OSPF Areas Overview

- OSPF areas add hierarchy and scalability to the routing domain
- An area defines a flooding domain
  - All devices in the area agree on the topology
  - Changes inside the area require LSA flooding and full SPF
- Routing between areas hides topology details
  - Inter-area routing similar to distance vector
  - Changes outside the area don't always require LSA flooding or SPF
  - Limits impact on router resources

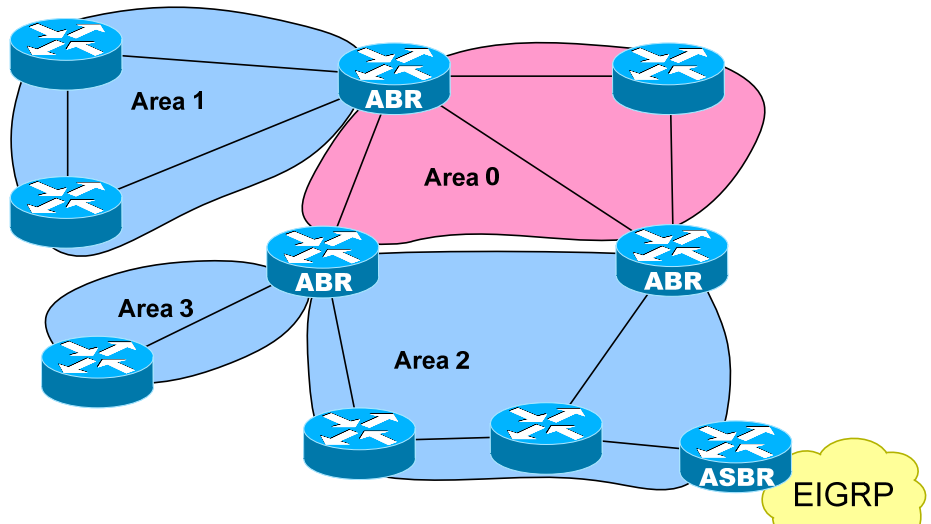
OSPF Area Types

- Backbone area
  - Area 0 (0.0.0.0)
  - Used to summarize topology information between other areas
  - Traffic from one area to another must pass through area 0
  - Must be contiguous
- Non-transit areas
  - All other areas 1 – 2^{32} (0.0.0.1 – 255.255.255.255)
  - Must use connections to area 0 to reach other areas

OSPF Router Types

- Backbone routers
  - At least one link in area 0
- Internal routers
  - All links in one non-transit area
- Area Border Router (ABR)
  - At least one link in area 0 and one link in a non-transit area
  - Used to summarize information between area 0 and non-transit area
- Autonomous System Boundary Router (ASBR)
  - At least one link in the OSPF domain
  - At least one link outside the OSPF domain
    - EIGRP, IS-IS, BGP, etc.
  - Used to redistribute information to/from other routing domains and OSPF

OSPF Multi-Area Topology Example



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Area 0 Continuity

- All inter-area traffic must pass through area 0
- If a non-transit area loses connectivity to area 0, all inter-area connectivity is lost
  - This state is called “discontiguous” areas or discontiguous area 0
- Repairs to these broken designs come in the form of virtual area 0 adjacencies called *virtual links*

OSPF Virtual Links

- Used to connect area 0 over a non-transit area
  - Virtual area 0 adjacency between two ABRs over a non-transit area
  - Provides continuity to the OSPF database calculation
- Non-transit area must have full routing information
  - Cannot be a stub area and should not have filtering
- Not a “tunnel” in traditional sense
  - Traffic does not flow over the virtual link itself
- Configured under the routing process of the ABRs
  - **`area [transit area-id] virtual-link [remote abr router-id]`**

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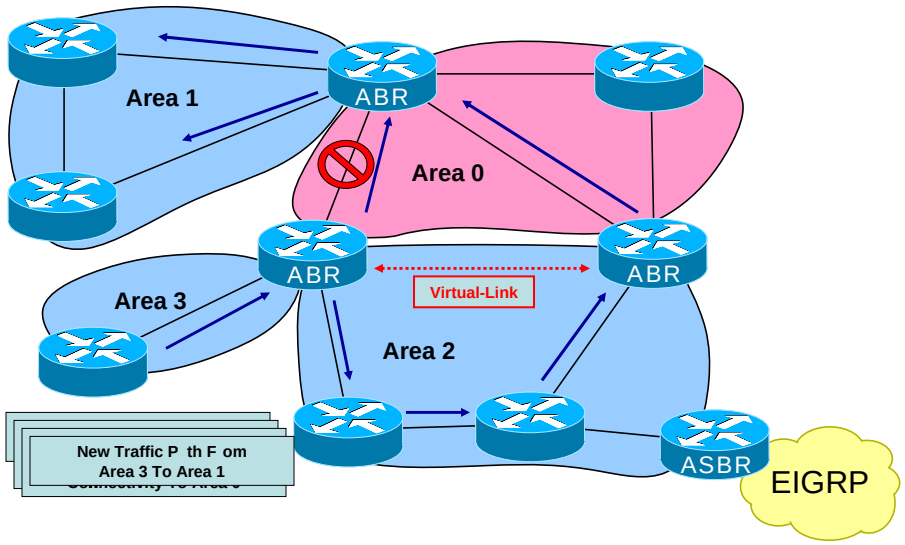
OSPF Virtual-Link Example



OSPF LSA Types

- With different router types in the OSPF domain, different types of advertisements are required
  - e.g DR, ABR, ASBR, etc.
- Different LSA formats used to represent this information
  - Format is defined by type code
  - Type 1, type 2, etc.
- Which LSA types are sent and received depends on
  - Router's type
  - OSPF network type
  - Area type

OSPF LSA Types (cont.)

- LSA types are…
  - Type 1 – Router LSA
  - Type 2 – Network LSA
  - Type 3 – Network Summary LSA
  - Type 4 – ASBR Summary LSA
  - Type 5 – External LSA
  - Type 7 – NSSA External LSA
- Other types exist outside our scope
  - Type 6 – Multicast LSA
    - Not implemented by Cisco
  - Types 8, 9, 10 – Opaque LSA
    - Used for extensibility

OSPF LSA Types (cont.)

- Routes that LSAs describe can be grouped together as…
  - Intra-Area Routes (O)
    - LSA Types 1 & 2
  - Inter-Area Routes (O IA)
    - LSA Types 3 & 4
  - External Routes
    - E1/E2
      - LSA Type 5
    - N1/N2
      - LSA Type 7

OSPF LSA Types In Detail (cont.)

- Type 1 – Router LSA
- Generated by every router in the OSPF domain
  - Not flooded outside the area they originate in
- Describes its directly connected links
  - What are my link costs
  - Who are my neighbors
- Used to build graph for intra-area SPF
- **`show ip ospf database router [Link ID]`**

OSPF LSA Types In Detail (cont.)

- Type 2 – Network LSA
- Generated by DR on broadcast and non-broadcast network types
  - Not flooded outside the area they originate in
- Describes who is adjacent with DR
- Used to reduce redundant information in the database
  - n*(n-1)/2 and flooding scalability issue
- **`show ip ospf database network [Link ID]`**

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OSPF LSA Types In Detail (cont.)

- Type 3 – Network Summary LSA
- Generated by ABR
  - Flooded from area 0 into non-transit area and vice-versa
- Describes ABR's reachability to links in other areas
  - Includes cost, but hides ABR's actual path to destination
- SPF not run to reach ABR advertised routes, instead logic is…
  - ABR can reach link A via SPT in cost X
  - I can reach ABR via SPT in cost Y
  - I can reach link A via SPT in cost X + Y
- This is why inter-area routing is considered distance vector
- **`show ip ospf database summary [`*`Link ID`*`]`**

OSPF LSA Types In Detail (cont.)

- Type 4 – ASBR Summary LSA
- Generated by ABR
  - Flooded from area 0 into non-transit area and vice-versa
- Describes ABR's reachability to ASBRs in other areas
  - Includes cost, but hides ABR's actual path to destination
- SPF not run to reach inter-area ASBR, instead logic is…
  - ABR can reach ASBR via SPT in cost X
  - I can reach ABR via SPT in cost Y
  - I can reach ASBR via SPT in cost X + Y
- This is why inter-area external routing is also considered distance vector
- **`show ip ospf database asbr-summary [`*`Link ID`*`]`**

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OSPF LSA Types In Detail (cont.)

- Type 5 – External LSA
- Generated by ASBR
  - Flooded to all non-stub areas
- Describes routes ASBR is redistributing
  - Metric
  - Metric Type
    - Type 1 = E1
    - Type 2 = E2 (default)
  - Forward Address
    - Who should I route towards to reach the link?
    - Usually the ASBR itself, but could be someone else in some designs
  - Route Tag
- **`show ip ospf database external [Link ID]`**

OSPF External Type 1 vs Type 2

- External route type controls how metric for external link is calculated
- Type 1 (E1)
  - Take the cost the ASBR reports in plus the cost to the ASBR
- Type 2 (E2)
  - Take just the cost the ASBR reports in
  - If there is a tie, then take the cost to the ASBR as well
- Type 1 is usually used when there are multiple ASBRs redistributing the same routes into OSPF

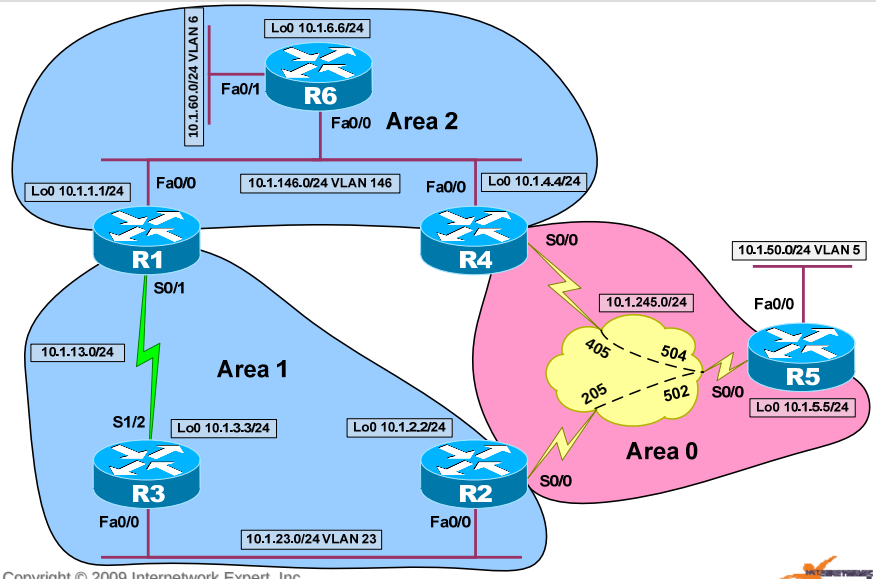
OSPF External Route Calculation

- Performs like distance vector routing similar to inter-area calculation
- Intra-area externals
  - ASBR can reach link A in cost X
  - I can reach ASBR via SPT in cost Y
  - I can reach link A via SPT in cost X + Y
- Inter-area externals
  - ASBR can reach link A in cost X
  - ABR can reach ASBR via SPT in cost Y
  - I can reach ABR via SPT in cost Z
  - I can reach link A via SPT in cost X + Y + Z

OSPF LSA Types In Detail (cont.)

- Type 7 – NSSA External LSA
- Special type of external route generated by ASBR redistributing routes inside a Not-So-Stubby Area
- More on this later…

OSPF Inter-Area Routing Example



Basic OSPF Configuration

```
R1#
router ospf 1
 network 10.1.1.1 0.0.0.0 area 2
 network 10.1.13.1 0.0.0.0 area 1
 network 10.1.146.1 0.0.0.0 area 2

R2#
router ospf 1
 network 10.1.2.2 0.0.0.0 area 1
 network 10.1.23.2 0.0.0.0 area 1
 network 10.1.245.2 0.0.0.0 area 0

R3#
router ospf 1
 network 10.1.3.3 0.0.0.0 area 1
 network 10.1.13.3 0.0.0.0 area 1
 network 10.1.23.3 0.0.0.0 area 1
```

```
R4#
router ospf 1
 network 10.1.4.4 0.0.0.0 area 2
 network 10.1.146.4 0.0.0.0 area 2
 network 10.1.245.4 0.0.0.0 area 0

R5#
router ospf 1
 network 10.1.5.5 0.0.0.0 area 0
 network 10.1.245.5 0.0.0.0 area 0
 neighbor 10.1.245.2
 neighbor 10.1.245.4
 redistribute connected subnets

R6#
router ospf 1
 network 10.1.6.6 0.0.0.0 area 2
 network 10.1.60.6 0.0.0.0 area 2
 network 10.1.146.6 0.0.0.0 area 2
```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OSPF Interface Verification

```
R1#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Se0/1        1     1               10.1.13.1/24       64    P2P   1/1
Fa0/0        1     2               10.1.146.1/24      1     DR    2/2
Lo0          1     2               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
Se0/0        1     0               10.1.245.2/24      64    BDR   1/1
Fa0/0        1     1               10.1.23.2/24       1     DR    1/1
Lo0          1     1               10.1.2.2/24        1     LOOP  0/0

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

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

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


OSPF Neighbor Verification

```
R1#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.3.3          0   FULL/  -        00:00:37    10.1.13.3       Serial0/1
10.1.4.4          1   FULL/BDR        00:00:31    10.1.146.4      FastEthernet0/0
10.1.6.6          1   FULL/DROTHER    00:00:30    10.1.146.6      FastEthernet0/0

R2#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.5.5          1   FULL/DR         00:01:53    10.1.245.5      Serial0/0
10.1.3.3          1   FULL/BDR        00:00:30    10.1.23.3       FastEthernet0/0

R3#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.2.2          1   FULL/DR         00:00:36    10.1.23.2       FastEthernet0/0
10.1.1.1          0   FULL/  -        00:00:39    10.1.13.1       Serial1/2

R4#show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.5.5          1   FULL/DR         00:01:49    10.1.245.5      Serial0/0
10.1.1.1          1   FULL/DR         00:00:32    10.1.146.1      FastEthernet0/0
10.1.6.6          1   FULL/DROTHER    00:00:33    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    00:01:38    10.1.245.2      Serial0/0
10.1.4.4          1   FULL/BDR        00:01:40    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/DR         00:00:37    10.1.146.1      FastEthernet0/0
10.1.4.4          1   FULL/BDR        00:00:39    10.1.146.4      FastEthernet0/0
```


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OSPF Database Verification (R1)

```
R1#show ip ospf database

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

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link
count
10.1.1.1        10.1.1.1        1771        0x80000003 0x00CD78 2
10.1.2.2        10.1.2.2        1788        0x80000006 0x005B4B 2
10.1.3.3        10.1.3.3        1786        0x80000005 0x004ED4 4

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.23.2       10.1.2.2        1788        0x80000002 0x00C025

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.1        10.1.2.2        1546        0x80000002 0x00FDDF
10.1.4.4        10.1.2.2        1546        0x80000002 0x00B424
10.1.5.5        10.1.2.2        1546        0x80000002 0x009F37
10.1.6.6        10.1.2.2        1546        0x80000002 0x00943F
10.1.60.0       10.1.2.2        1546        0x80000002 0x007C27
10.1.146.0      10.1.2.2        1546        0x80000002 0x00BC91
10.1.245.0      10.1.2.2        1790        0x80000002 0x006D7E

                Summary ASB Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.5.5        10.1.2.2        330         0x80000001 0x00894E

                Router Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum Link
count
10.1.1.1        10.1.1.1        1773        0x80000004 0x00D7E2 2
10.1.4.4        10.1.4.4        1773        0x80000003 0x003471 2
10.1.6.6        10.1.6.6        1776        0x80000004 0x001E21 3

                Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.146.1      10.1.1.1        1773        0x80000003 0x001140

                Summary Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.2.2        10.1.4.4        1520        0x80000002 0x00C414
10.1.3.3        10.1.4.4        1522        0x80000002 0x00B91C
10.1.5.5        10.1.4.4        1522        0x80000002 0x00854D
10.1.13.0       10.1.4.4        1522        0x80000002 0x00FCC2
10.1.23.0       10.1.4.4        1522        0x80000002 0x00F6D4
10.1.245.0      10.1.4.4        1775        0x80000002 0x005394

                Summary ASB Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.5.5        10.1.4.4        829         0x80000001 0x006F64

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
10.1.50.0       10.1.5.5        58          0x80000001 0x008DC0 0
```


OSPF Database Verification (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
10.1.2.2        10.1.2.2        1655        0x80000003 0x006267 1
10.1.4.4        10.1.4.4        1630        0x80000003 0x003A85 1
10.1.5.5        10.1.5.5        444         0x80000005 0x00DBB5 2

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.245.5      10.1.5.5        1631        0x80000002 0x0041A1

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.1        10.1.4.4        1883        0x80000002 0x0061B8
10.1.2.2        10.1.2.2        1898        0x80000002 0x005CC0
10.1.3.3        10.1.2.2        1898        0x80000002 0x0051C8
10.1.4.4        10.1.4.4        1883        0x80000002 0x0018FC
10.1.6.6        10.1.4.4        1883        0x80000002 0x00F718
10.1.13.0       10.1.2.2        1898        0x80000002 0x00946F
10.1.23.0       10.1.2.2        1899        0x80000002 0x008881
10.1.60.0       10.1.4.4        1884        0x80000002 0x00DFFF
10.1.146.0      10.1.4.4        1884        0x80000002 0x00206A

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link
count
10.1.1.1        10.1.1.1        1886        0x80000003 0x00CD78 2
10.1.2.2        10.1.2.2        1899        0x80000006 0x005B4B 2
10.1.3.3        10.1.3.3        1899        0x80000005 0x004ED4 4

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.23.2       10.1.2.2        1899        0x80000002 0x00C025

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.1        10.1.2.2        1656        0x80000002 0x00FDDF
10.1.4.4        10.1.2.2        1656        0x80000002 0x00B424
10.1.5.5        10.1.2.2        1656        0x80000002 0x009F37
10.1.6.6        10.1.2.2        1657        0x80000002 0x00943F
10.1.60.0       10.1.2.2        1659        0x80000002 0x007C27
10.1.146.0      10.1.2.2        1659        0x80000002 0x00BC91
10.1.245.0      10.1.2.2        1901        0x80000002 0x006D7E

                Summary ASB Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.5.5        10.1.2.2        441         0x80000001 0x00894E

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
10.1.50.0       10.1.5.5        139         0x80000001 0x008DC0 0
```


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OSPF Database Verification (R3)

```
R3#show ip ospf database

            OSPF Router with ID (10.1.3.3) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
10.1.1.1        10.1.1.1        1889        0x80000003 0x00CD78 2
10.1.2.2        10.1.2.2        1905        0x80000006 0x005B4B 2
10.1.3.3        10.1.3.3        1903        0x80000005 0x004ED4 4

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.23.2       10.1.2.2        1905        0x80000002 0x00C025

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.1        10.1.2.2        1662        0x80000002 0x00FDDF
10.1.4.4        10.1.2.2        1662        0x80000002 0x00B424
10.1.5.5        10.1.2.2        1662        0x80000002 0x009F37
10.1.6.6        10.1.2.2        1662        0x80000002 0x00943F
10.1.60.0       10.1.2.2        1662        0x80000002 0x007C27
10.1.146.0      10.1.2.2        1662        0x80000002 0x00BC91
10.1.245.0      10.1.2.2        1905        0x80000002 0x006D7E

                Summary ASB Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.5.5        10.1.2.2        446         0x80000001 0x00894E

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
10.1.50.0       10.1.5.5        139         0x80000001 0x008DC0 0
```


OSPF Database Verification (R4)

```
R4#show ip ospf database

            OSPF Router with ID (10.1.4.4) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link
count
10.1.2.2        10.1.2.2        1668        0x80000003 0x006267 1
10.1.4.4        10.1.4.4        1639        0x80000003 0x003A85 1
10.1.5.5        10.1.5.5        454         0x80000005 0x00DBB5 2

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.245.5      10.1.5.5        1641        0x80000002 0x0041A1

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.1        10.1.4.4        1892        0x80000002 0x0061B8
10.1.2.2        10.1.2.2        1910        0x80000002 0x005CC0
10.1.3.3        10.1.2.2        1910        0x80000002 0x0051C8
10.1.4.4        10.1.4.4        1892        0x80000002 0x0018FC
10.1.6.6        10.1.4.4        1892        0x80000002 0x00F718
10.1.13.0       10.1.2.2        1910        0x80000002 0x00946F
10.1.23.0       10.1.2.2        1911        0x80000002 0x008881
10.1.60.0       10.1.4.4        1893        0x80000002 0x00DFFF
10.1.146.0      10.1.4.4        1893        0x80000002 0x00206A

                Router Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum Link
count
10.1.1.1        10.1.1.1        1894        0x80000004 0x00D7E2 2
10.1.4.4        10.1.4.4        1893        0x80000003 0x003471 2
10.1.6.6        10.1.6.6        1897        0x80000004 0x001E21 3

                Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.146.1      10.1.1.1        1894        0x80000003 0x001140

                Summary Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.2.2        10.1.4.4        1640        0x80000002 0x00C414
10.1.3.3        10.1.4.4        1640        0x80000002 0x00B91C
10.1.5.5        10.1.4.4        1640        0x80000002 0x00854D
10.1.13.0       10.1.4.4        1640        0x80000002 0x00FCC2
10.1.23.0       10.1.4.4        1640        0x80000002 0x00F0D4
10.1.245.0      10.1.4.4        1893        0x80000002 0x005394

                Summary ASB Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.5.5        10.1.4.4        449         0x80000001 0x006F64

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
10.1.50.0       10.1.5.5        139         0x80000001 0x008DC0 0
```


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OSPF Database Verification (R5)

```
R5#show ip ospf database

            OSPF Router with ID (10.1.5.5) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
10.1.2.2        10.1.2.2        1673        0x80000003 0x006267 1
10.1.4.4        10.1.4.4        1647        0x80000003 0x003A85 1
10.1.5.5        10.1.5.5        460         0x80000005 0x00DBB5 2

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.245.5      10.1.5.5        1647        0x80000002 0x0041A1

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.1        10.1.4.4        1900        0x80000002 0x0061B8
10.1.2.2        10.1.2.2        1916        0x80000002 0x005CC0
10.1.3.3        10.1.2.2        1916        0x80000002 0x0051C8
10.1.4.4        10.1.4.4        1900        0x80000002 0x0018FC
10.1.6.6        10.1.4.4        1900        0x80000002 0x00F718
10.1.13.0       10.1.2.2        1916        0x80000002 0x00946F
10.1.23.0       10.1.2.2        1916        0x80000002 0x008881
10.1.60.0       10.1.4.4        1900        0x80000002 0x00DFFF
10.1.146.0      10.1.4.4        1900        0x80000002 0x00206A

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
10.1.50.0       10.1.5.5        139         0x80000001 0x008DC0 0
```


OSPF Database Verification (R6)

```
R6#show ip ospf database

            OSPF Router with ID (10.1.6.6) (Process ID 1)

                Router Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum Link count
10.1.1.1        10.1.1.1        1904        0x80000004 0x00D7E2 2
10.1.4.4        10.1.4.4        1903        0x80000003 0x003471 2
10.1.6.6        10.1.6.6        1905        0x80000004 0x001E21 3

                Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.146.1      10.1.1.1        1904        0x80000003 0x001140

                Summary Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.2.2        10.1.4.4        1650        0x80000002 0x00C414
10.1.3.3        10.1.4.4        1650        0x80000002 0x00B91C
10.1.5.5        10.1.4.4        1650        0x80000002 0x00854D
10.1.13.0       10.1.4.4        1650        0x80000002 0x00FCC2
10.1.23.0       10.1.4.4        1650        0x80000002 0x00F0D4
10.1.245.0      10.1.4.4        1903        0x80000002 0x005394

                Summary ASB Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.5.5        10.1.4.4        460         0x80000001 0x006F64

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
10.1.50.0       10.1.5.5        139         0x80000001 0x008DC0 0
```


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OSPF Routing Table Verification (R1)

```
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, 00:22:34, FastEthernet0/0
O IA    10.1.5.5/32 [110/66] via 10.1.146.4, 00:22:34, FastEthernet0/0
O       10.1.4.4/32 [110/2] via 10.1.146.4, 00:22:34, FastEthernet0/0
O       10.1.3.3/32 [110/65] via 10.1.13.3, 00:22:34, Serial0/1
O       10.1.2.2/32 [110/66] via 10.1.13.3, 00:22:34, Serial0/1
O       10.1.23.0/24 [110/65] via 10.1.13.3, 00:22:35, Serial0/1
O       10.1.60.0/24 [110/2] via 10.1.146.6, 00:22:35, FastEthernet0/0
O E2    10.1.50.0/24 [110/20] via 10.1.146.4, 00:22:35, FastEthernet0/0
C       10.1.146.0/24 is directly connected, FastEthernet0/0
O IA    10.1.245.0/24 [110/65] via 10.1.146.4, 00:22:35, FastEthernet0/0
```


OSPF Routing Table Verification (R2)

```
R2#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
O       10.1.13.0/24 [110/782] via 10.1.23.3, 00:22:36, FastEthernet0/0
C       10.1.2.0/24 is directly connected, Loopback0
O IA    10.1.6.6/32 [110/66] via 10.1.245.4, 00:22:36, Serial0/0
O       10.1.5.5/32 [110/65] via 10.1.245.5, 00:22:36, Serial0/0
O IA    10.1.4.4/32 [110/65] via 10.1.245.4, 00:22:36, Serial0/0
O       10.1.3.3/32 [110/2] via 10.1.23.3, 00:22:36, FastEthernet0/0
O IA    10.1.1.1/32 [110/66] via 10.1.245.4, 00:22:36, Serial0/0
C       10.1.23.0/24 is directly connected, FastEthernet0/0
O IA    10.1.60.0/24 [110/66] via 10.1.245.4, 00:22:37, Serial0/0
O E2    10.1.50.0/24 [110/20] via 10.1.245.5, 00:22:37, Serial0/0
O IA    10.1.146.0/24 [110/65] via 10.1.245.4, 00:22:37, Serial0/0
C       10.1.245.0/24 is directly connected, Serial0/0
```


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OSPF Routing Table Verification (R3)

```
R3#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, Serial1/2
C       10.1.3.0/24 is directly connected, Loopback0
O IA    10.1.6.6/32 [110/67] via 10.1.23.2, 00:22:38, FastEthernet0/0
O IA    10.1.5.5/32 [110/66] via 10.1.23.2, 00:22:38, FastEthernet0/0
O IA    10.1.4.4/32 [110/66] via 10.1.23.2, 00:22:38, FastEthernet0/0
O       10.1.2.2/32 [110/2] via 10.1.23.2, 00:22:38, FastEthernet0/0
O IA    10.1.1.1/32 [110/67] via 10.1.23.2, 00:22:38, FastEthernet0/0
C       10.1.23.0/24 is directly connected, FastEthernet0/0
O IA    10.1.60.0/24 [110/67] via 10.1.23.2, 00:22:40, FastEthernet0/0
O E2    10.1.50.0/24 [110/20] via 10.1.23.2, 00:22:40, FastEthernet0/0
O IA    10.1.146.0/24 [110/66] via 10.1.23.2, 00:22:40, FastEthernet0/0
O IA    10.1.245.0/24 [110/65] via 10.1.23.2, 00:22:40, FastEthernet0/0
```


OSPF Routing Table Verification (R4)

```
R4#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
O IA    10.1.13.0/24 [110/846] via 10.1.245.2, 00:22:41, Serial0/0
O       10.1.6.6/32 [110/2] via 10.1.146.6, 00:22:41, FastEthernet0/0
O       10.1.5.5/32 [110/65] via 10.1.245.5, 00:22:41, Serial0/0
O IA    10.1.3.3/32 [110/66] via 10.1.245.2, 00:22:41, Serial0/0
O IA    10.1.2.2/32 [110/65] via 10.1.245.2, 00:22:41, Serial0/0
O       10.1.1.1/32 [110/2] via 10.1.146.1, 00:22:41, FastEthernet0/0
C       10.1.4.0/24 is directly connected, Loopback0
O IA    10.1.23.0/24 [110/65] via 10.1.245.2, 00:22:41, Serial0/0
O       10.1.60.0/24 [110/2] via 10.1.146.6, 00:22:41, FastEthernet0/0
O E2    10.1.50.0/24 [110/20] via 10.1.245.5, 00:22:41, Serial0/0
C       10.1.146.0/24 is directly connected, FastEthernet0/0
C       10.1.245.0/24 is directly connected, Serial0/0
```


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OSPF Routing Table Verification (R5)

```
R5#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
O IA    10.1.13.0/24 [110/846] via 10.1.245.2, 00:22:44, Serial0/0
O IA    10.1.6.6/32 [110/66] via 10.1.245.4, 00:22:44, Serial0/0
O IA    10.1.4.4/32 [110/65] via 10.1.245.4, 00:22:44, Serial0/0
O IA    10.1.3.3/32 [110/66] via 10.1.245.2, 00:22:44, Serial0/0
O IA    10.1.2.2/32 [110/65] via 10.1.245.2, 00:22:44, Serial0/0
O IA    10.1.1.1/32 [110/66] via 10.1.245.4, 00:22:44, Serial0/0
C       10.1.5.0/24 is directly connected, Loopback0
O IA    10.1.23.0/24 [110/65] via 10.1.245.2, 00:22:44, Serial0/0
O IA    10.1.60.0/24 [110/66] via 10.1.245.4, 00:22:44, Serial0/0
C       10.1.50.0/24 is directly connected, FastEthernet0/0
O IA    10.1.146.0/24 [110/65] via 10.1.245.4, 00:22:44, Serial0/0
C       10.1.245.0/24 is directly connected, Serial0/0
```


OSPF Routing Table Verification (R6)

```
R6#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
O IA    10.1.13.0/24 [110/847] via 10.1.146.4, 00:22:45, FastEthernet0/0
O IA    10.1.5.5/32 [110/66] via 10.1.146.4, 00:22:45, FastEthernet0/0
O       10.1.4.4/32 [110/2] via 10.1.146.4, 00:22:45, FastEthernet0/0
O IA    10.1.3.3/32 [110/67] via 10.1.146.4, 00:22:45, FastEthernet0/0
O IA    10.1.2.2/32 [110/66] via 10.1.146.4, 00:22:45, FastEthernet0/0
O       10.1.1.1/32 [110/2] via 10.1.146.1, 00:22:45, FastEthernet0/0
C       10.1.6.0/24 is directly connected, Loopback0
O IA    10.1.23.0/24 [110/66] via 10.1.146.4, 00:22:46, FastEthernet0/0
C       10.1.60.0/24 is directly connected, FastEthernet0/1
O E2    10.1.50.0/24 [110/20] via 10.1.146.4, 00:22:46, FastEthernet0/0
C       10.1.146.0/24 is directly connected, FastEthernet0/0
O IA    10.1.245.0/24 [110/65] via 10.1.146.4, 00:22:46, FastEthernet0/0
```


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OSPF Type-1 LSA Verification Detail

```
R3#show ip ospf database router 10.1.3.3

           OSPF Router with ID (10.1.3.3) (Process ID 1)

               Router Link States (Area 1)

  LS age: 142
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 10.1.3.3
  Advertising Router: 10.1.3.3
  LS Seq Number: 80000007
  Checksum: 0x4AD6
  Length: 72
  Number of Links: 4

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

    Link connected to: another Router (point-to-point)
     (Link ID) Neighboring Router ID: 10.1.1.1
     (Link Data) Router Interface address: 10.1.13.3
      Number of TOS metrics: 0
       TOS 0 Metrics: 781

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.1.13.0
     (Link Data) Network Mask: 255.255.255.0
      Number of TOS metrics: 0
       TOS 0 Metrics: 781

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.1.3.3
     (Link Data) Network Mask: 255.255.255.255
      Number of TOS metrics: 0
       TOS 0 Metrics: 1
```


OSPF Type-2 LSA Verification Detail

```
R3#show ip ospf database network 10.1.23.2

            OSPF Router with ID (10.1.3.3) (Process ID 1)

                Net Link States (Area 1)

  Routing Bit Set on this LSA
  LS age: 151
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 10.1.23.2 (address of Designated Router)
  Advertising Router: 10.1.2.2
  LS Seq Number: 80000004
  Checksum: 0xBC27
  Length: 32
  Network Mask: /24
        Attached Router: 10.1.2.2
        Attached Router: 10.1.3.3
```


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OSPF Type-3 LSA Verification Detail

```
R3#show ip ospf database summary 10.1.245.0

            OSPF Router with ID (10.1.3.3) (Process ID 1)

                Summary Net Link States (Area 1)

  Routing Bit Set on this LSA
  LS age: 165
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.1.245.0 (summary Network Number)
  Advertising Router: 10.1.2.2
  LS Seq Number: 80000004
  Checksum: 0x6980
  Length: 28
  Network Mask: /24
        TOS: 0  Metric: 64
```


OSPF Type-4 LSA Verification Detail

```
R3#show ip ospf database asbr-summary 10.1.5.5

            OSPF Router with ID (10.1.3.3) (Process ID 1)

                Summary ASB Link States (Area 1)

  Routing Bit Set on this LSA
  LS age: 671
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(AS Boundary Router)
  Link State ID: 10.1.5.5 (AS Boundary Router address)
  Advertising Router: 10.1.2.2
  LS Seq Number: 80000002
  Checksum: 0x874F
  Length: 28
  Network Mask: /0
        TOS: 0  Metric: 64
```


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OSPF Type-5 LSA Verification Detail

```
R3#show ip ospf database external 10.1.50.0

            OSPF Router with ID (10.1.3.3) (Process ID 1)

                Type-5 AS External Link States

  Routing Bit Set on this LSA
  LS age: 130
  Options: (No TOS-capability, DC)
  LS Type: AS External Link
  Link State ID: 10.1.50.0 (External Network Number )
  Advertising Router: 10.1.5.5
  LS Seq Number: 80000002
  Checksum: 0x8BC1
  Length: 36
  Network Mask: /24
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 20
        Forward Address: 0.0.0.0
        External Route Tag: 0
```


OSPF Routing Table Verification Detail

```
R3#show ip route 10.1.2.2
Routing entry for 10.1.2.2/32
  Known via "ospf 1", distance 110, metric 2, type intra area
  Last update from 10.1.23.2 on FastEthernet0/0, 00:39:04 ago
  Routing Descriptor Blocks:
  * 10.1.23.2, from 10.1.2.2, 00:39:04 ago, via FastEthernet0/0
      Route metric is 2, traffic share count is 1

R3#show ip route 10.1.245.0
Routing entry for 10.1.245.0/24
  Known via "ospf 1", distance 110, metric 65, type inter area
  Last update from 10.1.23.2 on FastEthernet0/0, 00:39:06 ago
  Routing Descriptor Blocks:
  * 10.1.23.2, from 10.1.2.2, 00:39:06 ago, via FastEthernet0/0
      Route metric is 65, traffic share count is 1

R3#show ip route 10.1.50.0
Routing entry for 10.1.50.0/24
  Known via "ospf 1", distance 110, metric 20, type extern 2, forward metric 65
  Last update from 10.1.23.2 on FastEthernet0/0, 00:39:09 ago
  Routing Descriptor Blocks:
  * 10.1.23.2, from 10.1.5.5, 00:39:09 ago, via FastEthernet0/0
      Route metric is 20, traffic share count is 1
```


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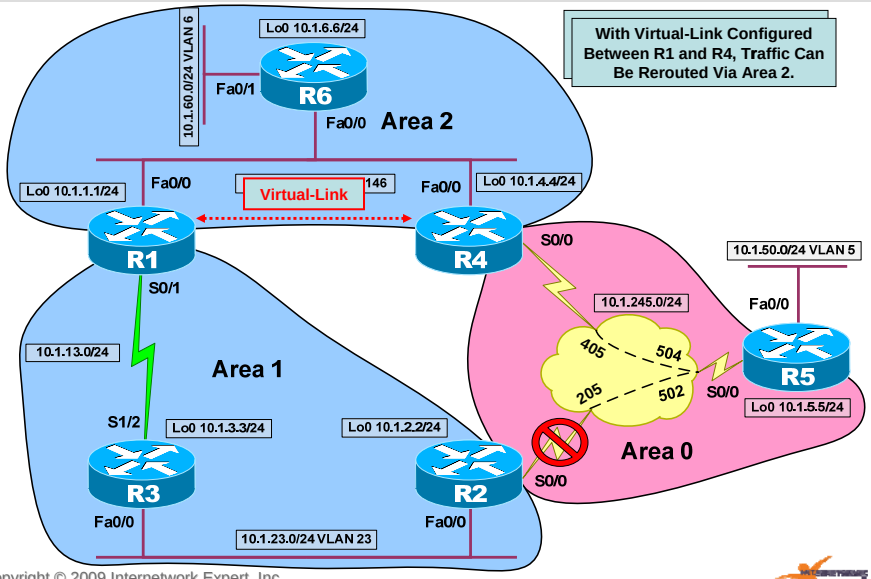
OSPF Virtual-Link Example



OSPF Virtual-Link Configuration

```
R1#
router ospf 1
 area 2 virtual-link 10.1.4.4

R4#
router ospf 1
 area 2 virtual-link 10.1.1.1

R1#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.4.4          0   FULL/  -            -        10.1.146.4      OSPF_VL0
10.1.3.3          0   FULL/  -        00:00:32     10.1.13.3       Serial0/1
10.1.4.4          1   FULL/BDR       00:00:38     10.1.146.4      FastEthernet0/0
10.1.6.6          1   FULL/DROTHER   00:00:35     10.1.146.6      FastEthernet0/0

R4#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
10.1.1.1          0   FULL/  -            -        10.1.146.1      OSPF_VL0
10.1.5.5          1   FULL/DR        00:01:45     10.1.245.5      Serial0/0
10.1.1.1          1   FULL/DR        00:00:37     10.1.146.1      FastEthernet0/0
10.1.6.6          1   FULL/DROTHER   00:00:38     10.1.146.6      FastEthernet0/0
```

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OSPF Virtual-Link Verification

```
R1#show ip ospf virtual-links
Virtual Link OSPF_VL0 to router 10.1.4.4 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 2, via interface FastEthernet0/0, Cost of using 1
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:07
    Adjacency State FULL (Hello suppressed)
    Index 1/4, retransmission queue length 0, number of retransmission 0
    First 0x0(0)/0x0(0) Next 0x0(0)/0x0(0)
    Last retransmission scan length is 0, maximum is 0
    Last retransmission scan time is 0 msec, maximum is 0 msec

R1#show ip ospf interface
OSPF_VL0 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 VIRTUAL_LINK, Cost: 1
  Configured as demand circuit.
  Run as demand circuit.
  DoNotAge LSA allowed.
  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 00:00:06
  Supports Link-local Signaling (LLS)
  Index 1/4, 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 0 msec
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.1.4.4  (Hello suppressed)
  Suppress hello for 1 neighbor(s)
<output omitted>
```


OSPF Virtual-Link Verification (cont.)

```
R3#show ip route 10.1.5.5
Routing entry for 10.1.5.5/32
  Known via "ospf 1", distance 110, metric 66, type inter area
  Last update from 10.1.23.2 on FastEthernet0/0, 00:07:16 ago
  Routing Descriptor Blocks:
  * 10.1.23.2, from 10.1.2.2, 00:07:16 ago, via FastEthernet0/0
      Route metric is 66, traffic share count is 1

R3#traceroute 10.1.5.5

Type escape sequence to abort.
Tracing the route to 10.1.5.5

  1 10.1.23.2 4 msec 0 msec 4 msec
  2 10.1.245.5 28 msec *  28 msec

R2#config t
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)#interface Serial0/0
R2(config-if)#shutdown
R2(config-if)#
OSPF-5-ADJCHG: Process 1, Nbr 10.1.5.5 on Serial0/0 from FULL to DOWN, Neighbor Down: Interface down or detached
%LINK-5-CHANGED: Interface Serial0/0, changed state to administratively down
%LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0, changed state to down

R3#show ip route 10.1.5.5
Routing entry for 10.1.5.5/32
  Known via "ospf 1", distance 110, metric 847, type inter area
  Last update from 10.1.13.1 on Serial1/2, 00:00:03 ago
  Routing Descriptor Blocks:
  * 10.1.13.1, from 10.1.1.1, 00:00:03 ago, via Serial1/2
      Route metric is 847, traffic share count is 1

R3#traceroute 10.1.5.5

Type escape sequence to abort.
Tracing the route to 10.1.5.5

  1 10.1.13.1 16 msec 16 msec 16 msec
  2 10.1.146.4 16 msec 12 msec 12 msec
  3 10.1.245.5 44 msec *  40 msec
```


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OSPF Scalability

- Less topology info & less routing info means lower resource utilization
- OSPF areas add scalability by hiding *topology* information, but they don't hide *reachability* information
- NLRI can be reduced in OSPF by implementing
  - Summarization
  - Stub areas

OSPF Summarization

- OSPF supports two types of summaries
  - Internal Summarization (Type-3 LSAs)
  - External Summarization (Type-5 & 7 LSAs)
- Unlike RIPv2, EIGRP, and BGP, OSPF summarization (aggregation) ***cannot*** be performed at arbitrary places in the topology
  - Internal summarization only on ABRs
  - External summarization only on ASBRs

OSPF Internal Summarization

- Configured only on ABRs
- Takes intra-area (O) routes and summarizes them into inter-area (O IA) routes as they move between areas
- **`area [`*`source area-id`*`] range [`*`network`*`] [`*`mask`*`]`**
- Automatically generates route to Null0

OSPF External Summarization

- Configured only on ASBRs
- Takes routes external to OSPF domain and summarizes them as OSPF external routes (E1/E2/N1/N2) when redistributed
- **`summary-address [`*`network`*`] [`*`mask`*`]`**
- Automatically generates routes to Null0

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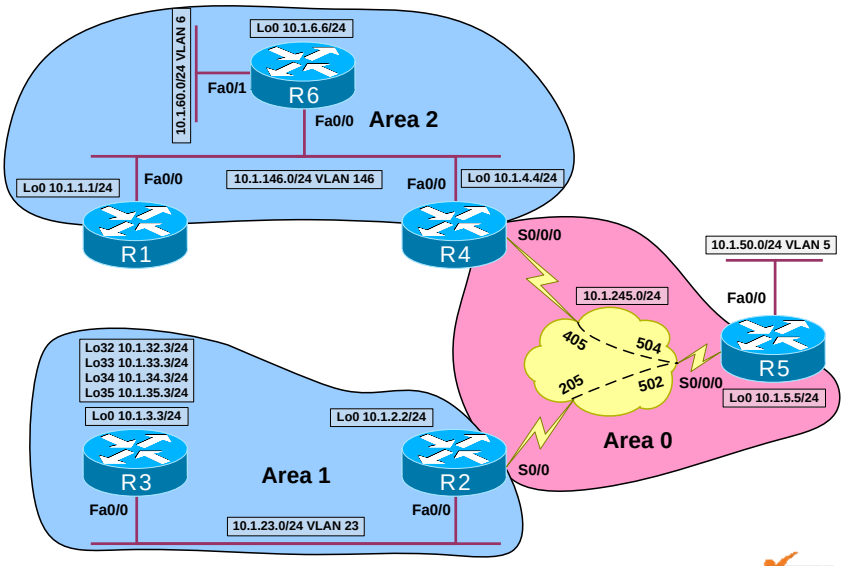
OSPF Internal Summarization Example



OSPF Internal Summarization Configuration

```
R2#
router ospf 1
 area 1 range 10.1.32.0 255.255.252.0

R3#
interface Loopback32
 ip address 10.1.32.3 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback33
 ip address 10.1.33.3 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback34
 ip address 10.1.34.3 255.255.255.0
 ip ospf network point-to-point
!
interface Loopback35
 ip address 10.1.35.3 255.255.255.0
 ip ospf network point-to-point
!
router ospf 1
 network 10.1.32.3 0.0.0.0 area 1
 network 10.1.33.3 0.0.0.0 area 1
 network 10.1.34.3 0.0.0.0 area 1
 network 10.1.35.3 0.0.0.0 area 1
```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Internal Summarization Verification

```
R2#show ip route ospf
     10.0.0.0/8 is variably subnetted, 16 subnets, 3 masks
O IA    10.1.6.6/32 [110/66] via 10.1.245.4, 00:05:05, Serial0/0
O       10.1.5.5/32 [110/65] via 10.1.245.5, 00:05:05, Serial0/0
O IA    10.1.4.4/32 [110/65] via 10.1.245.4, 00:05:05, Serial0/0
O       10.1.3.3/32 [110/2] via 10.1.23.3, 00:05:05, FastEthernet0/0
O IA    10.1.1.1/32 [110/66] via 10.1.245.4, 00:05:05, Serial0/0
O       10.1.35.0/24 [110/2] via 10.1.23.3, 00:05:05, FastEthernet0/0
O       10.1.34.0/24 [110/2] via 10.1.23.3, 00:05:05, FastEthernet0/0
O       10.1.33.0/24 [110/2] via 10.1.23.3, 00:05:05, FastEthernet0/0
O       10.1.32.0/24 [110/2] via 10.1.23.3, 00:05:05, FastEthernet0/0
O       10.1.32.0/22 is a summary, 00:05:05, Null0
O IA    10.1.60.0/24 [110/66] via 10.1.245.4, 00:05:05, Serial0/0
O E2    10.1.50.0/24 [110/20] via 10.1.245.5, 00:05:05, Serial0/0
O IA    10.1.146.0/24 [110/65] via 10.1.245.4, 00:05:05, Serial0/0

R5#show ip route ospf
     10.0.0.0/8 is variably subnetted, 12 subnets, 3 masks
O IA    10.1.6.6/32 [110/66] via 10.1.245.4, 00:07:48, Serial0/0
O IA    10.1.4.4/32 [110/65] via 10.1.245.4, 00:07:48, Serial0/0
O IA    10.1.3.3/32 [110/66] via 10.1.245.2, 00:07:48, Serial0/0
O IA    10.1.2.2/32 [110/65] via 10.1.245.2, 00:07:48, Serial0/0
O IA    10.1.1.1/32 [110/66] via 10.1.245.4, 00:07:48, Serial0/0
O IA    10.1.23.0/24 [110/65] via 10.1.245.2, 00:07:48, Serial0/0
O IA    10.1.32.0/22 [110/66] via 10.1.245.2, 00:05:10, Serial0/0
O IA    10.1.60.0/24 [110/66] via 10.1.245.4, 00:07:48, Serial0/0
O IA    10.1.146.0/24 [110/65] via 10.1.245.4, 00:07:48, Serial0/0

R6#show ip route ospf
     10.0.0.0/8 is variably subnetted, 12 subnets, 3 masks
O IA    10.1.5.5/32 [110/66] via 10.1.146.4, 00:09:58, FastEthernet0/0
O       10.1.4.4/32 [110/2] via 10.1.146.4, 00:11:12, FastEthernet0/0
O IA    10.1.3.3/32 [110/67] via 10.1.146.4, 00:09:48, FastEthernet0/0
O IA    10.1.2.2/32 [110/66] via 10.1.146.4, 00:09:48, FastEthernet0/0
O       10.1.1.1/32 [110/2] via 10.1.146.1, 00:11:12, FastEthernet0/0
O IA    10.1.23.0/24 [110/66] via 10.1.146.4, 00:09:48, FastEthernet0/0
O IA    10.1.32.0/22 [110/67] via 10.1.146.4, 00:07:16, FastEthernet0/0
O E2    10.1.50.0/24 [110/20] via 10.1.146.4, 00:07:15, FastEthernet0/0
O IA    10.1.245.0/24 [110/65] via 10.1.146.4, 00:11:12, FastEthernet0/0
```


Internal Summarization Verification (cont.)

```
R5#show ip ospf database summary 10.1.32.0

            OSPF Router with ID (10.1.5.5) (Process ID 1)

                Summary Net Link States (Area 0)

  Routing Bit Set on this LSA
  LS age: 466
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.1.32.0 (summary Network Number)
  Advertising Router: 10.1.2.2
  LS Seq Number: 80000002
  Checksum: 0x20E2
  Length: 28
  Network Mask: /22
        TOS: 0  Metric: 2

R6#show ip ospf database summary 10.1.32.0

            OSPF Router with ID (10.1.6.6) (Process ID 1)

                Summary Net Link States (Area 2)

  Routing Bit Set on this LSA
  LS age: 467
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.1.32.0 (summary Network Number)
  Advertising Router: 10.1.4.4
  LS Seq Number: 80000003
  Checksum: 0x8637
  Length: 28
  Network Mask: /22
        TOS: 0  Metric: 66
```


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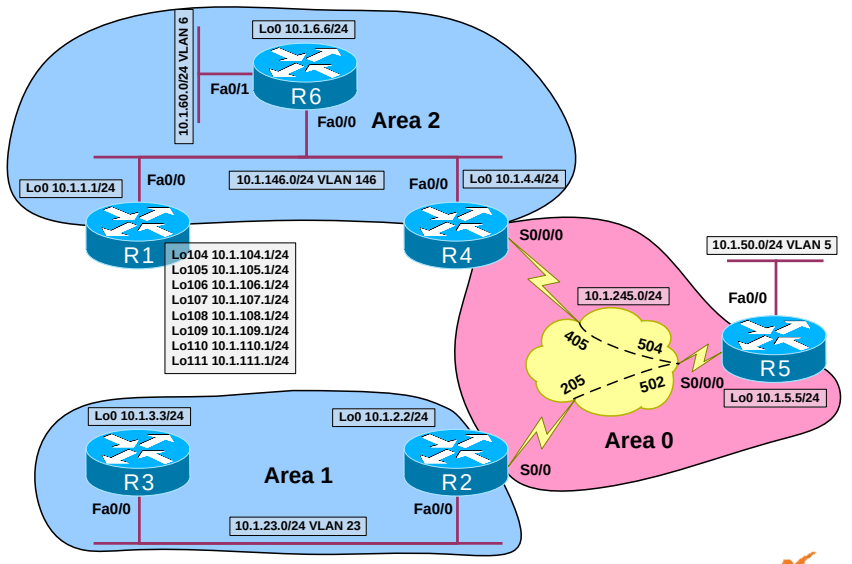
OSPF External Summarization Example



OSPF External Summarization Configuration

```
R1#
interface Loopback104
 ip address 10.1.104.1 255.255.255.0
!
interface Loopback105
 ip address 10.1.105.1 255.255.255.0
!
interface Loopback106
 ip address 10.1.106.1 255.255.255.0
!
interface Loopback107
 ip address 10.1.107.1 255.255.255.0
!
interface Loopback108
 ip address 10.1.108.1 255.255.255.0
!
interface Loopback109
 ip address 10.1.109.1 255.255.255.0
!
interface Loopback110
 ip address 10.1.110.1 255.255.255.0
!
interface Loopback111
 ip address 10.1.111.1 255.255.255.0
!
router ospf 1
 summary-address 10.1.104.0 255.255.248.0
 redistribute connected subnets
```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External Summarization Verification

```
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, 21 subnets, 4 masks
C       10.1.1.0/24 is directly connected, Loopback0
O       10.1.6.6/32 [110/2] via 10.1.146.6, 00:12:37, FastEthernet0/0
O IA    10.1.5.5/32 [110/66] via 10.1.146.4, 00:12:37, FastEthernet0/0
O       10.1.4.4/32 [110/2] via 10.1.146.4, 00:12:37, FastEthernet0/0
O IA    10.1.3.3/32 [110/67] via 10.1.146.4, 00:12:37, FastEthernet0/0
O IA    10.1.2.2/32 [110/66] via 10.1.146.4, 00:12:37, FastEthernet0/0
O IA    10.1.23.0/24 [110/66] via 10.1.146.4, 00:12:38, FastEthernet0/0
O IA    10.1.32.0/22 [110/67] via 10.1.146.4, 00:12:38, FastEthernet0/0
O       10.1.60.0/24 [110/2] via 10.1.146.6, 00:12:38, FastEthernet0/0
O E2    10.1.50.0/24 [110/20] via 10.1.146.4, 00:12:38, FastEthernet0/0
C       10.1.107.0/24 is directly connected, Loopback107
C       10.1.106.0/24 is directly connected, Loopback106
C       10.1.105.0/24 is directly connected, Loopback105
C       10.1.104.0/24 is directly connected, Loopback104
O       10.1.104.0/21 is a summary, 00:04:25, Null0
C       10.1.111.0/24 is directly connected, Loopback111
C       10.1.110.0/24 is directly connected, Loopback110
C       10.1.109.0/24 is directly connected, Loopback109
C       10.1.108.0/24 is directly connected, Loopback108
C       10.1.146.0/24 is directly connected, FastEthernet0/0
O IA    10.1.245.0/24 [110/65] via 10.1.146.4, 00:12:38, FastEthernet0/0
```


External Summarization Verification (cont.)

```
R3#show ip route ospf
     10.0.0.0/8 is variably subnetted, 16 subnets, 3 masks
O IA    10.1.6.6/32 [110/67] via 10.1.23.2, 00:28:51, FastEthernet0/0
O IA    10.1.5.5/32 [110/66] via 10.1.23.2, 00:28:51, FastEthernet0/0
O IA    10.1.4.4/32 [110/66] via 10.1.23.2, 00:28:51, FastEthernet0/0
O       10.1.2.2/32 [110/2] via 10.1.23.2, 00:28:51, FastEthernet0/0
O IA    10.1.1.1/32 [110/67] via 10.1.23.2, 00:28:51, FastEthernet0/0
O IA    10.1.60.0/24 [110/67] via 10.1.23.2, 00:28:51, FastEthernet0/0
O E2    10.1.50.0/24 [110/20] via 10.1.23.2, 00:11:28, FastEthernet0/0
O E2    10.1.104.0/21 [110/20] via 10.1.23.2, 00:07:20, FastEthernet0/0
O IA    10.1.146.0/24 [110/66] via 10.1.23.2, 00:28:51, FastEthernet0/0
O IA    10.1.245.0/24 [110/65] via 10.1.23.2, 00:28:51, FastEthernet0/0

R3#show ip ospf database external 10.1.104.0

            OSPF Router with ID (10.1.3.3) (Process ID 1)

                Type-5 AS External Link States

  Routing Bit Set on this LSA
  LS age: 460
  Options: (No TOS-capability, DC)
  LS Type: AS External Link
  Link State ID: 10.1.104.0 (External Network Number )
  Advertising Router: 10.1.1.1
  LS Seq Number: 80000002
  Checksum: 0x48DD
  Length: 36
  Network Mask: /21
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 20
        Forward Address: 0.0.0.0
        External Route Tag: 0
```


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