Building Scalable Cisco Internetworks (BSCI)

Open Shortest Path First (OSPF)

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What Is OSPF?

- Open Shortest Path First
- Open Standards Based Interior Gateway Routing Protocol (IGP)
  - RFC 2328 “OSPF Version 2”
- Link-State Protocol
  - Uses Dijkstra SPF Algorithm
- “Classless” Protocol
  - Supports VLSM And Summarization

Why Use OSPF?

- Guarantees Loop-Free Topology
  - All routers agree on overall topology
  - Uses Dijkstra SPF Algorithm for calculation
- Standards Based
  - Inter-operability between vendors
- Large Scalability
  - Hierarchy through "areas"
  - Topology summarization

Why Use OSPF? (cont.)

- Fast Convergence
  - Actively Tracks Neighbor Adjacencies
  - Event Driven Incremental Updates
- Efficient Updating
  - Uses reliable multicast and unicast updates
  - Non-OSPF devices do not need to process updates
- Bandwidth Based Cost Metric
  - More flexible than static hop count

Why Use OSPF? (cont.)

- Control Plane Security
  - Supports clear-text and MD5 based authentication
- Extensible
  - Future application support through “opaque” LSA, e.g. MPLS Traffic Engineering

Distance Vector Routing Review

- RIPv1/v2 & IGRP
- Uses Bellman-Ford based algorithm
- Routers only know what directly connected neighbors tell them
  - “Routing by Rumor”
- Entire routing table periodically advertised on hop-by-hop basis
  - Limits scalability
- Loop prevention and convergence time limitations
  - Split-horizon, poison reverse, holddown timers, etc.

Link State Routing Overview

- OSPF & IS-IS
- Uses Dijkstra Shortest Path First (SPF) based algorithm
  - Guarantees loop-free calculation
- Attributes of connected links (link-states) are advertised, not routes
  - Routers agree on overall picture of topology before making a decision

How Link State Routing Works

- Form adjacency relationship with connected neighbors
- Exchange link attributes in form of Link State Advertisements (LSAs) / Link State Packets (LSPs) with neighbors
- Store copy of all LSAs in Link State Database (LSDB) to form a “graph” of the network
- Run Dijkstra algorithm to find shortest path to all links
- Since all routers have same LSDB, all SPF calculations are loop-free

How OSPF Works

- Step 1 – Discover OSPF Neighbors & Exchange Topology Information
- Step 2 – Choose Best Path via SPF
- Step 3 – Neighbor and Topology Table Maintenance

Step 1 – Neighbor & Topology Discovery

- Like EIGRP, OSPF uses "hello" packets to discover neighbors on OSPF enabled attached links
  - Transport via IP protocol 89 (OSPF)
  - Sent as multicast to 224.0.0.5 or 224.0.0.6, or unicast
    - More on this later…
- Hello packets contain attributes that neighbors must agree on to form "adjacency"
- Once adjacency is negotiated, LSDB is exchanged

Negotiating OSPF Adjacencies

- OSPF adjacency occurs when connected neighbors use hello packets to agree on unique and common attributes
- Not all OSPF neighbors actually form adjacency
- Most OSPF configuration problems happen at this stage
- Unique attributes include…
  - Local Router-ID
  - Local Interface IP Address

Negotiating OSPF Adjacencies (cont.)

- Common attributes include…
  - Interface Area-ID
  - Hello interval & dead interval
  - Interface network address
  - Interface MTU
  - Network Type
  - Authentication
  - Stub Flags
  - Other optional capabilities

OSPF Hello Packets

- OSPF routers periodically send hello packets out OSPF enabled links every *hello interval*
- Hello packet contains
  - Local Router-ID
  - Local Area-ID
  - Local Interface Subnet Mask
  - Local Interface Priority
  - Hello Interval
  - Dead Interval
  - Authentication Type & Password
  - DR/BDR Addresses
  - Options (e.g. stub flags, etc.)
  - Router IDs of other neighbors on the link

OSPF Adjacency State Machine

- OSPF adjacency process uses 8 states to determine progress of adjacency establishment
- Down
  - No hellos have been received from neighbor
- Attempt
  - Unicast hello packet has been sent to neighbor, but no hello has been received back
  - Only used for manually configured NBMA neighbors (more on this later…)
- Init
  - I have received a hello packet from a neighbor, but they have not acknowledged a hello from me

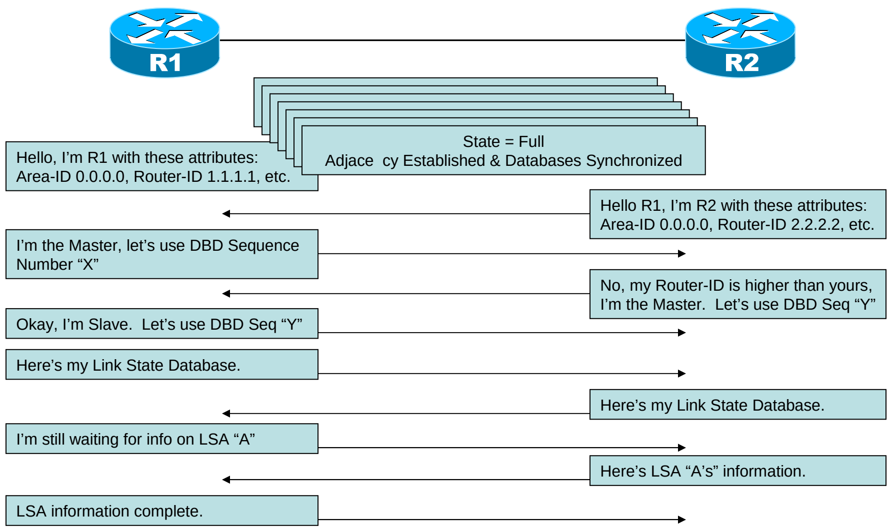
OSPF Adjacency State Machine (cont.)

- 2-Way
  - I have received a hello packet from a neighbor and they have acknowledged a hello from me
  - Indicated by my Router-ID in neighbor's hello packet
- ExStart
  - First step of actual adjacency
  - Master & slave relationship is formed, where master has higher Router-ID
  - Master chooses the starting sequence number for the Database Descriptor (DBD) packets that are used for actual LSA exchange

OSPF Adjacency State Machine (cont.)

- Exchange
  - Local link state database is sent through DBD packets
  - DBD sequence number is used for reliable acknowledgement/retransmission
- Loading
  - Link State Request packets are sent to ask for more information about a particular LSA
- Full
  - Neighbors are fully adjacent and databases are synchronized

OSPF Adjacency Example



Step 2 – Choose Best Path via SPF

- Once databases are synchronized, path selection begins
- Each router's LSAs include a "cost" attribute for each described link
- Best path to that link is lowest end-to-end cost
- Cisco's implementation uses bandwidth based cost, but per RFC it is arbitrary
  - Default Cisco Cost = 100Mbps / Link Bandwidth
  - Reference bandwidth can be modified to accommodate higher speed links (e.g. GigabitEthernet)

Why SPF is Needed

- With distance vector routing, you only know your neighbor's best path
- With link-state routing, you know *all* paths, including your neighbor's unused paths
- Dijkstra's SPF algorithm ensures that all routers agree on the same routing path, even though they make independent decisions
- Result of SPF is called the Shortest Path Tree (SPT)

SPF Calculation Overview

- To find the SPT, SPF uses three internal data sets:
  - Link State Database
    - All paths discovered from all neighbors
  - Candidate Database
    - Links possible to be in the Shortest Path Tree
  - Tree Database
    - Actual SPT once calculation is complete

SPF Calculation Overview (cont.)

- Entries in the Candidate and Tree databases describe individual branches of the tree between two nodes
- Denoted as (Router ID, Neighbor ID, Cost)
  - e.g. the branch between R1 and R2 with a cost of 10 is denoted as (R1,R2,10)
- R1's ultimate goal is to build tree with entries (R1,R_n,*cost*), where R_n is every node in the topology
  - i.e. calculate the shortest path from R1 to everywhere

SPF Calculation Logic

- Step 1 – Start by setting the local router as the "root" of the SPT, with a cost of zero to itself
- Step 2 – Find the links to all local neighbors and add them to the Candidate database
- Step 3 – Take the lowest cost branch from the Candidate database and move it to the Tree database

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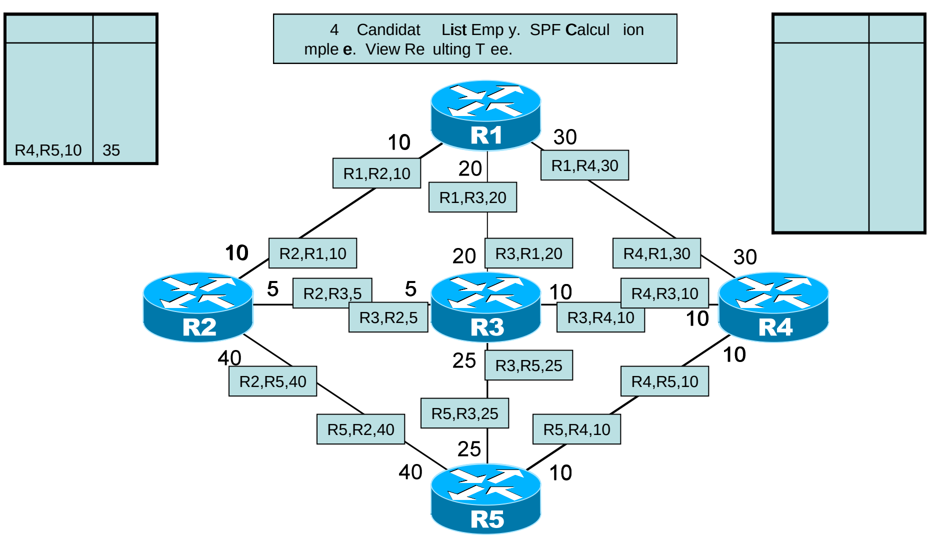
SPF Calculation Logic (cont.)

- Step 4 – For the branch just moved to the Tree database do the following
  - Find the remote node's links connecting to other neighbors
  - Move all these links to the Candidate database, with the exception of any links that go to a neighbor already in the Tree database
- Step 5 – If the Candidate database is not empty, go to Step 3, otherwise SPF is complete and the Tree database contains the SPT

SPF Calculation in Detail



Step 3 – Neighbor & Topology Maintenance

- Once adjacencies established and SPT built, OSPF state machine tracks neighbor and topology changes
- Hello packets used to track neighbor changes
- LSA fields used to track topology changes

Tracking Neighbor Changes

- Hello packets continue to be sent on each OSPF enabled link every *hello interval*
  - 10 or 30 seconds by default depending on interface type
- If a hello packet is not received from a neighbor within *dead interval*, the neighbor is declared down
  - Defaults to 4 times hello interval
  - Can be as low as 1 second for fast convergence

Tracking Topology Changes

- When a new LSA is received it is checked against the database for changes such as…
  - Sequence number
    - Used to track new vs old LSAs
  - Age
    - Used to keep information new and withdraw old information
    - Periodic flooding occurs after 30 minutes
      - “paranoid” update
    - LSAs that reach *maxage* (60 minutes) are withdrawn
  - Checksum
    - Used to avoid transmission & memory corruption

LSA Flooding

- When change is detected new LSA is generated and “flooded” (sent) out all links
  - OSPF does not use split horizon
- Not all LSA changes require SPF to recalculate
  - e.g. link up/down event vs. seq number change
  - See RFC 2328 “13. The Flooding Procedure” for details

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OSPF Media Dependencies

- Unlike EIGRP, OSPF behavior changes depending on what type of media it is configured on
  - e.g. Ethernet vs. Frame Relay vs. PPP
- OSPF defines different “network types” to deal with different media characteristics
- OSPF network types control…
  - How updates are sent
  - Who forms adjacency
  - How next-hop is calculated

OSPF Network Types

- Broadcast
- Non-Broadcast
- Point-to-Point
- Point-to-Multipoint
- Point-to-Multipoint Non-Broadcast
- Loopback

OSPF Network Broadcast

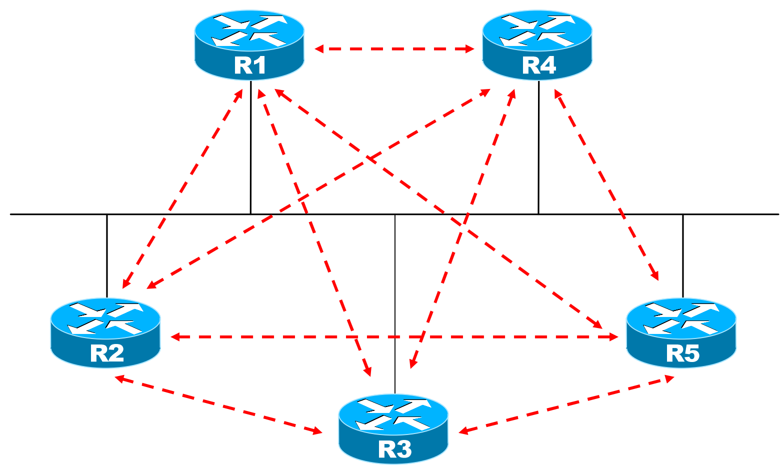
- `ip ospf network broadcast`
- Default on multi-access broadcast medias
  - Ethernet
  - Token Ring
  - FDDI
- Sends hellos and updates as multicast
  - 224.0.0.5 (AllSPFRouters)
  - 224.0.0.6 (AllDRouters)
- Performs Designated Router (DR) & Backup Designated Router (BDR) Election

DR / BDR Overview

- Designated Router (DR)
  - Used on broadcast links to
    - Minimize adjacencies
    - Minimize LSA replication
- Backup Designated Router (BDR)
  - Used for redundancy of DR
- DROthers
  - All other routers on link
  - Form full adjacency with DR & BDR
  - Stop at 2-Way adjacency with each other
- DR / BDR chosen through election process

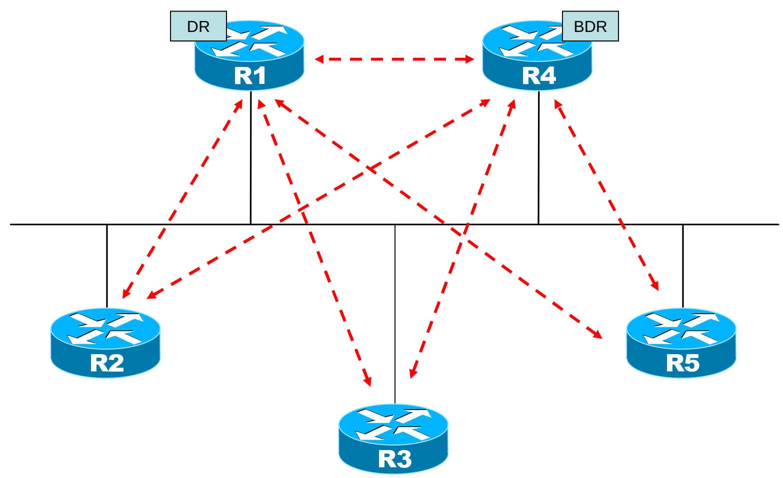
Adjacency Without DR/BDR

Without DR/BDR Adjacency Needs are n(n-1)/2



Adjacency With DR/BDR

With DR/BDR Adjacency Needs are n+(n-1)

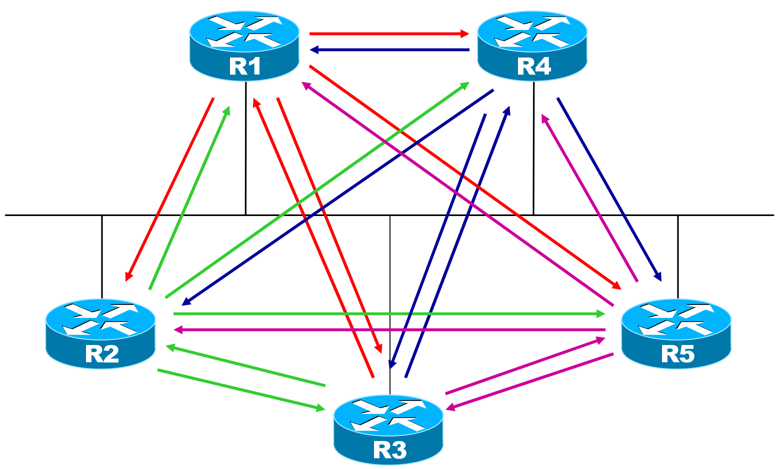


LSA Replication with DR/BDR

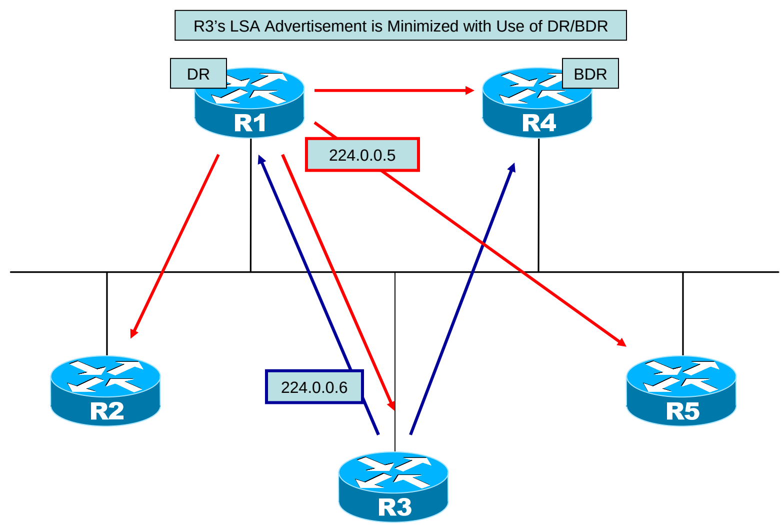
- DROthers send LSUs to DR/BDR via multicast 224.0.0.6
- DR forwards LSUs to DROthers via multicast 224.0.0.5
- Prevents constant forwarding of unneeded LSAs on the segment
- BDR does not forward LSUs, only waits for DR to fail

LSA Replication Without DR/BDR

R3's Single LSA Advertisement is Received 4 Times On Each Router



LSA Replication With DR/BDR



DR / BDR Election

- Election based on interface priority and Router-ID
  - Priority
    - 0 – 255
    - Higher better
    - 0 = never
  - Router-ID
    - Highest loopback / interface IP
    - Can be statically set
    - Higher better
- No preemption unlike IS-IS's DIS

OSPF Network Non-Broadcast

- **`ip ospf network non-broadcast`**
- Default on multipoint NBMA medias
  - Frame Relay / ATM
- Sends hellos as unicast
  - Manually defined addresses with **`neighbor`** command
- Performs DR/BDR Election
- Originally designed for legacy networks that didn't support broadcast transmission
  - i.e. X.25

OSPF Network Point-to-Point

- **`ip ospf network point-to-point`**
- Default on point-to-point medias
  - HDLC / PPP
- Sends hellos as multicast
  - 224.0.0.5
- No DR/BDR Election
- Supports only two neighbors on the link

OSPF Network Point-to-Multipoint

- **`ip ospf network point-to-multipoint`**
- Treats network as a collection of point-to-point links
- Sends hellos as multicast
  - 224.0.0.5
- No DR/BDR Election
- Special next-hop processing
- Usually best design option for partial mesh NBMA networks

Point-to-Multipoint Non-Broadcast

- **`ip ospf network point-to-multipoint non-broadcast`**
- Same as point-to-multipoint, but sends hellos as unicast
- Sends hellos as unicast
  - Manually defined addresses with **`neighbor`** command
- No DR/BDR Election
- Special next-hop processing

OSPF Network Loopback

- Special case for Loopback and Looped-back interfaces
- Advertises link as /32 stub host route
- **`ip ospf network point-to-point`** used to disable this behavior

Implementing Basic OSPF

- Enable the OSPF process
  - **router ospf [*process-id*]**
    - Process-id locally significant
    - Must be an “up/up” interface running IP to choose Router-ID from
- Enable the interface process
  - Process level
    - **network [*address*] [*wildcard*] area [*area-id*]**
  - Interface level
    - **ip ospf [process-id] area [area-id]**

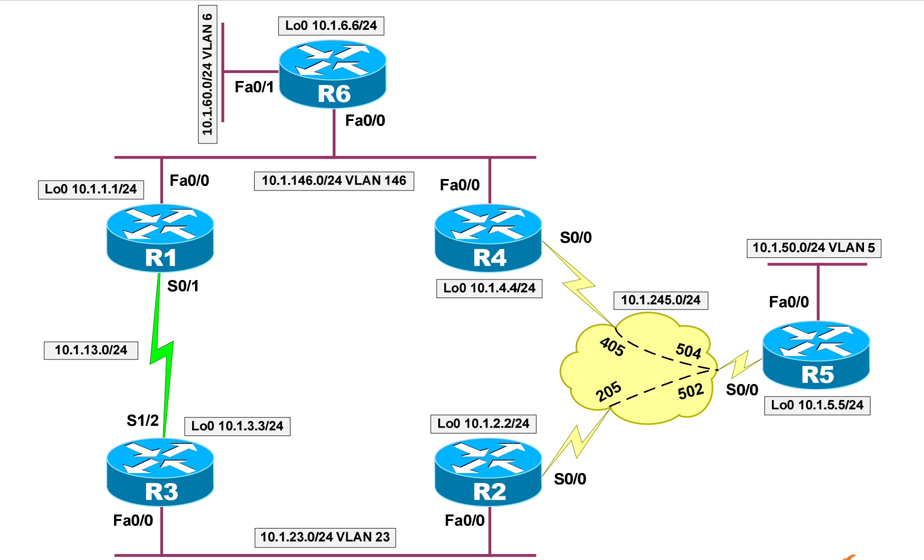
OSPF Network Statement

- Like EIGRP, enables OSPF on the interface
- Wildcard mask does not relate to subnet mask
- Most specific match wins
  - **network 0.0.0.0 255.255.255.255 area 0**
  - **network 1.0.0.0 0.255.255.255 area 1**
  - **network 1.2.0.0 0.0.255.255 area 2**
  - **network 1.2.3.0 0.0.0.255 area 3**
  - **network 1.2.3.4 0.0.0.0 area 4**
- Source of common confusion, new versions support interface level enabling as alternative

Verifying Basic OSPF

- Verify OSPF interfaces
  - **show ip ospf interface**
- Verify OSPF neighbors
  - **show ip ospf neighbors**
- Verify OSPF topology
  - **show ip ospf database**
- Verify OSPF routes in routing table
  - **show ip route [ospf]**

OSPF Configuration Example



Basic OSPF Configuration

```
R1#
router ospf 1
 network 10.1.1.0 0.0.0.255 area 0
 network 10.1.13.0 0.0.0.255 area 0
 network 10.1.146.0 0.0.0.255 area 0

R2#
router ospf 1
 network 10.1.0.0 0.0.255.255 area 0

R3#
router ospf 1
 network 10.0.0.0 0.255.255.255 area 0

R4#
router ospf 1
 network 10.1.4.4 0.0.0.0 area 0
 network 10.1.146.4 0.0.0.0 area 0
 network 10.1.245.4 0.0.0.0 area 0
```

```
R5#
router ospf 1
 network 0.0.0.0 255.255.255.255 area 0
 neighbor 10.1.245.2
 neighbor 10.1.245.4

R6#
interface Loopback0
 ip ospf 1 area 0
!
interface FastEthernet0/0
 ip ospf 1 area 0
!
interface FastEthernet0/1
 ip ospf 1 area 0
```

Verifying OSPF Interfaces

```
R1#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Fa0/0        1     0               10.1.146.1/24      1     DROTH 2/2
Se0/1        1     0               10.1.13.1/24       64    P2P   1/1
Lo0          1     0               10.1.1.1/24        1     LOOP  0/0

R2#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     0               10.1.2.2/24        1     LOOP  0/0
Se0/0        1     0               10.1.245.2/24      64    BDR   1/1
Fa0/0        1     0               10.1.23.2/24       1     BDR   1/1

R3#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     0               10.1.3.3/24        1     LOOP  0/0
Se1/2        1     0               10.1.13.3/24       781   P2P   1/1
Fa0/0        1     0               10.1.23.3/24       1     DR    1/1
R3#

R4#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     0               10.1.4.4/24        1     LOOP  0/0
Se0/0        1     0               10.1.245.4/24      64    BDR   1/1
Fa0/0        1     0               10.1.146.4/24      1     BDR   2/2

R5#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     0               10.1.5.5/24        1     LOOP  0/0
Se0/0        1     0               10.1.245.5/24      64    DR    2/2
Fa0/0        1     0               10.1.50.5/24       1     DR    0/0

R6#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     0               10.1.6.6/24        1     LOOP  0/0
Fa0/1        1     0               10.1.60.6/24       1     DR    0/0
Fa0/0        1     0               10.1.146.6/24      1     DR    2/2
```


Verifying OSPF Broadcast Interface Detail

```
R1#show ip ospf interface Fa0/0
FastEthernet0/0 is up, line protocol is up
  Internet Address 10.1.146.1/24, Area 0
  Process ID 1, Router ID 10.1.1.1, Network Type BROADCAST, Cost: 1
  Transmit Delay is 1 sec, State DROTHER, Priority 1
  Designated Router (ID) 10.1.6.6, Interface address 10.1.146.6
  Backup Designated router (ID) 10.1.4.4, Interface address 10.1.146.4
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:05
  Supports Link-local Signaling (LLS)
  Index 3/3, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 2
  Last flood scan time is 4 msec, maximum is 8 msec
  Neighbor Count is 2, Adjacent neighbor count is 2
    Adjacent with neighbor 10.1.4.4  (Backup Designated Router)
    Adjacent with neighbor 10.1.6.6  (Designated Router)
  Suppress hello for 0 neighbor(s)
```

Verifying OSPF Point-to-Point Int Detail

```
R1#show ip ospf interface Serial0/1
Serial0/1 is up, line protocol is up
  Internet Address 10.1.13.1/24, 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 00:00:02
  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 4 msec, maximum is 4 msec
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.1.3.3
  Suppress hello for 0 neighbor(s)
```


Verifying OSPF Non-Broadcast Int Detail

```
R5#show ip ospf interface Serial0/0
Serial0/0 is up, line protocol is up
  Internet Address 10.1.245.5/24, Area 0
  Process ID 1, Router ID 10.1.5.5, Network Type NON_BROADCAST, Cost: 64
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.1.5.5, Interface address 10.1.245.5
  Backup Designated router (ID) 10.1.4.4, Interface address 10.1.245.4
  Timer intervals configured, Hello 30, Dead 120, Wait 120, Retransmit 5
    oob-resync timeout 120
    Hello due in 00:00:24
  Supports Link-local Signaling (LLS)
  Cisco NSF helper support enabled
  IETF NSF helper support enabled
  Index 2/2, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 6
  Last flood scan time is 0 msec, maximum is 0 msec
  Neighbor Count is 2, Adjacent neighbor count is 2
    Adjacent with neighbor 10.1.2.2
    Adjacent with neighbor 10.1.4.4  (Backup Designated Router)
  Suppress hello for 0 neighbor(s)
```

Verifying OSPF Loopback Int Detail

```
R1#show ip ospf interface Loopback0
Loopback0 is up, line protocol is up
  Internet Address 10.1.1.1/24, Area 0
  Process ID 1, Router ID 10.1.1.1, Network Type LOOPBACK, Cost: 1
  Loopback interface is treated as a stub Host
```


OSPF Packet Level Debug

```
R1#debug ip packet detail
IP packet debugging is on (detailed)
IP: s=10.1.146.1 (local), d=224.0.0.5 (FastEthernet0/0), len 84,
   sending broad/multicast, proto=89
IP: s=10.1.146.6 (FastEthernet0/0), d=224.0.0.5, len 84, rcvd 0,
   proto=89
IP: s=10.1.13.3 (Serial0/1), d=224.0.0.5, len 80, rcvd 0, proto=89
IP: s=10.1.146.4 (FastEthernet0/0), d=224.0.0.5, len 84, rcvd 0,
   proto=89
```

Verifying OSPF Adjacency

```
R1#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.4.4          1   FULL/BDR        00:00:33    10.1.146.4      FastEthernet0/0
10.1.6.6          1   FULL/DR         00:00:37    10.1.146.6      FastEthernet0/0
10.1.3.3          0   FULL/  -        00:00:31    10.1.13.3       Serial0/1

R2#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.5.5          1   FULL/DR         00:01:45    10.1.245.5      Serial0/0
10.1.3.3          1   FULL/DR         00:00:33    10.1.23.3       FastEthernet0/0

R3#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.1.1          0   FULL/  -        00:00:35    10.1.13.1       Serial1/2
10.1.2.2          1   FULL/BDR        00:00:32    10.1.23.2       FastEthernet0/0

R4#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.5.5          1   FULL/DR         00:01:41    10.1.245.5      Serial0/0
10.1.1.1          1   FULL/DROTHER    00:00:34    10.1.146.1      FastEthernet0/0
10.1.6.6          1   FULL/DR         00:00:35    10.1.146.6      FastEthernet0/0

R5#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.2.2          1   FULL/DROTHER    00:01:39    10.1.245.2      Serial0/0
10.1.4.4          1   FULL/BDR        00:01:57    10.1.245.4      Serial0/0

R6#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.1.1          1   FULL/DROTHER    00:00:31    10.1.146.1      FastEthernet0/0
10.1.4.4          1   FULL/BDR        00:00:36    10.1.146.4      FastEthernet0/0
```


Verifying OSPF Database (R1)

```
R1#show ip ospf database

            OSPF Router with ID (10.1.1.1) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link
   count
10.1.1.1        10.1.1.1        581         0x80000004 0x003C98 4
10.1.2.2        10.1.2.2        474         0x80000003 0x002D24 3
10.1.3.3        10.1.3.3        593         0x80000002 0x0046DE 4
10.1.4.4        10.1.4.4        473         0x80000003 0x00B98D 3
10.1.5.5        10.1.5.5        474         0x80000002 0x0069DE 3
10.1.6.6        10.1.6.6        582         0x80000002 0x0084B7 3

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.23.3       10.1.3.3        593         0x80000001 0x00A340
10.1.146.6      10.1.6.6        582         0x80000001 0x0069DA
10.1.245.5      10.1.5.5        474         0x80000001 0x0043A0
```

Verifying OSPF Database (R2)

```
R2#show ip ospf database

            OSPF Router with ID (10.1.2.2) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link
   count
10.1.1.1        10.1.1.1        603         0x80000004 0x003C98 4
10.1.2.2        10.1.2.2        492         0x80000003 0x002D24 3
10.1.3.3        10.1.3.3        614         0x80000002 0x0046DE 4
10.1.4.4        10.1.4.4        495         0x80000003 0x00B98D 3
10.1.5.5        10.1.5.5        493         0x80000002 0x0069DE 3
10.1.6.6        10.1.6.6        604         0x80000002 0x0084B7 3

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.23.3       10.1.3.3        614         0x80000001 0x00A340
10.1.146.6      10.1.6.6        604         0x80000001 0x0069DA
10.1.245.5      10.1.5.5        493         0x80000001 0x0043A0
```


Verifying OSPF Database Detail

```
R1#show ip ospf database router 10.1.2.2

            OSPF Router with ID (10.1.1.1) (Process ID 1)

                Router Link States (Area 0)

  LS age: 1167
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 10.1.2.2
  Advertising Router: 10.1.2.2
  LS Seq Number: 80000003
  Checksum: 0x2D24
  Length: 60
  Number of Links: 3

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.1.2.2
     (Link Data) Network Mask: 255.255.255.255
      Number of TOS metrics: 0
       TOS 0 Metrics: 1

    Link connected to: a Transit Network
     (Link ID) Designated Router address: 10.1.245.5
     (Link Data) Router Interface address: 10.1.245.2
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Transit Network
     (Link ID) Designated Router address: 10.1.23.3
     (Link Data) Router Interface address: 10.1.23.2
      Number of TOS metrics: 0
       TOS 0 Metrics: 1
```

Verifying OSPF Routing Table

```
R1#show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     10.0.0.0/8 is variably subnetted, 12 subnets, 2 masks
C       10.1.13.0/24 is directly connected, Serial0/1
C       10.1.1.0/24 is directly connected, Loopback0
O       10.1.6.6/32 [110/2] via 10.1.146.6, 00:10:36, FastEthernet0/0
O       10.1.5.5/32 [110/66] via 10.1.146.4, 00:10:36, FastEthernet0/0
O       10.1.4.4/32 [110/2] via 10.1.146.4, 00:10:36, FastEthernet0/0
O       10.1.3.3/32 [110/65] via 10.1.13.3, 00:10:36, Serial0/1
O       10.1.2.2/32 [110/66] via 10.1.146.4, 00:10:36, FastEthernet0/0
                    [110/66] via 10.1.13.3, 00:10:37, Serial0/1
O       10.1.23.0/24 [110/65] via 10.1.13.3, 00:10:37, Serial0/1
O       10.1.60.0/24 [110/2] via 10.1.146.6, 00:10:37, FastEthernet0/0
O       10.1.50.0/24 [110/66] via 10.1.146.4, 00:10:37, FastEthernet0/0
C       10.1.146.0/24 is directly connected, FastEthernet0/0
O       10.1.245.0/24 [110/65] via 10.1.146.4, 00:10:38, FastEthernet0/0
```