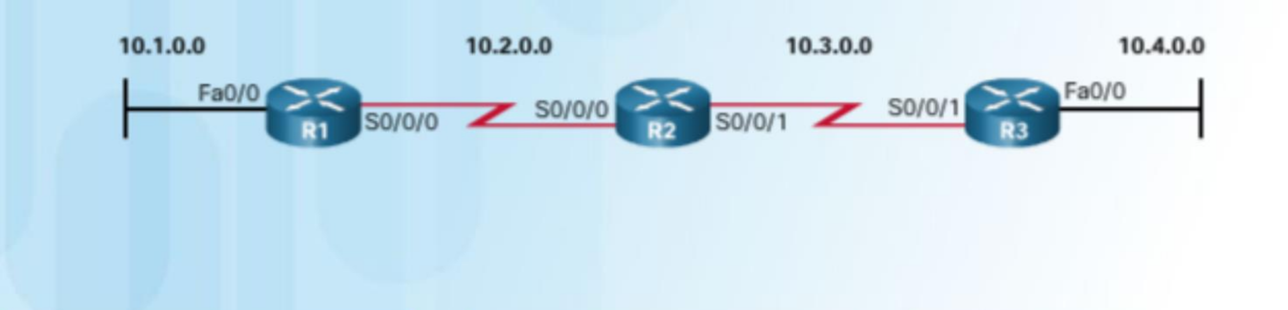
# Dynamic Routing Protocol Operation

- Operation of a dynamic routing protocol can be described as follows:
  - The router sends and receives routing messages on its interfaces.
  - The router shares routing messages and routing information with other routers using the same routing protocol.
  - Routers exchange routing information to learn about remote networks.
  - When a router detects a topology change, the routing protocol can advertise this change to other routers.



# Cold Start

- After a router boots successfully it applies the saved configuration, then the router initially discovers its own directly connected networks.
  - It adds those directly connected interface IP addresses to its routing table




| 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 |
| | | |
| | | |

# Network Discovery

- If a routing protocol is configured, the router exchanges routing updates to learn about any remote routes.
  - The router sends an update packet with its routing table information out all interfaces.
  - The router also receives updates from directly connected routers and adds new information to its routing table.


| 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 |

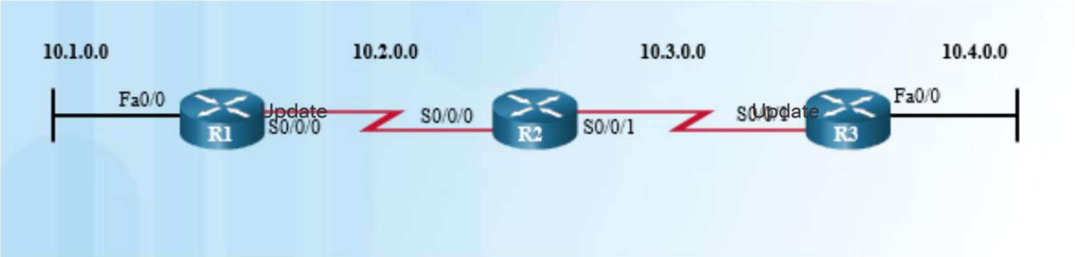
| Network | Interface | Hop |
|---|---|---|
| 10.2.0.0 | S0/0/0 | 0 |
| 10.3.0.0 | S0/0/1 | 0 |
| 10.1.0.0 | S0/0/0 | 1 |
| 10.4.0.0 | S0/0/1 | 1 |

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

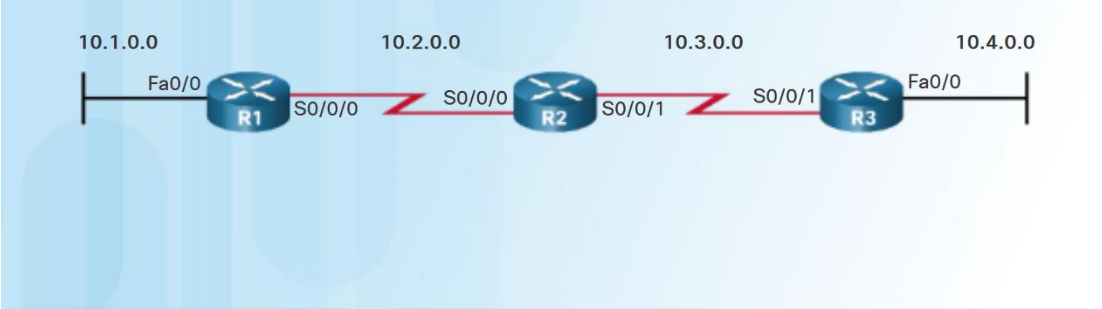
# Exchanging the Routing Information

- Working toward convergence, the routers exchange the next round of periodic updates.
- Distance vector routing protocols use split horizon to avoid loops.
- Split horizon prevents information from being sent out the same interface from which it was received.




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

# Achieving Convergence



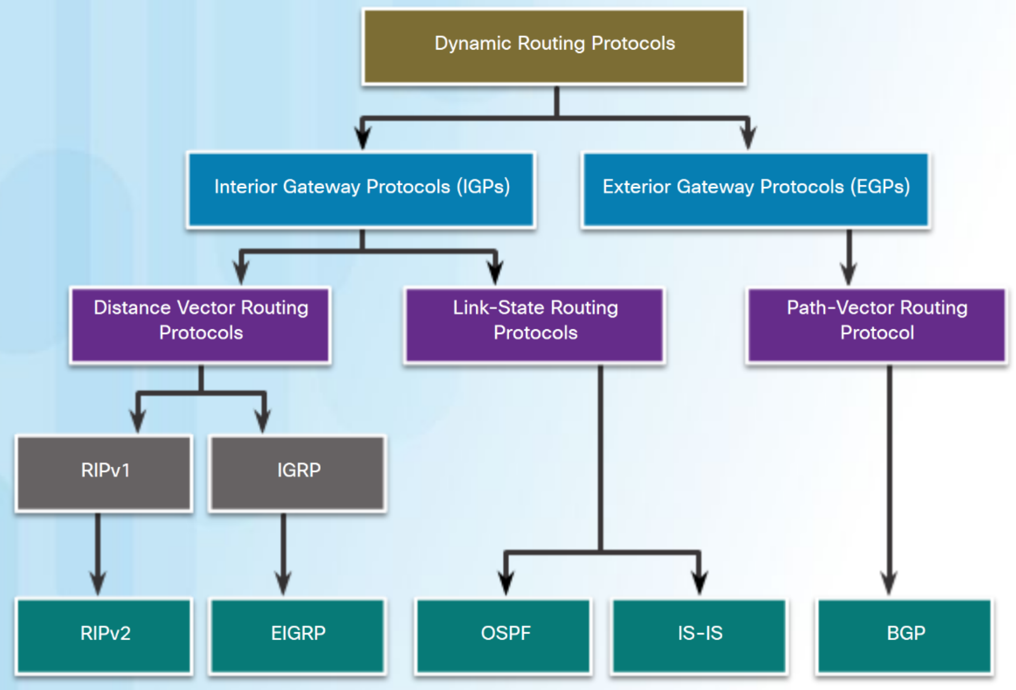

| Network | Interface | Hop |
|---|---|---|
| 10.1.0.0 | Fa0/0 | 0 |
| 10.2.0.0 | S0/0/0 | 0 |
| 10.3.0.0 | S0/0/0 | 1 |
| 10.4.0.0 | S0/0/0 | 2 |

| 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 |

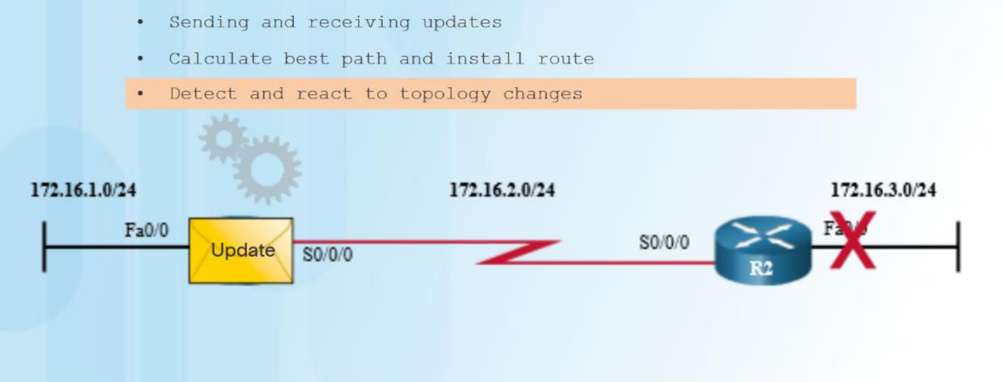
- The network has converged when all routers have complete and accurate information about the entire network
- Convergence time is the time it takes routers to share information, calculate best paths, and update routing tables.
- Routing protocols can be rated based on the speed to convergence; the faster the convergence, the better the routing protocol.

# Distance Vector Technologies




- Distance vector routing protocols share updates between neighbors.
- Routers using distance vector routing are not aware of the network topology.
- Some distance vector routing protocols send periodic updates.
  - RIPv1 sends updates as broadcasts 255.255.255.255.
  - RIPv2 and EIGRP can use multicast addresses to reach only specific neighbor routers.
  - EIGRP can use a unicast message to reach a specific neighbor router.
  - EIGRP only sends updates when needed, not periodically.

# Distance Vector Algorithm




| Network | Interface | Hop |
|---|---|---|
| 172.16.1.0/24 | Fa0/0 | 0 |
| 172.16.2.0/24 | S0/0/0 | 0 |
| 172.16.3.0/24 | S0/0/0 | 1 |

| Network | Interface | Hop |
|---|---|---|
| 172.16.2.0/24 | S0/0/0 | 0 |
| ~~172.16.3.0/24~~ | ~~Fa0/0~~ | ~~0~~ |
| 172.16.1.0/24 | S0/0/0 | 1 |

- The distance vector algorithm defines the following processes:
  - Mechanism for sending and receiving routing information
  - Mechanism for calculating the best paths and installing routes in the routing table
  - Mechanism for detecting and reacting to topology changes
- RIP uses the Bellman-Ford algorithm as its routing algorithm.
- IGRP and EIGRP use the Diffusing Update Algorithm (DUAL) routing algorithm.

# Routing Information Protocol

- The Routing Information Protocol (RIP)
  - Easy to confgure
  - Routing updates broadcasted (255.255.255.255) every 30 seconds
  - Metric is hop count
  - 15 hop limit
- RIPv2
  - **Classless routing protocol** - supports VLSM and CIDR
  - **Increased efficiency** – sends updates to multicast address 224.0.0.9
  - **Reduced routing entries** - supports manual route summarization
  - **Secure** - supports authentication

| 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 | ✗ | ✓ |

- RIPng
  - IPv6 enabled version of RIP
  - 15 hop limit and administrative distance is 120

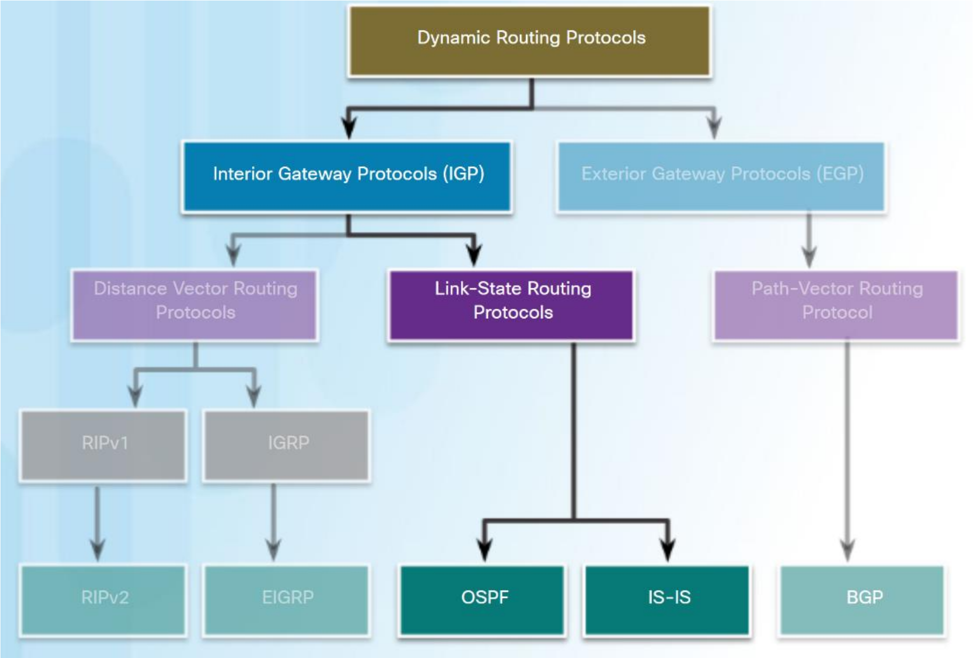
# Enhanced Interior-Gateway Routing Protocol

| 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 replaced IGRP in 1992. It includes the following features:
  - **Bounded triggered updates** – sends updates only to routers that need it.
  - **Hello keepalive mechanism** - Hello messages are periodically exchanged to maintain adjacencies.
  - **Maintains a topology table** - maintains all the routes received from neighbors (not only the best paths) in a topology table.
  - **Rapid convergence** – because it maintains alternate routes.
  - **Multiple network layer protocol support** – uses Protocol Dependent Modules (PDM) to support layer 3 protocols.

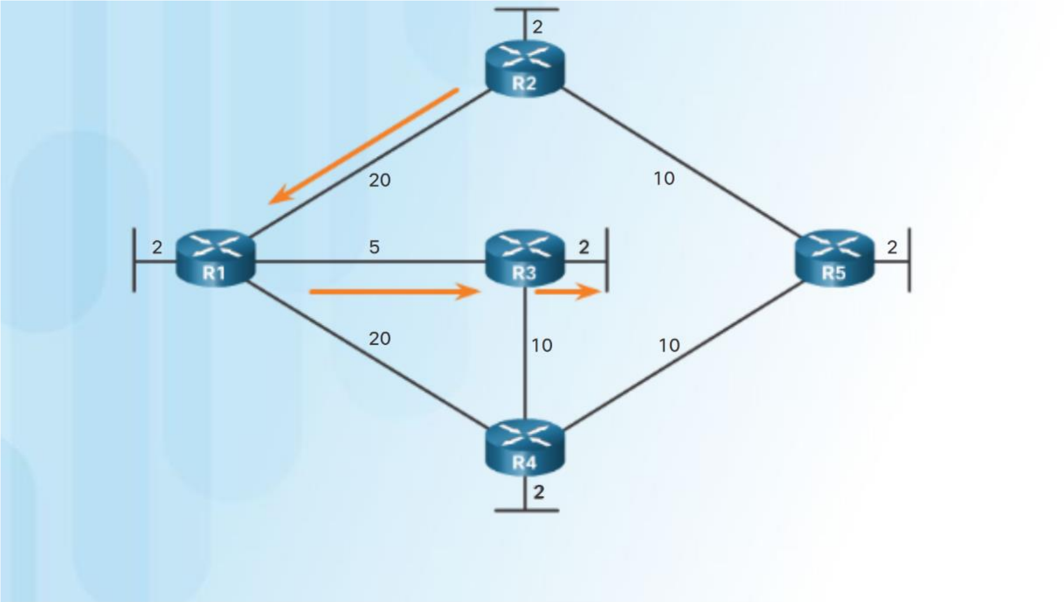
# 5.3 Link-State Dynamic Routing

# Shortest Path First Protocols




- Link-state routing protocols, also known as shortest path first protocols, are built around Edsger Dijkstra's shortest path first (SPF) algorithm.
- IPv4 Link-State routing protocols:
  - Open Shortest Path First (OSPF)
  - Intermediate System-to-Intermediate System (IS-IS)

# Dijkstra's Algorithm



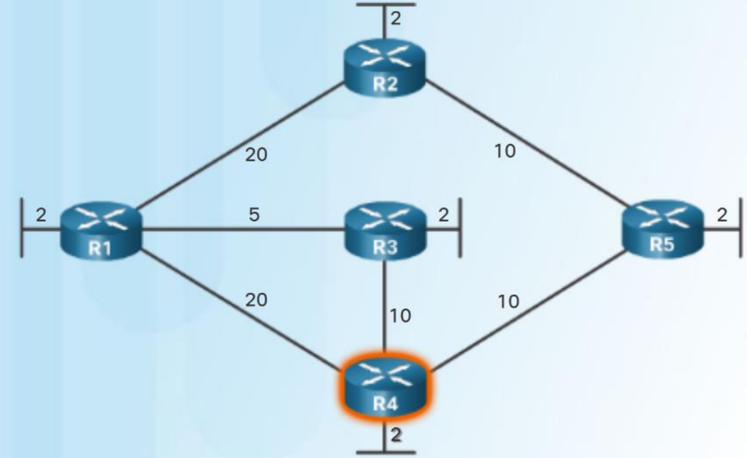

Shortest Path for host on R2 LAN to reach host on R3 LAN: R2 to R1 (20) + R1 to R3 (5) + R3 to LAN (2) = 27

- All link-state routing protocols apply Dijkstra's algorithm (also known as shortest path first (SPF)) to calculate the best path route:
  - Uses accumulated costs along each path, from source to destination.
  - Each router determines its own cost to each destination in the topology.

# SPF Example

- The table displays the shortest path and the accumulated cost to reach the identified destination networks from the perspective of R4.




| Destination | Shortest Path | Cost |
|---|---|---|
| R1 LAN | R4 to R3 to R1 | 17 |
| R2 LAN | R4 to R5 to R2 | 22 |
| R3 LAN | R4 to R3 | 12 |
| R5 LAN | R4 to R5 | 12 |

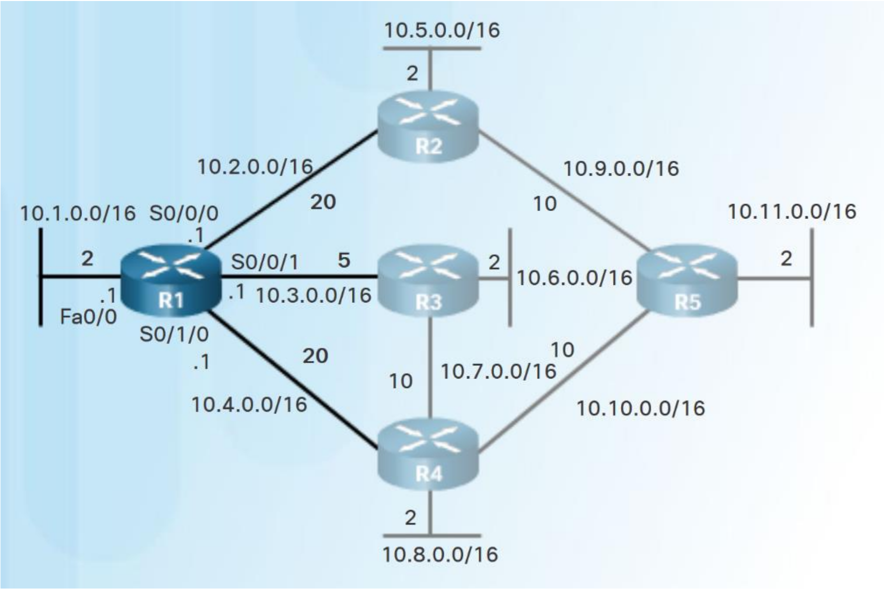
# Link-State Routing Process

## Link-State Routing Process

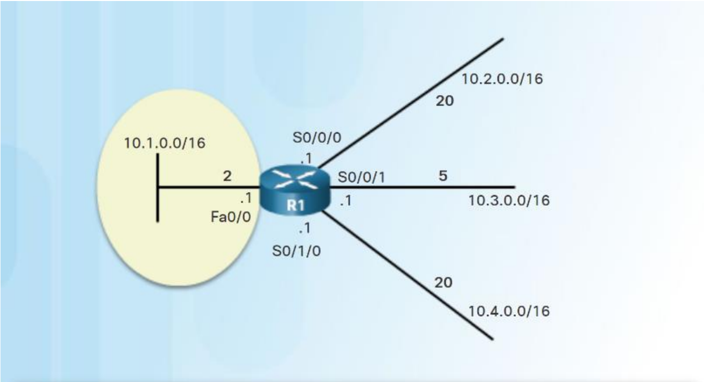
- Each router learns about each of its own directly connected networks.
- Each router is responsible for "saying hello" to its neighbors on directly connected networks.
- Each router builds a Link-State Packet (LSP) containing the state of each directly connected link.
- Each router floods the LSP to 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 computes the best path to each destination network.

Note: This process is the same for both OSPF for IPv4 and OSPF for IPv6.

# Link and Link-State



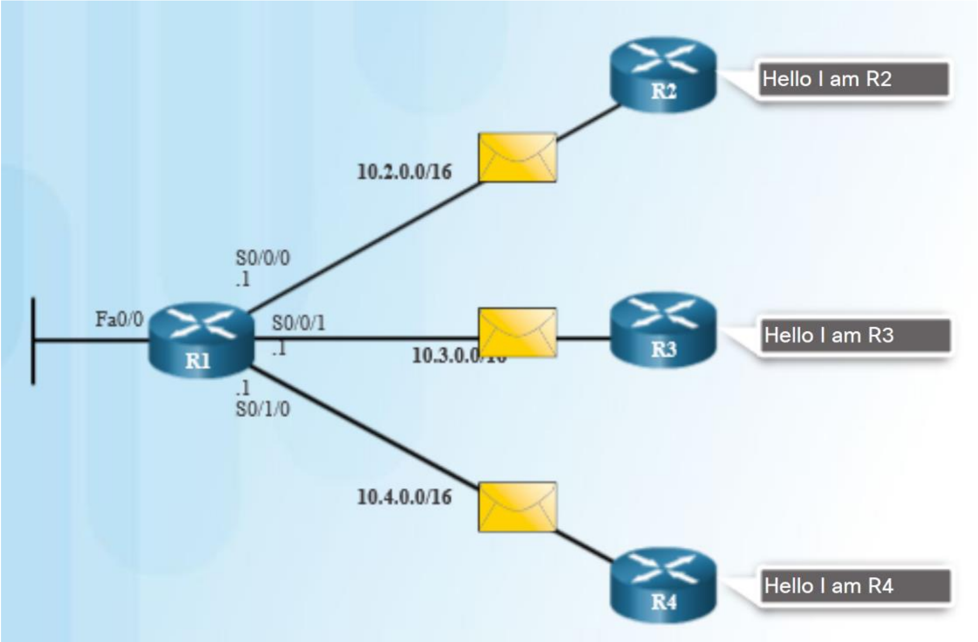

- The first step in the link-state routing process is that each router learns its own directly connected networks.




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

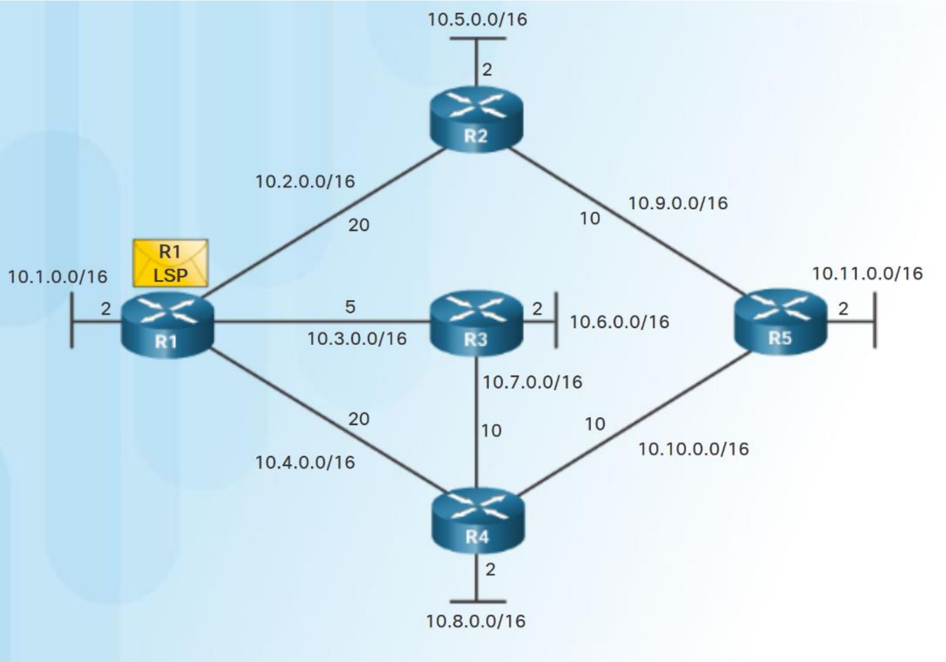
# Say Hello




- The second step in the link-state routing process is that each router uses a Hello protocol to discover any neighbors on its links.
- When two link-state routers learn that they are neighbors, they form an adjacency.
- If a router stops receiving Hello packets from a neighbor, that neighbor is considered unreachable.

# Building the Link-State Packet

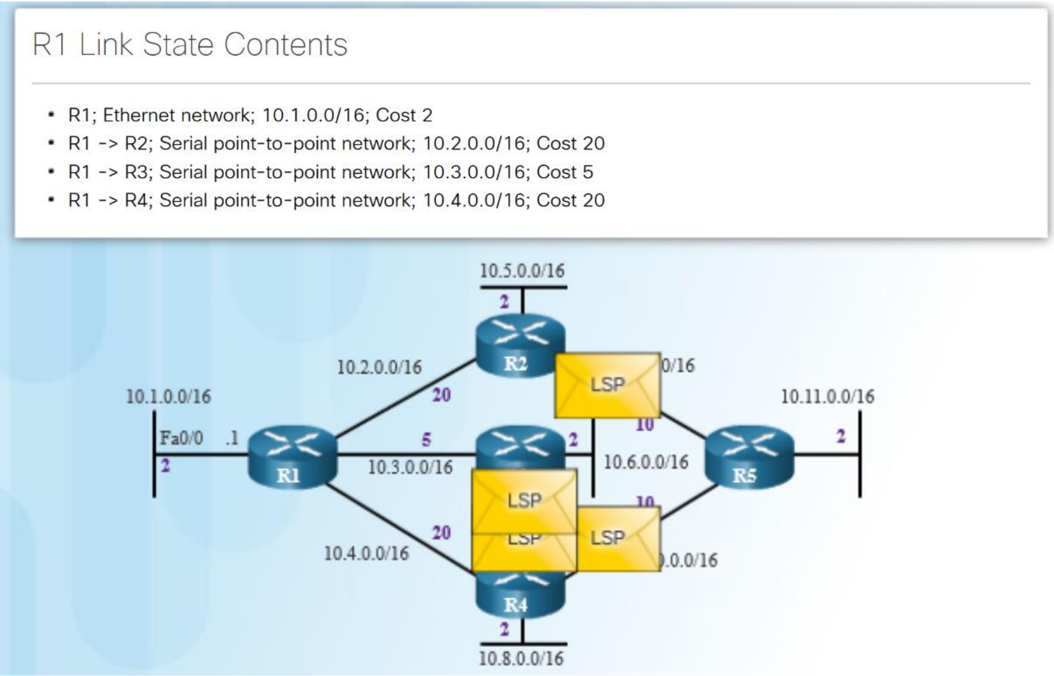
- The third step in the link-state routing process is that each router builds a link-state packet (LSP) that contains the link-state information about its links.
- R1 LSP (in diagram) would contain:
  - R1; Ethernet network 10.1.0.0/16; Cost 2
  - R1 -> R2; Serial point-to-point network; 10.2.0.0/16; 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



# Flooding the LSP

- The fourth step in the link-state routing process is that each router floods the LSP to all neighbors.
- An LSP only needs to be sent:
  - During initial startup of the routing protocol process on that router (e.g., router restart)
  - Whenever there is a change in the topology (e.g., a link going down)
- An LSP also includes sequence numbers and aging information:
  - used by each router to determine if it has already received the LSP.
  - used to determine if the LSP has newer information.



# 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.

**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

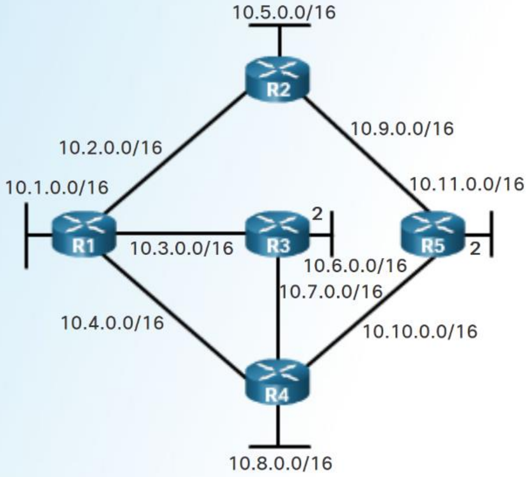
**R4 Link-states:**
- Connected to network 10.8.0.0/16, cost = 2
- Connected to R1 on network 10.4.0.0/16, cost = 20
- Connected to R3 on network 10.7.0.0/16, cost = 10
- Connected to R5 on network 10.10.0.0/16, cost = 10

**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

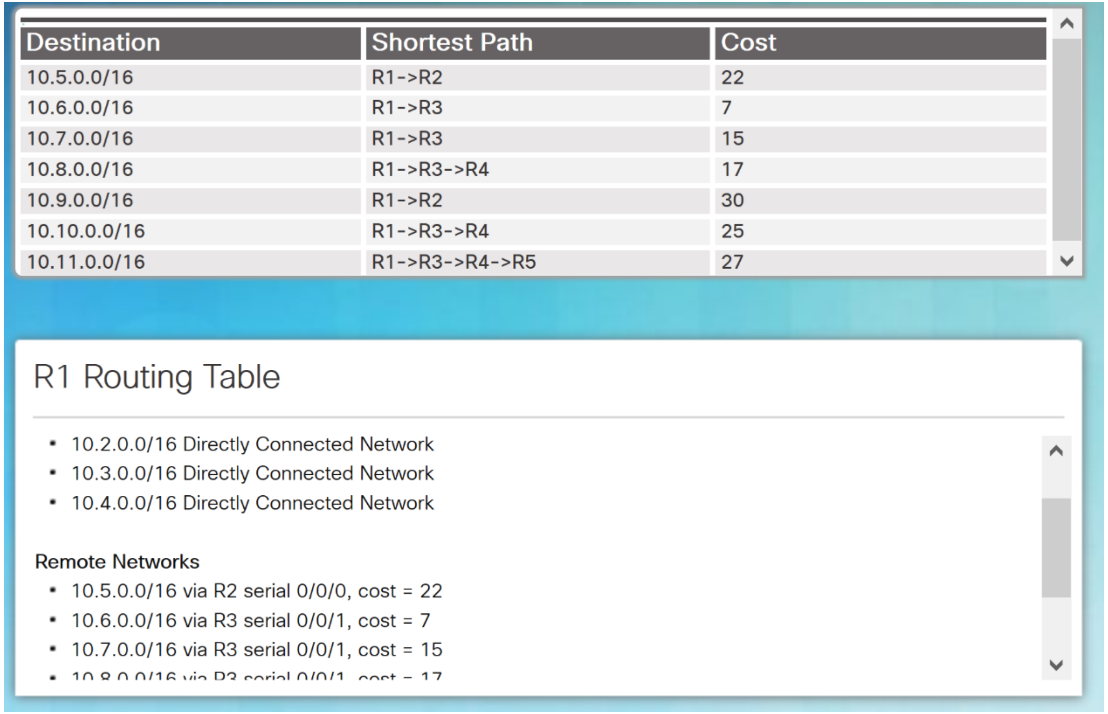
# Building the SPF Tree

| 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 |




- Each router uses the link-state database and SPF algorithm to construct the SPF tree.
  - R1 identifies its directly connected networks and costs.
  - R1 adds any unknown networks and associated costs.
  - The SPF algorithm then calculates the shortest paths to reach each individual network resulting in the SPF tree shown in the diagram.
- Each router constructs its own SPF tree independently from all other routers.

# Adding OSPF Routes to 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

- 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

- Using the shortest path information determined by the SPF algorithm, these best paths are then added to the routing table.
- Directly connected routes and static routes are also included in the routing table.

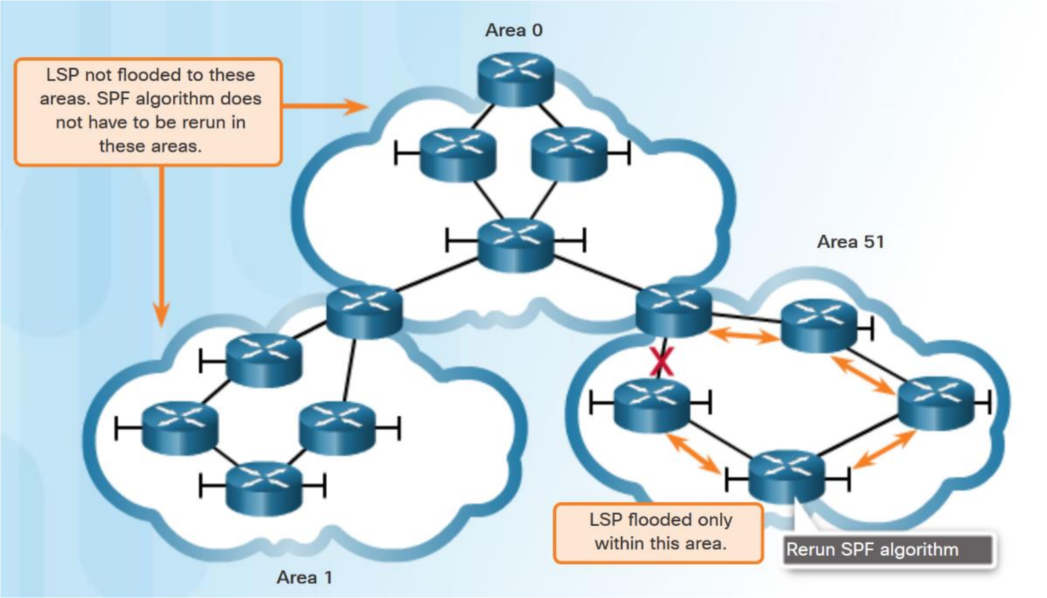
# Why Use Link-State Protocols?

## 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.

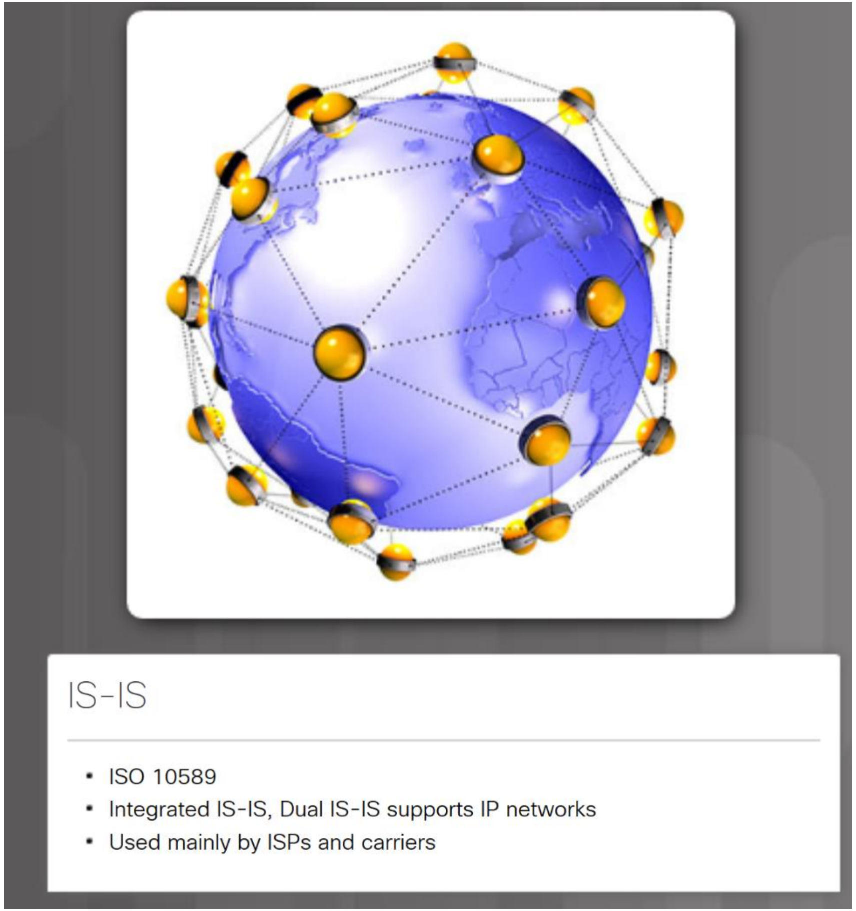
# Disadvantages of Link-State Protocols

- Disadvantages of Link-State protocols:
  - Memory Requirements - Link-state protocols require additional memory.
  - Processing Requirements - Link-state protocols can require more CPU processing.
  - Bandwidth Requirements - The flooding of link-state packets can adversely affect bandwidth.
- Using multiple areas can reduce the size of the link-state databases.
- Multiple areas can limit the amount of link-state information flooding and send LSPs only to those routers that need them.



# Protocols that Use Link-State

- Two link-state routing protocols, OSPF and IS-IS.Open Shortest Path First (OSPF) - most popular implementation with two versions in use:
  - OSPFv2- OSPF for IPv4 networks (RFC 1247 and RFC 2328)
  - OSPFv3- OSPF for IPv6 networks (RFC 2740)
- Integrated IS-IS, or Dual IS-IS, includes support for IP networks.
- used mainly by ISPs and carriers.



# 5.4 Chapter Summary

# Chapter 5: Dynamic Routing

- Explain the features and characteristics of dynamic routing protocols.
- Explain how distance vector routing protocols operate.
- Explain how link-state protocols operate.

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