Module 1: Single-Area OSPFv2 Concepts

Instructor Materials

Enterprise Networking, Security, and Automationv7.0 (ENSA)

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Module Objectives

Module Title: Single-Area OSPF Concepts

Module Objective: Explain how single-area OSPF operates in both point-to-point and broadcast multiaccess networks.

Topic Title	Topic Objective
OSPF Features and Characteristics	Describe basic OSPF features and characteristics.
OSPF Packets	Describe the OSPF packet types used in single-area OSPF.
OSPF Operation	Explain how single-area OSPF operates.

1.1 OSPF Features and Characteristics

Static or Dynamic?

The table shows a comparison of some the differences between dynamic and static routing.

Feature	Dynamic Routing	Static Routing
Configuration complexity	Independent of network size	Increases with network size
Topology changes	Automatically adapts to topology changes	Administrator intervention required
Scalability	Suitable for simple to complex network topologies	Suitable for simple topologies
Security	Security must be configured	Security is inherent
Resource Usage	Uses CPU, memory, and link bandwidth	No additional resources needed
Path Predictability	Route depends on topology and routing protocol used	Explicitly defined by the administrator

IGP and EGP Routing Protocols

An autonomous system (AS) represents a collection of network devices under a common administrator.

Routing protocols can be divided based on whether they exchange routes within an AS or between different autonomous systems:

Interior Gateway Protocols (IGP)

- Support small, medium-sized, and large organizations, but their scalability has its limits. Fast convergence, and basic functionality is not complex to configure. The most commonly used IGPs in enterprises are EIGRP, OSPF and RIP is rarely used. IS-IS is also commonly found as ISP IGP

Exterior Gateway Protocols (EGP)

- Used to exchange routes between different autonomous systems. BGP is the only EGP that is used today. The main function of BGP is to exchange a huge number of routes between different autonomous systems.

Types of Routing Protocols

Distance vector protocols

- The distance vector routing approach determines the direction (vector) and distance (such as link cost or number of hops) to any link in the network. The only information that a router knows about a remote network is the distance or metric to reach this network and which path or interface to use to get there. Distance vector routing protocols do not have an actual map of the network topology.

Link-state protocols

- The link-state approach uses the Shortest Path First (SPF) algorithm to create an abstract of the exact topology of the entire network or at least within its area. A link-state routing protocol is like having a complete map of the network topology. The map is used to determine best path to a destination.

Path vector protocols

- Path information is used to determine the best paths and to prevent routing loops. Similar to distance vector protocols, path vector protocols do not have an abstract of the network topology. Path vector protocols indicate direction and distance, but also include additional information about the specific path of the destination.

	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	MBGP

Introduction to OSPF

- OSPF is a link-state routing protocol that was developed as an alternative for the distance vector Routing Information Protocol (RIP). OSPF has significant advantages over RIP in that it offers faster convergence and scales to much larger network implementations.
- OSPF is a link-state routing protocol that uses the concept of areas. A network administrator can divide the routing domain into distinct areas that help control routing update traffic.
- A link is an interface on a router, a network segment that connects two routers, or a stub network such as an Ethernet LAN that is connected to a single router.
- Information about the state of a link is known as a link-state. All link-state information includes the network prefix, prefix length, and cost.
- This module covers basic, single-area OSPF implementations and configurations.

Components of OSPF

- All routing protocols share similar components. They all use routing protocol messages to exchange route information. The messages help build data structures, which are then processed using a routing algorithm.
- Routers running OSPF exchange messages to convey routing information using five types of packets:
  - Hello packet
  - Database description packet
  - Link-state request packet
  - Link-state update packet
  - Link-state acknowledgment packet
- These packets are used to discover neighboring routers and also to exchange routing information to maintain accurate information about the network.

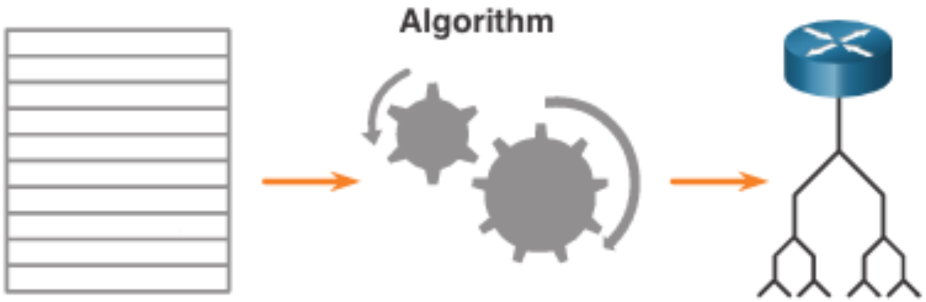
Components of OSPF (Cont.)

OSPF messages are used to create and maintain three OSPF databases, as follows:

Database	Table	Description
Adjacency Database	Neighbor Table	•List of all neighbor routers to which a router has established bi-directional communication. •This table is unique for each router. •Can be viewed using the **`show ip ospf neighbor`** command.
Link-state Database (LSDB)	Topology Table	•Lists information about all other routers in the network. •The database represents the network LSDB. •All routers within an area have identical LSDB. •Can be viewed using the **`show ip ospf database`** command.
Forwarding Database	Routing Table	•List of routes generated when an algorithm is run on the link-state database. •Each router's routing table is unique and contains information on how and where to send packets to other routers. •Can be viewed using the **`show ip route`** command.

Components of OSPF (Cont.)

- The router builds the topology table using results of calculations based on the Dijkstra shortest-path first (SPF) algorithm. The SPF algorithm is based on the cumulative cost to reach a destination.
- The SPF algorithm creates an SPF tree by placing each router at the root of the tree and calculating the shortest path to each node. The SPF tree is then used to calculate the best routes. OSPF places the best routes into the forwarding database, which is used to make the routing table.



Link-State Operation

To maintain routing information, OSPF routers complete a generic link-state routing process to reach a state of convergence. The following are the link-state routing steps that are completed by a router:

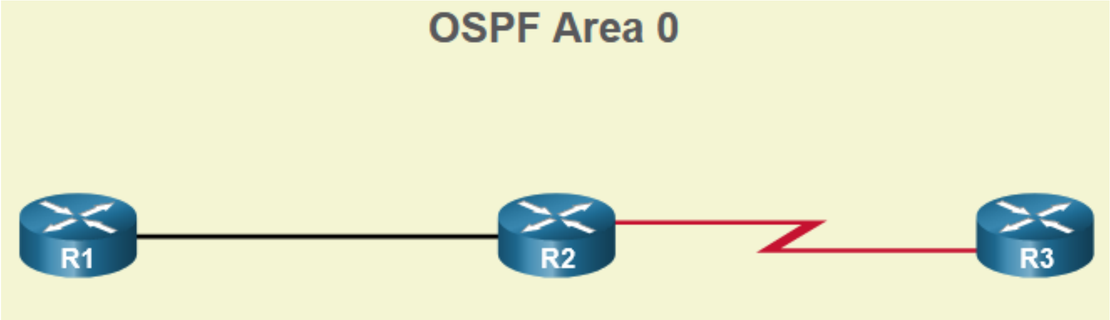
1. Establish Neighbor Adjacencies
2. Exchange Link-State Advertisements
3. Build the Link State Database
4. Execute the SPF Algorithm
5. Choose the Best Route

Single-Area and Multiarea OSPF

To make OSPF more efficient and scalable, OSPF supports hierarchical routing using areas. An OSPF area is a group of routers that share the same link-state information in their LSDBs. OSPF can be implemented in one of two ways, as follows:

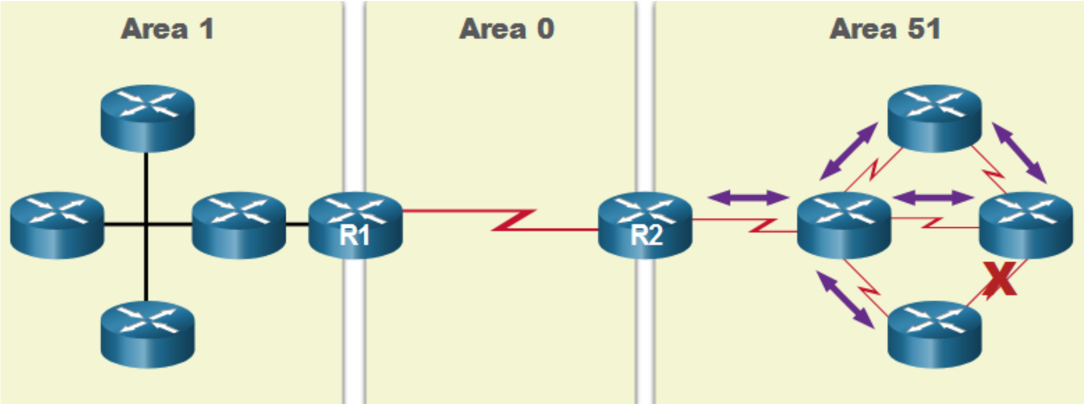
- **Single-Area OSPF** - All routers are in one area. Best practice is to use area 0.
- **Multiarea OSPF** - OSPF is implemented using multiple areas, in a hierarchical fashion. All areas must connect to the backbone area (area 0). Routers interconnecting the areas are referred to as Area Border Routers (ABRs).

The focus of this module is on single-area OSPFv2.



Multiarea OSPF

- The hierarchical-topology design options with multiarea OSPF can offer the following advantages.
- **Smaller routing tables** - Tables are smaller because there are fewer routing table entries. This is because network addresses can be summarized between areas. Route summarization is not enabled by default.
- **Reduced link-state update overhead** - Designing multiarea OSPF with smaller areas minimizes processing and memory requirements.
- **Reduced frequency of SPF calculations** –– Multiarea OSPF localize the impact of a topology change within an area. For instance, it minimizes routing update impact because LSA flooding stops at the area boundary.



OSPFv3

- OSPFv3 is the OSPFv2 equivalent for exchanging IPv6 prefixes. OSPFv3 exchanges routing information to populate the IPv6 routing table with remote prefixes.
- **Note**: With the OSPFv3 Address Families feature, OSPFv3 includes support for both IPv4 and IPv6. OSPF Address Families is beyond the scope of this curriculum.
- OSPFv3 has the same functionality as OSPFv2, but uses IPv6 as the network layer transport, communicating with OSPFv3 peers and advertising IPv6 routes. OSPFv3 also uses the SPF algorithm as the computation engine to determine the best paths throughout the routing domain.
- OSPFv3 has separate processes from its IPv4 counterpart. The processes and operations are basically the same as in the IPv4 routing protocol, but run independently.

1.2 OSPF Packets

Types of OSPF Packets

The table summarizes the five different types of Link State Packets (LSPs) used by OSPFv2. OSPFv3 has similar packet types.

Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them
2	Database Description (DBD)	Checks for database synchronization between routers
3	Link-State Request (LSR)	Requests specific link-state records from router to router
4	Link-State Update (LSU)	Sends specifically requested link-state records
5	Link-State Acknowledgment (LSAck)	Acknowledges the other packet types

Link-State Updates

- LSUs are also used to forward OSPF routing updates. An LSU packet can contain 11 different types of OSPFv2 LSAs. OSPFv3 renamed several of these LSAs and also contains two additional LSAs.
- LSU and LSA are often used interchangeably, but the correct hierarchy is LSU packets contain LSA messages.

LSUs

Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them
2	DBD	Checks for database synchronization between routers
3	LSR	Requests specific link-state records from router to router
4	LSU	Sends specifically requested link-state records
5	LSAck	Acknowledges the other packet types

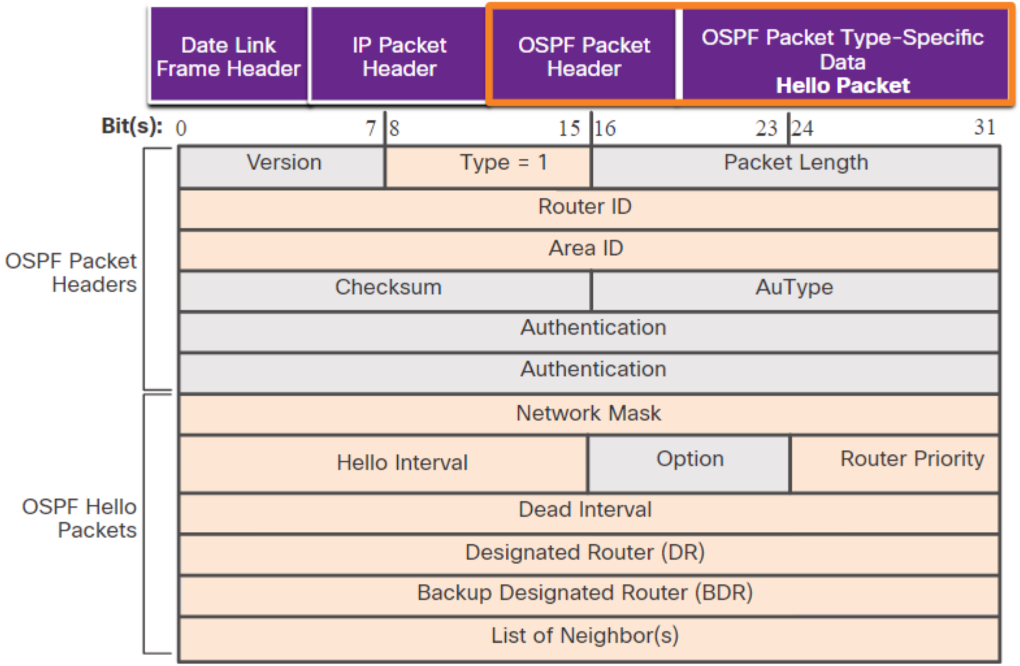
LSAs

LSA Type	Description
1	Router LSAs
2	Checks for database synchronization between routers
3 or 4	Summary LSAs
5	Autonomous System External LSAs
6	Multicast OSPF LSAs
7	Defined for Not-So-Stubby Areas
8	External Attributes LSA for Border Gateway Patrol (BGPs)

Hello Packet

The OSPF Type 1 packet is the Hello packet. Hello packets are used to do the following:

- Discover OSPF neighbors and establish neighbor adjacencies.
- Advertise parameters on which two routers must agree to become neighbors.
- Elect the Designated Router (DR) and Backup Designated Router (BDR) on multiaccess networks like Ethernet. Point-to-point links do not require DR or BDR.



1.3 OSPF Operation

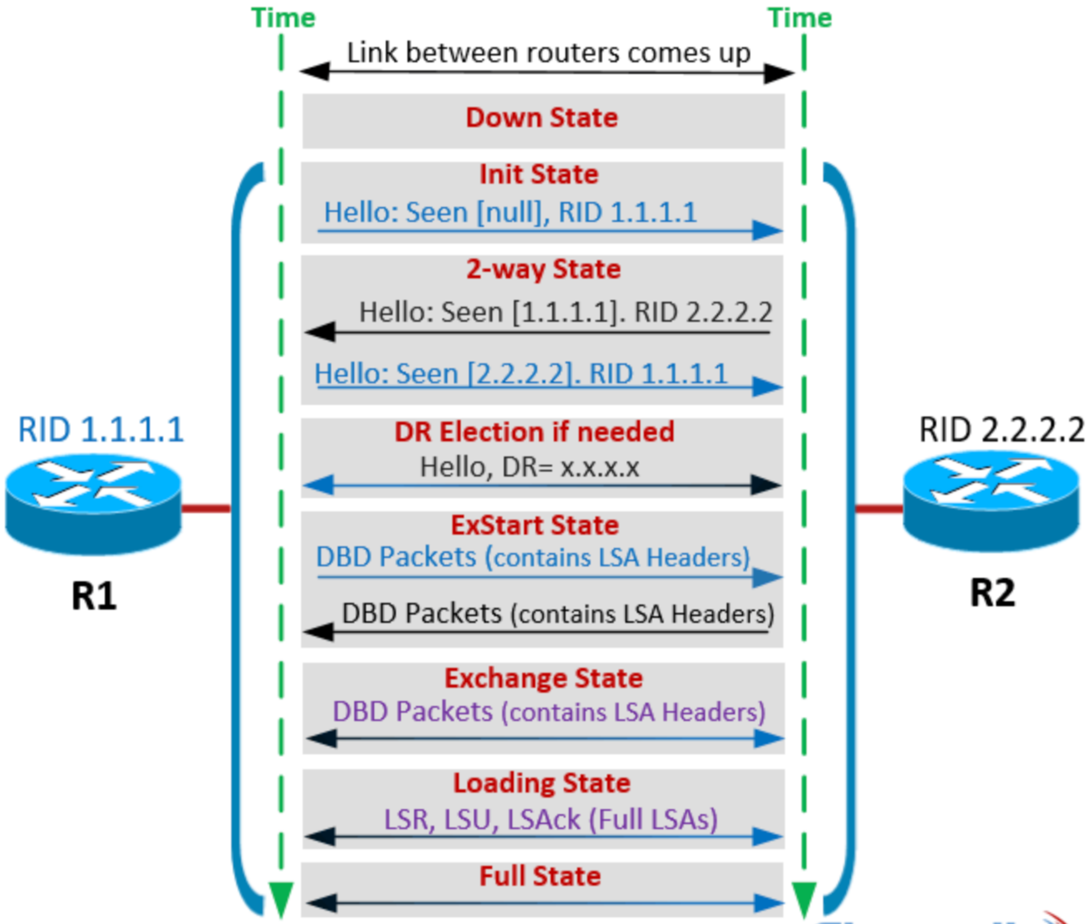
OSPF Operational States

State	Description
Down State	• No Hello packets received = Down. • Router starts to send Hello packets. • Transition to Init state.
Init State	• Hello packets are received from the neighbor. • They contain the Router ID of the sending router. • Transition to Two-Way state.
Two-Way State	• In this state, communication between the two routers is bidirectional. • On multiaccess links, the routers elect a DR and a BDR. • Transition to ExStart state.

OSPF Operational States (Cont.)

State	Description
ExStart State	On point-to-point networks, the two routers decide which router will initiate the DBD packet exchange and decide upon the initial DBD packet sequence number.
Exchange State	• Routers exchange DBD packets. • If additional router information is required then transition to Loading; otherwise, transition to the Full state.
Loading State	• LSRs and LSUs are used to gain additional route information. • Routes are processed using the SPF algorithm. • Transition to the Full state.
Full State	The link-state database of the router is fully synchronized.

OSPF Operational States (Cont.)



Establish Neighbor Adjacencies

- To determine if there is an OSPF neighbor on the link, the router sends a Hello packet that contains its **router ID** out all OSPF-enabled interfaces. The Hello packet is sent to the reserved All OSPF Routers IPv4 multicast address 224.0.0.5. Only OSPFv2 routers will process these packets.
- The OSPF **router ID** is used by the OSPF process to uniquely identify each router in the OSPF area. A router ID is a 32-bit number formatted like an IPv4 address and assigned to uniquely identify a router among OSPF peers.
- When a neighboring OSPF-enabled router receives a Hello packet with a router ID that is not within its neighbor list, the receiving router attempts to establish an adjacency with the initiating router.

Establish Neighbor Adjacencies (Cont.)

The process routers use to establish adjacency on a multiaccess network:

1	**Down to Init State**	When OSPFv2 is enabled on the interface, R1 transitions from Down to Init and starts sending OSPFv2 Hellos out of the interface in an attempt to discover neighbors.
2	**Init State**	When a R2 receives a hello from the previously unknown router R1, it adds R1's router ID to the neighbor list and responds with a Hello packet containing its own router ID.
3	**Two-Way State**	R1 receives R2's hello and notices that the message contains the R1 router ID in the list of R2's neighbors. R1 adds R2's router ID to the neighbor list and transitions to the Two-Way State. If R1 and R2 are connected with a point-to-point link, they transition to ExStart (R2 & R3) If R1 and R2 are connected over a common Ethernet network, the DR/BDR election occurs.
4	**Elect the DR & BDR**	The DR and BDR election occurs, where the router with the highest router ID or highest priority is elected as the DR, and second highest is the BDR

Synchronizing OSPF Databases

After the Two-Way state, routers transition to database synchronization states. This is a three step process, as follows:

- Decide first router: The router with the highest router ID sends its DBD first.
- Exchange DBDs: As many as needed to convey the database. The other router must acknowledge each DBD with an LSAck packet.
- Send an LSR: Each router compares the DBD information with the local LSDB. If the DBD has more current link information, the router transitions to the loading state.

After all LSRs have been exchanged and satisfied, the routers are considered synchronized and in a full state.

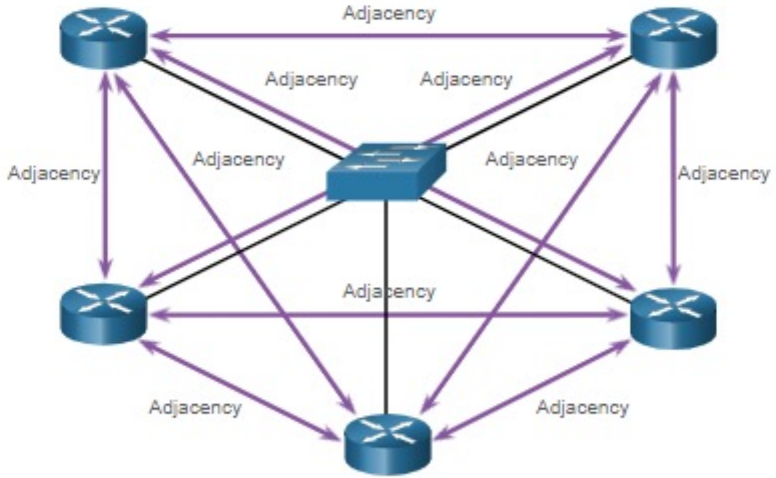
Updates (LSUs) are sent:

- When a change is perceived (incremental updates)
- Every 30 minutes

The Need for a DR

Multiaccess networks can create two challenges for OSPF regarding the flooding of LSAs, as follows:

- **Creation of multiple adjacencies** - Ethernet networks could potentially interconnect many OSPF routers over a common link. Creating adjacencies with every router would lead to an excessive number of LSAs exchanged between routers on the same network.
- **Extensive flooding of LSAs** - Link-state routers flood their LSAs any time OSPF is initialized, or when there is a change in the topology. This flooding can become excessive.



- Number of Adjacencies = n (n - 1) / 2
- n = number of routers
- Example: 5 (5 - 1) / 2 = 10 adjacencies

LSA Flooding with a DR

- An increase in the number of routers on a multiaccess network also increases the number of LSAs exchanged between the routers. This flooding of LSAs significantly impacts the operation of OSPF.
- If every router in a multiaccess network had to flood and acknowledge all received LSAs to all other routers on that same multiaccess network, the network traffic would become quite chaotic.
- On multiaccess networks, OSPF elects a DR to be the collection and distribution point for LSAs sent and received. A BDR is also elected in case the DR fails. All other routers become DROTHERs. A DROTHER is a router that is neither the DR nor the BDR.
- **Note**: The DR is only used for the dissemination of LSAs. The router will still use the best next-hop router indicated in the routing table for the forwarding of all other packets.

1.4 Module Practice and Quiz

What Did I Learn In This Module?

- Open Shortest Path First (OSPF) is a link-state routing protocol that was developed as an alternative for the distance vector Routing Information Protocol (RIP).
- OSPF is a link-state routing protocol that uses the concept of areas for scalability.
- A link is an interface on a router. A link is also a network segment that connects two routers, or a stub network such as an Ethernet LAN that is connected to a single router.
- All link-state information includes the network prefix, prefix length, and cost.
- All routing protocols use routing protocol messages to exchange route information. The messages help build data structures, which are then processed using a routing algorithm.
- Routers running OSPF exchange messages to convey routing information using five types of packets: the Hello packet, the database description packet, the link-state request packet, the link-state update packet, and the link-state acknowledgment packet.
- OSPF messages are used to create and maintain three OSPF databases: the adjacency database creates the neighbor table, the link-state database (LSDB) creates the topology table, and the forwarding database creates the routing table.
- The router builds the topology table using results of calculations based on the Dijkstra SPF (shortest-path first) algorithm. The SPF algorithm is based on the cumulative cost to reach a destination. In OSPF, cost is used to determine the best path to the destination.

What Did I Learn In This Module?

- To maintain routing information, OSPF routers complete a generic link-state routing process to reach a state of convergence: Establish Neighbor Adjacencies, Exchange Link-State Advertisements, Build the Link State Database, Execute the SPF Algorithm, Choose the Best Route
- With single-area OSPF any number can be used for the area, best practice is to use area 0.
- Single-area OSPF is useful in smaller networks with few routers.
- With multiarea OSPF, one large routing domain can be divided into smaller areas, to support hierarchical routing. Routing still occurs between the areas (interarea routing), while many of the processor intensive routing operations, such as recalculating the database, are kept within an area.
- OSPFv3 is the OSPFv2 equivalent for exchanging IPv6 prefixes. Recall that in IPv6, the network address is referred to as the prefix and the subnet mask is called the prefix-length.
- OSPF uses the following link-state packets (LSPs) to establish and maintain neighbor adjacencies and exchange routing updates: 1 Hello, 2 DBD, 3 LSR, 4 LSU, and 5 LSAck.
- LSUs are also used to forward OSPF routing updates, such as link changes.
- Hello packets are used to: Discover OSPF neighbors and establish neighbor adjacencies, Advertise parameters on which two routers must agree to become neighbors, and Elect the Designated Router (DR) and Backup Designated Router (BDR) on multiaccess networks like Ethernet. Point-to-point links do not require DR or BDR.

What Did I Learn In This Module?

- Some important fields in the Hello packet are type, router ID, area ID, network mask, hello interval, router priority, dead interval, DR, BDR and list of neighbors.
- The states that OSPF progresses through to do reach convergence are down state, init state, two-way state, ExStart state, Exchange state, loading state, and full state.
- When OSPF is enabled on an interface, the router must determine if there is another OSPF neighbor on the link by sending a Hello packet that contains its router ID out all OSPF-enabled interfaces.
- The Hello packet is sent to the reserved All OSPF Routers IPv4 multicast address 224.0.0.5. Only OSPFv2 routers will process these packets.
- When a neighboring OSPF-enabled router receives a Hello packet with a router ID that is not within its neighbor list, the receiving router attempts to establish an adjacency with the initiating router.
- After the Two-Way state, routers transition to database synchronization states, which is a three step process:
- Multiaccess networks can create two challenges for OSPF regarding the flooding of LSAs: the creation of multiple adjacencies and extensive flooding of LSAs.

What Did I Learn In This Module?

- A dramatic increase in the number of routers also dramatically increases the number of LSAs exchanged between the routers.
- This flooding of LSAs significantly impact the operation of OSPF. If every router in a multiaccess network had to flood and acknowledge all received LSAs to all other routers on that same multiaccess network, the network traffic would become quite chaotic. This is why DR and BDR election is necessary.
- On multiaccess networks, OSPF elects a DR to be the collection and distribution point for LSAs sent and received. A BDR is also elected in case the DR fails.

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