OSPF Virtual Links: Transit capability

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Introduction

The purpose of this document is to demonstrate the Open Shortest Path First (OSPF) behavior when the V-bit (Virtual-link bit) is present in a non-backbone area. The V-bit is signaled in Type-1 LSA only if the router is the endpoint of one or more fully adjacent virtual links. When the V-bit is set this could change path calculation preference between intra-area and inter-area routes.

Prerequisites

Refer to the network diagram in Figure 1 as you use this document:

![Network Diagram](image)

Figure 1

In the network diagram above, we have both backbone area 0 and non-backbone area 1. R1 is an Area Border Router (ABR) connecting both area 0 and area 1, R4 and R3 have a similar role in this network. In this topology area 0 is discontiguous since R3 and R4 are not connected via area 0.

Background Information
All areas in an OSPF autonomous system must be connected to the backbone area (area 0). In some cases where you have a non-backbone area between your backbone area, this could cause some areas of the autonomous system to become unreachable and results in your network being discontiguous. When it is not possible to have a contiguous backbone area, you may use a virtual link to connect your backbone through a non-backbone area. The area through which you configure the virtual link is known as a transit area.

**Scenario 1**

**Network Diagram:**

![Network Diagram](image)

**Figure 2**

In this scenario, we will be going over expected path calculation in the above network topology. We will be investigating what path is preferred when routing from R1 towards R6 loopback 100 which has an ip address of 192.0.2.100/32.

Let's have a look at the OSPF database on R1 to further understand the topology:

```
R1#show ip ospf database

OSPF Router with ID (1.1.1.1) (Process ID 1)

Router Link States (Area 0)

Link ID  ADV Router  Age  Seq#  Checksum  Link count
1.1.1.1  1.1.1.1    22   0x8000000C  0x00CD7A  2
4.4.4.4  4.4.4.4    289  0x8000000F  0x00434E  4
6.6.6.6  6.6.6.6    374  0x80000009  0x00630A  3

Summary Net Link States (Area 0)

Link ID  ADV Router  Age  Seq#  Checksum
192.168.13.0  1.1.1.1    18   0x80000001  0x00348D
192.168.13.0  4.4.4.4    207  0x80000001  0x00E3D0
192.168.34.0  1.1.1.1     8   0x80000001  0x005655
192.168.34.0  4.4.4.4    683  0x80000001  0x00F1AE

Router Link States (Area 1)

Link ID  ADV Router  Age  Seq#  Checksum  Link count
1.1.1.1  1.1.1.1    17   0x80000009  0x00EC2B  2
3.3.3.3  3.3.3.3    18   0x8000000E  0x005A64  4
```
4.4.4.4 4.4.4.4 544 0x80000005 0x0007CF 2

Summary Net Link States (Area 1)

<table>
<thead>
<tr>
<th>Link ID</th>
<th>ADV Router</th>
<th>Age</th>
<th>Seq#</th>
<th>Checksum</th>
</tr>
</thead>
<tbody>
<tr>
<td>155.1.37.0</td>
<td>3.3.3.3</td>
<td>1558</td>
<td>0x80000004</td>
<td>0x00A7C3</td>
</tr>
<tr>
<td>192.0.2.100</td>
<td>1.1.1.1</td>
<td>23</td>
<td>0x80000001</td>
<td>0x009F0C</td>
</tr>
<tr>
<td>192.0.2.100</td>
<td>4.4.4.4</td>
<td>370</td>
<td>0x80000001</td>
<td>0x0059AA</td>
</tr>
<tr>
<td>192.168.14.0</td>
<td>1.1.1.1</td>
<td>23</td>
<td>0x80000001</td>
<td>0x000B52</td>
</tr>
<tr>
<td>192.168.14.0</td>
<td>4.4.4.4</td>
<td>331</td>
<td>0x80000001</td>
<td>0x00CEE5</td>
</tr>
<tr>
<td>192.168.34.0</td>
<td>1.1.1.1</td>
<td>3608</td>
<td>0x80000002</td>
<td>0x00406C</td>
</tr>
<tr>
<td>192.168.46.0</td>
<td>1.1.1.1</td>
<td>23</td>
<td>0x80000001</td>
<td>0x00B388</td>
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<td>4.4.4.4</td>
<td>484</td>
<td>0x80000001</td>
<td>0x006D27</td>
</tr>
</tbody>
</table>

From the above output we can see that R1 learns R6 Lo100:192.0.2.100 via R4 as a Type-3 Summary LSA, R1 is also originating itself a Type-3 Summary LSA since it knows R6 Lo100:192.0.2.100 via intra-area backbone. In the below output we can see that R6 has 192.0.2.100 directly connected.

R1#show ip ospf da router 6.6.6.6

OSPF Router with ID (1.1.1.1) (Process ID 1)

Router Link States (Area 0)

LS age: 614
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 6.6.6.6
Advertising Router: 6.6.6.6
LS Seq Number: 8000000D
Checksum: 0x5B0E
Length: 60
Number of Links: 3

Link connected to: a Stub Network
(Link ID) Network/subnet number: 192.0.2.100 <-- Loopback 100 directly connected
(Link Data) Network Mask: 255.255.255.255
Number of MTID metrics: 0
TOS 0 Metrics: 1

Link connected to: another Router (point-to-point)
(Link ID) Neighboring Router ID: 4.4.4.4
(Link Data) Router Interface address: 192.168.46.6
Number of MTID metrics: 0
TOS 0 Metrics: 1

Link connected to: a Stub Network
(Link ID) Network/subnet number: 192.168.46.0
(Link Data) Network Mask: 255.255.255.0
Number of MTID metrics: 0
TOS 0 Metrics: 1

Abstract from RFC 2328 Section 16.2

16.2. Calculating the inter-area routes

(5) Next, look up the routing table entry for the destination N.
If N is an AS boundary router, look up the "router" routing table entry associated with Area A. If no entry exists for N or if the entry’s path type is "type 1 external" or "type 2 external", then install the inter-area path to N, with associated area Area A, cost IAC, next hop equal to the list of next hops to router BR, and Advertising router equal to BR.

6) Else, if the paths present in the table are intra-area paths, do nothing with the LSA (intra-area paths are always preferred).

7) Else, the paths present in the routing table are also inter-area paths. Install the new path through BR if it is cheaper, overriding the paths in the routing table. Otherwise, if the new path is the same cost, add it to the list of paths that appear in the routing table entry.

In the above output we can see that it is stated intra-area routes are preferred over inter-area routes. So in our scenario R1 should prefer going via intra-area backbone per RFC 2328.

Let's check if this behaviour is observed in our topology:

R1#show ip ospf rib 192.0.2.100

OSPF Router with ID (1.1.1.1) (Process ID 1)

Base Topology (MTID 0)

OSPF local RIB
Codes: * - Best, > - Installed in global RIB
LSA: type/LSID/originator

*> 192.0.2.100/32, Intra, cost 102, area 0
SPF Instance 9, age 02:19:34
Flags: RIB, HiPrio
via 192.168.14.4, GigabitEthernet3 label 1048578
Flags: RIB
LSA: 1/6.6.6.6/6.6.6.6

R1#show ip route 192.0.2.100
Routing entry for 192.0.2.100/32
Known via "ospf 1", distance 110, metric 102, type intra area
Last update from 192.168.14.4 on GigabitEthernet3, 02:26:29 ago
Routing Descriptor Blocks:
* 192.168.14.4, from 6.6.6.6, 02:26:29 ago, via GigabitEthernet3
Route metric is 102, traffic share count is 1

As you can see from the outputs above we prefer going over backbone area 0 towards R6 loopback100. In our Link State Database we are also aware of an inter-area path through R3 then R4. The summary LSA which is learned via R4 with a cost of 2 can be seen below:

R1#show ip ospf database summary 192.0.2.100

OSPF Router with ID (1.1.1.1) (Process ID 1)

Summary Net Link States (Area 1)

LS age: 523
Options: (No TOS-capability, DC, Upward)
LS Type: Summary Links(Network)
**Scenario 2**

Network Diagram:
In this scenario we set the V-bit on R3 and R4 so we could check path preference when this bit is present in Type-1 LSA of non-backbone area 1.

Abstract from RFC 2328 Section 6

6. The Area Data Structure

TransitCapability
This parameter indicates whether the area can carry data traffic that neither originates nor terminates in the area itself. This parameter is calculated when the area’s shortest-path tree is built (see Section 16.1, where TransitCapability is set to TRUE if and only if there are one or more fully adjacent virtual links using the area as Transit area), and is used as an input to a subsequent step of the routing table build process (see Section 16.3). When an area’s TransitCapability is set to TRUE, the area is said to be a “transit area”.

Abstract from RFC 2328 Section 16.1

16.1 Calculating the shortest-path tree for an area

(2) Call the vertex just added to the tree vertex V. Examine the LSA associated with vertex V. This is a lookup in the Area A's link state database based on the Vertex ID. If this is a router-LSA, and bit V of the router-LSA (see Section A.4.2) is set, set Area A's TransitCapability to TRUE. In any case, each link described by the LSA gives the cost to an adjacent vertex. For each described link, (say it joins vertex V to vertex W):

From the above statement in RFC we can see that when the V-bit is set in the router-LSA, we know that area in which the bit is set to be transit capable or in other words when running Dijkstra algorithm the TransitCapability is true for that area.
Once we know that an area could be considered for capability transit if there is a V-bit set, we must check if this functionality is configured. The OSPF Area Transit Capability feature is enabled by default.

R1#show run all | sec ospf
capability opaque
capability lls
capability transit

To set the V-bit in area 1 we will create a virtual-link from R3 towards R4. When the virtual link is brought up, we should see the V-bit set in the Type-1 LSA.

R3(config)#router ospf 1
R3(config-router)#area 1 virtual-link 4.4.4.4

As we can see in the above output, R3 now has the V-bit set on its Type-1 LSA for area 1 and has capability transit enabled in routing process level.
We can also see that R1 has capability transit enabled for area 1 in the below output:

```
R1#show ip ospf
Routing Process "ospf 1" with ID 1.1.1.1
Start time: 00:02:48.412, Time elapsed: 01:27:00.690
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Supports NSSA (compatible with RFC 3101)
Supports Database Exchange Summary List Optimization (RFC 5243)
Event-log enabled, Maximum number of events: 1000, Mode: cyclic
It is an area border router
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msecs
Minimum hold time between two consecutive SPFs 10000 msecs
Maximum wait time between two consecutive SPFs 10000 msecs
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msecs
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msecs
Retransmission pacing timer 66 msecs
EXCHANGE/LOADING adjacency limit: initial 300, process maximum 300
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 2. 2 normal 0 stub 0 nssa
Number of areas transit capable is 1
External flood list length 0
IETF NSF helper support enabled
Cisco NSF helper support enabled
Reference bandwidth unit is 100 mbps
Area BACKBONE(0)
    Number of interfaces in this area is 1
    Area has no authentication
    SPF algorithm last executed 00:00:33.554 ago
    SPF algorithm executed 11 times
    Area ranges are
    Number of LSA 10. Checksum Sum 0x05EB7B
    Number of opaque link LSA 0. Checksum Sum 0x000000
    Number of DCbitless LSA 0
    Number of indication LSA 0
    Number of DoNotAge LSA 0
    Flood list length 0
Area 1
    Number of interfaces in this area is 1
    This area has transit capability <-- This area is transit capabile
    Area has no authentication
    SPF algorithm last executed 00:00:04.259 ago
    SPF algorithm executed 8 times
    Area ranges are
    Number of LSA 10. Checksum Sum 0x0517AA
    Number of opaque link LSA 0. Checksum Sum 0x000000
    Number of DCbitless LSA 0
    Number of indication LSA 0
    Number of DoNotAge LSA 0
    Flood list length 0
```
Since area 1 now passes all criteria to become a transit area we should now observe a different path calculation/preference then seen before in our first scenario.

It is stated RFC 2328 if an area is considered as transit area it should be examined differently than non-transit areas

Abstract from RFC 2328 Section 16.1

16.3. Examining transit areas' summary-LSAs

This step is only performed by area border routers attached to one or more non-backbone areas that are capable of carrying transit traffic (i.e., "transit areas", or those areas whose TransitCapability parameter has been set to TRUE in Step 2 of the Dijkstra algorithm (see Section 16.1).

The purpose of the calculation below is to examine the transit areas to see whether they provide any better (shorter) paths than the paths previously calculated in Sections 16.1 and 16.2. Any paths found that are better than or equal to previously discovered paths are installed in the routing table.

According to the RFC, if the area is transit-capable, it is subject to the path calculation described in section 16.3 of RFC 2328

Note: that in this example the virtual link enables transit data traffic to be forwarded through Area 1, but the actual path the transit data traffic takes does not need follow the virtual link. In other words, virtual links allow transit traffic to be forwarded through an area, but do not dictate the precise path that the traffic will take.

Let's assume capability transit was disabled on R1. Let's check the path towards the destination R6 loopback:100 192.0.2.100 with a traceroute.

R1#traceroute 192.0.2.100
Tracing the route to 192.0.2.100
VRF info: (vrf in name/id, vrf out name/id)
1 192.168.14.4 2 msec 2 msec 2 msec <--R4
2 192.168.46.6 3 msec 3 msec * <--R6

Once we turn this functionality on with the V-bit set in area 1 we observe the following logs:

R1#debug ip ospf spf intra
OSPF SPF intra debugging is on
R1#debug ip ospf spf inter OSPF SPF inter debugging is on R1(config)#router ospf 1 R1(config-router)#capability transit R1(config-router)#
*Aug 14 15:28:07.934: OSPF-1 INTER: Running spf for summaries in transit area 1
*Aug 14 15:28:07.934: OSPF-1 INTER: Summary transit processing lsid 192.0.2.100 adv_rtr 4.4.4.4 type 3 seq 0x8000000B
*Aug 14 15:28:07.934: OSPF-1 INTER: Summary metric 2
*Aug 14 15:28:07.934: OSPF-1 INTER: found best path to adv_rtr: i,ABR [2] via 192.168.13.3, GigabitEthernet1, Area 1 orp_texit_adv_rtr 0.0.0.0 pathflag 0x0
*Aug 14 15:28:07.934: OSPF-1 INTER: Add transit path via area 1
*Aug 14 15:28:07.934: OSPF-1 INTRA: Route update succeeded for 192.0.2.100/255.255.255.255, metric 4, Next Hop: GigabitEthernet1/192.168.13.3 area 0

Now let's check how R1 routes towards R6 loopback100
**Abstract from RFC 2328 Section 16.3**

16.3. Examining transit areas' summary-LSAs

(4) Look up the routing table entry for the advertising router BR associated with the Area A. If it is unreachable, examine the next LSA. Otherwise, the cost to destination N is the sum of the cost in BR's Area A routing table entry and the cost advertised in the LSA. Call this cost IAC.

(5) If this cost is less than the cost occurring in N's routing table entry, overwrite N's list of next hops with those used for BR, and set N's routing table cost to IAC. Else, if IAC is the same as N's current cost, add BR's list of next hops to N's list of next hops. In any case, the area associated with N's routing table entry must remain the backbone area, and the path type (either intra-area or inter-area) must also remain the same.

R1 is preferring inter-area Type-3 over Type-1 intra-area route, although it is stated as intra-area in the output. We clearly see the next-hop is not associated to area 0.
Neighbor 4.4.4.4, interface address 192.168.14.4
In the area 0 via interface GigabitEthernet3
Neighbor priority is 0, State is FULL, 6 state changes
DR is 0.0.0.0 BDR is 0.0.0.0
Options is 0x12 in Hello (E-bit, L-bit)
Options is 0x52 in DBD (E-bit, L-bit, O-bit)
LLS Options is 0x1 (LR)
Dead timer due in 00:00:36
Neighbor is up for 00:30:20
Index 1/1/1, retransmission queue length 0, number of retransmission 3
First 0x0(0)/0x0(0)/0x0(0) Next 0x0(0)/0x0(0)/0x0(0)
Last retransmission scan length is 1, maximum is 2
Last retransmission scan time is 135 msec, maximum is 135 msec

Neighbor 3.3.3.3, interface address 192.168.13.3
In the area 1 via interface GigabitEthernet1
Neighbor priority is 0, State is FULL, 6 state changes
DR is 0.0.0.0 BDR is 0.0.0.0
Options is 0x12 in Hello (E-bit, L-bit)
Options is 0x52 in DBD (E-bit, L-bit, O-bit)
LLS Options is 0x1 (LR)
Dead timer due in 00:00:39
Neighbor is up for 00:30:20
Index 1/1/2, retransmission queue length 0, number of retransmission 3
First 0x0(0)/0x0(0)/0x0(0) Next 0x0(0)/0x0(0)/0x0(0)
Last retransmission scan length is 4, maximum is 4
Last retransmission scan time is 126 msec, maximum is 126 msec

Let's also traceroute towards the destination of R6 loopback100:

R1#traceroute 192.0.2.100
Tracing the route to 192.0.2.100
VRF info: (vrf in name/id, vrf out name/id)
1 192.168.13.3 2 msec 4 msec 3 msec <-- R3
2 192.168.34.4 5 msec 3 msec 3 msec <-- R4
3 192.168.46.6 5 msec 6 msec * <-- R6
R1#
Hence in the above output we see that the non-backbone area 1 is preferred over the backbone area 0 to reach R6 loopback 100.

It is also possible to have ECMP (Equal Cost Multipath) using both intra-area and inter-area routes if the cost between them is equal. This could be done in our topology by decreasing R1s link towards R4 from 100 to 2.

When this is done we have the following output in both RIB and OSPF RIB:

R1#show ip ospf rib 192.0.2.100 OSPF Router with ID (1.1.1.1) (Process ID 1) Base Topology (MTID 0) OSPF local RIB Codes: * - Best, > - Installed in global RIB LSA: type/LSID/originator type/LSID/originator type/LSID/originator type/LSID/originator * 192.168.14.4, GigabitEthernet3 label 1048578 Flags: RIB LSA: 1/6.6.6.6/6.6.6.6 via 192.168.14.4, GigabitEthernet3 label 1048578 Flags: RIB LSA: 1/6.6.6.6/6.6.6.6

R1#show ip route 192.0.2.100
Routing entry for 192.0.2.100/32
Known via "ospf 1", distance 110, metric 4, type intra area
Last update from 192.168.14.4 on GigabitEthernet3, 00:12:44 ago
Routing Descriptor Blocks:
192.168.14.4, from 6.6.6.6, 00:12:44 ago, via GigabitEthernet3
Route metric is 4, traffic share count is 1
* 192.168.13.3, from 6.6.6.6, 00:12:44 ago, via GigabitEthernet1
Route metric is 4, traffic share count is 1