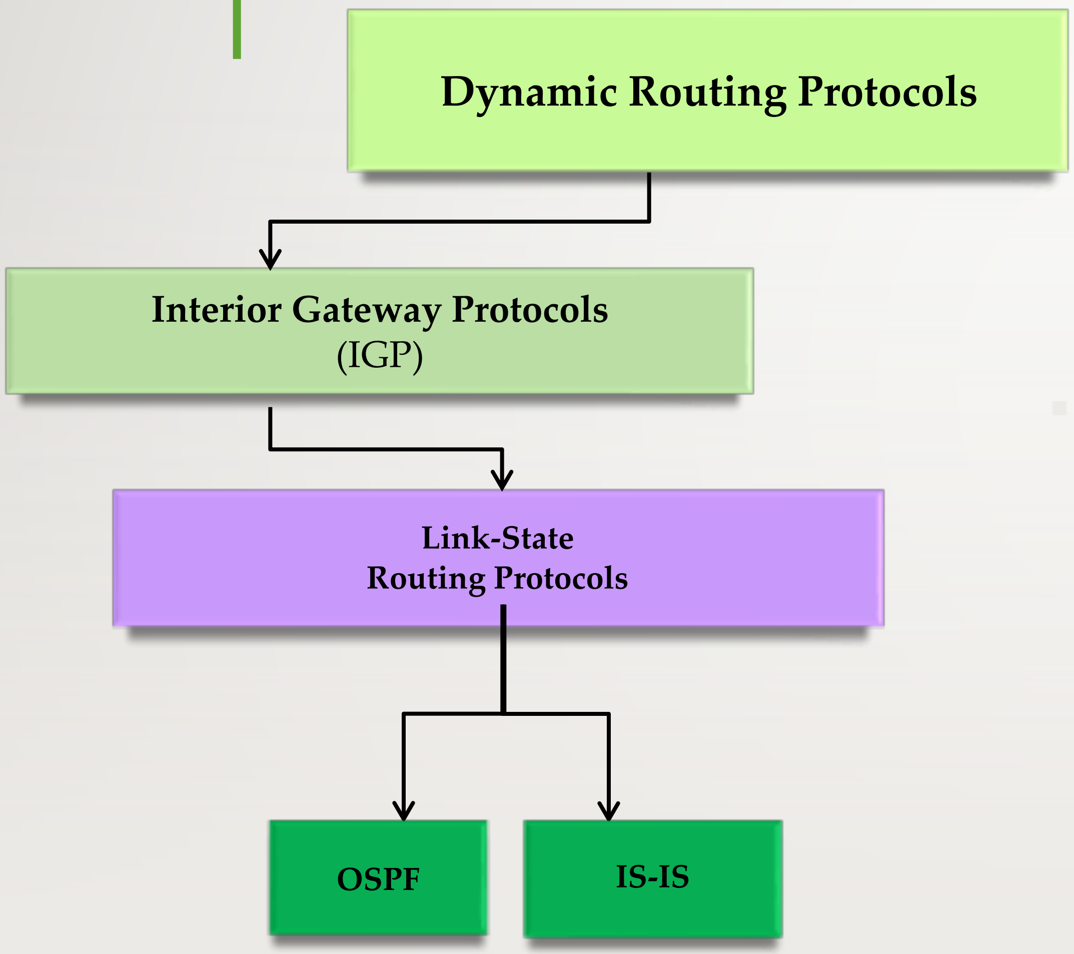
Chapter – 6

Link-State Routing Protocols

Link- state Routing Protocol



- **Open Shortest Path First (OSPF)** is the most common IGP routing protocol implemented within an organizational AS.
  - Began in 1987
  - OSPFv2 - OSPF for IPv4 networks
  - OSPFv3 - OSPF for IPv6 networks
- **Intermediate-System to Intermediate-System (IS-IS)** is a less popular link-state protocol sometimes used within service provider networks.
  - IS-IS was designed by International Organization for Standardization (ISO)

Link-State Routing Process

1. Each router learns about its own links, its own directly connected networks. *(Interface is "up")*

2. Each router is responsible for meeting its neighbors on directly connected networks. *(OSPF Hello packets)*

3. Each router builds a ***link-state packet (LSP)*** containing the state of each directly connected link. *(neighbor ID, link type, and bandwidth)*

4. Each router floods the LSP to all neighbors, who then store all LSPs received in a database.

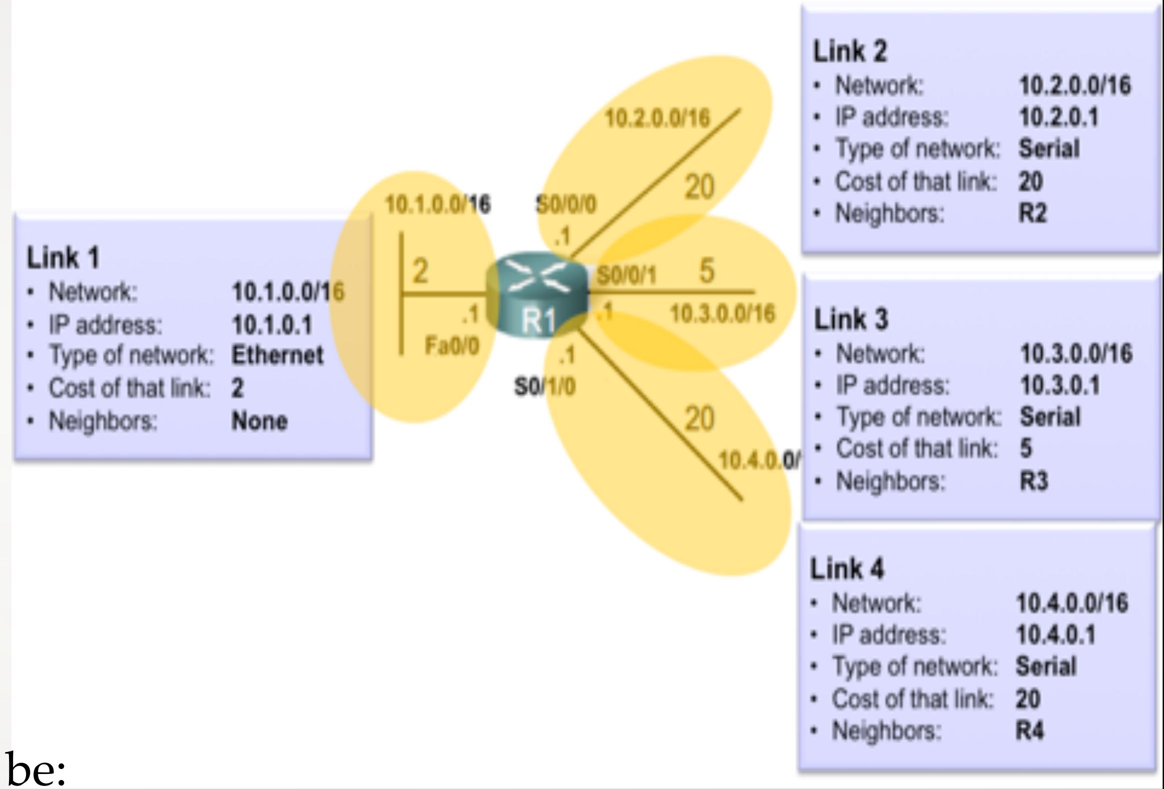
- Neighbors then flood the LSPs to their neighbors until all routers in the area have received the LSPs.

5. Each router uses the database to construct a complete map of the topology and computes the best path to each destination network.

- The SPF algorithm is used to construct the map of the topology and to determine the best path to each network. *(Road map)*
- All routers will have a common map or tree of the topology, but each router will independently determine the best path to each network within that topology.

Step 1: Each router learns about its own links, its own directly connected networks

- ***Link states*** - Information about the state of a router's links
- This information includes interface's:
  - IP address/mask
  - Type of network
    - Ethernet (broadcast) or serial point-to-point link
  - Cost of that link
  - Any neighbor routers on that link



For the link participate in the link-state routing process, it must be:

In the up state.

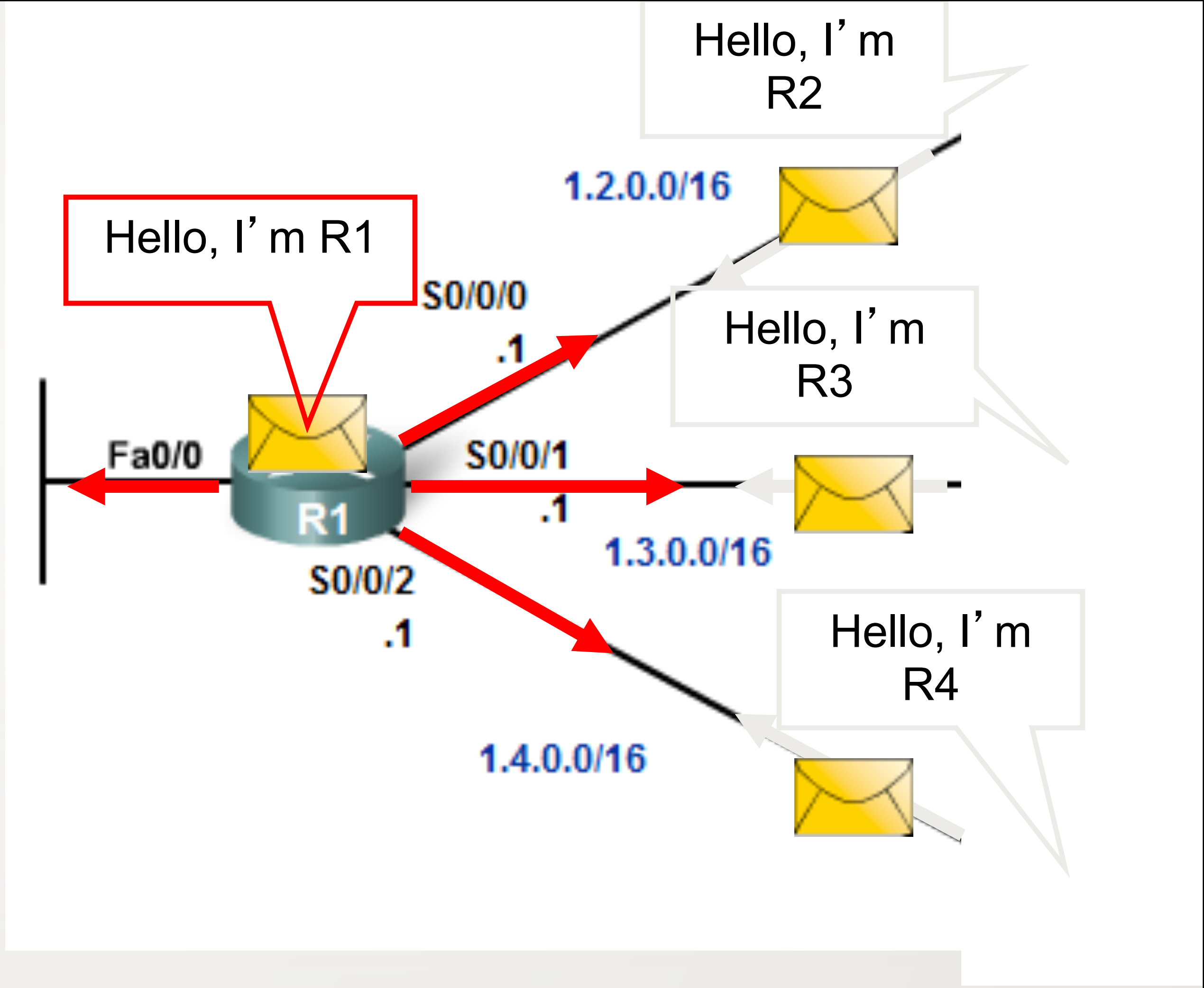
Included in the routing protocol (coming).

Initially:

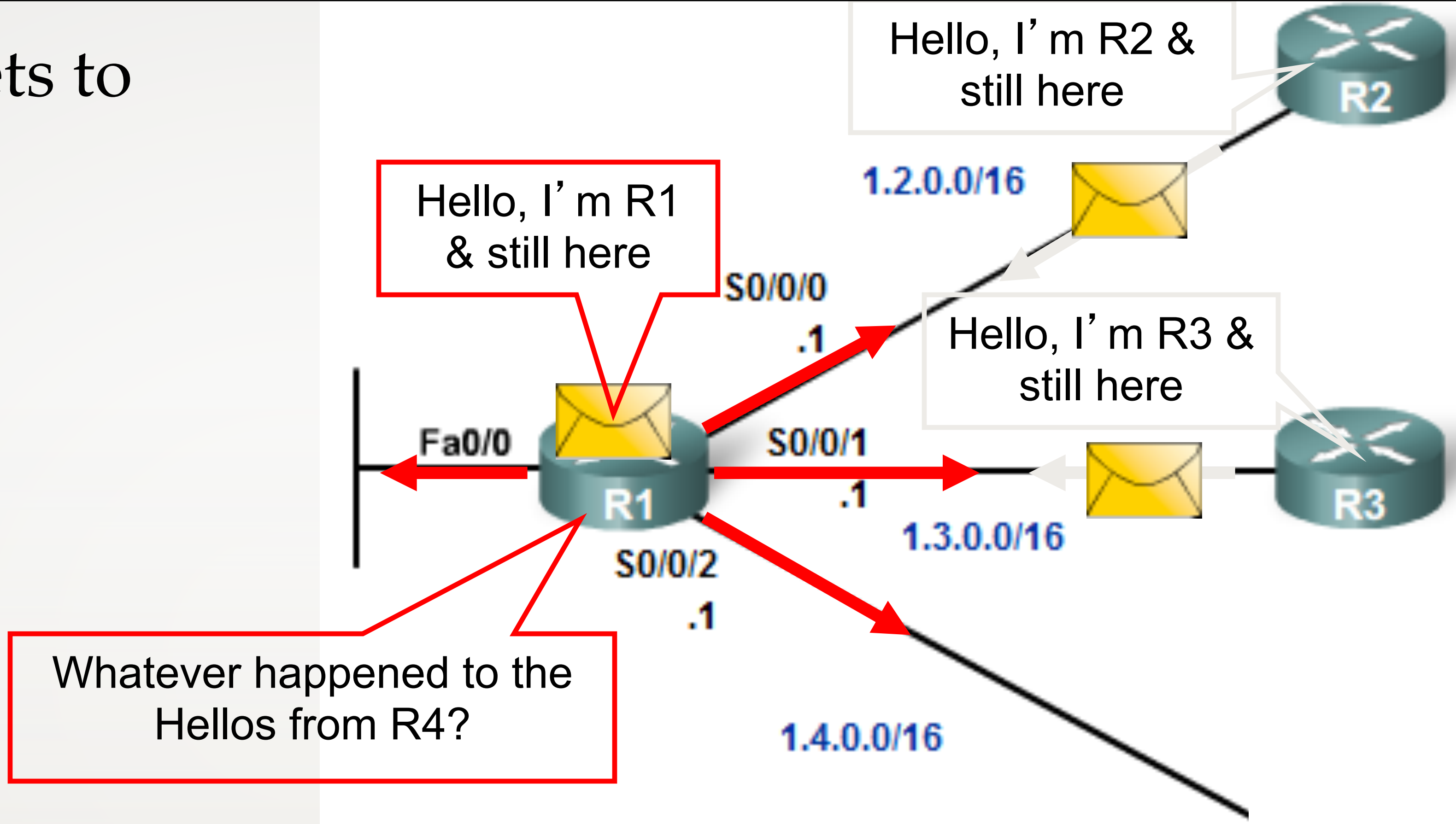
- Router <u>unaware of any neighbor routers</u> on the link.
- <u>Learns of neighbor</u> when receives a <u>Hello packet</u> from the adjacent neighbor.

Step 2: Sending Hello Packets to Neighbors

- **Step 2:** ***Each router is responsible for meeting its neighbors on directly connected networks.***
    - Use a Hello protocol to discover any neighbors on their links.
    - A **neighbor** is any other router that is enabled with the same link-state routing protocol.



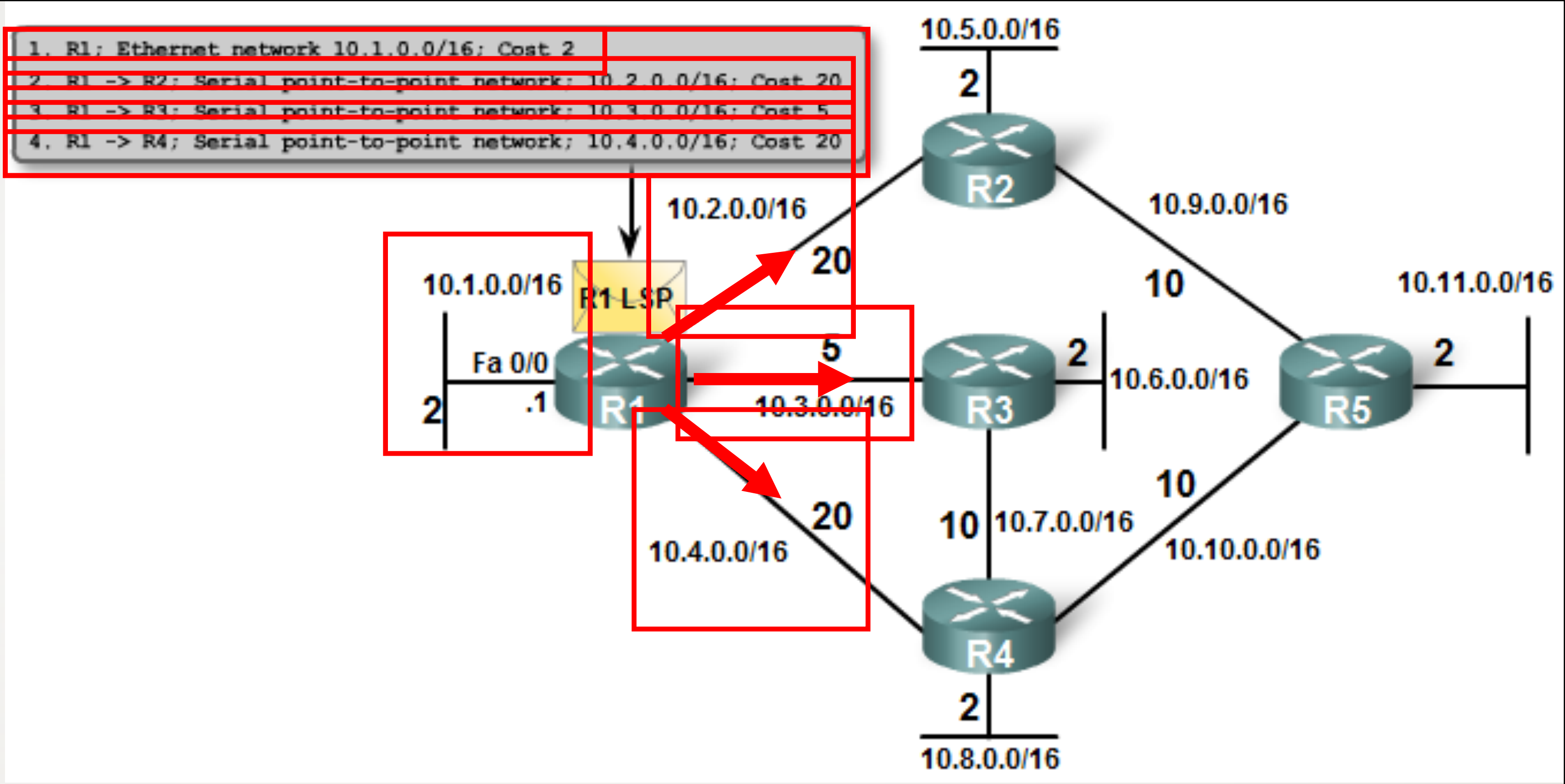
Step 2: Sending Hello Packets to Neighbors



Hello packets

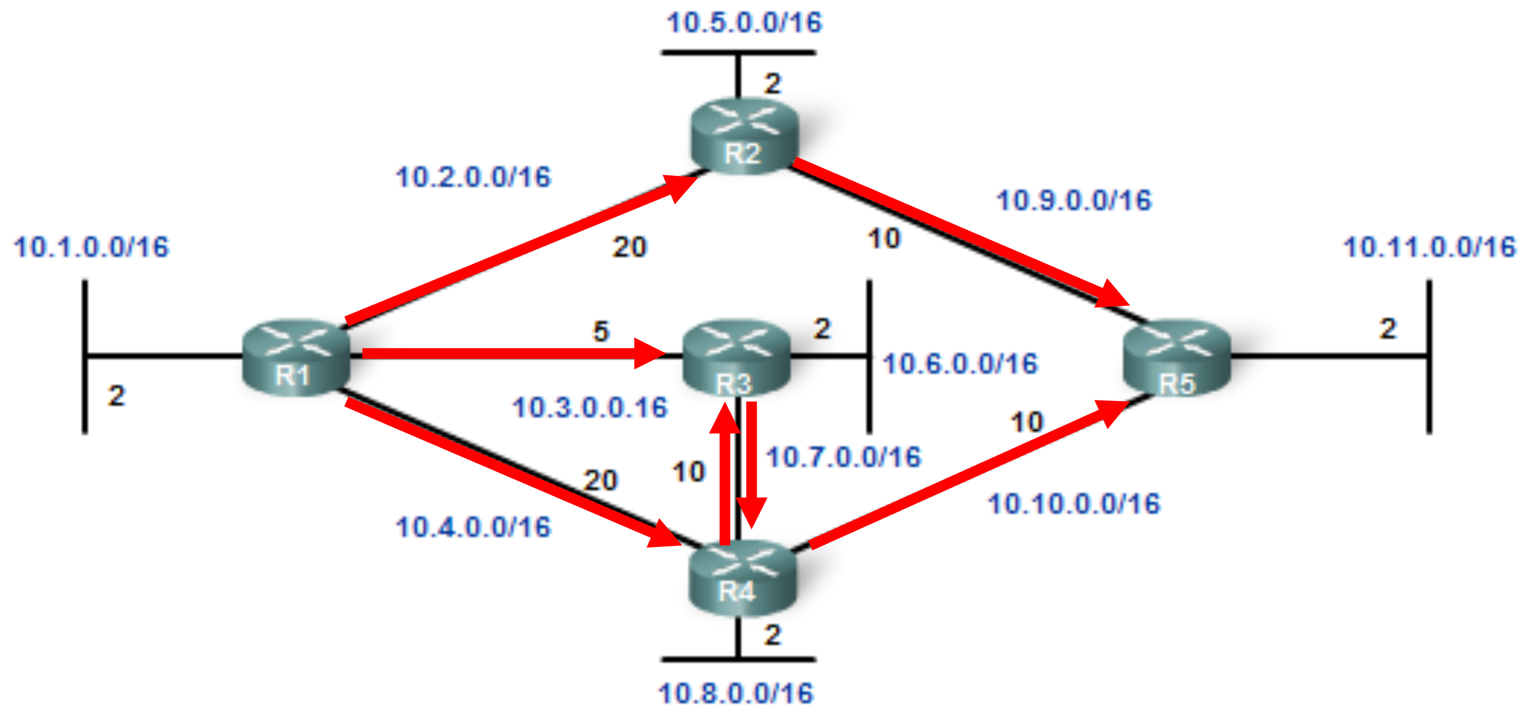
- "Keepalive" function
- Stops receiving Hello packets from a neighbor, that neighbor is considered unreachable and the adjacency is broken.

Step 3:
Building the Link-State Packet



- **After established its adjacencies**
  - Builds its LSPs
    - Link-state information about its links.
  - Sends LSPs out interfaces where it has established adjacencies with other routers.
    - R1 not sent LSPs out its Ethernet interface.

Step 4: Flooding Link-State Packets to Neighbors



- **Step 4:** ***Each router floods the LSP to all neighbors, who then store all LSPs received in a database.***
    - Each router floods its link-state information to all other link-state routers.
    - When a router receives an LSP from a neighboring router, sends that LSP out all other interfaces, except the interface that received the LSP.
    - Flooding effect of LSPs throughout the routing area.
- Link-state routing protocols calculate the SPF algorithm after the flooding is complete.

Step 5:

Constructing a Link-State Database

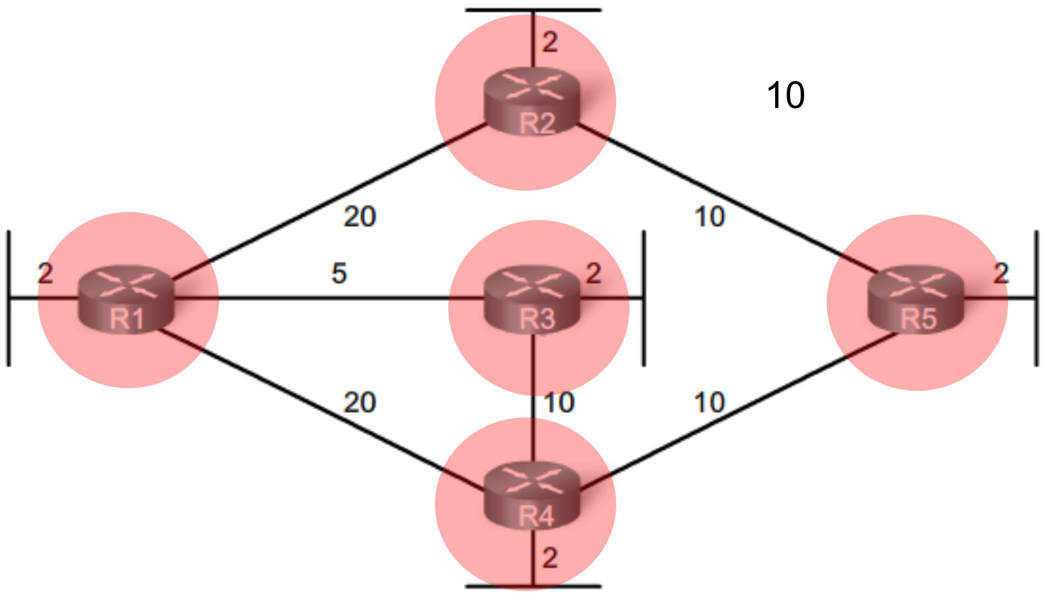
Link State Database for R1

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

- Step 5 (Final Step): *Each router uses the database to construct a complete map of the topology and computes the best path to each destination network.*

- After propagation of LSPs
  - Each router will then have an LSP from every link-state router.
  - LSPs stored in the link-state database.

Determining Shortest Path



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

Destination	Shortest Path	Cost
R1 LAN	R2 to R1	22
R3 LAN	R2 to R1 to R3	27
R4 LAN	R2 to R5 to R4	22
R5 LAN	R2 to R5	12

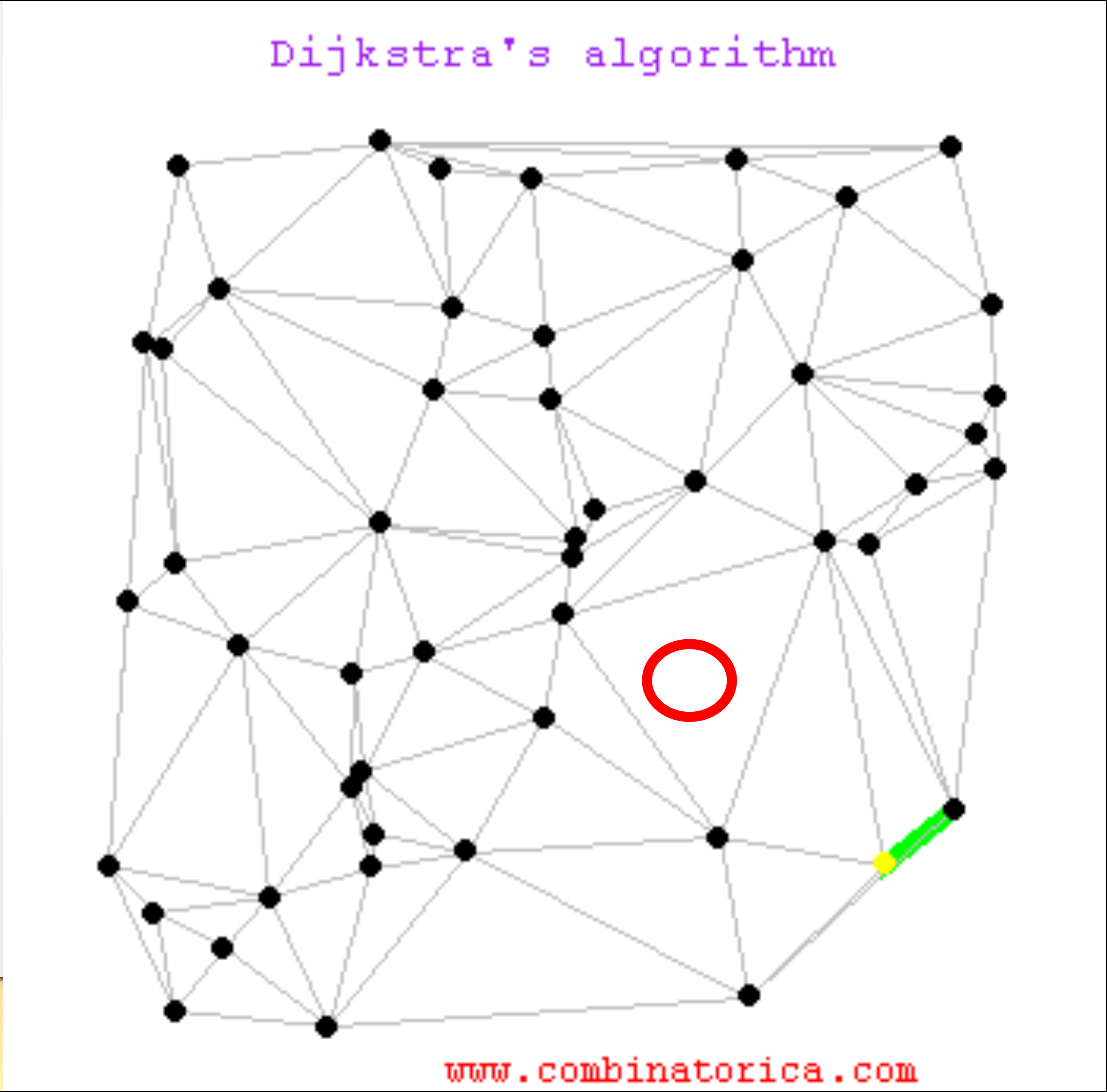
Destination	Shortest Path	Cost
R1 LAN	R4 to R3 to R1	17
R2 LAN	R4 to R5 to R2	22
R3 LAN	R4 to R3	12
R5 LAN	R4 to R5	12

Destination	Shortest Path	Cost
R1 LAN	R3 to R1	7
R2 LAN	R3 to R1 to R2	27
R4 LAN	R3 to R4	12
R5 LAN	R3 to R4 to R5	22

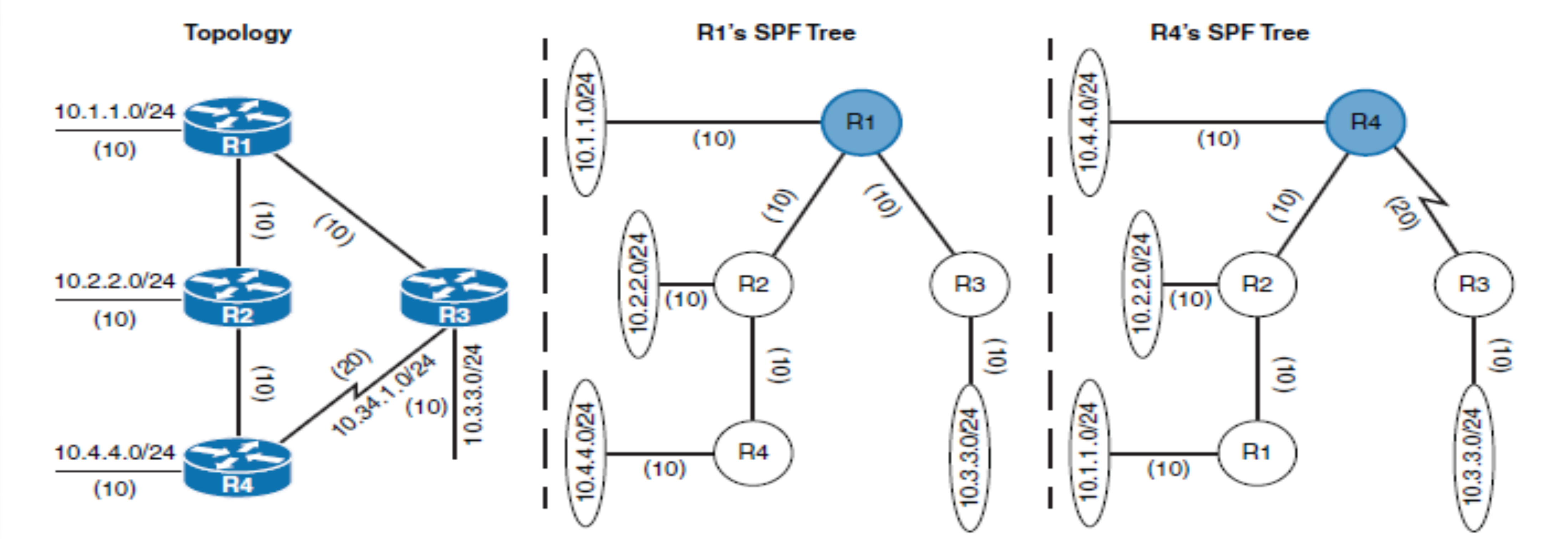
Destination	Shortest Path	Cost
R1 LAN	R5 to R4 to R3 to R1	27
R2 LAN	R5 to R2	12
R3 LAN	R5 to R4 to R3	22
R4 LAN	R5 to R4	12

Running SPF Algorithm

- Each router in the routing area can now use the SPF algorithm to construct the SPF trees that you saw earlier.



SPF Tree



Topology
R1's SPF Tree
R4's SPF Tree
10.1.1.0/24
(10)
R1
10.2.2.0/24
R2
R3
10.4.4.0/24
R4
(20)
10.34.1.0/24
10.3.3.0/24

Generating a Routing Table from the SPF Tree

SPF Tree for R1

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

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

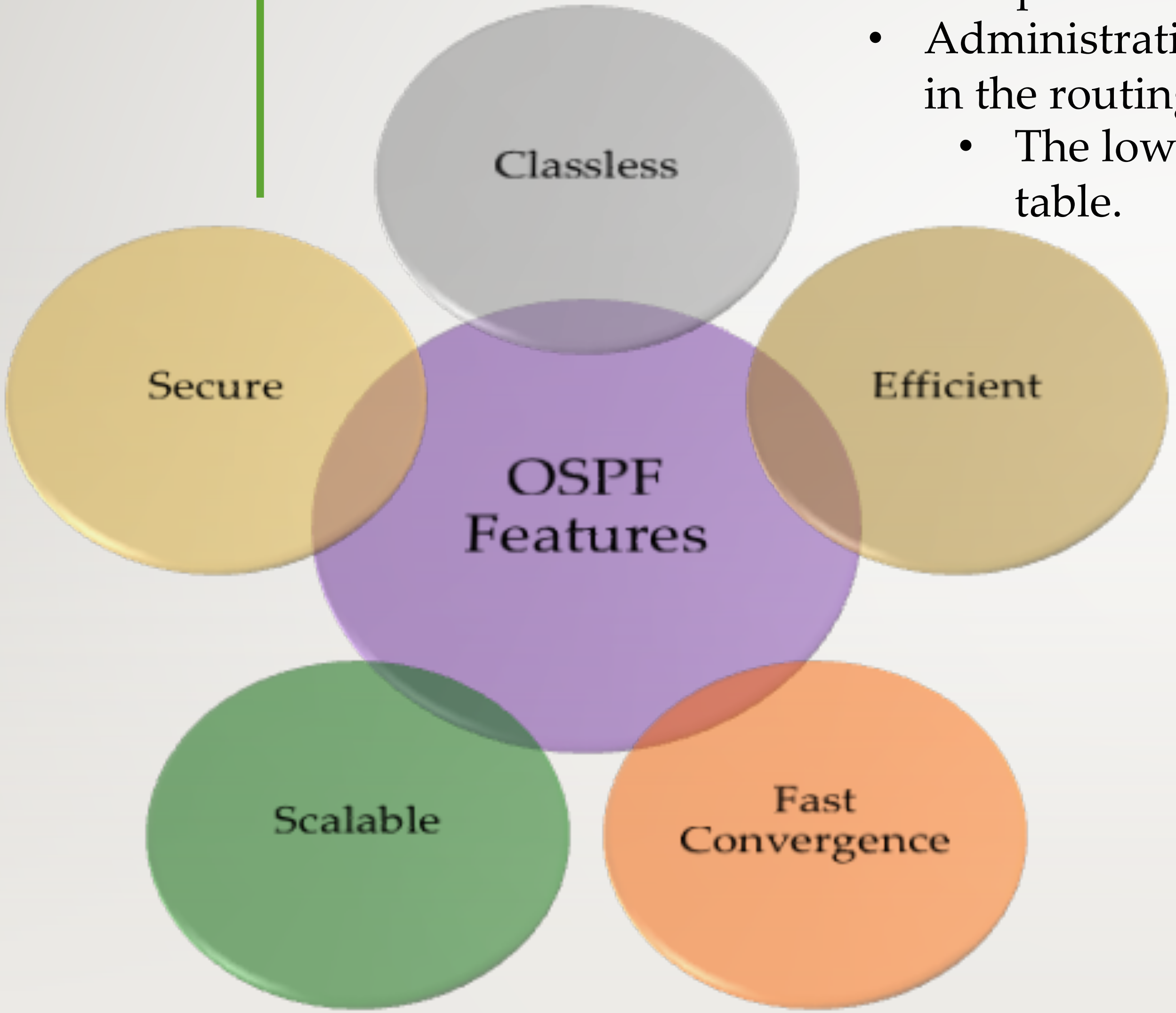
Remote Networks

- 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

- These paths listed previously can now be added to the routing table.
- The routing table will also include
  - Directly connected networks
  - Routes from any other sources, such as static routes.
- Packets will now be forwarded according to these entries in the routing table.

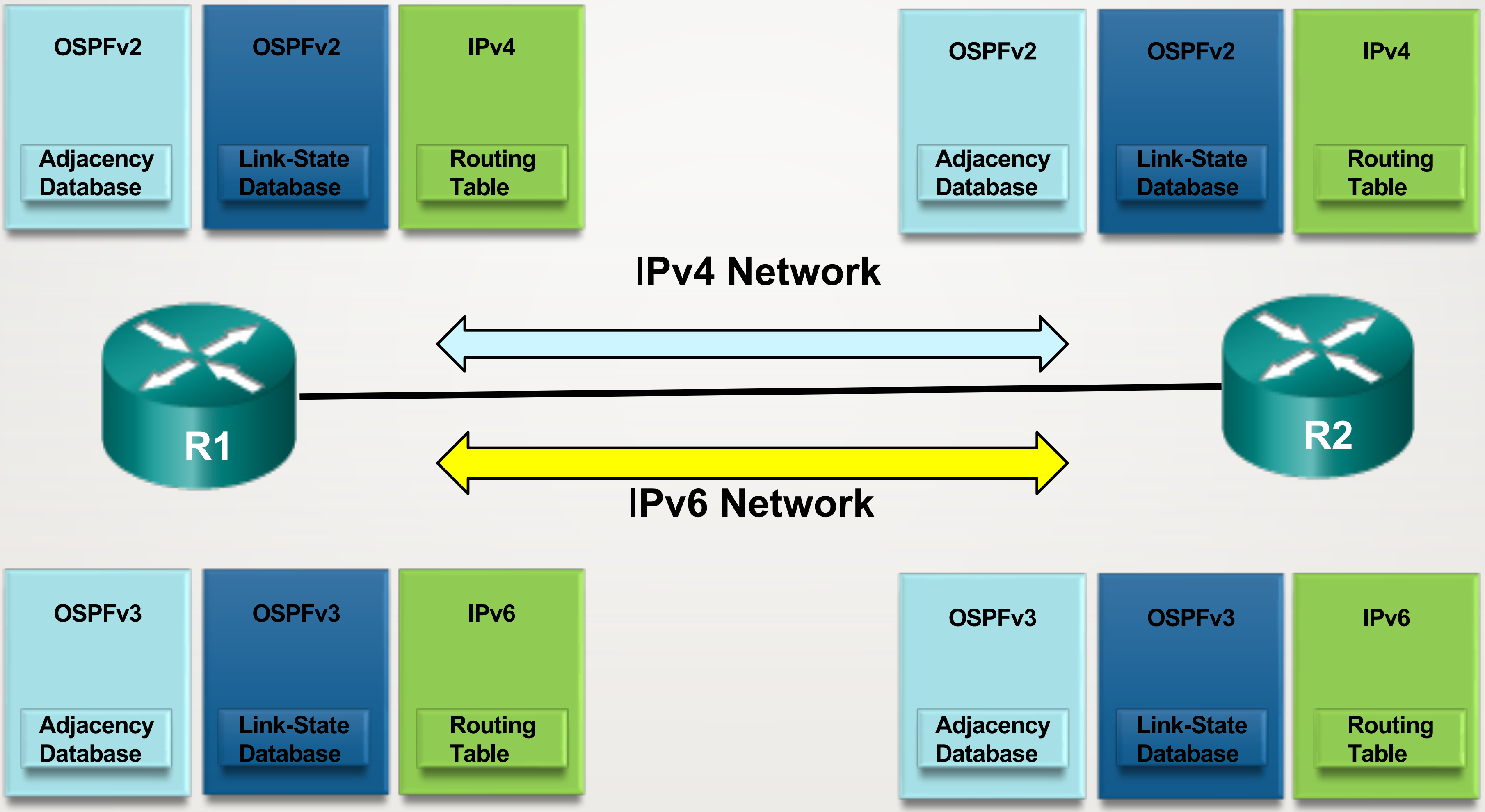
OSPF

Features of OSPF



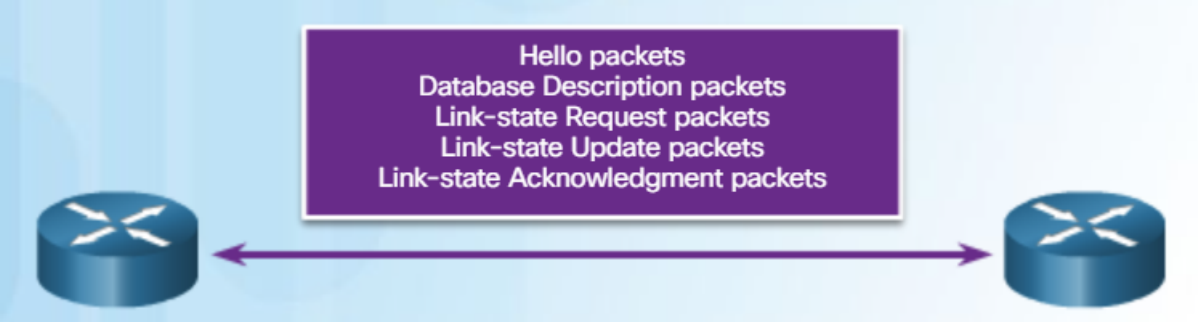
- OSPF uses the Dijkstra shortest path first (SPF) algorithm to choose the best path.
- Administrative distance is used in determining what route gets installed in the routing table when the route is learned from multiple sources.
  - The lowest administrative distance is the one added to the routing table.

Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
External EIGRP	170
Internal BGP	200


OSPFv2
Adjacency Database
OSPFv2
Link-State Database
IPv4
Routing Table
OSPFv2
Adjacency Database
OSPFv2
Link-State Database
IPv4
Routing Table
IPv4 Network
R1
R2
IPv6 Network
OSPFv3
Adjacency Database
OSPFv3
Link-State Database
IPv6
Routing Table
OSPFv3
Adjacency Database
OSPFv3
Link-State Database
IPv6
Routing Table

Open Shortest Path First

Components of OSPF

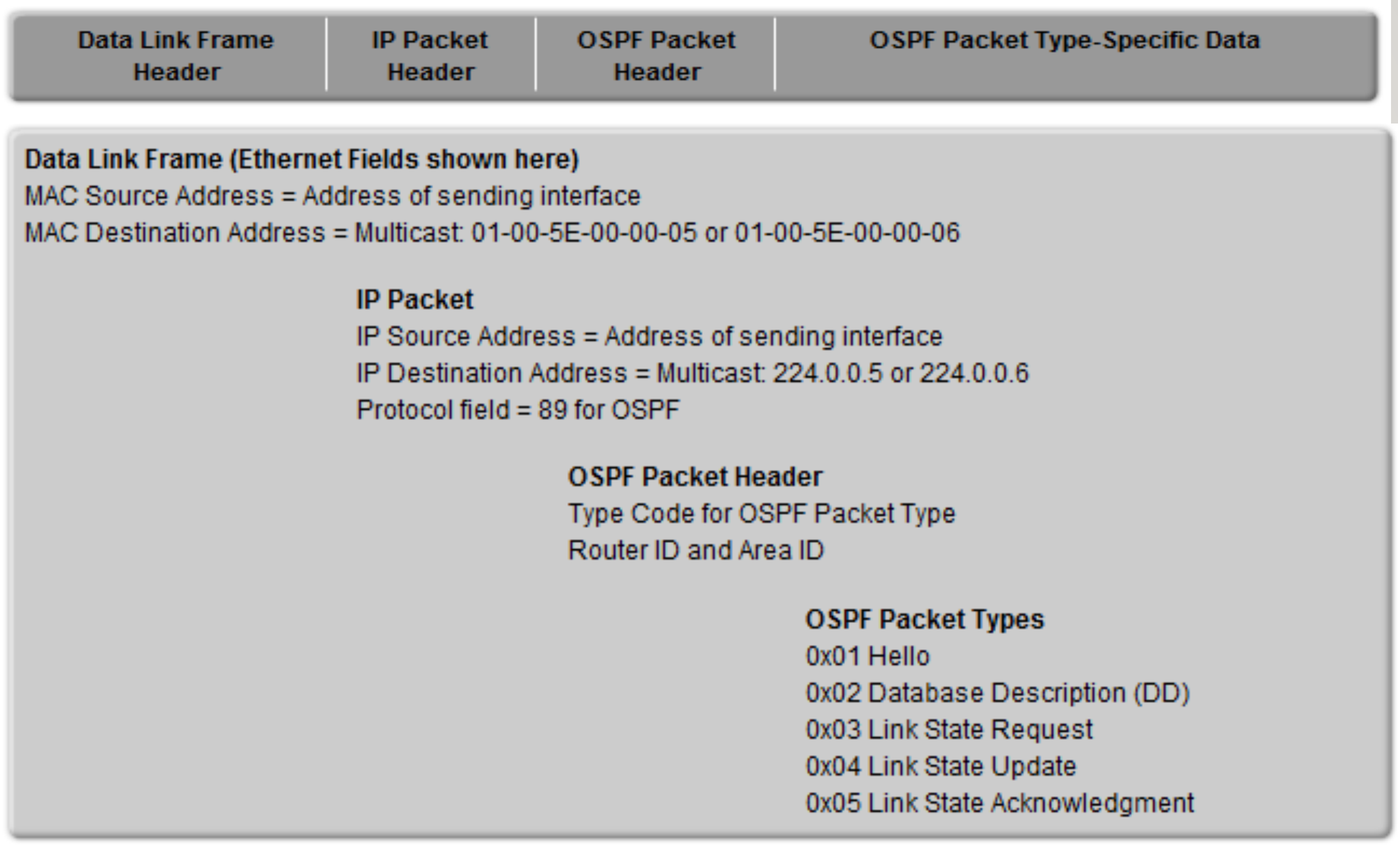


Database	Table	Description
Adjacency	Neighbor	• Lists all neighbor routers to which a router has established bidirectional communication • Unique for each router • View using the **show ip ospf neighbor** command
Link-state (LSDB)	Topology	• Lists information about all other routers • Represents the network topology • Contains the same LSDB as all other routers in the same area • View using the **show ip ospf database** command
Forwarding	Routing	• Lists routes generated when the SPF algorithm is run on the link-state database. • Unique to each router and contains information on how and where to send packets destined for remote networks • View using the **show ip route** command

- OSPF packet types: hello, database description, link-state request, link-state update, link-state acknowledgment

OSPF Messages

Encapsulating OSPF Messages

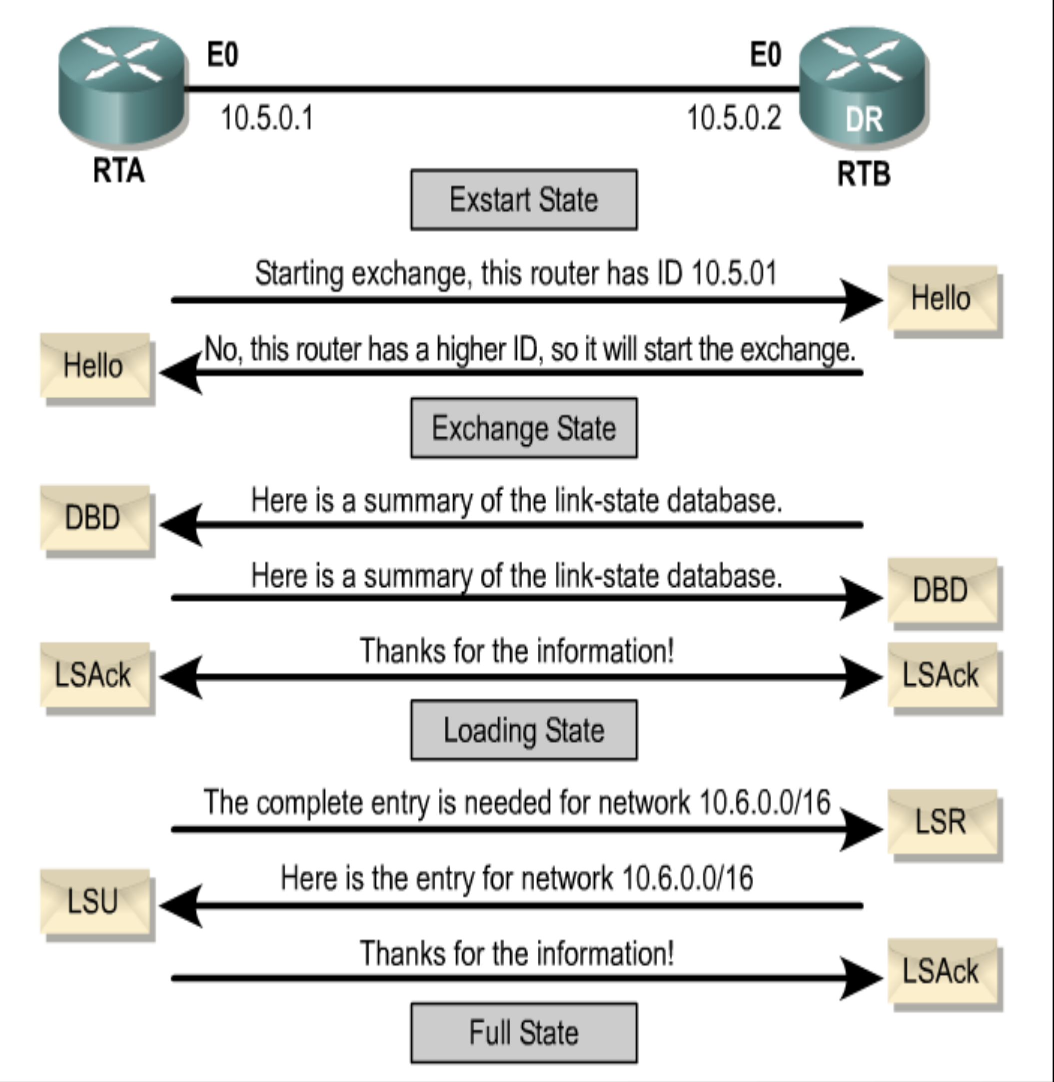


- In the IP packet header:
  - **Protocol field** is set to 89 (OSPF)
  - **Destination address** is typically set to one of two multicast addresses:
    - 224.0.0.5
    - 224.0.0.6
- Destination MAC address is also a multicast address:
  - 01-00-5E-00-00-05
  - 01-00-5E-00-00-06
- OSPF Packet Header identifies the type of OSPF packet, the router ID, and the area ID
- OSPF Packet Type contains the specific OSPF packet type information

OSPF Packet Types

Five types of OSPF LSPs (link-state packets).

- **Hello**: Used to discovers neighbors and builds adjacencies between them
- **DBD (Database Description):** Checks for database synchronization between routers
- **LSR (Link-State Request)** : Used by routers to request more information about any entry in the DBD.
- **LSU: (Link-State Update):** Sends specifically requested link-state records
- **LSAck (LSA Acknowledgment)**: Router sends a link-state (LSAck) to confirm receipt of the LSU.

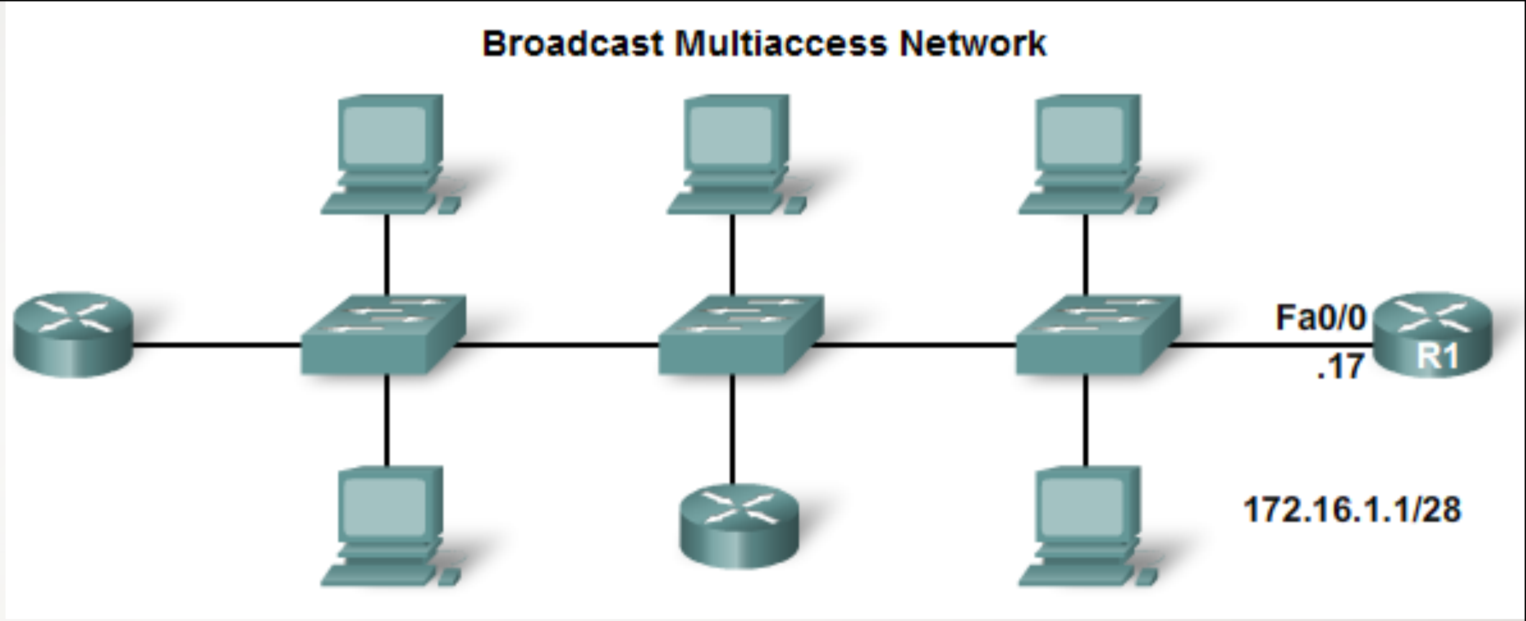


Hello Protocol

Hello packets :

- Discover neighbors (OSPF neighbors)
- Establish adjacencies
- Advertise parameters on which two routers must agree to become neighbors
  - **Hello Interval, Dead Interval, Network Type**
- Router priority (default is 1; 0-255 with the higher number influencing the DR/BDR election process)
- Elect the Designated Router and Backup Designated Router on ***multiaccess networks*** such as Ethernet and Frame Relay

Electing a DR and BDR



Router priority (default is 1; 0-255 with the higher number influencing the DR/BDR election process)

- Election of ***Designated Router (DR)*** and ***Backup Designated Router (BDR)***.
  - Used to reduce the amount of OSPF traffic on multiaccess networks
  - **DR** is responsible for updating all other OSPF routers.
  - **BDR** is the backup if the current DR fails.

Electing a DR and BDR

- **DR and BDR rules:**

1. Router is highest OSPF priority will become DR and router with second-highest priority will become BDR.
2. If the priority of the routers are same then, the router with the highest Router ID is selected as DR and the router with second-highest Router ID is selected as BDR.

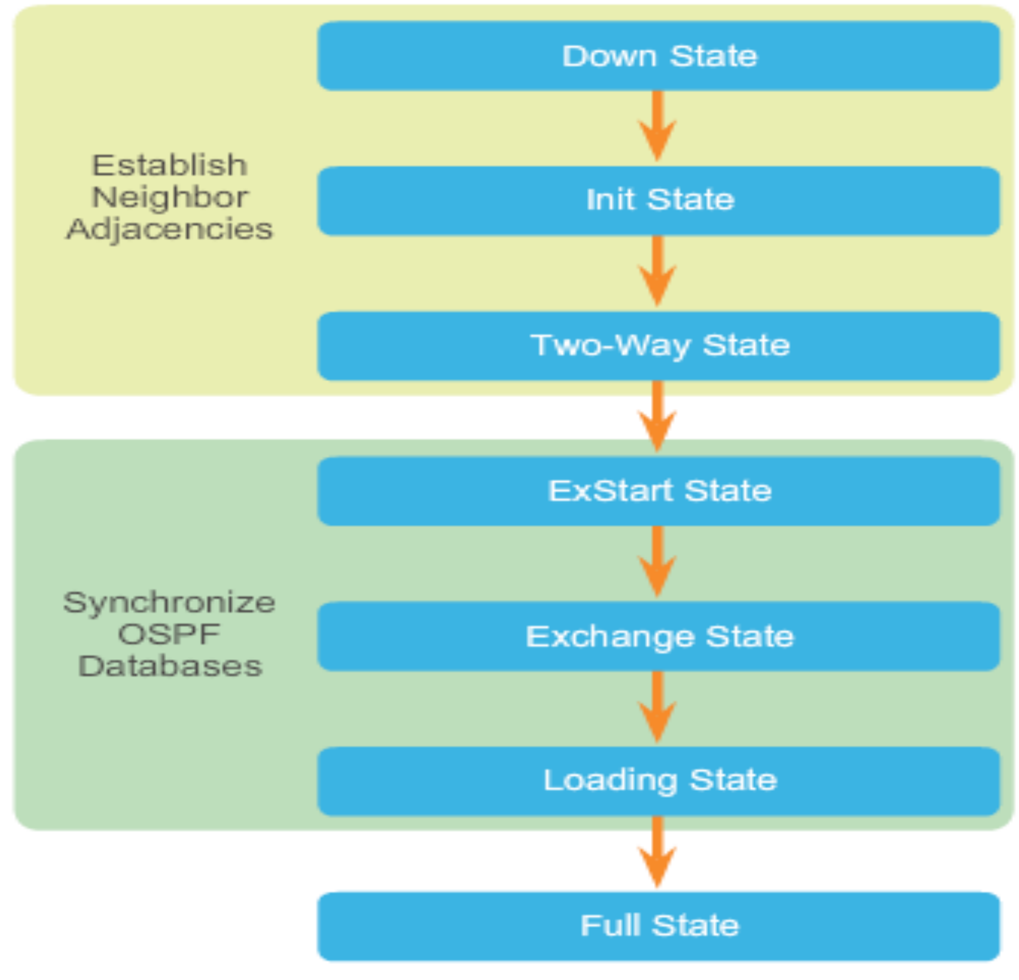
- **Router ID election:**

1. Manually configured Router ID in OSPF.
2. If Router ID is not manually configured, the highest IP address on any of the loopback interfaces is selected as Router ID.
3. If there are no loopback interfaces the highest IP address given to any active interface is selected as router ID.

OSPF Operations

Steps to OSPF Operation with States

1. **Establishing router adjacencies (Routers are adjacent)**
   - Down State – No Hello received
   - Init State – Hello received, but not with this router's Router ID
     - "Hi, my name is Ali."
     - "Hi, my name is Salem."
   - Two-way State – Hello received, and with this router's Router ID
     - "Hi, Salem, my name is Ali."
     - "Hi, Ali, my name is Salem."
2. **Electing DR and BDR – Multi-access (broadcast) segments only**
   - ExStart State with DR and BDR
   - Two-way State with all other routers
3. **Discovering Routes**
   - ExStart State
   - Exchange State
   - Loading State
   - Full State (Routers are "fully adjacent")



4. **Calculating the Routing Table**

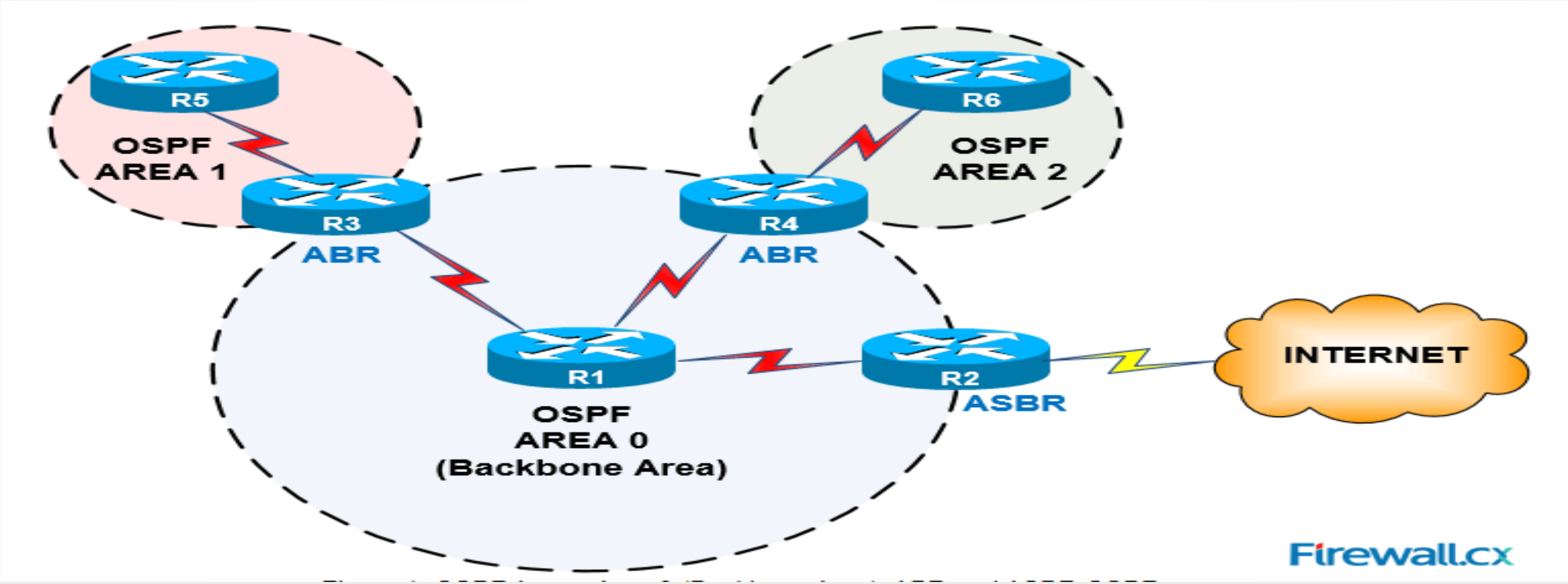
5. **Maintaining the LSDB and Routing Table**

Configuring Single Area OSPF

OSPF Area

- An OSPF network can be divided into sub-domains called areas. An area is a logical collection of OSPF networks, routers, and links that have the same area identification. A router within an area must maintain a topological database for the area to which it belongs. The router does not have detailed information about network topology outside of its area, which thereby reduces the size of its database.
- This reduces the number of link-state advertisements (LSAs) and other OSPF overhead traffic sent on the network, and it reduces the size of the topology database that each router must maintain.

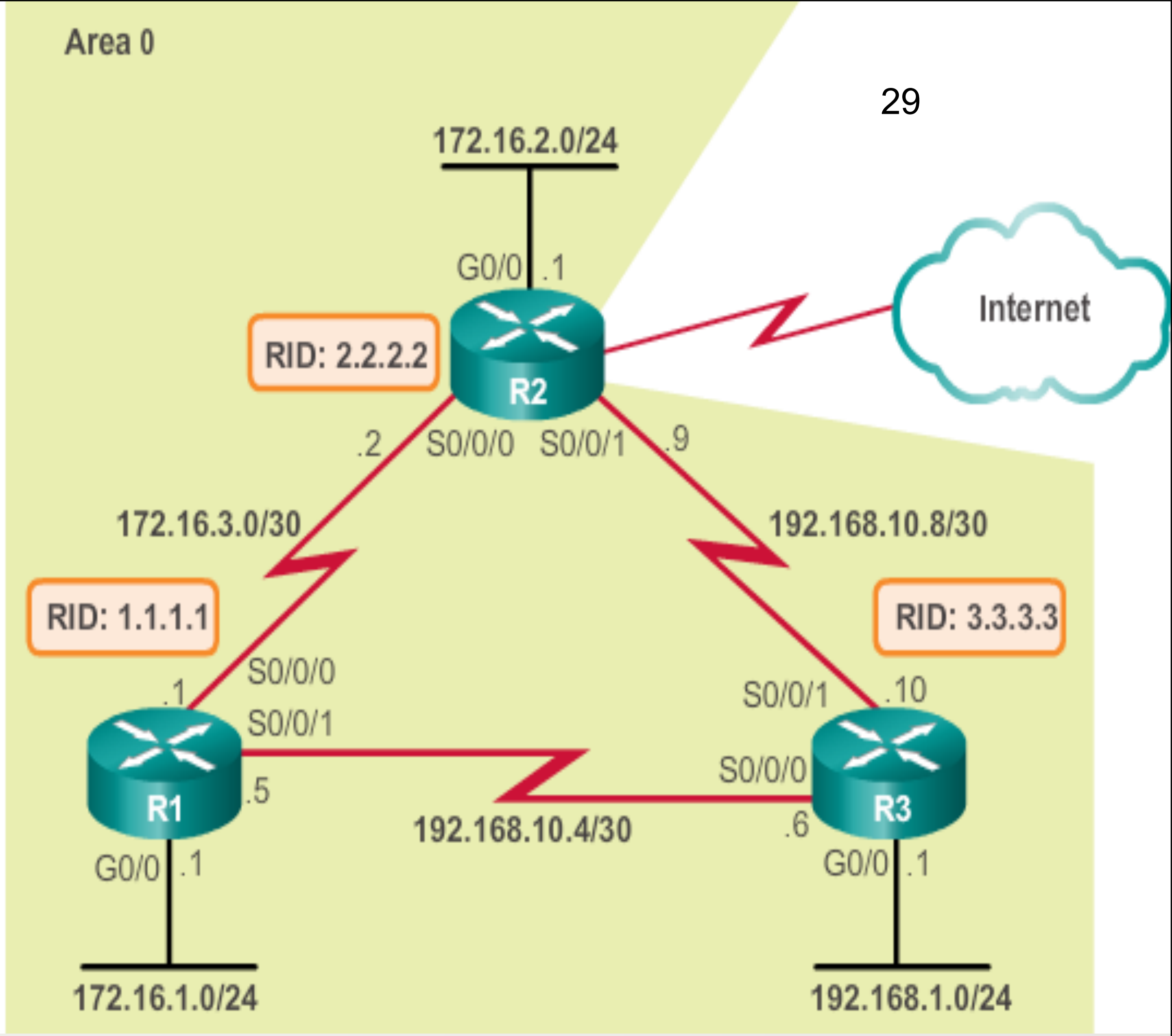
All areas in an OSPF autonomous system must be physically connected to the backbone area (area 0).



OSPF Reference Topology

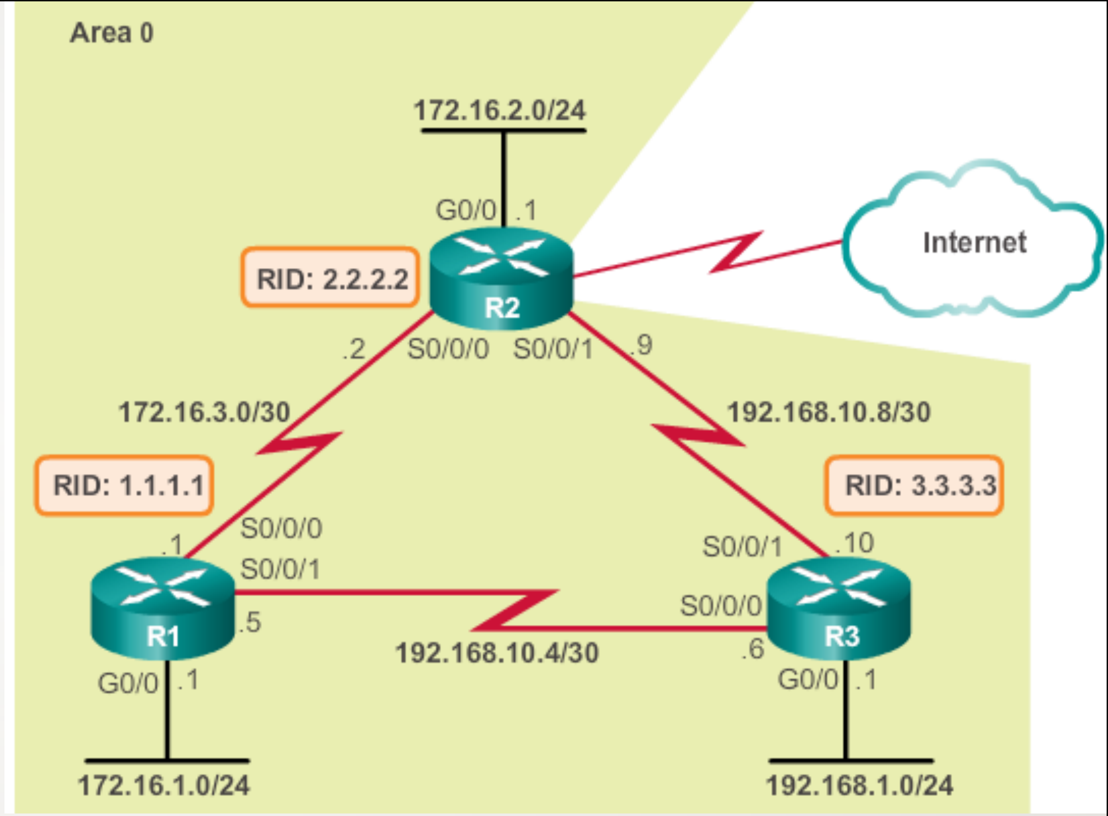

```
R1(config)# router ospf 10
R1(config-router)#router-id ip-address
```

- The ***process-id***
  - Between 1 and 65,535
  - Chosen by the network administrator.
- Locally significant:
  - Does not have to match other OSPF routers.
  - This differs from EIGRP.
- We are using the same process ID simply for consistency.

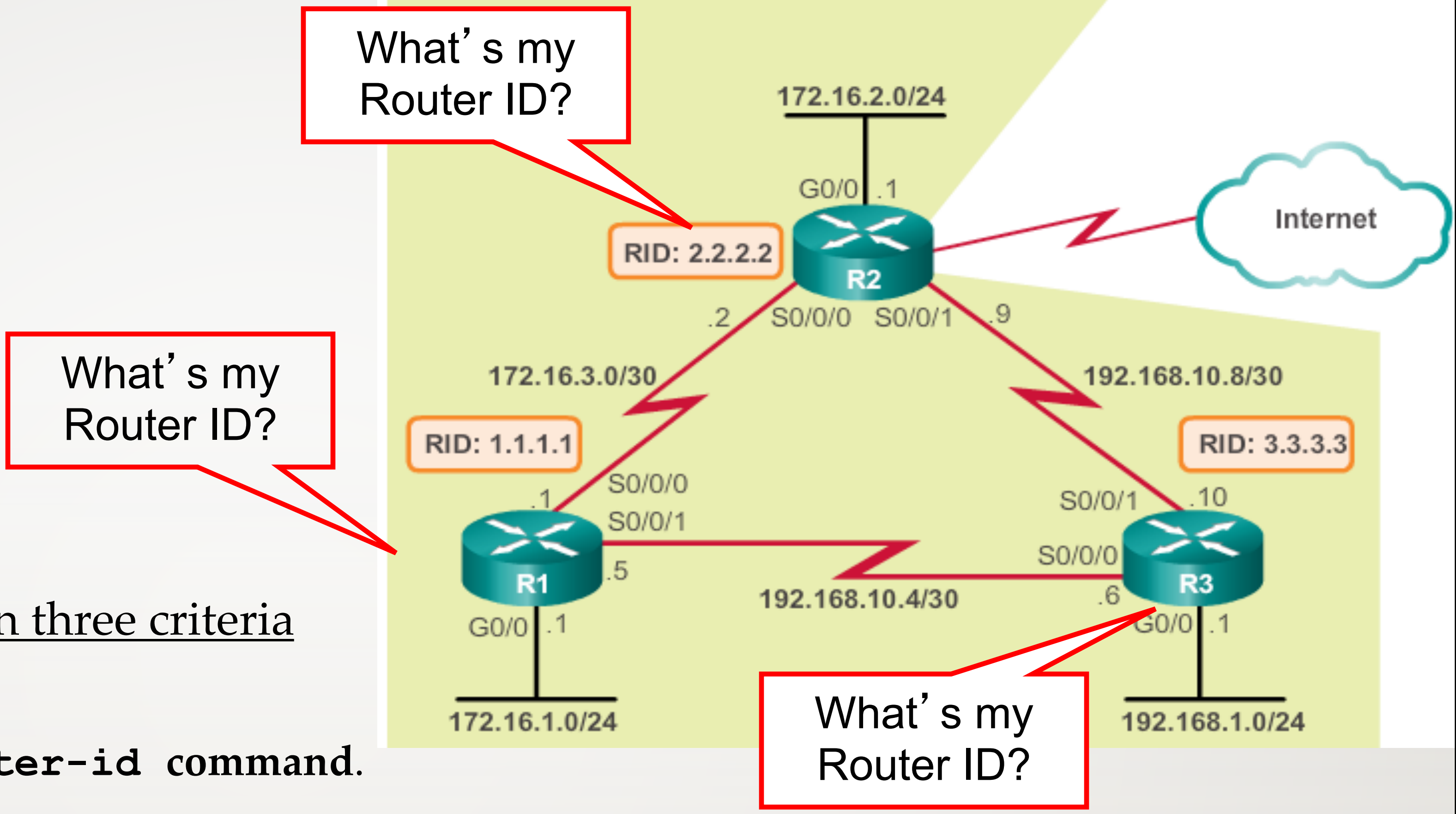


OSPF Router ID

- A router is known to OSPF by the OSPF router ID number.
  - LSDBs use the OSPF router ID to differentiate one router from the next.
- By default, the router ID is the highest IP address on an active interface at the moment of OSPF process startup.
- However, for stability reason, it is recommended that the `router-id` command or a loopback interface be configured.



OSPF Router ID



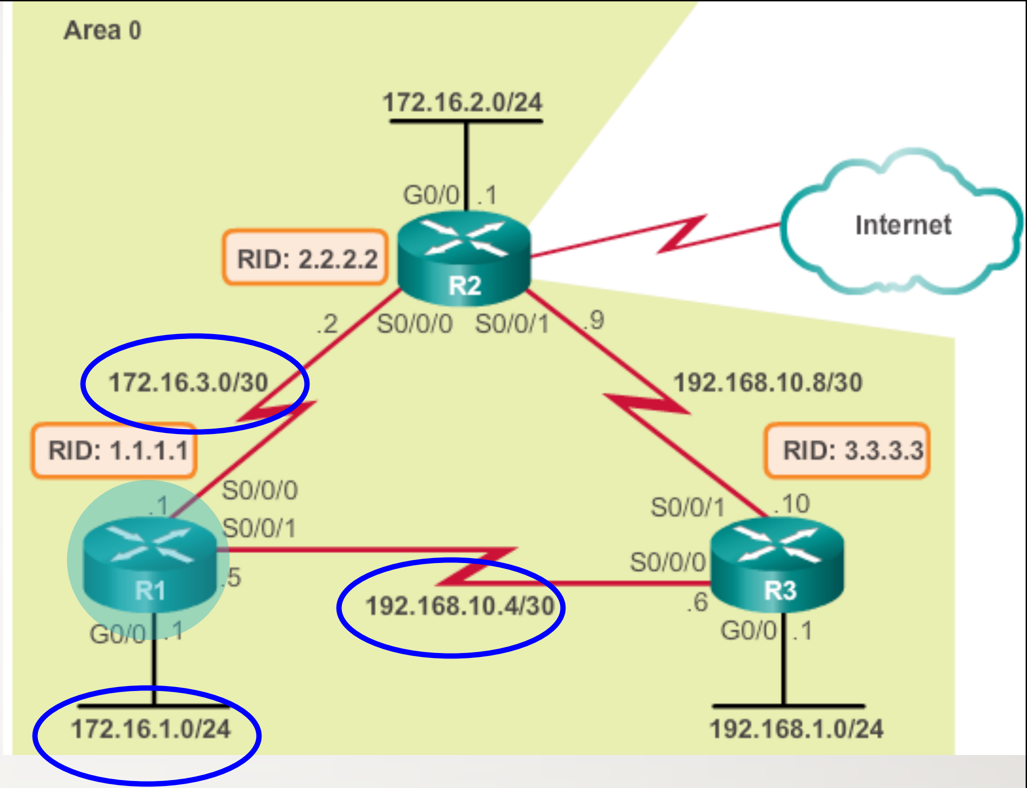
- Cisco routers derive the router ID based on three criteria and with the following precedence:
  1. IP address configured with the **OSPF `router-id` command**.
  2. **Highest IP address** of any of its **loopback interfaces.**
  3. **Highest *active* IP address** of any of its physical interfaces.
     - The interface does not need to be enabled for OSPF, i.e. it does not need to be included in one of the OSPF **`network`** commands.

Advertising OSPF Networks

```
R1(config)# router ospf 10
R1(config-router)# route-id 1.1.1.1
R1(config-router)# network 172.16.1.0 0.0.0.255 area 0
R1(config-router)# network 172.16.3.0 0.0.0.3 area 0
R1(config-router)# network 192.168.10.4 0.0.0.3 area 0
R1(config-router)# end
R1#

R2(config)# router ospf 10
R2(config-router)# route-id 2.2.2.2
R2(config-router)# network 172.16.2.0 0.0.0.255 area 0
R2(config-router)# network 172.16.3.0 0.0.0.3 area 0
R2(config-router)# network 192.168.10.8 0.0.0.3 area 0
R2#

R3(config)# router ospf 10
R3(config-router)# router-id 3.3.3.3
R3(config-router)# network 192.168.1.1 0.0.0.0 area 0
R3(config-router)# network 192.168.10.6 0.0.0.0 area 0
R3(config-router)# network 192.168.10.10 0.0.0.0 area 0
R3(config-router)#
```



Configuring Passive Interfaces on R1

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

End of Chapter 6