Chapter 10

Link-State Routing Protocols

Note for Instructors

- These presentations are the result of a collaboration among the instructors at St. Clair College in Windsor, Ontario.
- Thanks must go out to Rick Graziani of Cabrillo College. His material and additional information was used as a reference in their creation.
- If anyone finds any errors or omissions, please let me know at:
  - tdame@stclaircollege.ca.

EIGRP

Link-State Routing

	Interior Gateway Protocols				Exterior Gateway Protocols
	Distance Vector Routing Protocols		Link State Routing Protocols		Path Vector
Classful	**RIP**	IGRP			EGP
Classless	**RIPv2**	**EIGRP**	**OSPFv2**	IS-IS	BGPv4
IPv6	RIPng	**EIGRP** for IPv6	OSPFv3	**IS-IS** for IPv6	**BGPv4** for IPv6

Link-State Routing Protocols

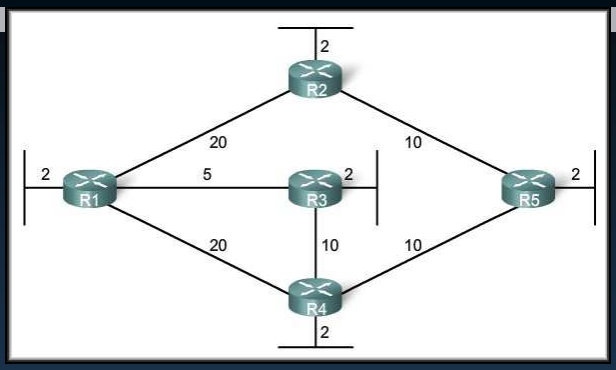
	Interior Gateway Protocols				Exterior Gateway Protocols
	Distance Vector Routing Protocols		Link State Routing Protocols		Path Vector
Classful	RIP	IGRP			EGP
Classless	RIPv2	EIGRP	OSPFv2	IS-IS	BGPv4
IPv6	RIPng	EIGRP for IPv6	OSPFv3	IS-IS for IPv6	BGPv4 for IPv6

- Link-state routing protocols are also known as **shortest path first protocols** and are built around Edsger Dijkstra's shortest path first (SPF) algorithm.
- While they have the reputation of being much more complex than distance vector, the basic functionality and configuration of link state routing protocols are not complex.

Link-State Routing Protocols

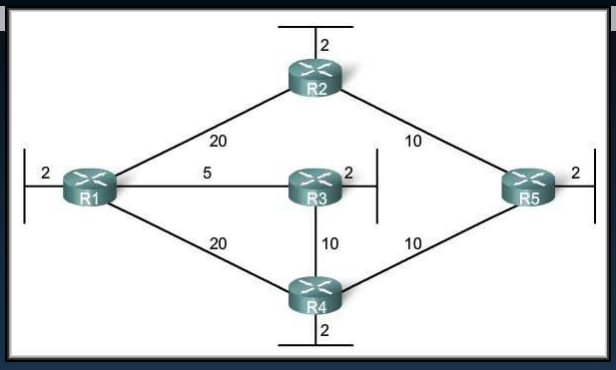
- Distance Vector routing protocols are like road signs.
  - Routers must make preferred path decisions based on a distance or metric to a network.
- Link-State routing protocols are more like a road map.
  - They create a topological map of the network and each router uses this map to determine the shortest path to each network.

Introduction to the SPF Algorithm



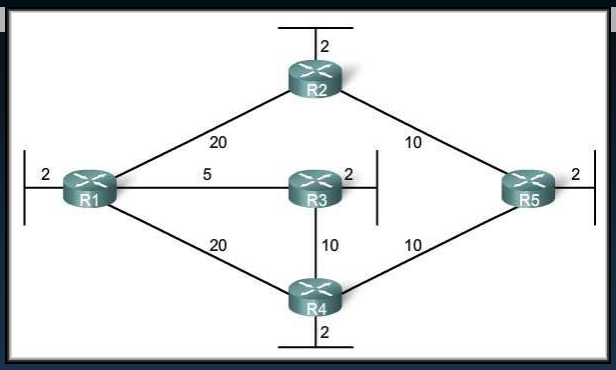
- Dijkstra's algorithm is commonly referred to as the Shortest Path First (SPF) algorithm.
- This algorithm accumulates costs along each path, from source to destination.

Introduction to the SPF Algorithm



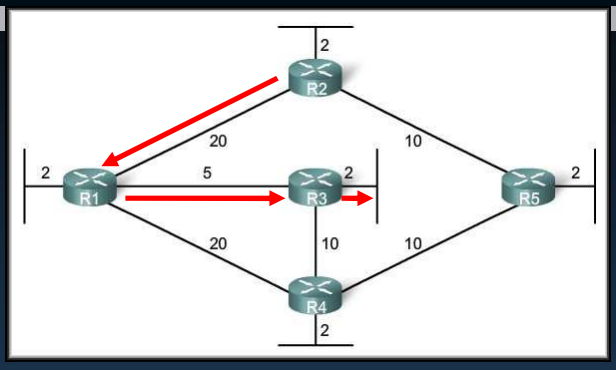
- *We will see that **Cisco's implementation of OSPF** specifies the **cost of the link** (the OSPF routing metric) as the **bandwidth** of the outgoing interface.*

Introduction to the SPF Algorithm



- To illustrate how SPF operates, each path in the figure is labeled with an arbitrary value for **cost**.
- Each router calculates the SPF algorithm and determines the cost of a link **from its own perspective**.

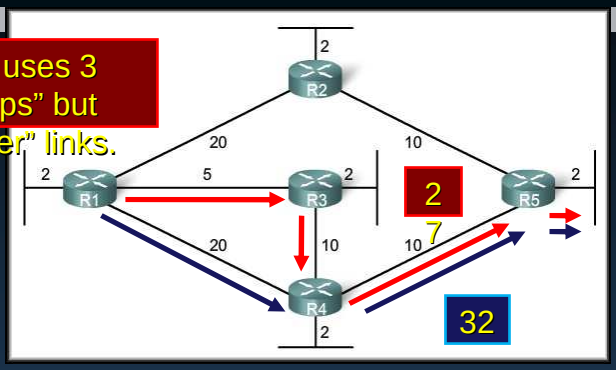
Introduction to the SPF Algorithm



- For example:
  - The cost of the shortest path for R2 to send packets to the LAN attached to R3 is 27 (20 + 5 + 2 = 27).

Introduction to the SPF Algorithm

R1 uses 3 "hops" but "faster" links.



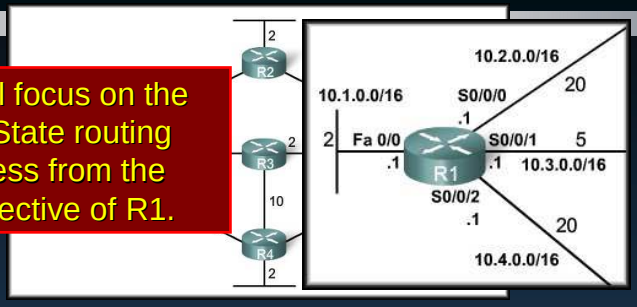
- R1 has data to send to the network on R5.
  - You might think that R1 would send directly to R4 (2 hops) instead of to R3 (3 hops).

Link-State Routing Process

- *How does a link-state routing protocol work?*
- 5 Step Process:
  1. Each router learns about its own directly connected networks.
  2. Each router is responsible for contacting its neighbors on directly connected networks.
  3. Each router builds a link-state packet (LSP) containing the state of each directly connected link.
  4. Each router floods the LSP to all neighbors, who then store all LSPs received in a database.
  5. Each router uses the LSPs to construct a database that is a complete map of the topology and computes the best path to each destination network.

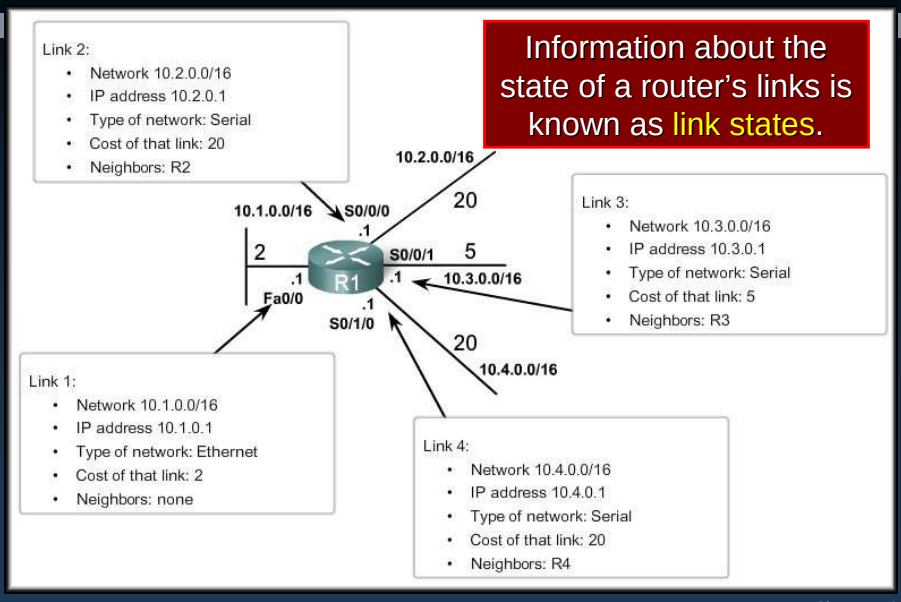
Step 1: Directly Connected Networks

We will focus on the Link-State routing process from the perspective of R1.

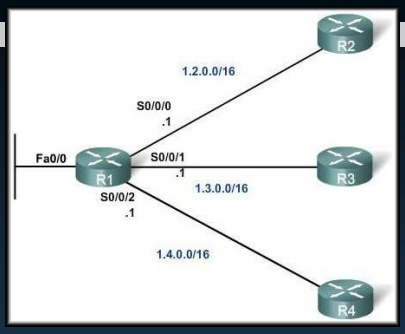


- **Step 1**: Each router learns about its own **directly connected networks**.
- When a router interface is configured with an IP address and subnet mask and activated, the interface becomes part of that network.
- **Regardless of the routing protocols used**, these directly connected networks are now part of the routing table.

Step 1: Directly Connected Networks

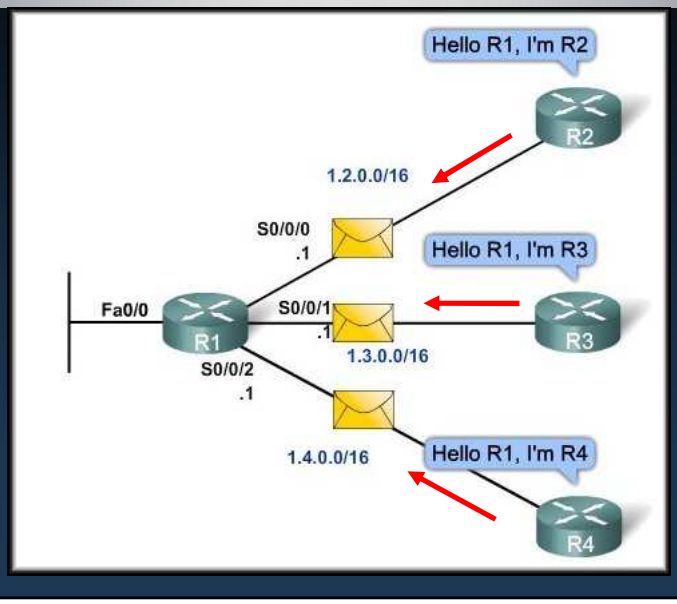


Step 2: Hello Packets



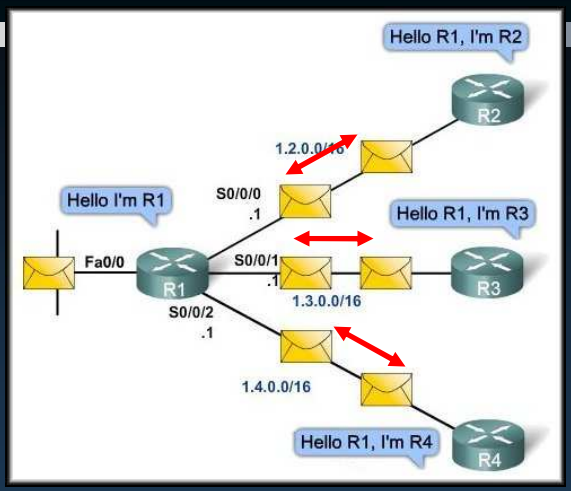
- **Step 2:** Each router is responsible for **contacting its neighbors** on directly connected networks.
- The router will not be aware of any neighbor routers on the link until it receives a **Hello packet** from that neighbor.
- At that time, it establishes an adjacency with the neighboring router.

Step 2: Hello Packets



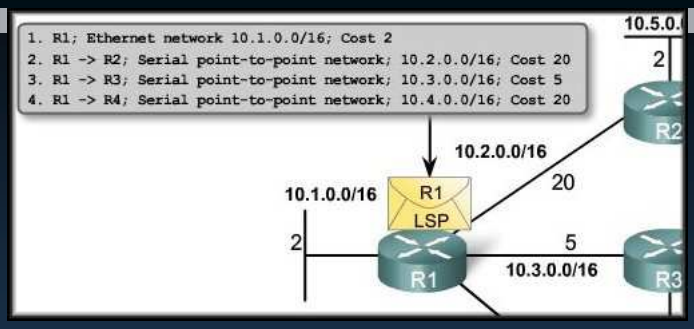
Step 2: Hello Packets

- A **neighbor** is any other router that is enabled with the **same link-state routing protocol**.
- These small Hello packets continue to be exchanged between two adjacent neighbors.



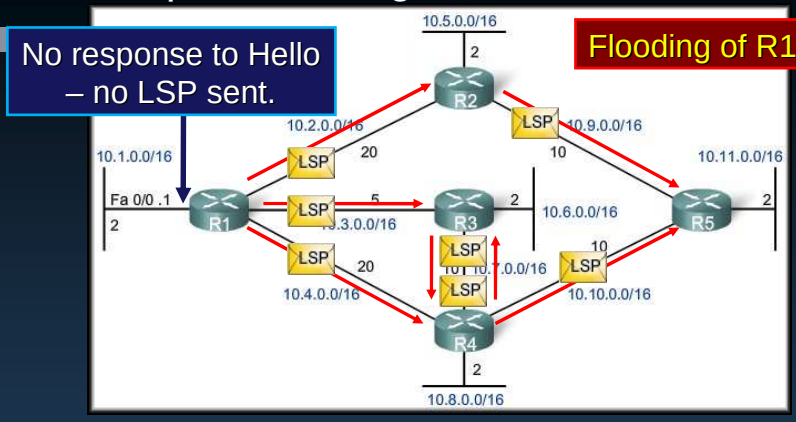
- These packets serve as a **keepalive** function to monitor the state of the neighbor.

Step 3: Build the Link-State Packet (LSP)



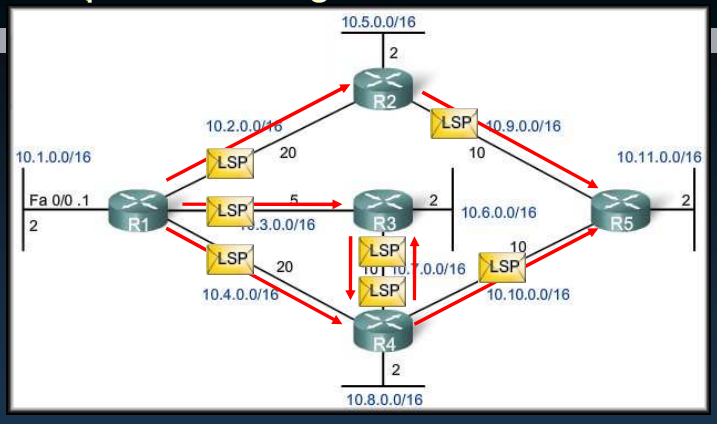
- Step 3: Each router builds a link-state packet (LSP) containing the state of each directly connected link.
- The LSP contains the link-state information about the sending router's links.
- The router only sends LSPs out interfaces where it has established adjacencies with other routers.

Step 4: Flooding Link-State Packets



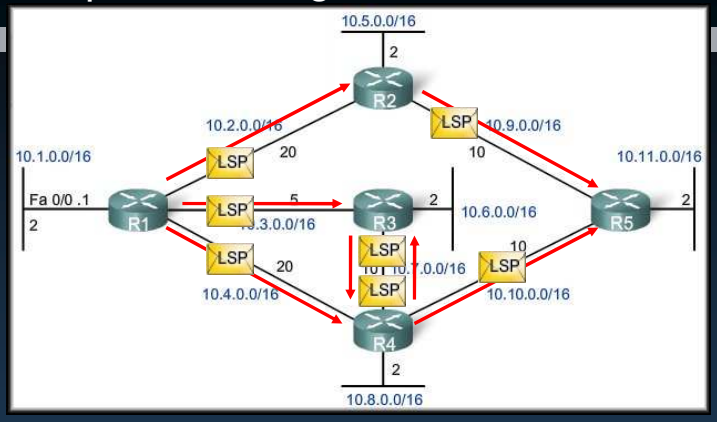
- Step 4: Each router floods the LSP to all neighbors, who then store all LSPs received in a database.
  - Whenever a router receives an LSP from a neighboring router, it immediately sends that LSP out all other interfaces, except the interface that received the LSP.

Step 4: Flooding Link-State Packets



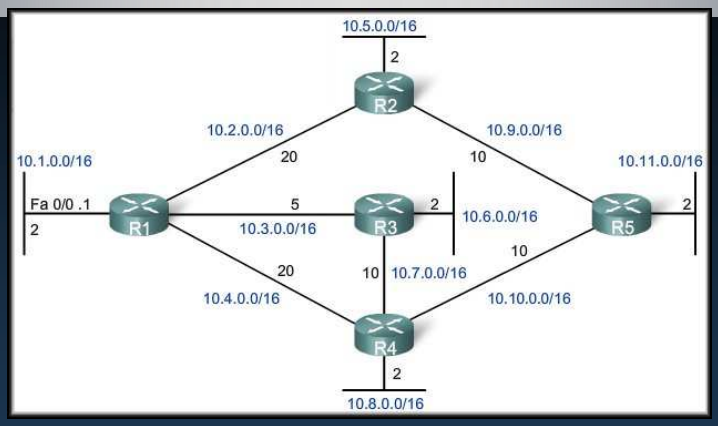
- Link-state routing protocols calculate the SPF algorithm **after the flooding** is complete.
- As a result, link-state routing protocols **reach convergence much faster** than distance vector routing protocols.

Step 4: Flooding Link-State Packets



- An LSP needs to be sent only:
  - During **initial startup** of the router or routing protocol.
  - Whenever there is a **change in the topology** (link going down or coming up) or a neighbor adjacency being established or broken.

Step 5: Constructing a Link-State Database



- Step 5: Each router uses the LSPs to construct a database that is a complete map of the topology and computes the best path to each destination network.

Step 5: Constructing a Link-State Database

R1s Link-State Database

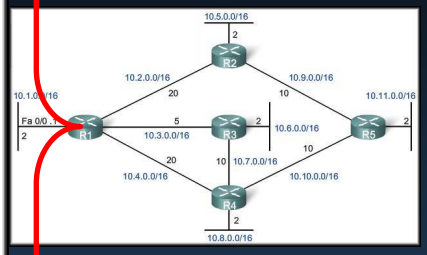
LSPs from R2:
- Connected to neighbor R1 on network 10.2.0.0/16, cost of 20
- Connected to neighbor R5 on network 10.9.0.0/16, cost of 10
- Has a network 10.5.0.0/16, cost of 2

LSPs from R3:
- Connected to neighbor R1 on network 10.3.0.0/16, cost of 5
- Connected to neighbor R4 on network 10.7.0.0/16, cost of 10
- Has a network 10.6.0.0/16, cost of 2

LSPs from R4:
- Connected to neighbor R1 on network 10.4.0.0/16, cost of 20
- Connected to neighbor R3 on network 10.7.0.0/16, cost of 10
- Connected to neighbor R5 on network 10.10.0.0/16, cost of 10
- Has a network 10.8.0.0/16, cost of 2

LSPs from R5:
- Connected to neighbor R2 on network 10.9.0.0/16, cost of 10
- Connected to neighbor R4 on network 10.10.0.0/16, cost of 10
- Has a network 10.11.0.0/16, cost of 2

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

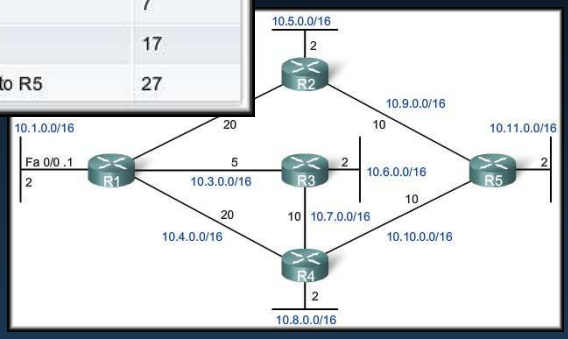


- As a result of the flooding process, router R1 has learned the link-state information for each router in its routing area.

Step 5: Constructing a Link-State Database

Destination	Shortest Path	Cost
R2 LAN	R1 to R2	22
R3 LAN	R1 to R3	7
R4 LAN	R1 to R3 to R4	17
R5 LAN	R1 to R3 to R4 to R5	27

Each router in the topology determines the shortest path from its own perspective.



- With a complete link-state database, R1 can now use the database and the shortest path first (SPF) algorithm to calculate the preferred path or shortest path to each network.

R1: Building the SPF Tree

R1 Link State Database

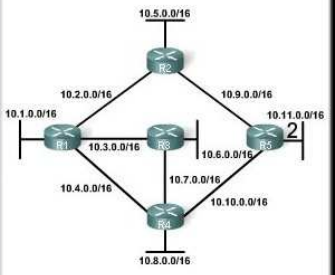
R1 Links-states:
- Connected to neighbor R2 on network 10.2.0.0/16, cost of 20
- Connected to neighbor R3 on network 10.3.0.0/16, cost of 5
- Connected to neighbor R4 on network 10.4.0.0/16, cost of 20
- Has a network 10.1.0.0/16, cost of 2

LSPs from R2:
- Connected to neighbor R1 on network 10.2.0.0/16, cost of 20
- Connected to neighbor R5 on network 10.9.0.0/16, cost of 10
- Has a network 10.5.0.0/16, cost of 2

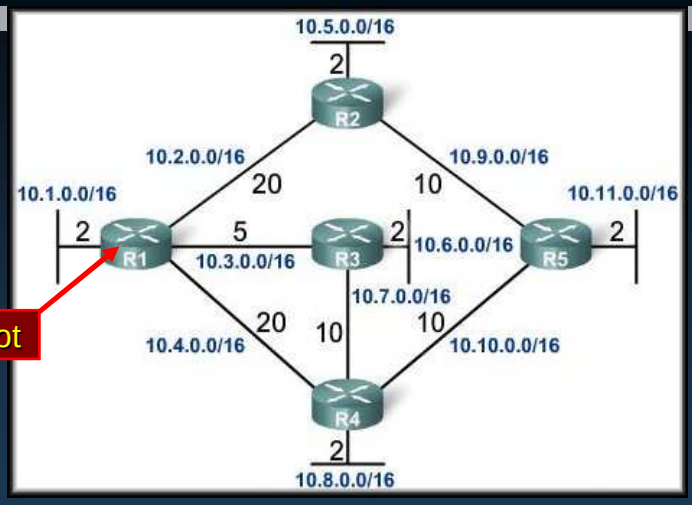
LSPs from R3:
- Connected to neighbor R1 on network 10.3.0.0/16, cost of 5
- Connected to neighbor R4 on network 10.7.0.0/16, cost of 10
- Has a network 10.6.0.0/16, cost of 2

LSPs from R4:
- Connected to neighbor R1 on network 10.4.0.0/16, cost of 20
- Connected to neighbor R3 on network 10.7.0.0/16, cost of 10
- Connected to neighbor R5 on network 10.10.0.0/16, cost of 10
- Has a network 10.8.0.0/16, cost of 2

LSPs from R5:
- Connected to neighbor R2 on network 10.9.0.0/16, cost of 10
- Connected to neighbor R4 on network 10.10.0.0/16, cost of 10
- Has a network 10.11.0.0/16, cost of 2

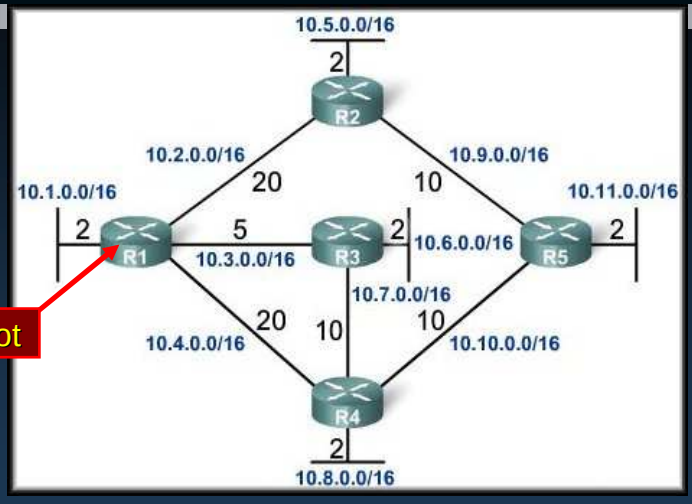


R1: Building the SPF Tree



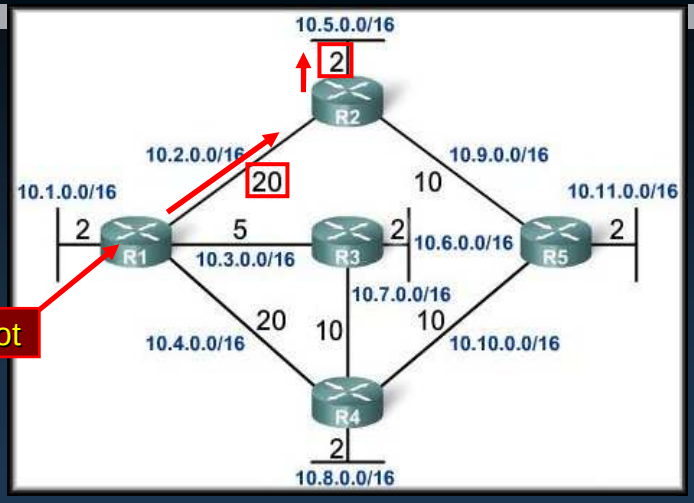
- All LSPs have been processed using the SPF algorithm and R1 has now constructed the complete SPF tree.

R1: Determining the Shortest Path



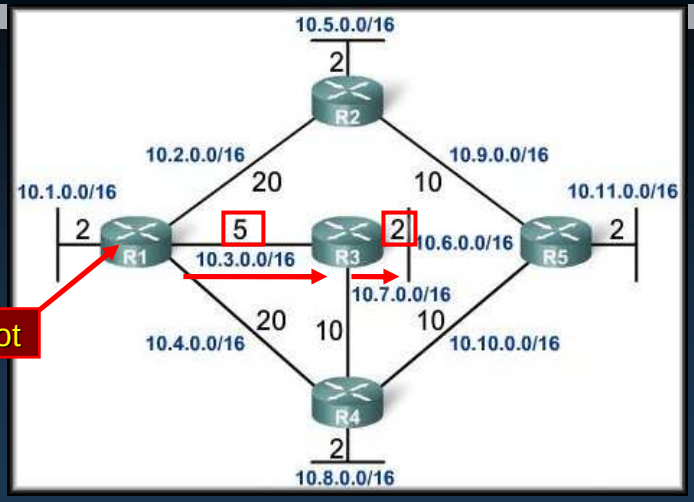
- Using this tree, the SPF algorithm results indicate the shortest path to each network.

R1: Determining the Shortest Path



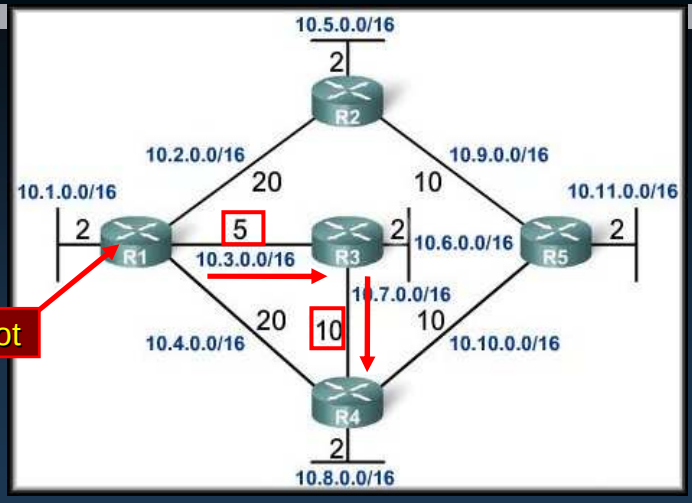
Network 10.5.0.0/16 via R2 Serial 0/0/0 at a cost of 22

R1: Determining the Shortest Path



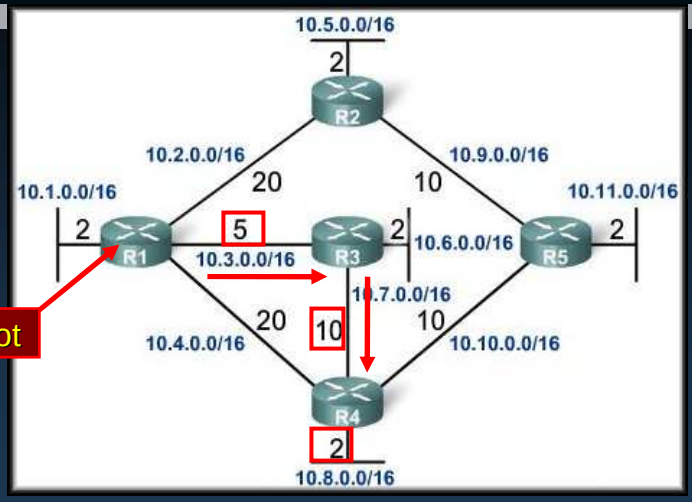
Network 10.6.0.0/16 via R3 Serial 0/0/1 at a cost of 7

R1: Determining the Shortest Path



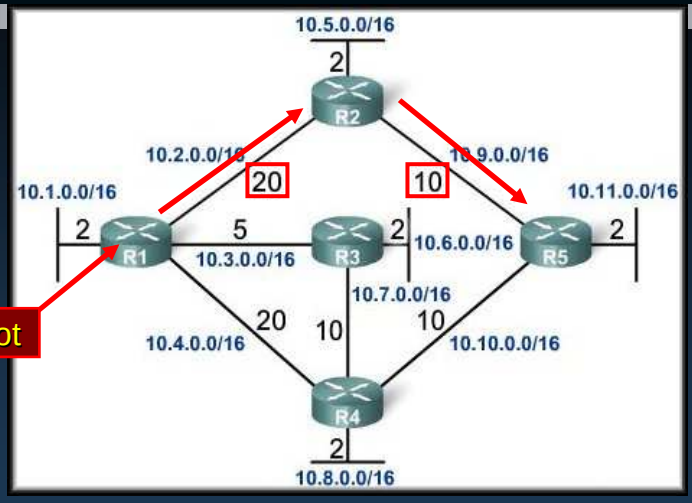
Network 10.7.0.0/16 via R3 Serial 0/0/1 at a cost of 15

R1: Determining the Shortest Path



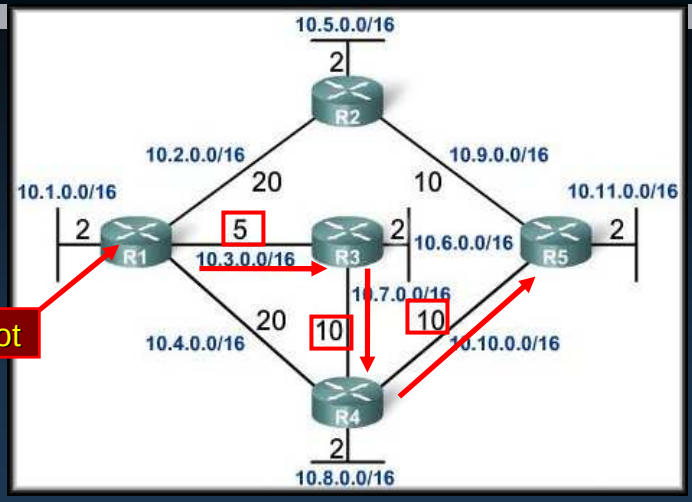
Network 10.8.0.0/16 via R3 Serial 0/0/1 at a cost of 17

R1: Determining the Shortest Path



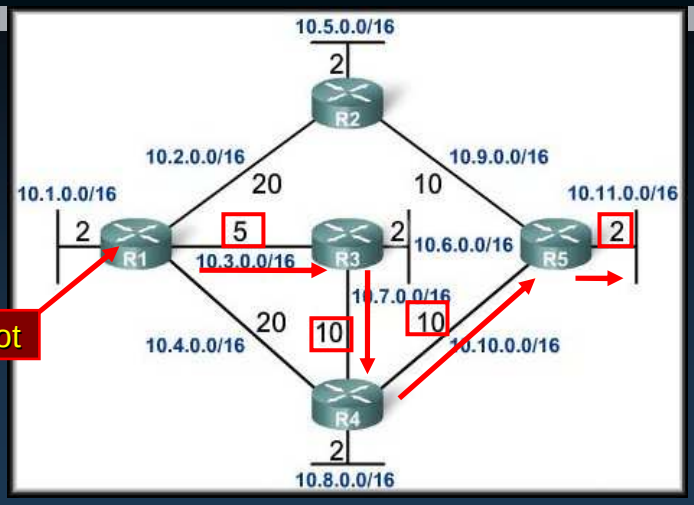
Network 10.9.0.0/16 via R2 Serial 0/0/0 at a cost of 30

R1: Determining the Shortest Path



Network 10.10.0.0/16 via R3 Serial 0/0/1 at a cost of 25

R1: Determining the Shortest Path

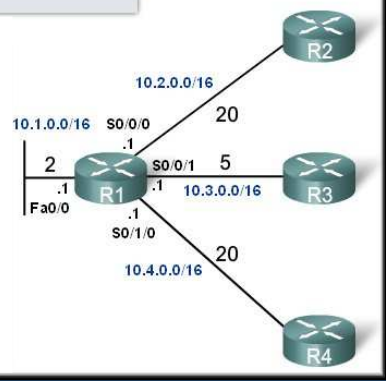


Network 10.11.0.0/16 via R3 Serial 0/0/1 at a cost of 27

Generating a Routing Table

SPF Information

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



EIGRP

Implementing Link-State Routing Protocols

	Interior Gateway Protocols			Exterior Gateway Protocols
	Distance Vector Routing Protocols		Link State Routing Protocols	Path Vector
Classful	**RIP**	IGRP		EGP
Classless	**RIPv2**	**EIGRP**	**OSPFv2** IS-IS	BGPv4
IPv6	RIPng	**EIGRP** for IPv6	OSPFv3 **IS-IS** for IPv6	**BGPv4** for IPv6

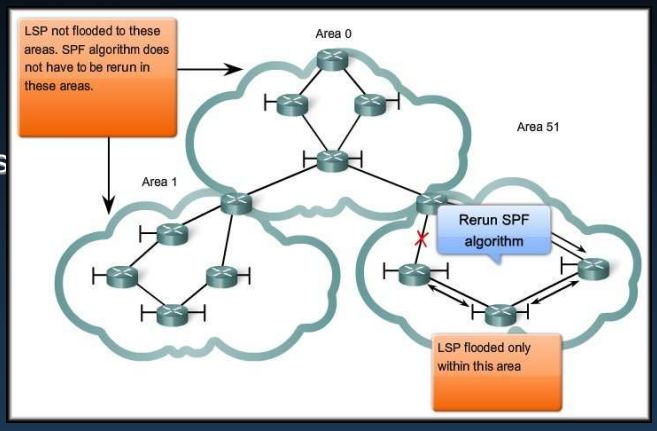
Advantages: Link-State

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.

Hierarchical Design

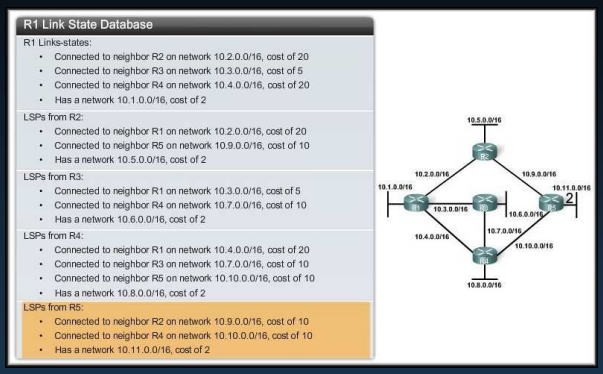
- Link-state routing protocols such as OSPF and IS-IS use the concept of areas.



- Multiple areas create a hierarchical design to networks, allowing better route aggregation (summarization) and the isolation of routing issues within an area.

Requirements: Link-State

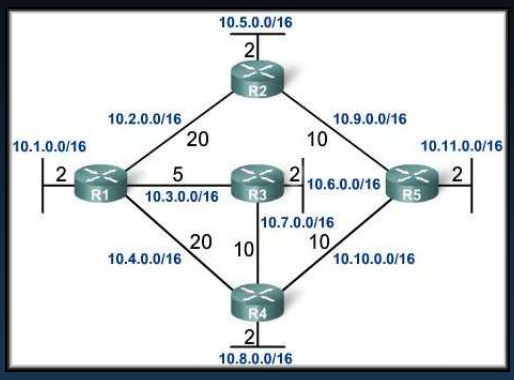
- Memory Requirements:
- Link-state routing protocols typically require more memory, more CPU processing and, at times, more bandwidth than distance vector routing protocols.



- The memory requirements are because of the use of:
  - Link-state databases.
  - Creation of the SPF tree.

Requirements: Link-State

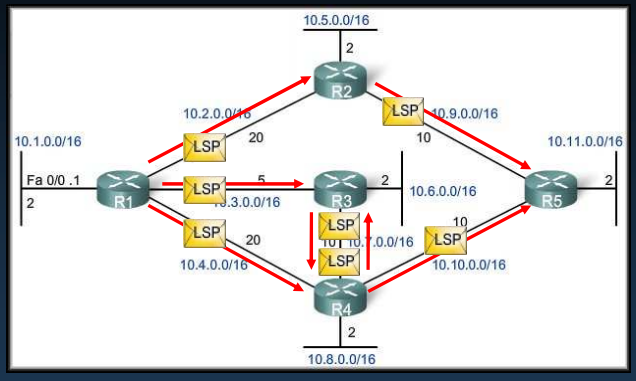
- **Processing Requirements:**
- Link-state protocols can also require more CPU processing than distance vector routing protocols.



- The SPF algorithm requires more CPU time than distance vector algorithms because link-state protocols build a complete map of the topology.

Requirements: Link-State

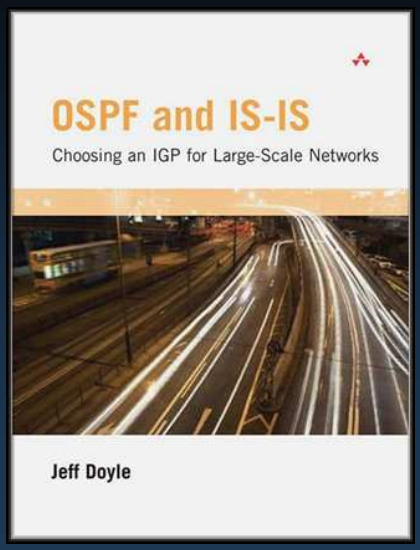
- **Bandwidth Requirements:**
- The flooding of link-state packets can adversely affect the available bandwidth on a network.



- This should only occur during initial startup of routers, but it can also be an issue on unstable networks.

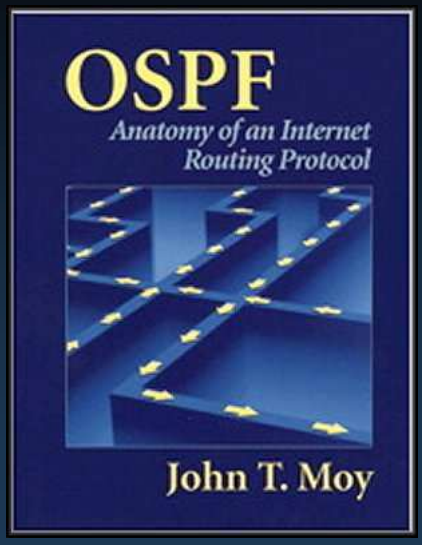
Comparison: Link-State

- There are two link-state routing protocols used for routing IP today:
- Open Shortest Path First (OSPF)
- Intermediate System to Intermediate System (IS-IS)



Comparison: Link-State

- OSPF was designed by the IETF (Internet Engineering Task Force) OSPF Working Group.
- It which still exists today.
- The development of OSPF began in 1987 and there are two current versions in use:
  - OSPFv2:
    - OSPF for IPv4 networks
  - OSPFv3:
    - OSPF for IPv6 networks



Comparison: Link-State

- IS-IS was designed by the ISO (International Organization for Standardization).
- IS-IS was originally designed for the OSI protocol suite.
- Later, Integrated IS-IS, or Dual IS-IS, included support for IP networks.
- Although IS-IS has been known as the routing protocol used mainly by ISPs and carriers, more enterprise networks are beginning to use IS-IS.