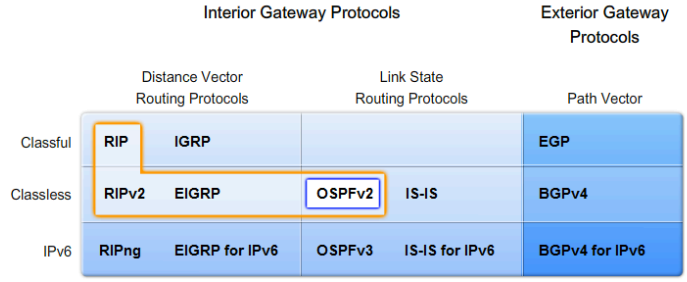
The Network Layer

Routing Algorithms

Open Shortest Path First

- OSPF
  - Replacement for the distance vector routing protocol RIP
  - OSPF is a classless routing protocol that uses the concept of areas for scalability
  - RFC 2328 defines the OSPF metric as an arbitrary value called cost.
    - Cisco IOS uses bandwidth as the OSPF cost metric.
  - Fast convergence

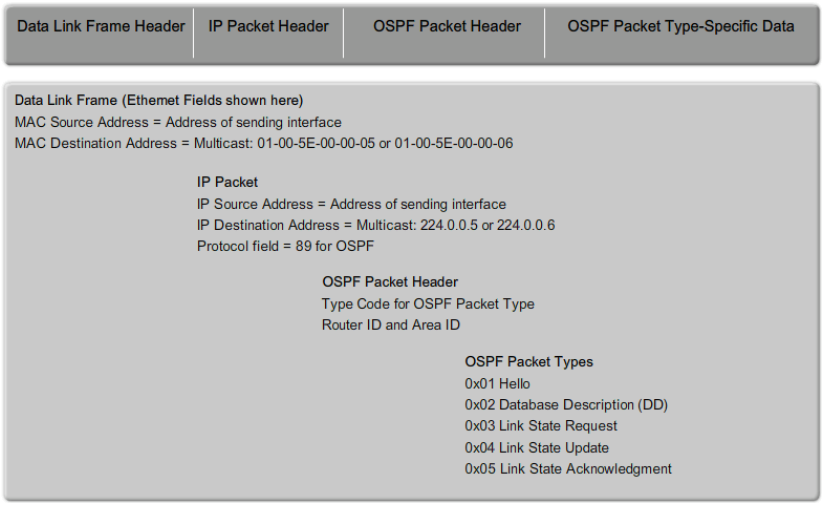
OSPF



In this chapter, you will learn to:

- Describe the background and basic features of OSPF.
- Identify and apply the basic OSPF configuration commands.
- Describe, modify and calculate the metric used by OSPF.
- Describe the Designated Router/Backup Designated Router (DR/BDR) election proess in multiaccess networks.
- Employ the **`default-information originate`** command to configure and propagate a default route in OSPF.

OSPF Message Encapsulation



"OSPF Version 2," http://www.ietf.org/rfc/rfc2328.txt

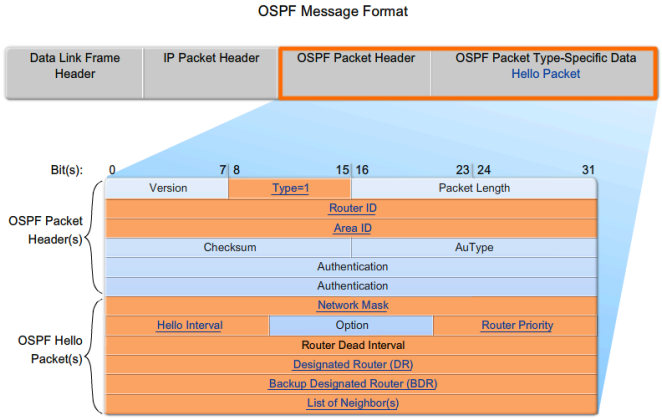
OSPF Message Types

1. **Hello**
   - Hello packets are used to establish and maintain adjacency with other OSPF routers.
2. **DBD**
   - The Database Description (DBD) packet contains an abbreviated list of the sending router's link-state database and is used by receiving routers to check against the local link-state database.
3. **LSR**
   - Receiving routers can then request more information about any entry in the DBD by sending a Link-State Request (LSR).
4. **LSU**
   - Link-State Update (LSU) packets are used to reply to LSRs as well as to announce new information. LSUs contain seven different types of Link-State Advertisements (LSAs).
5. **LSAck**
   - When an LSU is received, the router sends a Link-State Acknowledgement (LSAck) to confirm receipt of the LSU.

OSPF Message 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 Acknowledgement (LSAck)	Acknowledges the other packet types

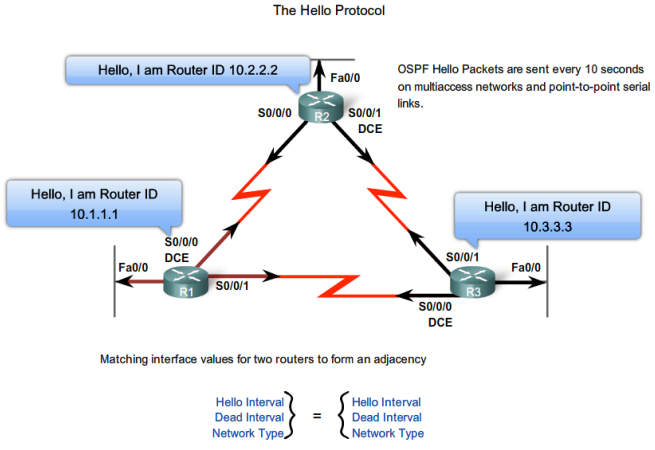
Hello Protocol



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

- 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 and Frame Relay.

Neighbour Establishment



- OSPF Hello packets are sent as multicast to an address reserved for ALLSPFRouters at 224.0.0.5
- By default, Dead interval is four times the hello interval

OSPF Link State Updates

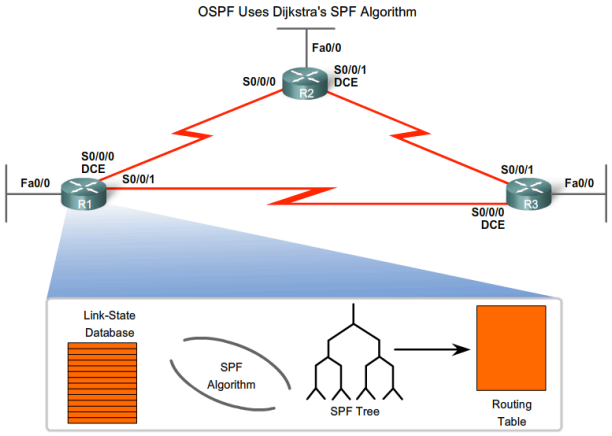
LSUs Contain Link-State Advertisements (LSAs)

Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them
2	DBD	Checks for database synchronization between router
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

The roles of each LSA type will be presented in the next class when we talk about multi area OSPF

LSA Type	Description
1	Router LSAs
2	Network LSAs
3 or 4	Summary LSAs
5	Autonomous System Extrenal LSAs
6	Multicast OSPF LSAs
7	Defined for Not-So-Stubby Areas
8	External Attributes LSA for Border Gatway Protocol (BGP)
9, 10, 11	Opaque LSAs

OSPF Algorithm

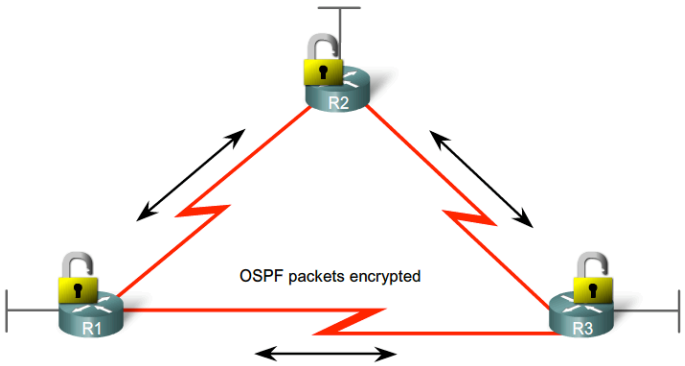


- OSPF uses Dijkstra's shortest path first (SPF) algorithm to create an SPF tree.
- The SPF tree is then used to populate the IP routing table with the best paths to each network.

OSPF Administrative Distance

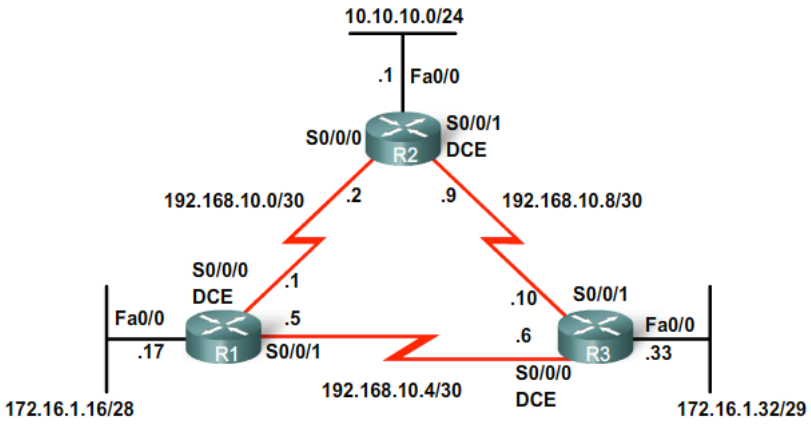
Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
External EIGRP	170
Internal BGP	200

OSPF Authentication



- RIPv2, EIGRP, OSPF, IS-IS, and BGP can all be configured to encrypt and authenticate their routing information.
- Note: Authentication does not encrypt the router's routing table.

OSPF Example



OSPF Example

```
R1(config)#router ospf 1
R1(config-router)#network 172.16.1.16 0.0.0.15 area 0
R1(config-router)#network 192.168.10.0 0.0.0.3 area 0
R1(config-router)#network 192.168.10.4 0.0.0.3 area 0
```

```
R2(config)#router ospf 1
R2(config-router)#network 10.10.10.0 0.0.0.255 area 0
R2(config-router)#network 192.168.10.0 0.0.0.3 area 0
R2(config-router)#network 192.168.10.8 0.0.0.3 area 0
```

```
R3(config)#router ospf 1
R3(config-router)#network 172.16.1.32 0.0.0.7 area 0
R3(config-router)#network 192.168.10.4 0.0.0.3 area 0
R3(config-router)#network 192.168.10.8 0.0.0.3 area 0
```

- The process-id is a number between 1 and 65535 and is chosen by the network administrator
- The process-id is locally significant, it does not have to match other OSPF routers in order to establish adjacencies with those neighbors
- OSPF uses wildcard masks – Simply subtract the netmask from 255.255.255.255.
- 172.16.1.16/28 has a 255.255.255.240 mask so the wildcard mask is 0.0.0.15 (255.255.255.255 – 255.255.255.240)

OSPF Router ID

The OSPF router ID is used to uniquely identify each router in the OSPF routing domain. A router ID is simply an IP address. Cisco routers derive the router ID based on three criteria and with the following precedence:

1. Use the IP address configured with the OSPF router-id command.

2. If the router-id is not configured, the router chooses highest IP address of any of its loopback interfaces.

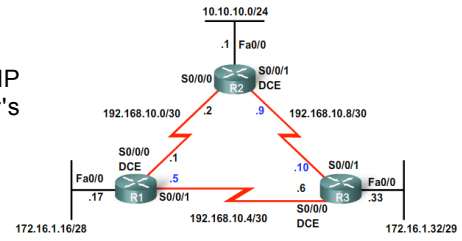
3. If no loopback interfaces are configured, the router chooses highest **active** IP address of any of its physical interfaces.

Router ID is determined in the following order:

1. Use the IP address configured with the OSPF router-id command.
2. If the router-id is not configured, then the router chooses highest IP address of any of its loopback interfaces.
3. If no loopback interfaces are configured, then the router chooses highest active IP address of any of its physical interfaces.

OSPF Router ID

No router IDs command…
No loopback interfaces…
Router ID: the highest active IP address on any of the router's physical interfaces.




```
R1#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 192.168.10.5
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
<output omitted>
```

```
R2#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 192.168.10.9
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
<output omitted>
```

```
R3#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 192.168.10.10
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
<output omitted>
```

OSPF Router ID

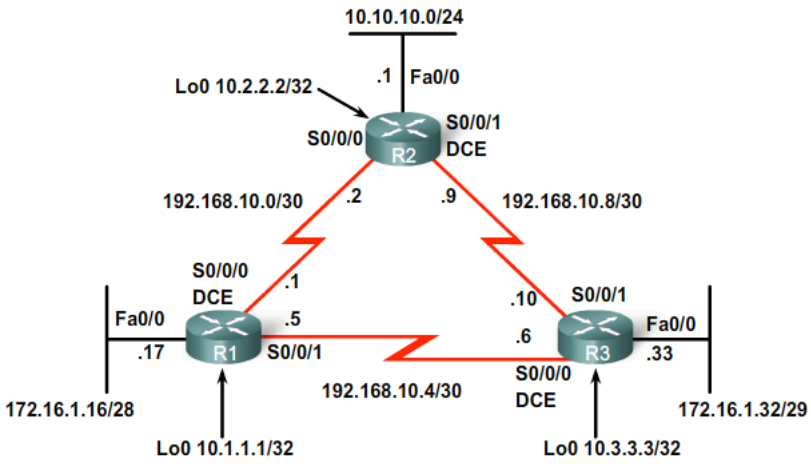
```
R1(config)#interface loopback 0
R1(config-if)#ip add 10.1.1.1 255.255.255.255
R2(config)#interface loopback 0
R2(config-if)#ip add 10.2.2.2 255.255.255.255
R3(config)#interface loopback 0
R3(config-if)#ip add 10.3.3.3 255.255.255.255
```

```
R1#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
<output omitted>
```

```
R2#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.2.2.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
<output omitted>
```

```
R3#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.3.3.3
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
<output omitted>
```

OSPF Example



Verifying OSPF

```
R1#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
10.3.3.3          1   FULL/  -        00:00:30    192.168.10.6    Serial0/0/1
10.2.2.2          1   FULL/  -        00:00:33    192.168.10.2    Serial0/0/0
```

```
R2#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
10.3.3.3          1   FULL/  -        00:00:36    192.168.10.10   Serial0/0/1
10.1.1.1          1   FULL/  -        00:00:37    192.168.10.1    Serial0/0/0
```

```
R3#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
10.2.2.2          1   FULL/  -        00:00:34    192.168.10.9    Serial0/0/1
10.1.1.1          1   FULL/  -        00:00:38    192.168.10.5    Serial0/0/0
```

```
R1#show ip route

Codes: <some code output omitted>
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area

Gateway of last resort is not set

     192.168.10.0/30 is subnetted, 3 subnets
C       192.168.10.0 is directly connected, Serial0/0/0
C       192.168.10.4 is directly connected, Serial0/0/1
O       192.168.10.8 [110/128] via 192.168.10.2, 14:27:57, Serial0/0/0
     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
O       172.16.1.32/29 [110/65] via 192.168.10.6, 14:27:57, Serial0/0/1
C       172.16.1.16/28 is directly connected, FastEthernet0/0
     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
O       10.10.10.0/24 [110/65] via 192.168.10.2, 14:27:57, Serial0/0/0
C       10.1.1.1/32 is directly connected, Loopback0
```

Verifying OSPF

```
R1#show ip protocols
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    172.16.1.16 0.0.0.15 area 0
    192.168.10.0 0.0.0.3 area 0
    192.168.10.4 0.0.0.3 area 0
 Reference bandwidth unit is 100 mbps
  Routing Information Sources:
    Gateway         Distance      Last Update
    10.2.2.2              110      11:29:29
    10.3.3.3              110      11:29:29
  Distance: (default is 110)
```

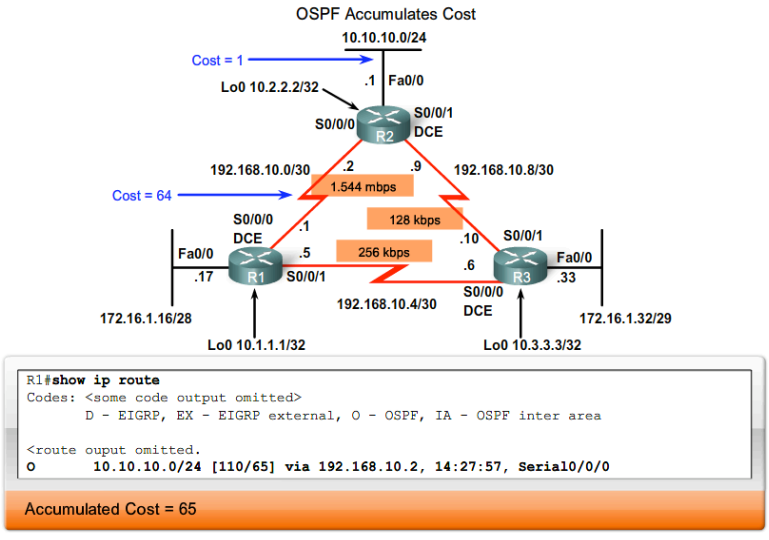
```
R1#show ip ospf interface serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Internet Address 192.168.10.1/30, Area 0
  Process ID 1, Router ID 10.1.1.1, Network Type POINT_TO_POINT, Cost: 64
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:07
  Supports Link-local Signaling (LLS)
  Index 2/2, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 1
  Last flood scan time is 0 msec, maximum is 4 msec
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.2.2.2
  Suppress hello for 0 neighbor(s)
```

OSPF Metric

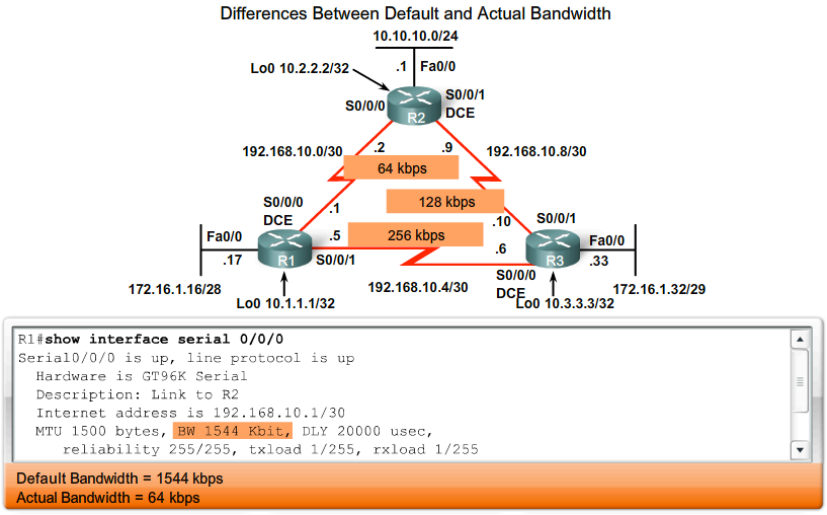
Interface Type	10^8/ bps = Cost
Fast Ethernet and faster	10^8/ 100,000,000 bps = 1
Ethernet	10^8/ 10,000,000 bps = 10
E1	10^8/ 2,048,000 bps = 48
T1	10^8/ 1,544,000 bps = 64
128 kbps	10^8/ 128,000 bps = 781
64 kbps	10^8/ 64,000 bps = 1562
56 kbps	10^8/ 56,000 bps = 1785

- The OSPF metric is called cost.
- From RFC 2328: "*A cost is associated with the output side of each router interface. This cost is configurable by the system administrator. The lower the cost, the more likely the interface is to be used to forward data traffic.*"
- The reference bandwidth defaults to 100Mbps (but can be changed)

OSPF Metric



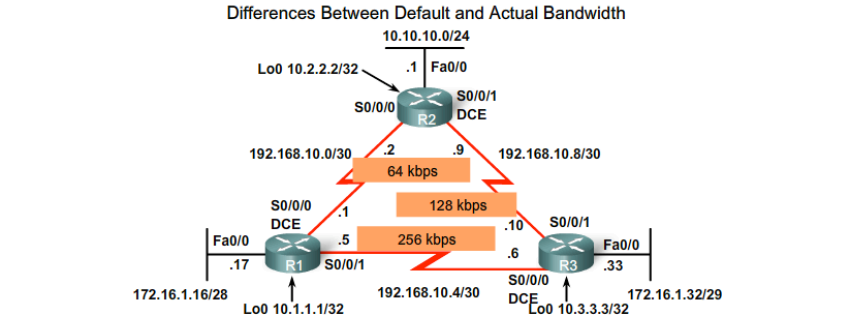
OSPF Metric




```
R1#show interface serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is GT96K Serial
  Description: Link to R2
  Internet address is 192.168.10.1/30
  MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
```

Default Bandwidth = 1544 kbps
Actual Bandwidth = 64 kbps

OSPF Metric




```
R1#show ip route
Codes: <some code output omitted>
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area

O       192.168.10.8 [110/128] via 192.168.10.6, 14:27:57, Serial0/0/1
                     [110/128] via 192.168.10.2, 14:27:57, Serial0/0/0
```

R1 assumes that cost to 192.168.10.8 is equal through R2 or R3.

OSPF Metric

```
R1(config)#inter serial 0/0/0
R1(config-if)#bandwidth 64
R1(config-if)#inter serial 0/0/1
R1(config-if)#bandwidth 256
R1(config-if)#end
R1#show ip ospf interface serial 0/0/0
Serial0/0 is up, line protocol is up
  Internet Address 192.168.10.1/30, Area 0
  Process ID 1, Router ID 10.1.1.1, Network Type POINT_TO_POINT, Cost: 1562
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  <output omitted>
```

$10^8/64{,}000$ bps = 1562

```
R2(config)#inter serial 0/0/0
R2(config-if)#bandwidth 64
R2(config-if)#inter serial 0/0/1
R2(config-if)#bandwidth 128
```

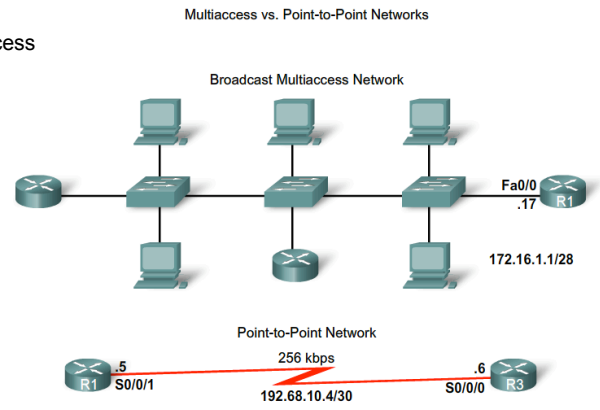
```
R3(config)#inter serial 0/0/0
R3(config-if)#bandwidth 256
R3(config-if)#inter serial 0/0/1
R3(config-if)#bandwidth 128
```

```
R1(config)#inter serial 0/0/0
R1(config-if)#ip ospf cost 1562
R1(config-if)#end
R1#show ip ospf interface serial 0/0/0
Serial0/0 is up, line protocol is up
  Internet Address 192.168.10.1/30, Area 0
  Process ID 1, Router ID 10.1.1.1, Network Type POINT_TO_POINT, Cost: 1562
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  <output omitted>
```

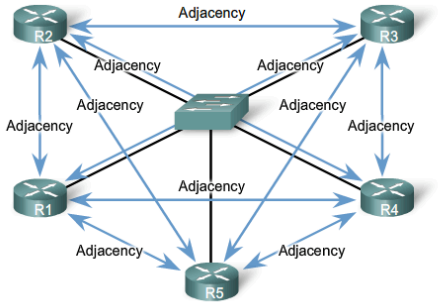
No Calculation Needed

OSPF and Multiaccess Networks

- OSPF defines five network types:
  - Point-to-point
  - Broadcast Multiaccess
  - Nonbroadcast Multiaccess (NBMA)
  - Point-to-multipoint
  - Virtual links



OSPF and Multiaccess Networks

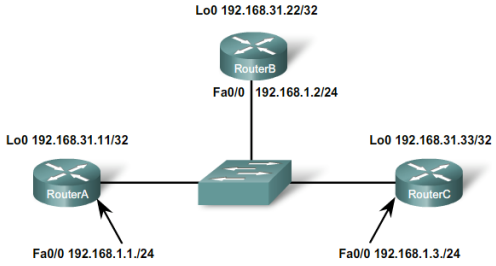


Routers	Adjacencies
n	n(n-1)/2
5	10
10	45
20	190
100	4,950

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

Multiaccess networks can create two challenges for OSPF regarding the flooding of LSAs:
1. Creation of multiple adjacencies, one adjacency for every pair of routers.
2. Extensive flooding of LSAs (Link-State Advertisements).

DR and BDR Election Process



Designated Router /Backup Designated Router Election

How do the DR and BDR get elected? The following criteria are applied:

1.DR: Router with the highest OSPF interface priority.
2.BDR: Router with the second highest OSPF interface priority.
3.If OSPF interface priorities are equal, the highest router ID is used to break the tie.

DR and BDR Election Process

```
RouterA#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.31.33     1   FULL/DR         00:00:39    192.168.1.3     FastEthernet0/0
192.168.31.22     1   FULL/BDR        00:00:36    192.168.1.2     FastEthernet0/0
```

```
RouterB#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.31.33     1   FULL/DR         00:00:34    192.168.1.3     FastEthernet0/0
192.168.31.11     1   FULL/DROTHER    00:00:38    192.168.1.1     FastEthernet0/0
```

```
RouterC#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.31.22     1   FULL/BDR        00:00:35    192.168.1.2     FastEthernet0
192.168.31.11     1   FULL/DROTHER    00:00:32    192.168.1.1     FastEthernet0
```

Priority is equal at the default value of 1.

- DROthers only form FULL adjacencies with the DR and BDR, but will still form a neighbor adjacency with any DROthers that join the network
- When two DROther routers form a neighbor adjacency, the neighbor state is displayed as 2WAY

Fine Tuning OSPF

Changing Router Priority

```
RouterA(config)#interface fastethernet 0/0
RouterA(config-if)#ip ospf priority 200
```

Redistributing a default route

```
R1(config)#interface loopback 1
R1(config-if)#ip add 172.30.1.1 255.255.255.252
R1(config-if)#exit
R1(config)#ip route 0.0.0.0 0.0.0.0 loopback 1
R1(config)#router ospf 1
R1(config-router)#default-information originate
```

Fine Tuning OSPF

```
R1#show ip route
Codes: <some code output omitted>
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       E1 - OSPF external type 1, E2 - OSPF external type 2

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

     192.168.10.0/30 is subnetted, 3 subnets
C       192.168.10.0 is directly connected, Serial0/0/0
C       192.168.10.4 is directly connected, Serial0/0/1
O       192.168.10.8 [110/1171] via 192.168.10.6, 00:00:58, Serial0/0/1
     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
O       172.16.1.32/29 [110/391] via 192.168.10.6, 00:00:58, Serial0/0/1
C       172.16.1.16/28 is directly connected, FastEthernet0/0
     172.30.0.0/30 is subnetted, 1 subnets
C       172.30.1.0 is directly connected, Loopback1
     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
O       10.10.10.0/24 [110/1172] via 192.168.10.6, 00:00:58, Serial0/0/1
C       10.1.1.1/32 is directly connected, Loopback0
S*   0.0.0.0/0 is directly connected, Loopback1
```

```
R2#show ip route
Codes: <some code output omitted>
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       E1 - OSPF external type 1, E2 - OSPF external type 2

Gateway of last resort is 192.168.10.10 to network 0.0.0.0

     192.168.10.0/30 is subnetted, 3 subnets
C       192.168.10.0 is directly connected, Serial0/0/0
O       192.168.10.4 [110/1171] via 192.168.10.10, 00:00:25, Serial0/0/1
C       192.168.10.8 is directly connected, Serial0/0/1
     172.16.0.0/16 is variably subnetted, 2 subnets, 2 masks
O       172.16.1.32/29 [110/782] via 192.168.10.10, 00:00:25, Serial0/0/1
O       172.16.1.16/28 [110/1172] via 192.168.10.10, 00:00:25, Serial0/0/1
     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C       10.2.2.2/32 is directly connected, Loopback0
C       10.10.10.0/24 is directly connected, FastEthernet0/0
O*E2    0.0.0.0/0 [110/1] via 192.168.10.10, 00:00:13, Serial0/0/1
```