Chapter 4: Dynamic Routing

Redes de Computadores II

Chapter 4: Dynamic Routing

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Redes de Computadores II

Chapter 4 - 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.

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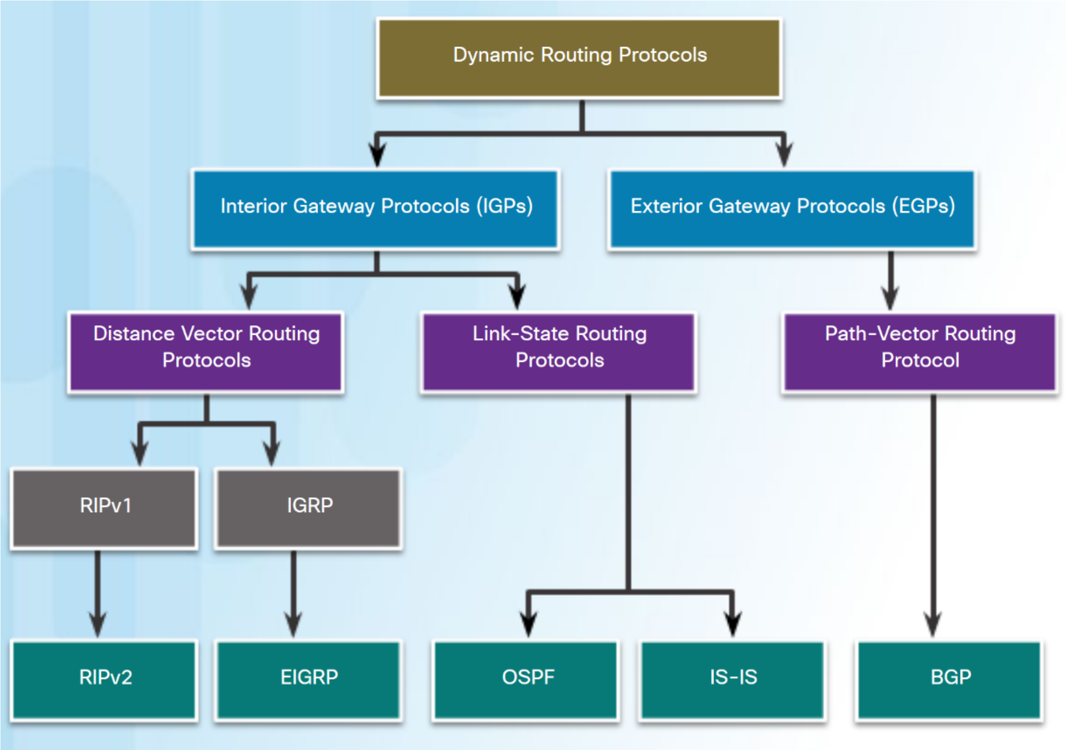
5.1 Dynamic Routing Protocols

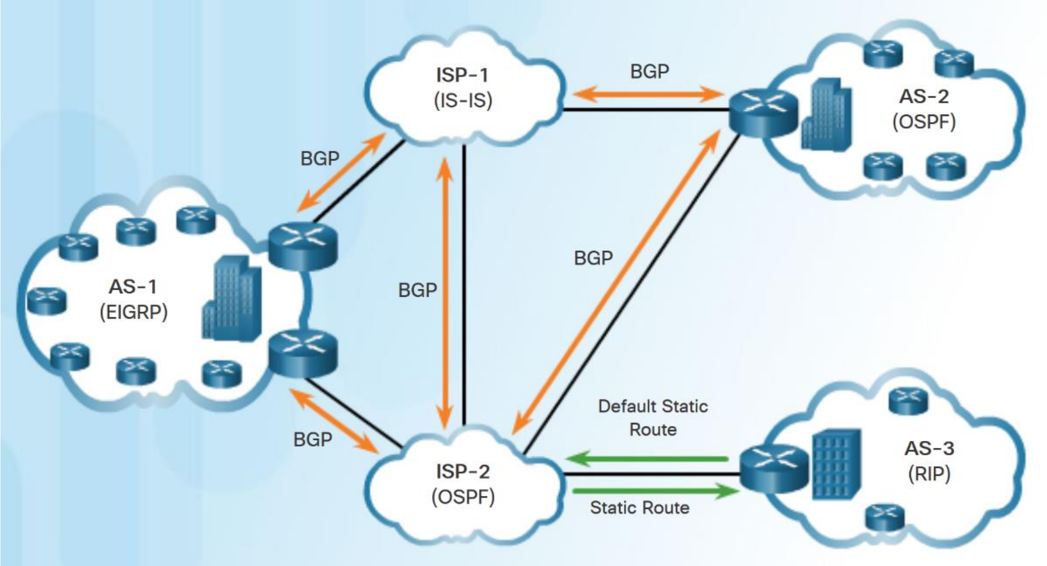
Classifying Routing Protocols

- 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



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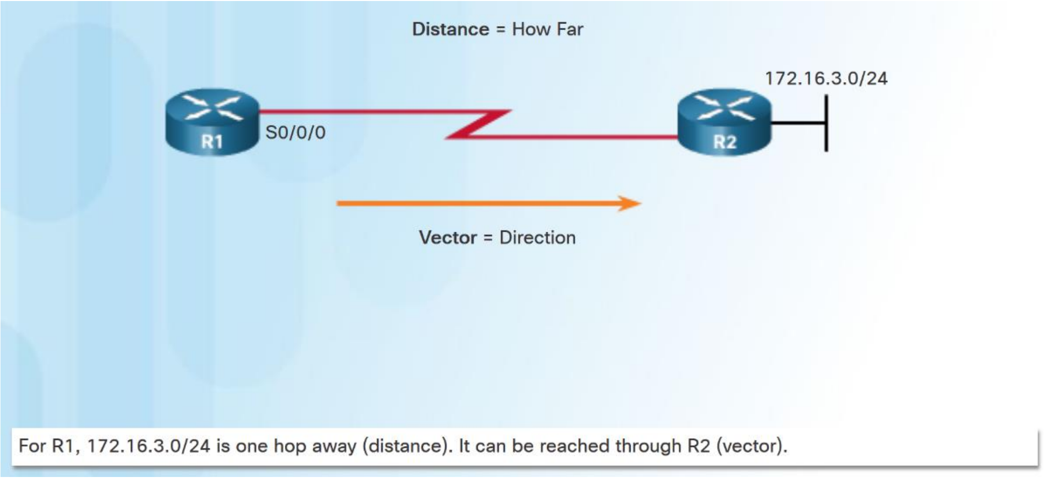
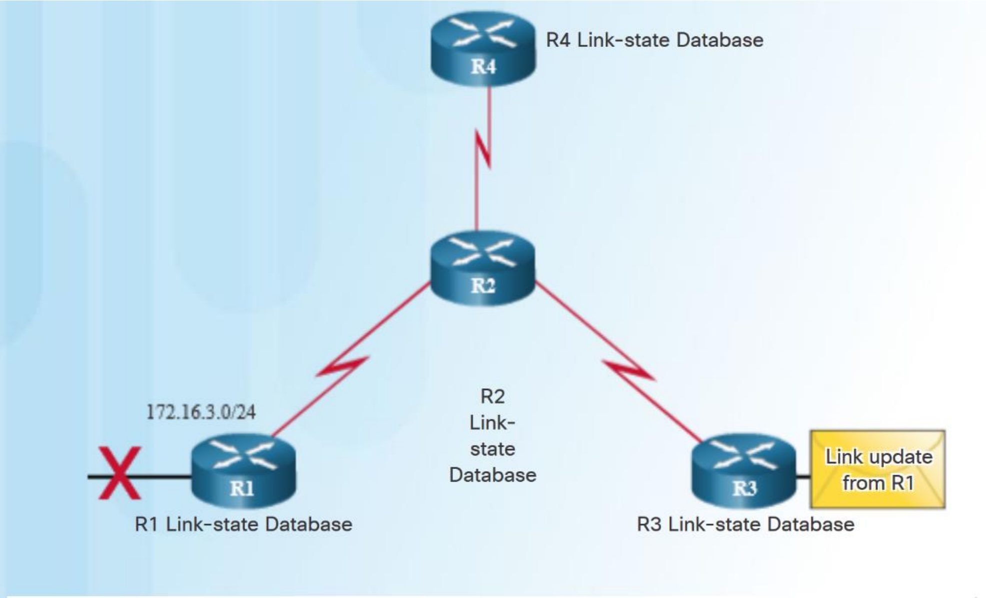
Distance Vector Routing Protocols



- 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

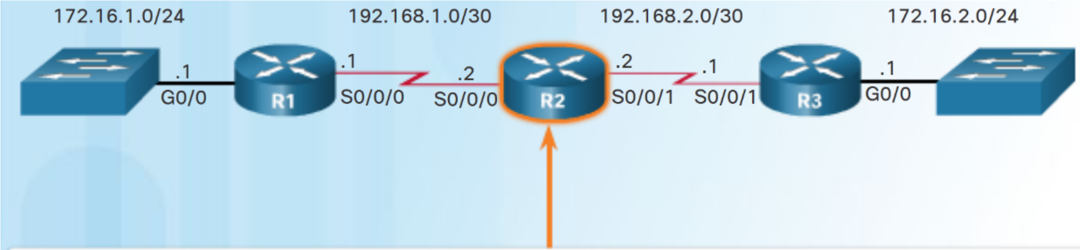


Link-state protocols forward updates when the state of a link changes.

- 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

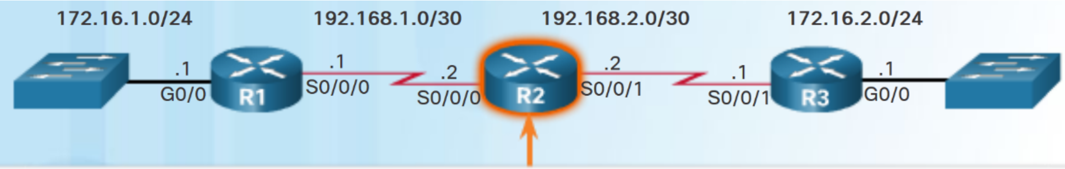
- Classless routing protocols include subnet mask information in the routing updates.
- Classful routing protocols do not send subnet mask information in routing updates.
- Classful routing protocols cannot support variable-length subnet masks (VLSMs) and classless interdomain routing (CIDR).
- Classful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



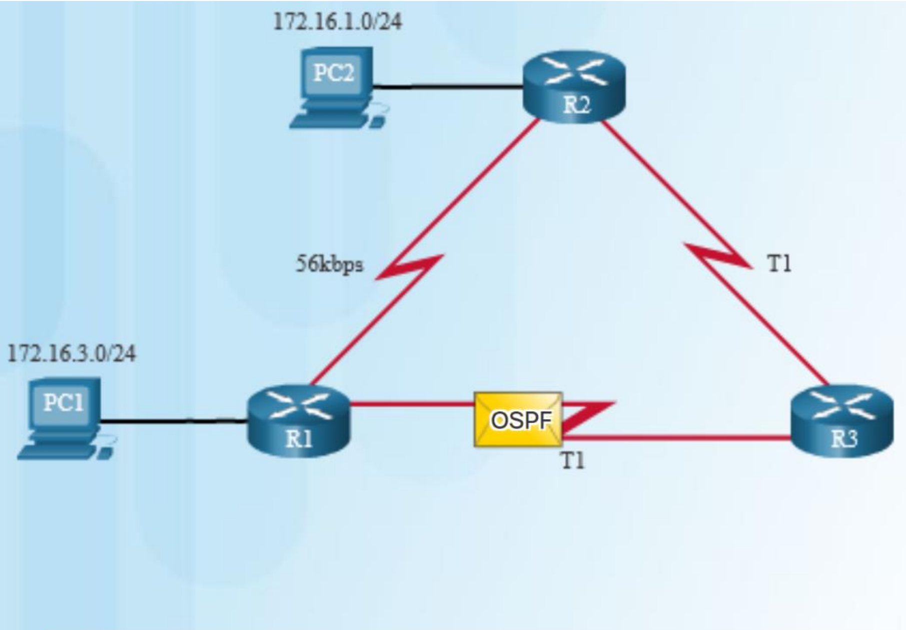

```
R2# ping 172.16.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 12/14/16 ms
R2#
R2# traceroute 172.16.1.1
Type escape sequence to abort.
Tracing the route to 172.16.1.1
VRF info: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



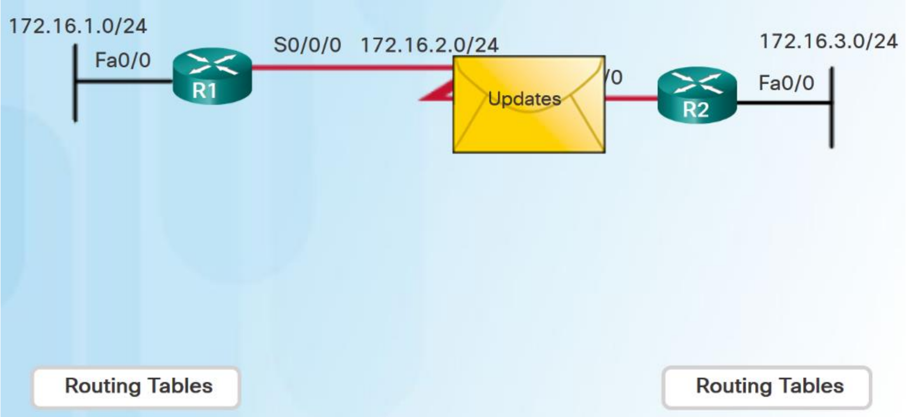
RIP chooses best path based on hop count.
OSPF chooses best path based on bandwidth.

- 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.



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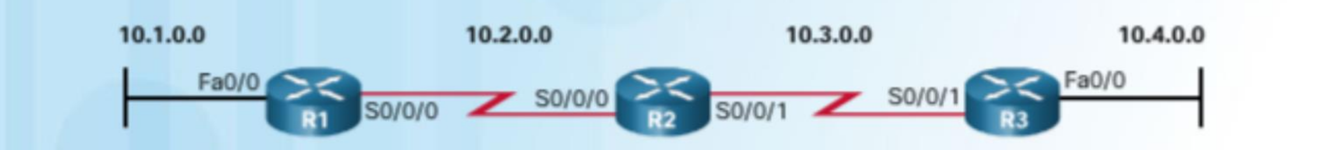
Cold Start

- 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



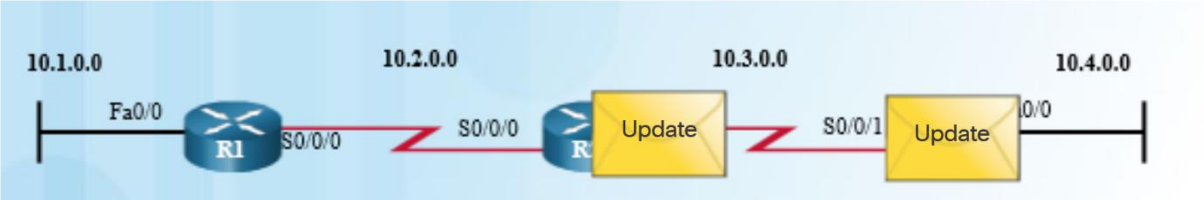
Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0

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

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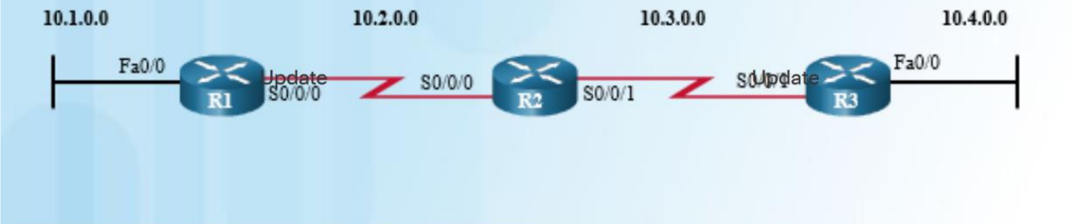
Exchanging the Routing Information

- 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.

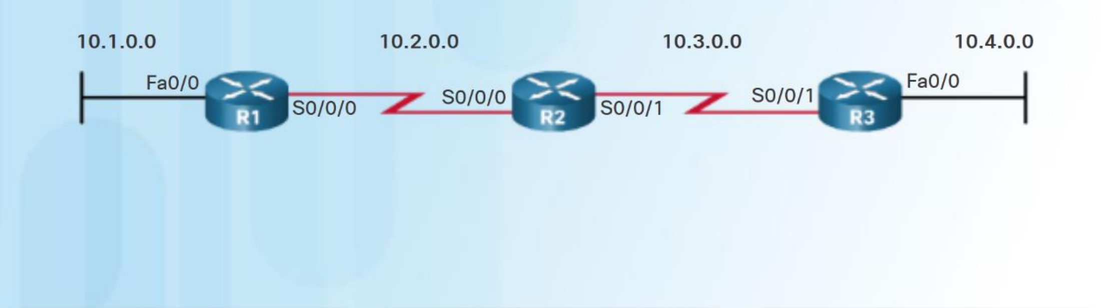


Network	Interface	Hop
10.1.0.0	Fa0/0	0
10.2.0.0	S0/0/0	0
10.3.0.0	S0/0/0	1
10.4.0.0	S0/0/0	2

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

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 Fundamentals

Packet Tracer - Investigating Convergence

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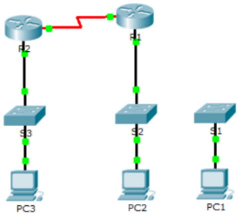
Packet Tracer – Investigating Convergence

Topology



Addressing Table

Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	G0/0	209.165.0.1	255.255.255.0	N/A
	G0/1	64.100.0.1	255.0.0.0	N/A
	S0/0/0	192.168.1.2	255.255.255.0	N/A
R2	G0/0	10.0.0.1	255.0.0.0	N/A
	S0/0/0	192.168.1.1	255.255.255.0	N/A
PC1	NIC	64.100.0.2	255.0.0.0	64.100.0.1
PC2	NIC	209.165.0.2	255.255.255.0	209.165.0.1
PC3	NIC	10.0.0.2	255.0.0.0	10.0.0.1

Objectives

Part 1: View the Routing Table of a Converged Network

Part 2: Add a New LAN to the Topology

Part 3: Watch the Network Converge

Background

This activity will help you identify important information in routing tables and witness the process of network convergence.

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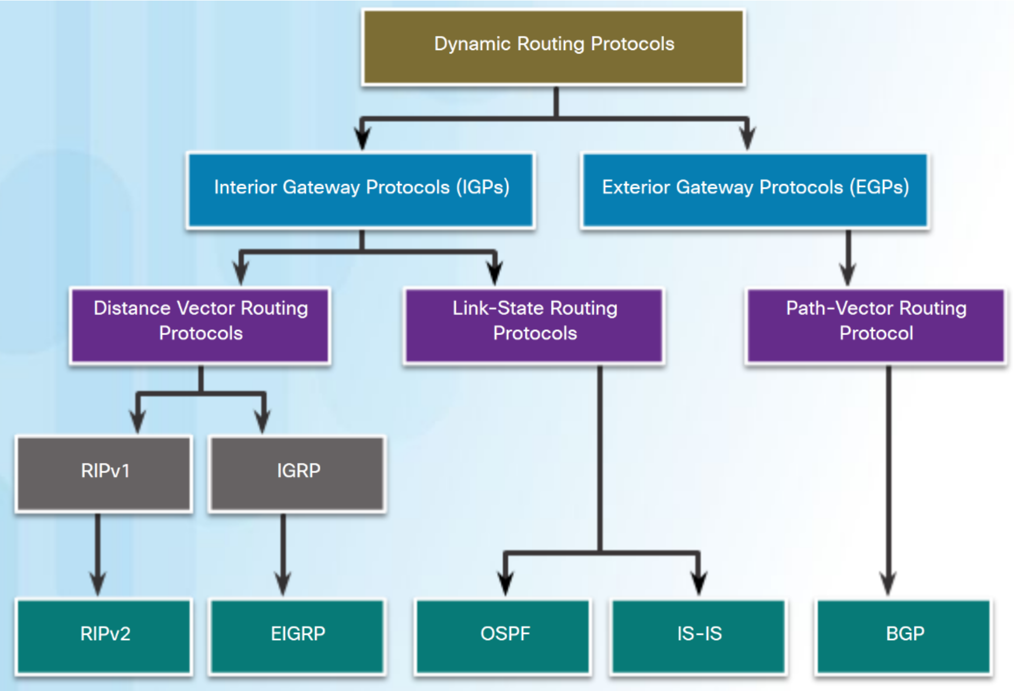
Distance Vector Technologies



- 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.

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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

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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.

Packet Tracer - Comparing RIP and EIGRP Path Selection

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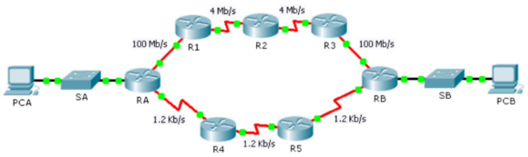
Packet Tracer – Comparing RIP and EIGRP Path Selection

Topology



Objectives

Part 1: Predict the Path

Part 2: Trace the Route

Part 3: Reflection Questions

Scenario

PCA and **PCB** need to communicate. The path that the data takes between these end devices can travel through **R1**, **R2**, and **R3,** or it can travel through **R4** and **R5**. The process by which routers select the best path depends on the routing protocol. We will examine the behavior of two distance vector routing protocols, Enhanced Interior Gateway Routing Protocol (EIGRP) and Routing Information Protocol version 2 (RIPv2).

Part 1: Predict the Path

Metrics are factors that can be measured. Routing protocols are each designed to consider various metrics when considering which route is the best to send data along. These metrics include, hop count, bandwidth, delay, reliability, path cost, and more.

Step 1: Consider EIGRP Metrics.

a. EIGRP can consider many metrics. By default, however, bandwidth and delay are used to determine best path selection.

b. Based on the metrics, what path would you predict data would take from **PCA** to **PCB**?

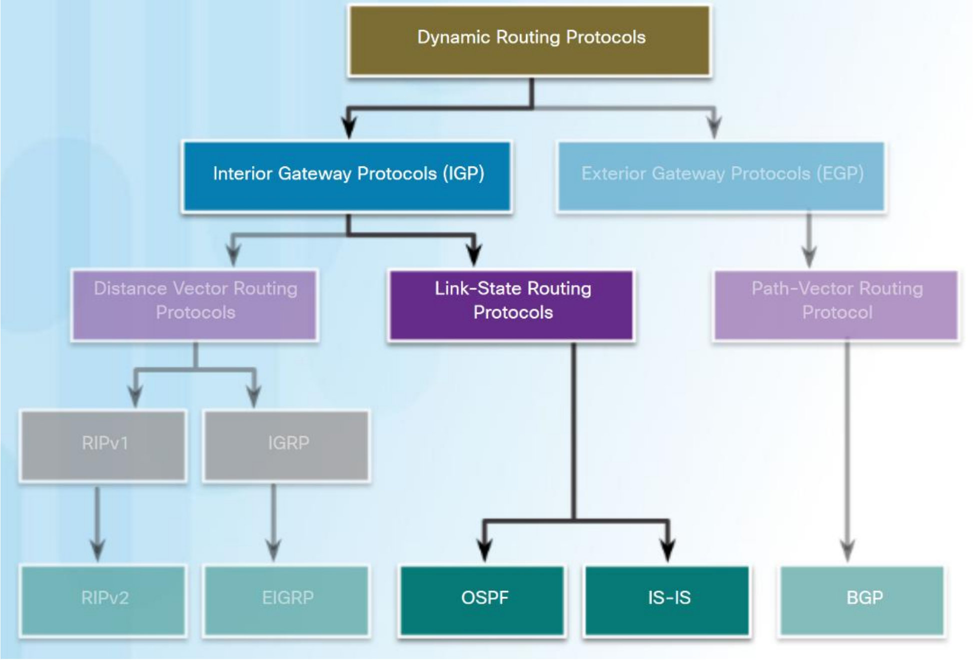
Step 2: Consider RIP Metrics.

a. What metric(s) are used by RIP?

b. Based on the metrics, what path would you predict data would take from **PCA** to **PCB**?

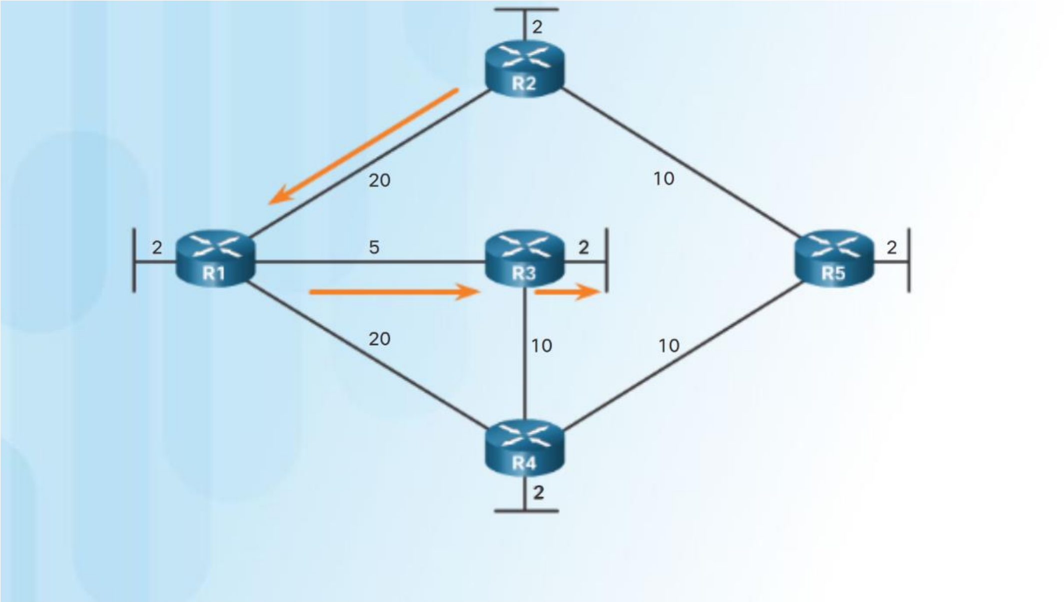
5.3 Link-State Dynamic Routing

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

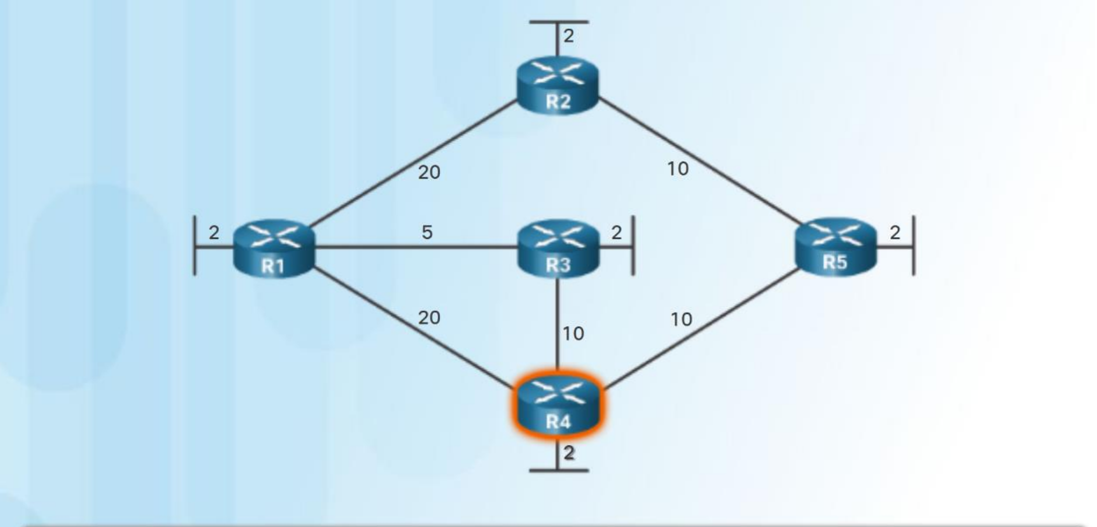


Shortest Path for host on R2 LAN to reach host on R3 LAN: R2 to R1 (20) + R1 to R3 (5) + R3 to LAN (2) = 27

- 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.

Link-State Routing Protocol Operation
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

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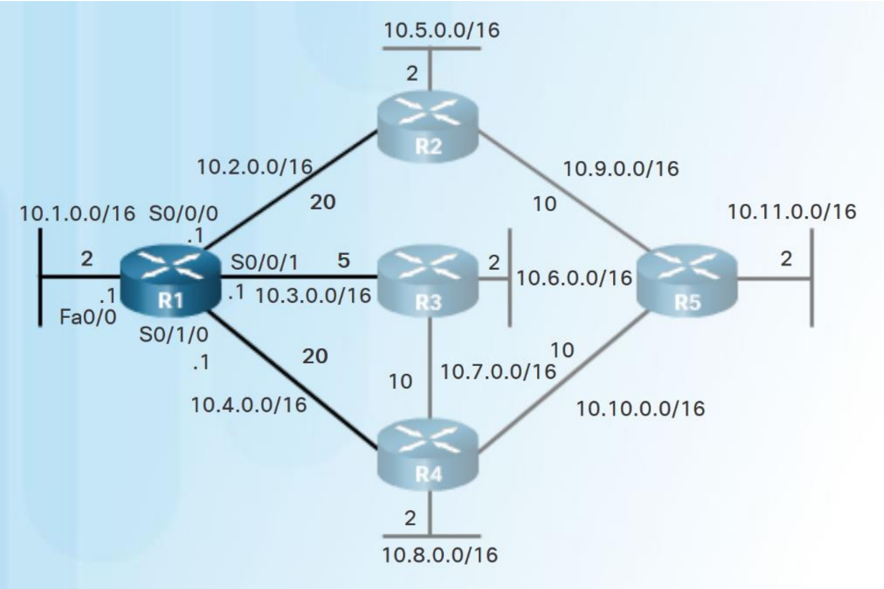
Link-State Routing Process

Link-State Routing Process

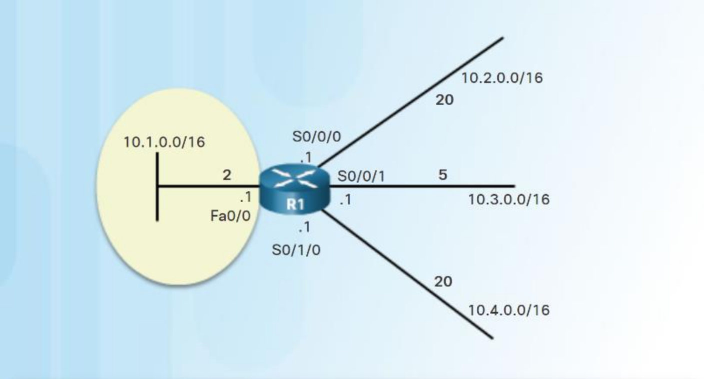
- Each router learns about each of its own directly connected networks.
- Each router is responsible for " saying hello" to its neighbors on directly connected networks.
- Each router builds a Link-State Packet (LSP) containing the state of each directly connected link.
- Each router floods the LSP to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

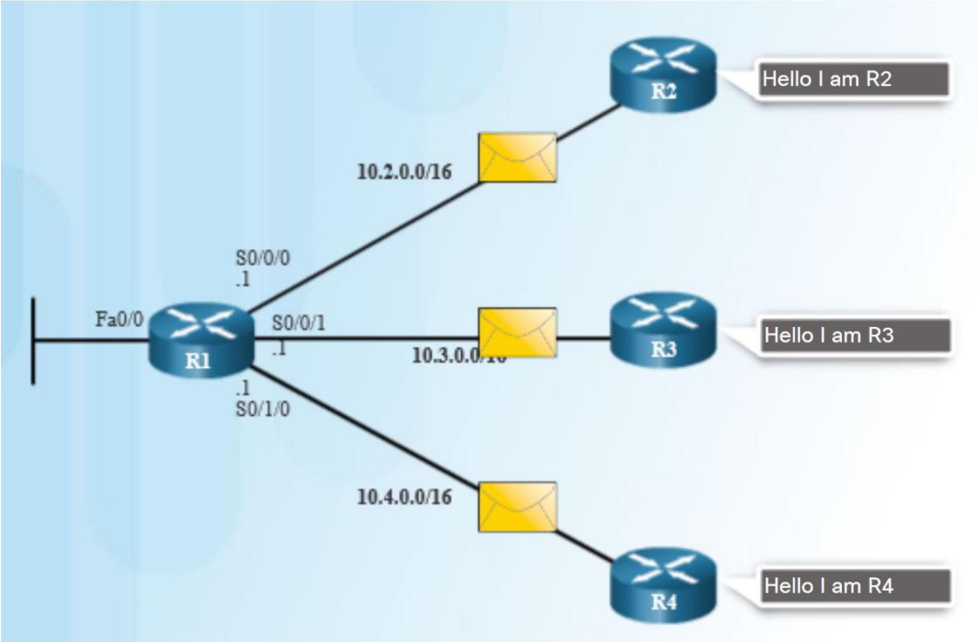


Link 1

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

Link-State Updates

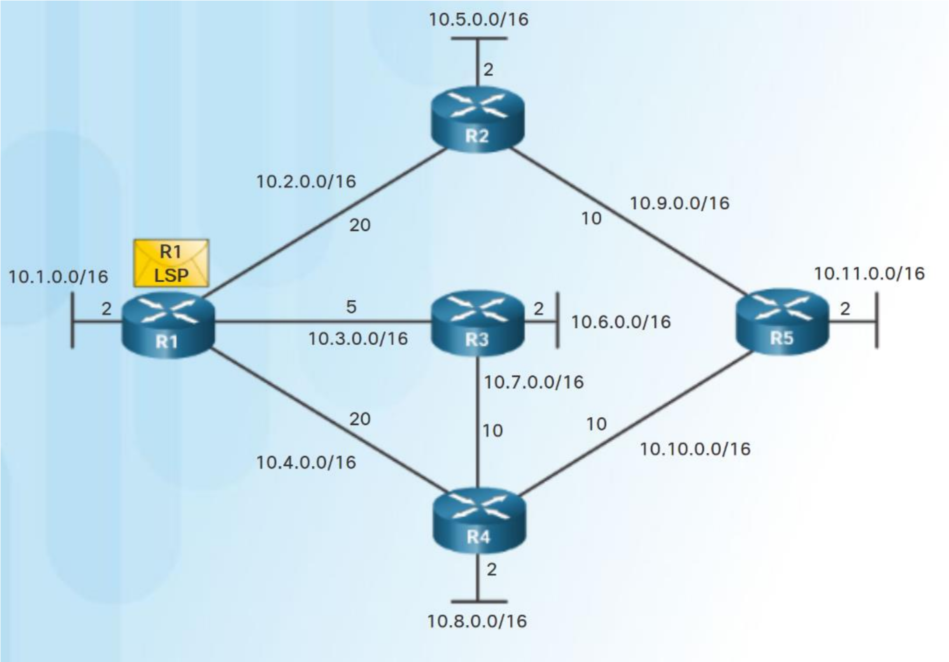
Say Hello



- 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.

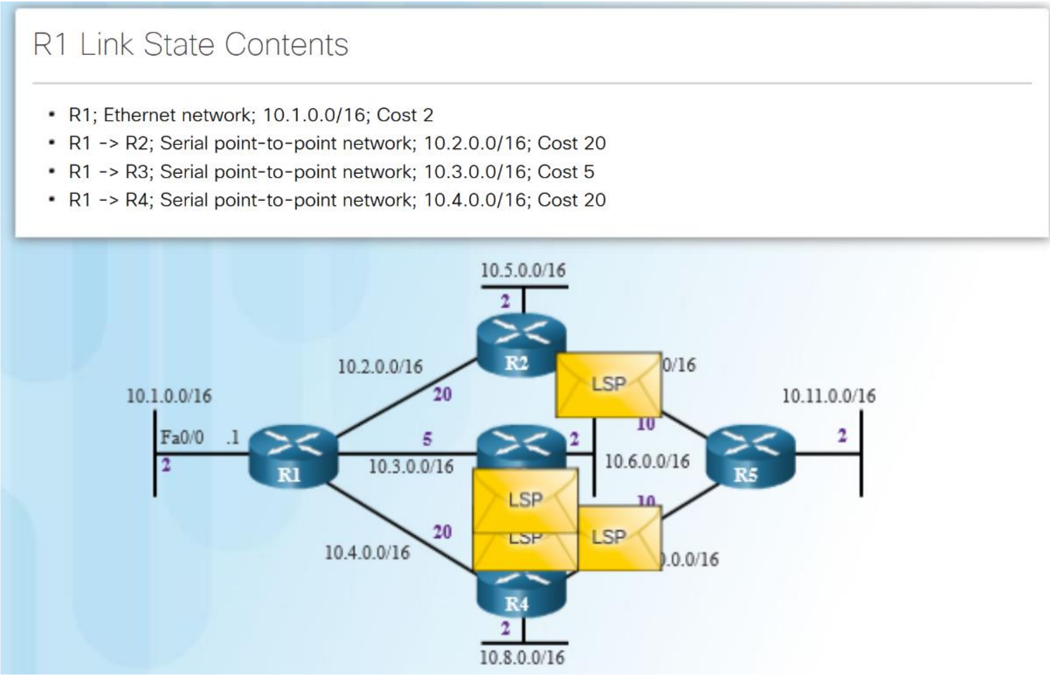
Building the Link-State Packet

- 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

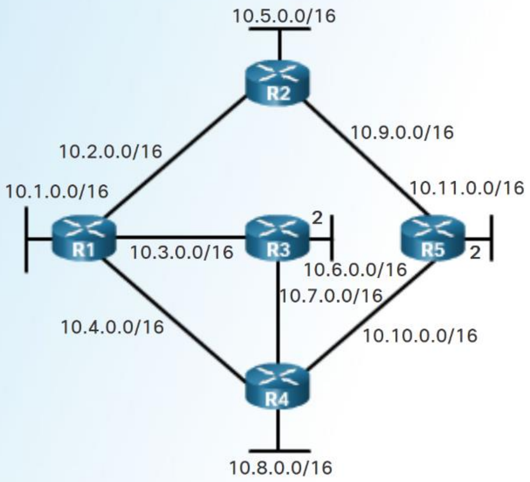
R3 Link-states:
- Connected to network 10.6.0.0/16, cost = 2
- Connected to R1 on network 10.3.0.0/16, cost = 5
- Connected to R4 on network 10.7.0.0/16, cost = 10

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

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
- 10.8.0.0/16 via R3 serial 0/0/1, cost = 17

- 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.

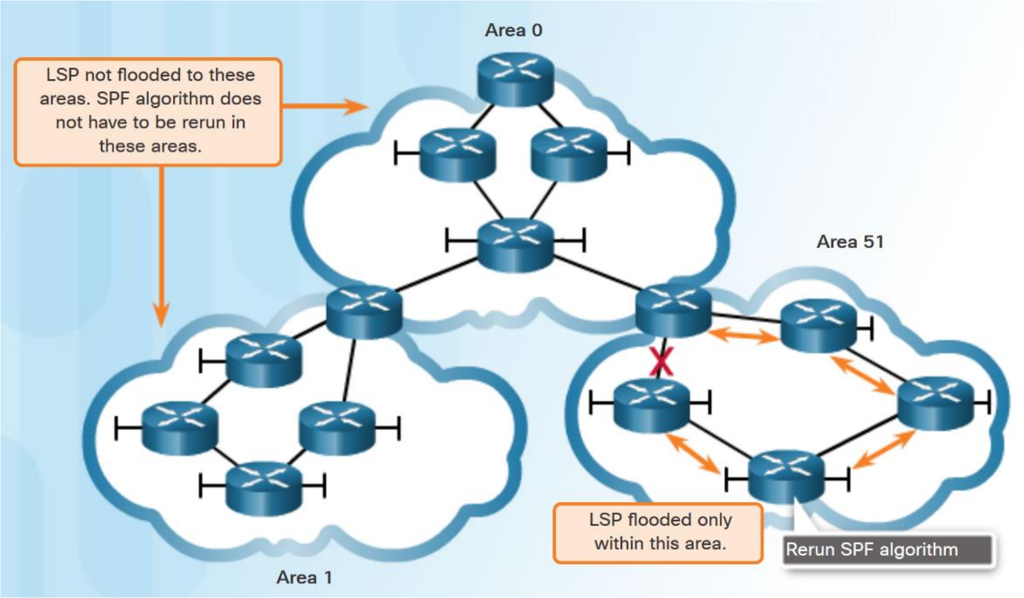
Why Use Link-State Protocols?

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

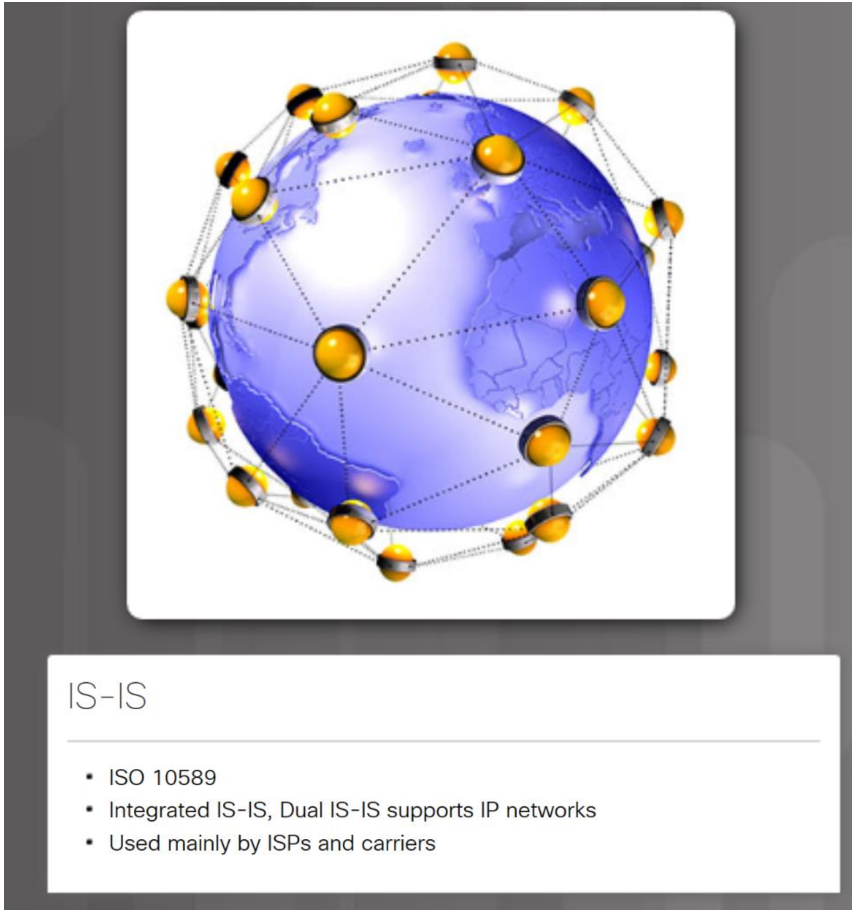
- Disadvantages of Link-State protocols:
  - Memory Requirements - Link-state protocols require additional memory.
  - Processing Requirements - Link-state protocols can require more CPU processing.
  - Bandwidth Requirements - The flooding of link-state packets can adversely affect bandwidth.
- Using 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.



Link-State Routing Protocol Benefits

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

Conclusion

Chapter 4: 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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