Chapter 3:
Open Short Path First

CCNP ROUTE: Implementing IP Routing

Cisco | Networking Academy®
Mind Wide Open™

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Features

- OSPF was developed by the Internet Engineering Task Force (IETF) to overcome the limitations of distance vector routing protocols.
- One of the main reasons why OSPF is largely deployed in today's enterprise networks is the fact that it is an open standard;
- OSPF offers a large level of scalability and fast convergence.
- Despite its relatively simple configuration in small and medium-size networks, OSPF implementation and troubleshooting in large-scale networks can at times be challenging.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Features

Independent transport

- OSPF works on top of IP and uses protocol number 89.
- It does not rely on the functions of the transport layer protocols TCP or UDP.

Efficient use of updates

- When an OSPF router first discovers a new neighbor, it sends a *full update* with all known link-state information.
- All routers within an OSPF area must have identical and synchronized link-state information in their OSPF ink-state databases.
- When an OSPF network is in a converged state and a new link comes up or a link becomes unavailable, an OSPF router sends only a *partial update* to all its neighbors.
- This update will then be flooded to all OSPF routers within an area.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Features

Metric

- OSPF uses a metric that is based on the cumulative costs of all <u>outgoing</u> interfaces from source to destination. The interface cost is inversely proportional to the *interface bandwidth* and can be also set up explicitly.

Update destination address

- OSPF uses multicast and unicast, rather than broadcast, for sending messages.
- The IPv4 multicast addresses used for OSPF *are 224.0.0.5 to send information to all OSPF routers and 224.0.0.6 to send information to DR/BDR routers.*
- The IPv6 multicast addresses are FF02::5 for all OSPFv3 routers and FF02::6 for all DR/BDR routers.
- If the underlying network does not have broadcast capabilities, you must establish OSPF neighbor relationships using a unicast address.
- For IPv6, this address will be a link-local IPv6 address.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Features

VLSM support

- OSPF is a classless routing protocol. It supports variable-length subnet masking (VLSM) and discontinuous networks.
- It carries subnet mask information in the routing updates.

Manual route summarization

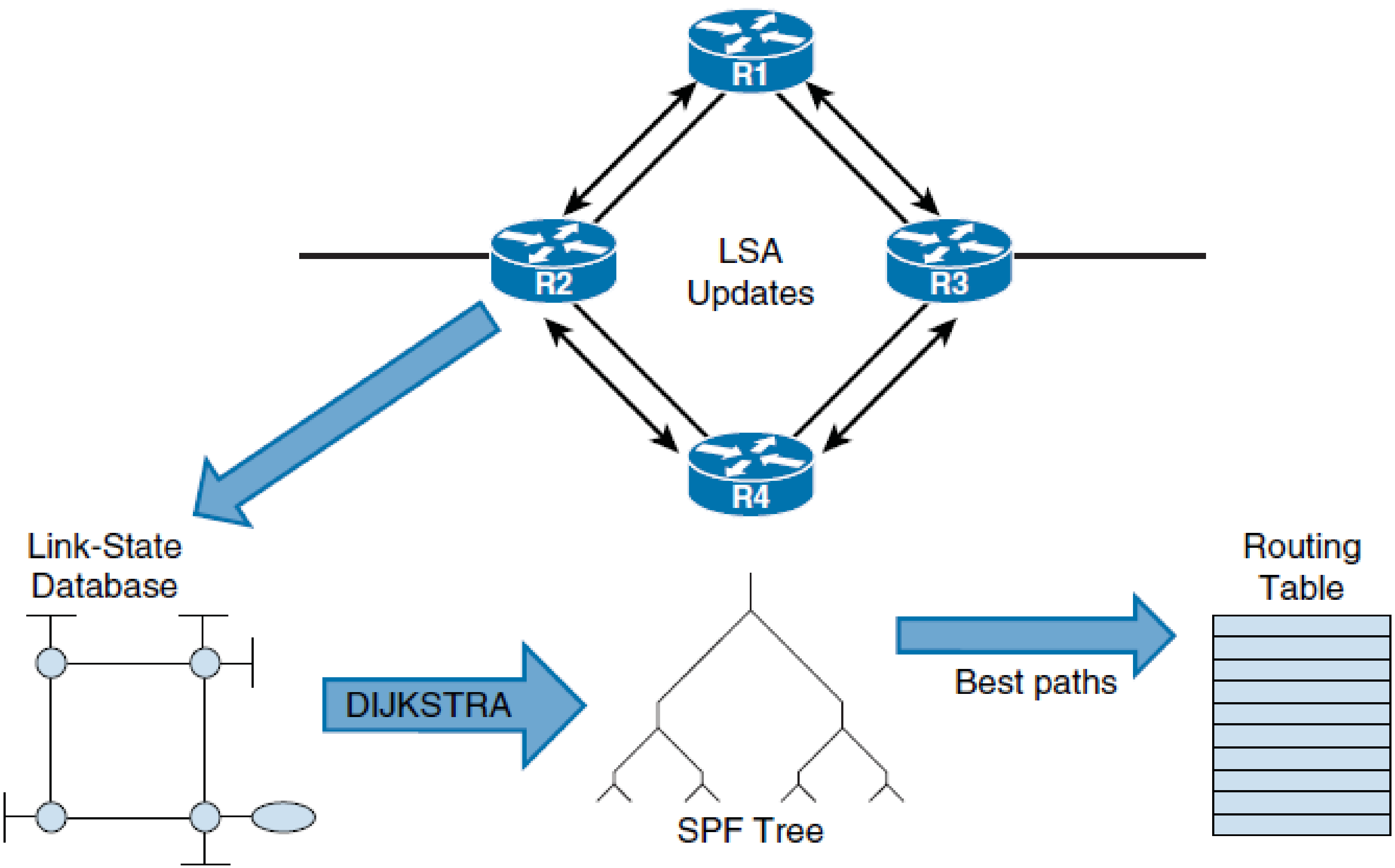
- You can manually summarize OSPF interarea routes at the Area Border Router (ABR), and you have the possibility to summarize OSPF external routes at the Autonomous System Boundary Router (ASBR).
- OSPF does not know the concept of auto-summarization.

Authentication

- OSPF supports clear-text, MD5, and SHA authentication.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Operation Overview



© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Operation Overview

1. **Establish neighbor adjacencies**

- OSPF-enabled routers must form adjacencies with their neighbor before they can share information with that neighbor.
- An OSPF enabled router sends Hello packets out all OSPF-enabled interfaces to determine whether neighbors are present on those links.
- If a neighbor is present, the OSPF enabled router attempts to establish a neighbor adjacency with that neighbor.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Operation Overview

2. **Exchange link-state advertisements**

- After adjacencies are established, routers then exchange link-state advertisements (LSAs).
- LSAs contain the state and cost of each directly connected link.
- Routers flood their LSAs to adjacent neighbors. Adjacent neighbors receiving the LSA immediately flood the LSA to other directly connected neighbors, until all routers in the area have all LSAs.

3. **Build the topology table**

- After the LSAs are received, OSPF-enabled routers build the topology table (LSDB) based on the received LSAs.
- This database eventually holds all the information about the topology of the network.
- *It is important that all routers in the area have the same information in their LSDBs.*

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

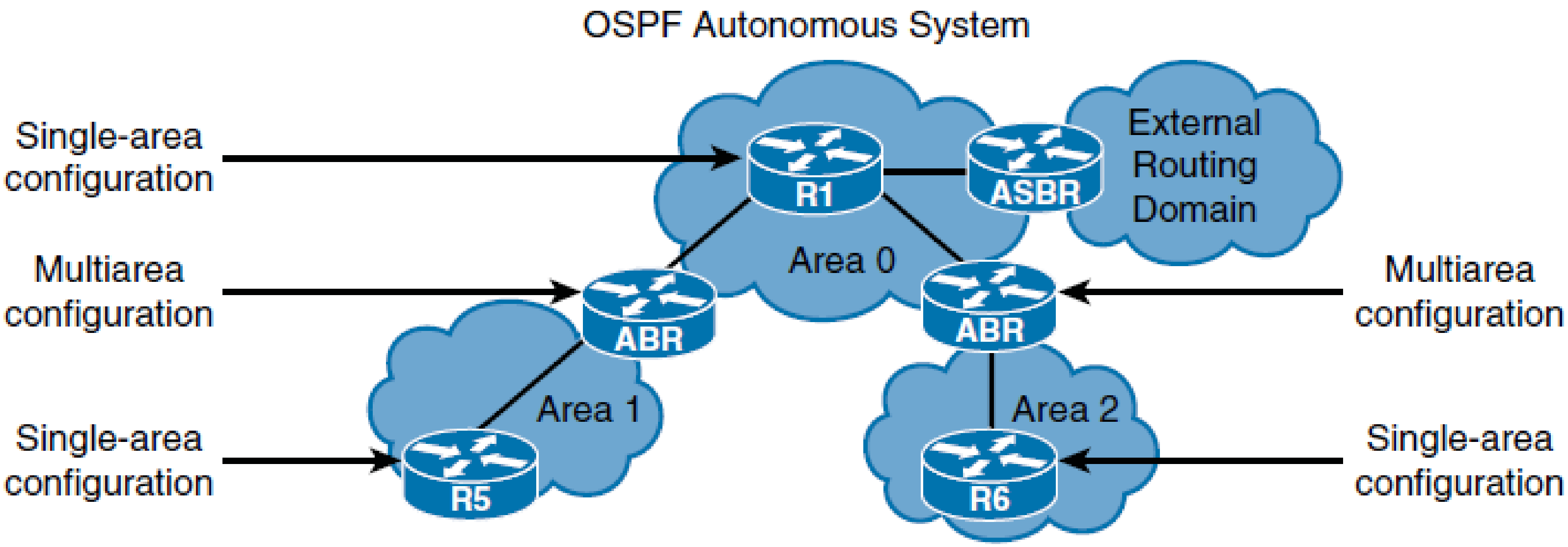
OSPF Operation Overview

4. **Execute the SPF algorithm**
- Routers then execute the SPF algorithm. The SPF algorithm creates the SPF tree.

5. **Build the routing table**
- *From the SPF tree, the best paths are inserted into the routing table.* Routing decisions are made based on the entries in the routing table.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Hierarchical Structure of OSPF



© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Hierarchical Structure of OSPF

OSPF uses a two-layer area hierarchy:

Backbone area, transit area or area 0

- Two principal requirements for the backbone area are that it must connect to all other nonbackbone areas and this area must be always contiguous; it is not allowed to have split up the backbone area.
- *Generally, end users are not found within a backbone area.*

Nonbackbone area

- The primary function of this area is to connect end users and resources. Nonbackbone areas are usually set up according to functional or geographic groupings.
- Traffic between different nonbackbone areas must always pass through the backbone area.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Hierarchical Structure of OSPF

- In the multi-area topology there are special commonly OSPF terms:

ABR

- A router that has interfaces connected to at least two different OSPF areas, including the backbone area. *ABRs contain LSDB information for each area*, make route calculation for each area and advertise routing information between areas.

ASBR

- ASBR is a router that has at least one of its interfaces connected to an OSPF area and *at least one of its interfaces connected to an external non-OSPF domain.*

Internal router

- A router that has all its interfaces connected to only one OSPF area.

Backbone router

- A router that has at least one interface connected to the backbone area.

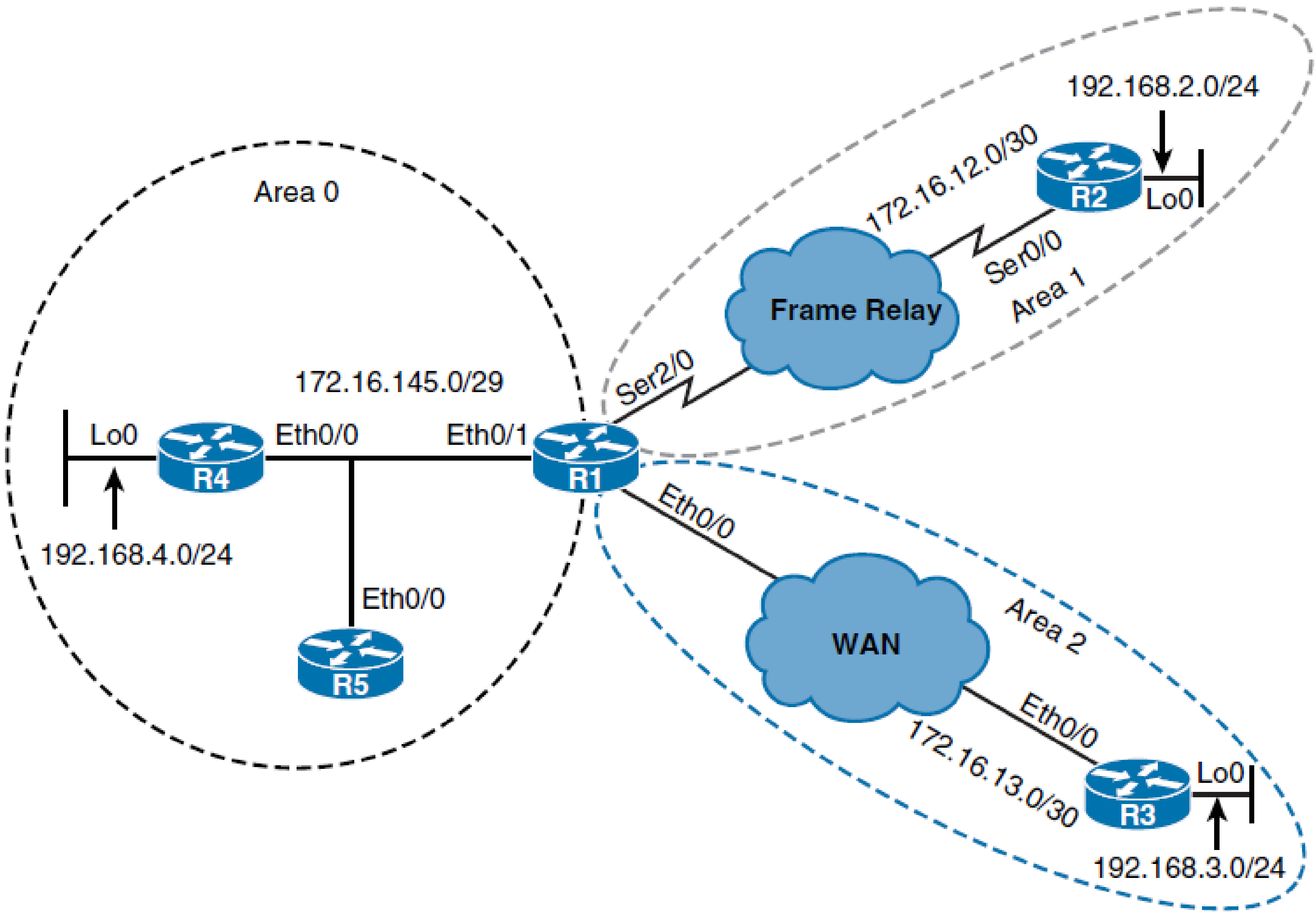
© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Message Types

- **Type 1: Hello packet:** Hello packets are used to discover, build, and maintain OSPF neighbor adjacencies.
- **Type 2: Database Description (DBD) packet:** When the OSPF neighbor adjacency is already established, a DBD packet is used to describe LSDB so that routers can compare whether databases are in sync.
- **Type 3: Link-State Request (LSR) packet** : The router will send an LSR packet to inform OSPF neighbors to send the most recent version of the missing LSAs.
- **Type 4: Link-State Update (LSU) packet** : LSU packets are used for the flooding of LSAs and sending LSA responses to LSR packets.
- **Type 5: Link-State Acknowledgment (LSAck) packet** : LSAcks are used to make flooding of LSAs reliable.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Basic OSPF Configuration



© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Basic OSPF Configuration

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# router ospf 2
R2(config-router)# network 172.16.12.0 0.0.0.3 area 1
R2(config-router)# network 192.168.2.0 0.0.0.255 area 1
```

```
R3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R3(config)# router ospf 3
R3(config-router)# network 172.16.13.0 0.0.0.3 area 2
R3(config-router)# network 192.168.3.0 0.0.0.255 area 2
```

- To enable the OSPF process on the router, use the **router ospf** *process-id* command.
- *Process ID numbers between neighbors do not need to match for the routers to establish an OSPF adjacency.*

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Basic OSPF Configuration

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# router ospf 2
R2(config-router)# network 172.16.12.0 0.0.0.3 area 1
R2(config-router)# network 192.168.2.0 0.0.0.255 area 1
```

```
R3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R3(config)# router ospf 3
R3(config-router)# network 172.16.13.0 0.0.0.3 area 2
R3(config-router)# network 192.168.3.0 0.0.0.255 area 2
```

- *To establish OSPF full adjacency, two neighbor routers must be in the same area.*
- Any individual interface can only be attached to a single area.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Configuration of OSPF Router IDs

- To choose the OSPF router ID at the time of OSPF process initialization, the router uses the following criteria:
  1. *Use the router ID specified in the **router-id** ip-address command.*
  2. *Use the highest IPv4 address of all active loopback interfaces on the router.*
  3. *Use the highest IPv4 address among all active nonloopback interfaces.*
- At least one primary IPv4 address on an interface in the up/up state must be configured for a router to be able to choose router ID; otherwise, an error message is logged, and the OSPF process does not start.

```
R2(config-router)# router-id 2.2.2.2
% OSPF: Reload or use "clear ip ospf process" command, for this to take effect
```

```
R3(config-router)# router-id 3.3.3.3
% OSPF: Reload or use "clear ip ospf process" command, for this to take effect
```


© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Clearing the OSPF Processes

- OSPF routing process can be cleared for the manually configured router ID to take effect.

```
R2# clear ip ospf process
Reset ALL OSPF processes? [no]: yes
R2#
*Nov 24 08:37:24.679: %OSPF-5-ADJCHG: Process 2, Nbr 1.1.1.1 on Serial0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
R2#
*Nov 24 08:39:24.734: %OSPF-5-ADJCHG: Process 2, Nbr 1.1.1.1 on Serial0/0 from
LOADING to FULL, Loading Done
```

```
R3# clear ip ospf 3 process
Reset OSPF process 3? [no]: yes
R3#
*Nov 24 09:06:00.275: %OSPF-5-ADJCHG: Process 3, Nbr 1.1.1.1 on Ethernet0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
R3#
*Nov 24 09:06:40.284: %OSPF-5-ADJCHG: Process 3, Nbr 1.1.1.1 on Ethernet0/0 from
LOADING to FULL, Loading Done
```


© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Verifying OSPF Neighborships

```
R2# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DR         00:01:57    172.16.12.1     Serial0/0
```

```
R3# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DR         00:00:39    172.16.13.1     Ethernet0/0
```

- **Neighbor ID :** Represents neighbor router ID.
- **Priority :** Priority on the neighbor interface used for the DR/BDR election.
- **State :** OSPF neighbor establishment process
- **Dead Time :** Represents value of the dead timer
- **Address :** Primary IPv4 address of the neighbor router.
- **Interface :** Local interface over which an OSPF neighbor relationship is established.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Verifying the OSPF-Enabled Interfaces

```
R2# show ip ospf interface
Loopback0 is up, line protocol is up
  Internet Address 192.168.2.1/24, Area 1, Attached via Network Statement
  Process ID 2, Router ID 2.2.2.2, Network Type LOOPBACK, Cost: 1
<Output omitted>
Serial0/0 is up, line protocol is up
  Internet Address 172.16.12.2/30, Area 1, Attached via Network Statement
  Process ID 2, Router ID 2.2.2.2, Network Type NON_BROADCAST, Cost: 64
<Output omitted>
```

```
R3# show ip ospf interface
Loopback0 is up, line protocol is up
  Internet Address 192.168.3.1/24, Area 2, Attached via Network Statement
  Process ID 3, Router ID 3.3.3.3, Network Type LOOPBACK, Cost: 1
<Output omitted>
Ethernet0/0 is up, line protocol is up
  Internet Address 172.16.13.2/30, Area 2, Attached via Network Statement
  Process ID 3, Router ID 3.3.3.3, Network Type BROADCAST, Cost: 10
<Output omitted>
```


© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Verifying the OSPF Routes

```
R5# show ip route ospf

Gateway of last resort is not set

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.12.0/30 [110/74] via 172.16.145.1, 00:39:00, Ethernet0/0
O IA     172.16.13.0/30 [110/20] via 172.16.145.1, 00:19:29, Ethernet0/0
      192.168.2.0/32 is subnetted, 1 subnets
O IA     192.168.2.1 [110/75] via 172.16.145.1, 00:07:27, Ethernet0/0
      192.168.3.0/32 is subnetted, 1 subnets
O IA     192.168.3.1 [110/21] via 172.16.145.1, 00:08:30, Ethernet0/0
O     192.168.4.0/24 [110/11] via 172.16.145.4, 00:39:10, Ethernet0/0
```


© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Routes

```
R5# show ip ospf route

            OSPF Router with ID (5.5.5.5) (Process ID 1)

                Base Topology (MTID 0)

    Area BACKBONE(0)

    Intra-area Route List
*   172.16.145.0/29, Intra, cost 10, area 0, Connected
      via 172.16.145.5, Ethernet0/0
*>  192.168.4.0/24, Intra, cost 11, area 0
      via 172.16.145.4, Ethernet0/0

    Intra-area Router Path List
i 1.1.1.1 [10] via 172.16.145.1, Ethernet0/0, ABR, Area 0, SPF 2

    Inter-area Route List
*>  192.168.2.1/32, Inter, cost 75, area 0
      via 172.16.145.1, Ethernet0/0
*>  192.168.3.1/32, Inter, cost 21, area 0
      via 172.16.145.1, Ethernet0/0
*>  172.16.12.0/30, Inter, cost 74, area 0
      via 172.16.145.1, Ethernet0/0
*>  172.16.13.0/30, Inter, cost 20, area 0
      via 172.16.145.1, Ethernet0/0
```

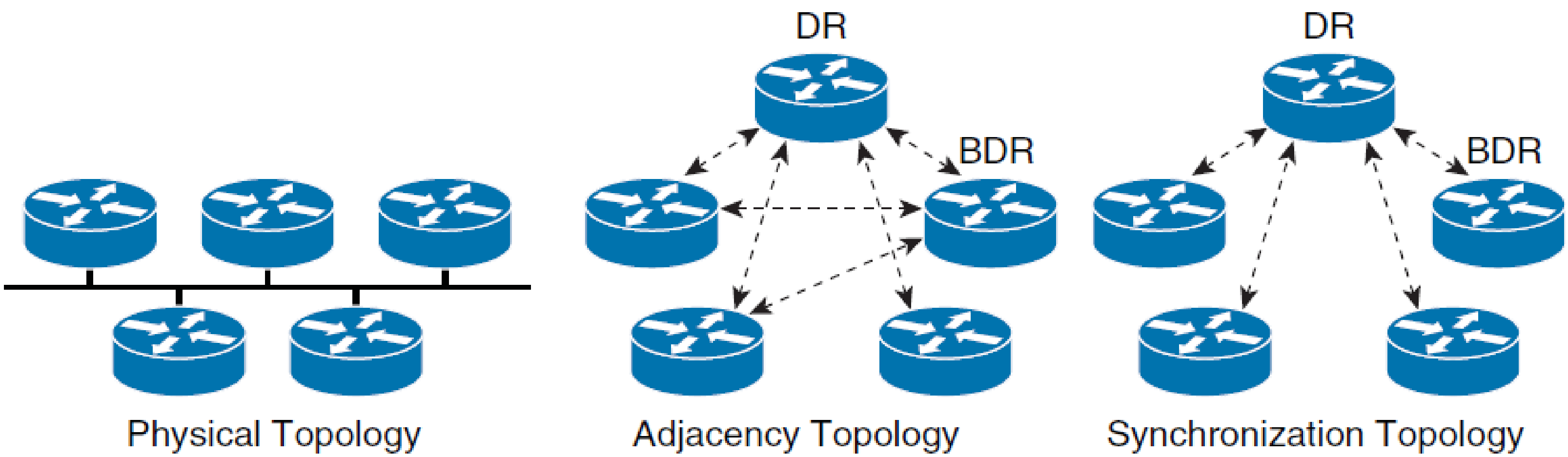

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Adjacency Establishment Steps

1. **Down state** - the initial state of a neighbor conversation that indicates that no Hello's have been heard from the neighbor.
2. **Init state -** a router receives a Hello from the neighbor but has not yet seen its own router ID in the neighbor Hello packet
3. **2-Way state** - When the router sees its own router ID in the Hello packet received from the neighbor
4. **ExStart state** - In the DBD exchange process, *the router with the higher router ID will become master, and it will be the only router that can increment sequence numbers*. With master/slave selection complete, database exchange can start
5. **Exchange state** - To describe the content of the database, one or multiple DBD packets may be exchanged. A router compares the content of its own Database Summary list with the list received from the neighbor, and if there are differences, it adds missing LSAs to the Link State Request list.
6. **Loading state** - LSR packet is sent to the neighbor requesting full content of the missing LSAs from the LS Request list
7. **Full state** - Finally, when neighbors have a complete version of the LSDB, which means that databases on the routers are synchronized and that neighbors are fully adjacent.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Optimizing OSPF Adjacency Behavior



- As the number of routers on the segment grows, the number of OSPF adjacencies increases exponentially. Every router must synchronize its OSPF database with every other router, and in the case of a large number of routers, this leads to inefficiency.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Adjacencies on Multiaccess Networks

- The routers on the multiaccess segment elect a designated router (**DR**) and backup designated router (**BDR**), which centralizes communications for all routers connected to the segment.
- The DR and BDR improve network functioning in the following ways:
  - **Reducing routing update traffic:** The DR and BDR act as a central point of contact for link-state information exchange on a *multiaccess network*; therefore, each router must establish a full adjacency with the DR and the BDR only.
  - **Managing link-state synchronization:** The DR and BDR ensure that the other routers on the network have the same link-state information about the common segment.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Adjacencies on Multiaccess Networks

- Only LSAs are sent to the DR/BDR. The normal routing of packets on the segment will go to the best next-hop router.
- When the DR is operating, the BDR does not perform any DR functions. Instead, the BDR receives all the information, but the DR performs the LSA forwarding and LSDB synchronization tasks.
- The BDR performs the DR tasks only if the DR fails.
- When the DR fails, the BDR automatically becomes the new DR, and a new BDR election occurs.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Neighbor Status

```
R1# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
4.4.4.4           1   FULL/BDR        00:00:37    172.16.145.4    Ethernet0/1
5.5.5.5           1   FULL/DR         00:00:39    172.16.145.5    Ethernet0/1
2.2.2.2           1   FULL/DR         00:01:53    172.16.12.2     Serial2/0
3.3.3.3           1   FULL/DR         00:00:35    172.16.13.2     Ethernet0/0
```

```
R4# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DROTHER    00:00:39    172.16.145.1    Ethernet0/0
5.5.5.5           1   FULL/DR         00:00:39    172.16.145.5    Ethernet0/0
```

```
R5# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DROTHER    00:00:39    172.16.145.1    Ethernet0/0
4.4.4.4           1   FULL/BDR        00:00:35    172.16.145.4    Ethernet0/0
```


© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

DR/BDR Election Process

- The DR/BDR election process takes place on broadcast and NBMA networks.
- Routers send OSPF Hello packets to discover which OSPF neighbors are active on the common Ethernet segment.
- Once OSPF neighbors are in the 2-Way state, the DR/BDR election process begins.
- The OSPF Hello packet contains three specific fields used for the DR/BDR election:
  - Designated Router, Backup Designated Router, and Router Priority.
- From all routers listed in this fields, the router with the highest priority becomes the DR, and the one with the next highest priority becomes the BDR.
- If the priority values are equal, the router with the highest OSPF router ID becomes the DR, and the one with the next highest OSPF router ID becomes the BDR.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

DR/BDR Election Process

- On the multiaccess broadcast networks, routers use multicast destination **IPv4 address 224.0.0.6** to communicate with the DR , and the DR uses multicast destination **IPv4 address 224.0.0.5** to communicate with all other non-DR routers
- On NBMA networks, the DR and adjacent routers communicate using unicast addresses.
- The DR/BDR election process not only occurs when the network first becomes active but also when the DR becomes unavailable.
- In this case, the BDR will immediately become the DR, and the election of the new BDR starts.
- On the multi-access segment, it is normal behavior that the router in DROTHER status is fully adjacent with DR/BDR and in 2-WAY state with all other DROTHER routers present on the segment.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Using OSPF Priority in the DR/BDR Election

Every broadcast and NBMA OSPF-enabled interface is assigned a priority value between 0 and 255. By default, the OSPF interface priority is 1 and can be manually changed by using the **ip ospf priority** interface command.

- *The router with the highest priority value is elected as the DR.*
- The router with the second-highest priority value is the BDR.
- In case of a tie where two routers have the same priority value, router ID is used as the tiebreaker. The router with the highest router ID becomes the DR. The router with the second-highest router ID becomes the BDR.
- A router with a priority that is set to 0 cannot become the DR or BDR. A router that is not the DR or BDR is called a DROTHER.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Configuring the OSPF Priority on an Interface

```
R1(config)# interface ethernet 0/1
R1(config-if)# ip ospf priority 100
```

```
R4# clear ip ospf process
Reset ALL OSPF processes? [no]: yes
*Dec 10 13:08:48.610: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
*Dec 10 13:08:48.610: %OSPF-5-ADJCHG: Process 1, Nbr 5.5.5.5 on Ethernet0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
*Dec 10 13:09:01.294: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from
LOADING to FULL, Loading Done
*Dec 10 13:09:04.159: %OSPF-5-ADJCHG: Process 1, Nbr 5.5.5.5 on Ethernet0/0 from
LOADING to FULL, Loading Done
```


© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Verifying OSPF Neighbor Status

```
R1# show ip ospf interface ethernet 0/1
Ethernet0/1 is up, line protocol is up
  Internet Address 172.16.145.1/29, Area 0, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 10
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           10        no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 100
  Designated Router (ID) 1.1.1.1, Interface address 172.16.145.1
  Backup Designated router (ID) 5.5.5.5, Interface address 172.16.145.5
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:06
  Supports Link-local Signaling (LLS)
  Cisco NSF helper support enabled
  IETF NSF helper support enabled
  Index 1/3, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 5
  Last flood scan time is 0 msec, maximum is 1 msec
  Neighbor Count is 2, Adjacent neighbor count is 2
    Adjacent with neighbor 4.4.4.4
    Adjacent with neighbor 5.5.5.5  (Backup Designated Router)
  Suppress hello for 0 neighbor(s)
```

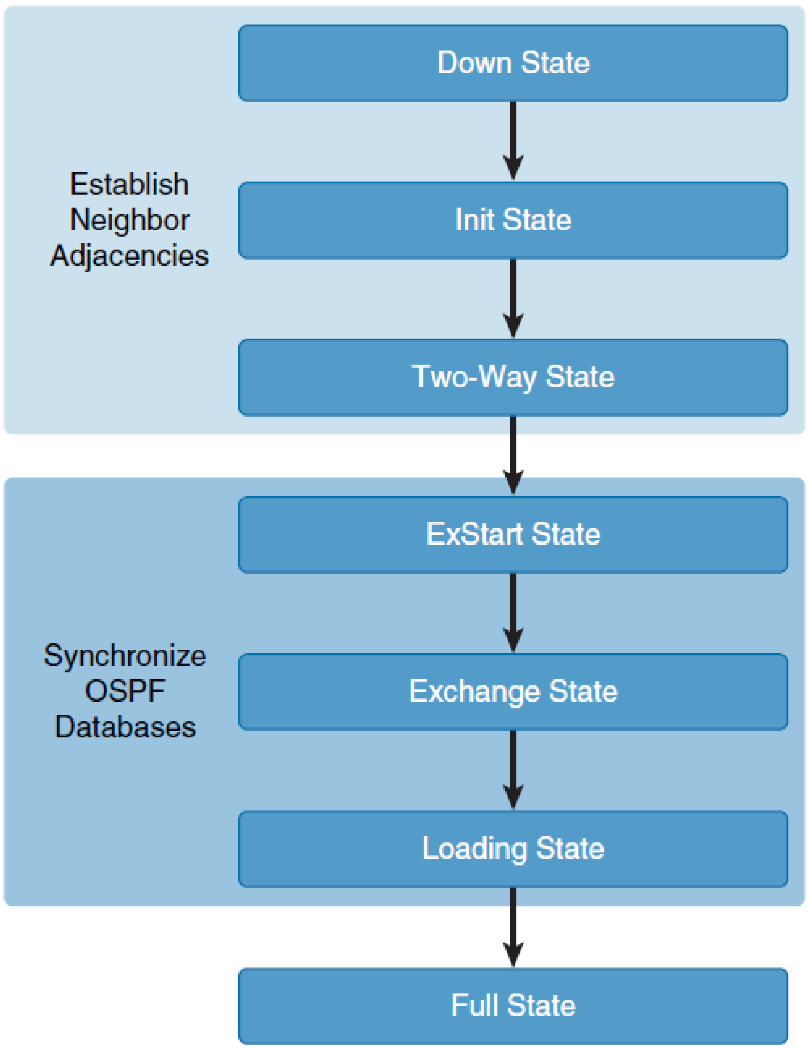

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Relationship over Point-to-Point Links

- The routers dynamically detects its neighboring routers by multicasting its Hello packets to all OSPF routers, using the 224.0.0.5 address.
- No DR or BDR election is performed
- The default OSPF hello and dead timers on point-to-point links are 10 seconds and 40 seconds, respectively.

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

OSPF Neighbor States



© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public

Default OSPF Costs

Link Type	Default Cost
T1 (1.544-Mbps serial link)	64
Ethernet	10
Fast Ethernet	1
Gigabit Ethernet	1
10-Gigabit Ethernet	1

© 2007 – 2016, Cisco Systems, Inc. All rights reserved. Cisco Public