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OSPF extensions for Computed Multicast applied to MPLS based Segment
Routing
draft-allan-ospf-spring-multicast-00

Abstract

This document describes the OSPFv2 extensions required to support multicast for MPLS based Segment Routing. In this approach OSPF speakers compute their role in multicast tree construction based on the information in the OSPF routing information base.

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1. Introduction

[ALLAN-1] describes a solution for multicast for Segment Routing with MPLS data plane in which source specific multicast distribution trees (MDTs) are computed from information distributed via an IGP. Using this approach, both any-source multicast (ASM) and engineered p2mp trees can be supported.

This memo describes three additional TLVs for OSPF to support the segment routing multicast approach described in [ALLAN-1]

1.1. Authors

David Allan, Uma Chunduri

1.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC2119 [RFC2119].

2. Conventions used in this document

2.1. Terminology

Candidate replication point - is a node will potentially need to install state as determined at some intermediate step in MDT computation. It will either resolve to having no role or a role as a replication point once multicast has converged.

Candidate role - refers to any potential combination of roles on a given MDT as determined at some intermediate step in MDT computation. For example, a node with a candidate role may be a leaf and may be a candidate replication point.

Downstream - refers to the direction along the shortest path to one or more leaves for a given multicast distribution tree

Multicast convergence - is when all computation and state installation to ensure the FIB reflects the multicast information in the IGP is complete.

Pinned path - Is a unique shortest path extending from a leaf upstream towards the root for a given MDT. Therefore is a component of an MDT that must be there. It will not necessarily extend from the leaf all the way to the root during intermediate computation steps. A pinned path can result from pruning operations.

Role - refers specifically to a node that is either a root, a leaf or a replication node for a given multicast distribution tree

Unicast convergence- is when all computation and state installation to ensure the FIB reflects the unicast information in the IGP is complete.

Upstream - refers to the direction along the shortest path to the root of a given multicast distribution tree

3. Overview

The role of the IGP in the multicast architecture described in [ALLAN-1] is to synchronize knowledge of the topology, knowledge of

unicast SIDs, knowledge of multicast SIDs, multicast group membership and agreement on the algorithm to use for computation of multicast distribution trees(MDTs) across the set of IGP speakers. This document specifies the TLVs necessary for OSPF version 2 to be the IGP in said multicast architecture.

4. New TLVs

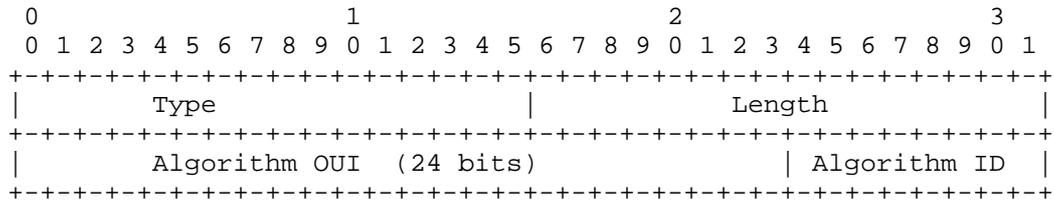
4.1. Additional Router Information TLVs

The following three TLV are in the Router Information Opaque LSA specified in RFC 7770 for SRM compute capabilities and other TLVs in OSPFv2 Extended Prefix Opaque LSA as specified in [RFC7684].

4.1.1. SRM Compute Capability TLV

The presence of this TLV in a router information LSA [RFC7770] indicates both that the originating node supports computed spring multicast, but also indicates the algorithm that is configured to be used. All nodes supporting computed multicast are required to agree on the algorithm for correct operation of the network.

The format of the sub-TLV is:



Where:

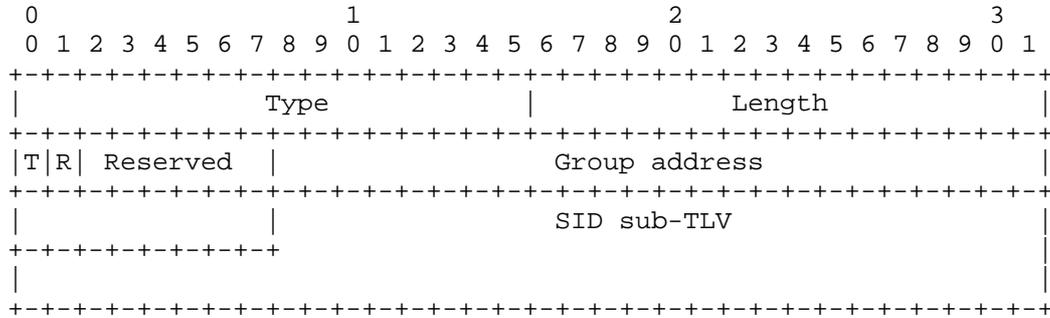
The upper 24 bits contains an organizationally unique identifier (as per RFC 7042) and the lower 8 bits contains an algorithm identifier.

The default algorithm supported as per [ALLAN-1] is identified by Algorithm OUI = 0x008037 (Ericsson), Algorithm ID = 0x01 (default).

4.1.2. SRM SID Multicast Group Binding Sub-TLV

The SID Multicast Group Binding TLV communicates the binding between the SID specific to the MDT for the multicast group originating at the advertising node and the multicast group address, as well as transmit and receive interest for the advertising node. Note that if the sub-TLV does not have the T bit set, the SID TLV is not included

in the message. This sub-TLV is part of OSPFv2 Extended Prefix TLV as a sub-TLV from OSPFv2 Extended Prefix Opaque LSA as specified in [RFC7684].



Where:

Type = TBD (IANA assignment from OSPFv2 Extended Prefix TLV Sub-TLVs Registry)

Length = octet size of the T/R, reserved fields, Group ID and the SID sub-tlv information

T-bit indicates that this node is a source for the multicast group specified in the sub-tlv.

R-bit indicates that this node is a receiver for the multicast group specified in the sub-tlv.

Group ID: 4 octet IPv4 multicast address

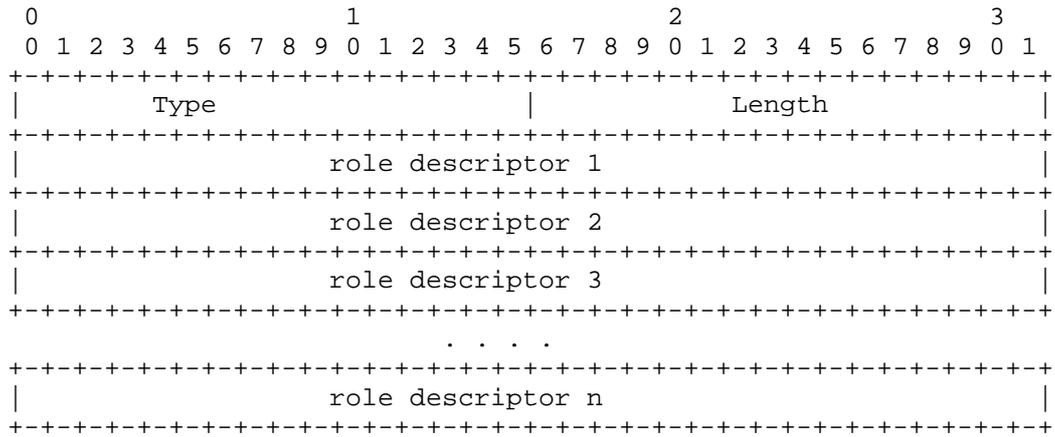
SID sub-TLV = the segment ID to use for this source/group MDT. The format is as per the SID/label sub-TLV defined in section 2.1 of [SPRING-OSPF].

4.1.3. SRM Pinned Tree Descriptor sub-TLV

The pinned tree descriptor defines all nodes that have a role in a multicast distribution tree, and their relationship to the individual multicast segments that define the tree. This sub-TLV is part of OSPFv2 Extended Prefix TLV as a sub-TLV from OSPFv2 Extended Prefix Opaque LSA as specified in [RFC7684]. The encoding is an unstructured list, where if the tree description exceeds the size, it may simply use more than one sub-TLV.

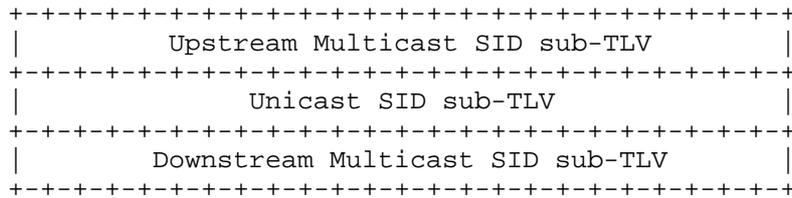
The encoding of a role descriptor is in the form of upstream_SID/unicast_SID/downstream_SID, where each of the SIDs is encoded as a sub-TLV as per [SPRING-OSPF].

The root of the MDT (and originator of the TLV) will have a NULL upstream SID, transit waypoints will have both a defined upstream and downstream multicast segment SID, and a leaf will have a NULL downstream SID. The unicast SID corresponds to the node for which the entry defines its role.



Where:

The encoding of a role descriptor is in the form:



5. Acknowledgements

6. Security Considerations

For a future version of this document.

7. IANA Considerations

This memo requires the assignment of 1 value from the OSPF Router Information (RI) TLV registry:

- SRM Compute Capability TLV

This memo also requires the assignment of the following 2 Sub-TLV values from the OSPFv2 Extended Prefix TLV Sub-TLV registry:

- SRM SID Multicast Group Binding sub-TLV
- SRM Pinned Tree Descriptor sub-TLV

8. References

8.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.
- [RFC7042] Eastlake, D. et. al., "IANA Considerations and IETF Protocol and Documentation Usage for IEEE 802 Parameters", IETF RFC 7042, October 2013
- [RFC7684] Psenak et.al., "OSPFv2 Prefix/Link Attribute Advertisement", IETF RFC 7684, November 2015
- [RFC7770] Lindem et.al., "Extensions to OSPF for Advertising Optional Router Capabilities", IETF RFC 7770, February 2016
- [SPRING-OSPF] Psenak et.al., "OSPF Extensions for Segment Routing", IETF work in progress, draft-ietf-ospf-segment-routing-extensions-08, April 2016

8.2. Informative References

- [ALLAN-1] Allan et.al., "A Framework for Computed Multicast applied to MPLS based Segment Routing", draft-allan-spring-mpls-mcast-framework-01, July 2016

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Open Shortest Path First IGP
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OSPFv3 Extensions for Segment Routing
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Abstract

Segment Routing (SR) allows a flexible definition of end-to-end paths within IGP topologies by encoding paths as sequences of topological sub-paths, called "segments". These segments are advertised by the link-state routing protocols (IS-IS and OSPF).

This draft describes the OSPFv3 extensions required for Segment Routing with MPLS data plane.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

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1. Introduction

Segment Routing (SR) allows a flexible definition of end-to-end paths within IGP topologies by encoding paths as sequences of topological sub-paths, called "segments". These segments are advertised by the link-state routing protocols (IS-IS and OSPF). Prefix segments represent an ECMP-aware shortest-path to a prefix (or a node), as per the state of the IGP topology. Adjacency segments represent a hop over a specific adjacency between two nodes in the IGP. A prefix segment is typically a multi-hop path while an adjacency segment, in most cases, is a one-hop path. SR's control-plane can be applied to both IPv6 and MPLS data-planes, and does not require any additional signalling (other than IGP extensions). The IPv6 data plane is out of the scope of this specification - OSPFv3 extension for SR with IPv6 data plane will be specified in a separate document. When used in MPLS networks, SR paths do not require any LDP or RSVP-TE signalling. However, SR can interoperate in the presence of LSPs established with RSVP or LDP.

This draft describes the OSPFv3 extensions required for Segment Routing with MPLS data plane.

Segment Routing architecture is described in [RFC8402].

Segment Routing use cases are described in [RFC7855].

2. Terminology

This section lists some of the terminology used in this document:

ABR - Area Border Router

Adj-SID - Adjacency Segment Identifier

AS - Autonomous System

ASBR - Autonomous System Boundary Router

DR - Designated Router

IS-IS - Intermediate System to Intermediate System

LDP - Label Distribution Protocol

LSP - Label Switched Path

MPLS - Multi Protocol Label Switching

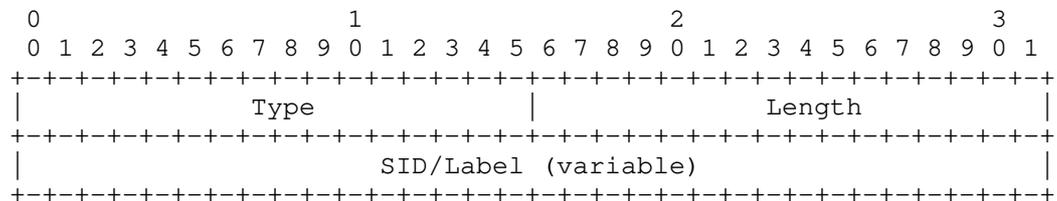
- OSPF - Open Shortest Path First
- SPF - Shortest Path First
- RSVP - Resource Reservation Protocol
- SID - Segment Identifier
- SR - Segment Routing
- SRGB - Segment Routing Global Block
- SRLB - Segment Routing Local Block
- SRMS - Segment Routing Mapping Server
- TLV - Type Length Value

3. Segment Routing Identifiers

Segment Routing defines various types of Segment Identifiers (SIDs): Prefix-SID, Adjacency-SID, and LAN Adjacency SID.

3.1. SID/Label Sub-TLV

The SID/Label Sub-TLV appears in multiple TLVs or Sub-TLVs defined later in this document. It is used to advertise the SID or label associated with a prefix or adjacency. The SID/Label Sub-TLV has following format:



where:

Type: 7

Length: Either 3 or 4 octets

SID/Label: If length is set to 3, then the 20 rightmost bits represent a label. If length is set to 4, then the value represents a 32-bit SID.

The receiving router MUST ignore the SID/Label Sub-TLV if the length is other than 3 or 4.

4. Segment Routing Capabilities

Segment Routing requires some additional router capabilities to be advertised to other routers in the area.

These SR capabilities are advertised in the OSPFv3 Router Information Opaque LSA (defined in [RFC7770]) and specified in [I-D.ietf-ospf-segment-routing-extensions].

5. OSPFv3 Extended Prefix Range TLV

In some cases it is useful to advertise attributes for a range of prefixes in a single advertisement. The Segment Routing Mapping Server, which is described in [I-D.ietf-spring-segment-routing-ldp-interop], is an example of where SIDs for multiple prefixes can be advertised. To optimize such advertisement in case of multiple prefixes from a contiguous address range, OSPFv3 Extended Prefix Range TLV is defined."

The OSPFv3 Extended Prefix Range TLV is a top-level TLV of the following LSAs defined in [RFC8362]:

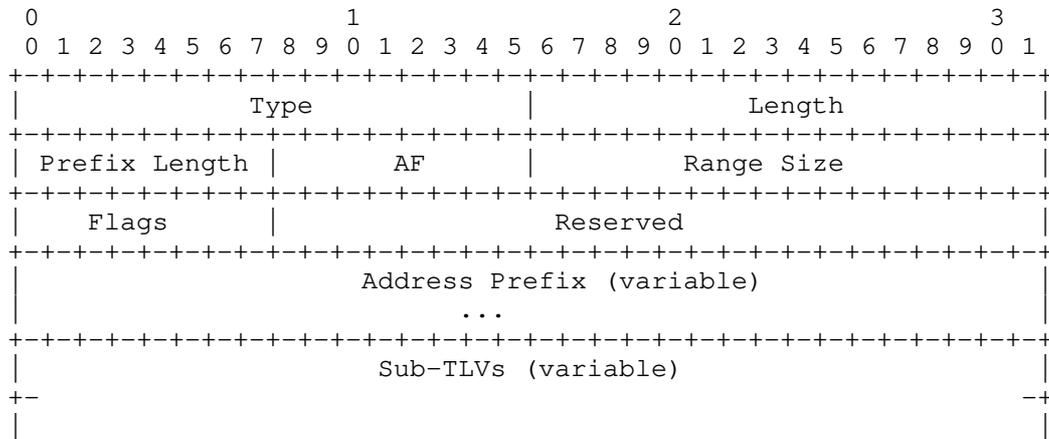
E-Intra-Area-Prefix-LSA

E-Inter-Area-Prefix-LSA

E-AS-External-LSA

E-Type-7-LSA

Multiple OSPFv3 Extended Prefix Range TLVs MAY be advertised in each LSA mentioned above. The OSPFv3 Extended Prefix Range TLV has the following format:



where:

Type: 9

Length: Variable, in octets, dependent on Sub-TLVs.

Prefix length: Length of prefix in bits.

AF: Address family for the prefix.

AF: 0 - IPv4 unicast

AF: 1 - IPv6 unicast

Range size: Represents the number of prefixes that are covered by the advertisement. The Range Size MUST NOT exceed the number of prefixes that could be satisfied by the prefix length without including:

Addresses from the IPv4 multicast address range (224.0.0.0/3), if the AF is IPv4 unicast

Addresses other than the IPv6 unicast addresses, if the AF is IPv6 unicast

Flags: Reserved. MUST be zero when sent and are ignored when received.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Address Prefix:

For the address family IPv4 unicast, the prefix itself is encoded as a 32-bit value. The default route is represented by a prefix of length 0.

For the address family IPv6 unicast, the prefix, encoded as an even multiple of 32-bit words, padded with zeroed bits as necessary. This encoding consumes $((\text{PrefixLength} + 31) / 32)$ 32-bit words.

Prefix encoding for other address families is beyond the scope of this specification. Prefix encoding for other address families can be defined in the future standard-track IETF specifications.

The range represents the contiguous set of prefixes with the same prefix length as specified by the Prefix Length field. The set starts with the prefix that is specified by the Address Prefix field. The number of prefixes in the range is equal to the Range size.

If the OSPFv3 Extended Prefix Range TLVs advertising the exact same range appears in multiple LSAs of the same type, originated by the same OSPFv3 router, the LSA with the numerically smallest Instance ID MUST be used and subsequent instances of the OSPFv3 Extended Prefix Range TLVs MUST be ignored.

6. Prefix SID Sub-TLV

The Prefix SID Sub-TLV is a Sub-TLV of the following OSPFv3 TLVs as defined in [RFC8362] and in Section 5:

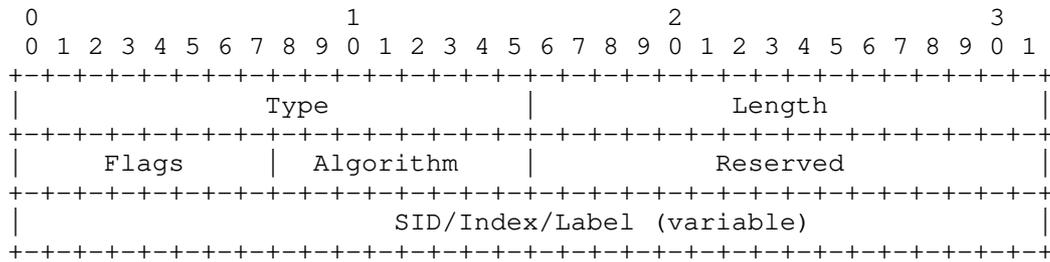
Intra-Area Prefix TLV

Inter-Area Prefix TLV

External Prefix TLV

OSPFv3 Extended Prefix Range TLV

It MAY appear more than once in the parent TLV and has the following format:

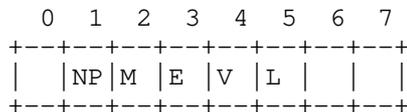


where:

Type: 4

Length: 7 or 8 octets, dependent on the V-flag

Flags: Single octet field. The following flags are defined:



where:

NP-Flag: No-PHP flag. If set, then the penultimate hop MUST NOT pop the Prefix-SID before delivering packets to the node that advertised the Prefix-SID.

M-Flag: Mapping Server Flag. If set, the SID was advertised by a Segment Routing Mapping Server as described in [I-D.ietf-spring-segment-routing-ldp-interop].

E-Flag: Explicit-Null Flag. If set, any upstream neighbor of the Prefix-SID originator MUST replace the Prefix-SID with the Explicit-NULL label (0 for IPv4, 2 for IPv6) before forwarding the packet.

V-Flag: Value/Index Flag. If set, then the Prefix-SID carries an absolute value. If not set, then the Prefix-SID carries an index.

L-Flag: Local/Global Flag. If set, then the value/index carried by the Prefix-SID has local significance. If not set, then the value/index carried by this Sub-TLV has global significance.

Other bits: Reserved. These MUST be zero when sent and are ignored when received.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Algorithm: Single octet identifying the algorithm the Prefix-SID is associated with as defined in [I-D.ietf-ospf-segment-routing-extensions].

A router receiving a Prefix-SID from a remote node and with an algorithm value that such remote node has not advertised in the SR-Algorithm Sub-TLV [I-D.ietf-ospf-segment-routing-extensions] MUST ignore the Prefix-SID Sub-TLV.

SID/Index/Label: According to the V-Flag and L-Flag, it contains:

V-flag is set to 0 and L-flag is set to 0: The SID/Index/Label field is a 4 octet index defining the offset in the SID/Label space advertised by this router

V-flag is set to 1 and L-flag is set to 1: The SID/Index/Label field is a 3 octet local label where the 20 rightmost bits are used for encoding the label value.

All other combinations of V-flag and L-flag are invalid and any SID advertisement received with an invalid setting for V and L flags MUST be ignored.

If an OSPFv3 router advertises multiple Prefix-SIDs for the same prefix, topology, and algorithm, all of them MUST be ignored.

When calculating the outgoing label for the prefix, the router MUST take into account, as described below, the E, NP, and M flags advertised by the next-hop router if that router advertised the SID for the prefix. This MUST be done regardless of whether the next-hop router contributes to the best path to the prefix.

The NP-Flag (No-PHP) MUST be set and the E-flag MUST be clear for Prefix-SIDs allocated to prefixes that are propagated between areas by an ABR based on intra-area or inter-area reachability, unless the advertised prefix is directly attached to such ABR.

The NP-Flag (No-PHP) MUST be set and the E-flag MUST be clear for Prefix-SIDs allocated to redistributed prefixes, unless the redistributed prefix is directly attached to the advertising ASBR.

If the NP-Flag is not set, then any upstream neighbor of the Prefix-SID originator MUST pop the Prefix-SID. This is equivalent to the penultimate hop popping mechanism used in the MPLS dataplane. If the NP-flag is not set, then the received E-flag is ignored.

If the NP-flag is set then:

If the E-flag is not set, then any upstream neighbor of the Prefix-SID originator MUST keep the Prefix-SID on top of the stack. This is useful when the originator of the Prefix-SID needs to stitch the incoming packet into a continuing MPLS LSP to the final destination. This could occur at an ABR (prefix propagation from one area to another) or at an ASBR (prefix propagation from one domain to another).

If the E-flag is set, then any upstream neighbor of the Prefix-SID originator MUST replace the Prefix-SID with an Explicit-NULL label. This is useful, e.g., when the originator of the Prefix-SID is the final destination for the related prefix and the originator wishes to receive the packet with the original Traffic Class field [RFC5462].

When the M-Flag is set, the NP-flag and the E-flag MUST be ignored on reception.

As the Mapping Server does not specify the originator of a prefix advertisement, it is not possible to determine PHP behavior solely based on the Mapping Server advertisement. However, PHP behavior SHOULD be done in following cases:

The Prefix is intra-area type and the downstream neighbor is the originator of the prefix.

The Prefix is inter-area type and the downstream neighbor is an ABR, which is advertising prefix reachability and is setting the LA-bit in the Prefix Options as described in [RFC8362].

The Prefix is external type and the downstream neighbor is an ASBR, which is advertising prefix reachability and is setting the LA-bit in the Prefix Options as described in [RFC8362].

When a Prefix-SID is advertised in the OSPFv3 Extended Prefix Range TLV, then the value advertised in the Prefix SID Sub-TLV is interpreted as a starting SID/Label value.

Example 1: If the following router addresses (loopback addresses) need to be mapped into the corresponding Prefix SID indexes:

```
Router-A: 2001:DB8::1/128, Prefix-SID: Index 1
Router-B: 2001:DB8::2/128, Prefix-SID: Index 2
Router-C: 2001:DB8::3/128, Prefix-SID: Index 3
Router-D: 2001:DB8::4/128, Prefix-SID: Index 4
```

then the Address Prefix field in the OSPFv3 Extended Prefix Range TLV would be set to 2001:DB8::1, the Prefix Length would be set to 128, the Range Size would be set to 4, and the Index value in the Prefix-SID Sub-TLV would be set to 1.

Example 2: If the following prefixes need to be mapped into the corresponding Prefix-SID indexes:

- 2001:DB8:1::0/120, Prefix-SID: Index 51
- 2001:DB8:1::100/120, Prefix-SID: Index 52
- 2001:DB8:1::200/120, Prefix-SID: Index 53
- 2001:DB8:1::300/120, Prefix-SID: Index 54
- 2001:DB8:1::400/120, Prefix-SID: Index 55
- 2001:DB8:1::500/120, Prefix-SID: Index 56
- 2001:DB8:1::600/120, Prefix-SID: Index 57

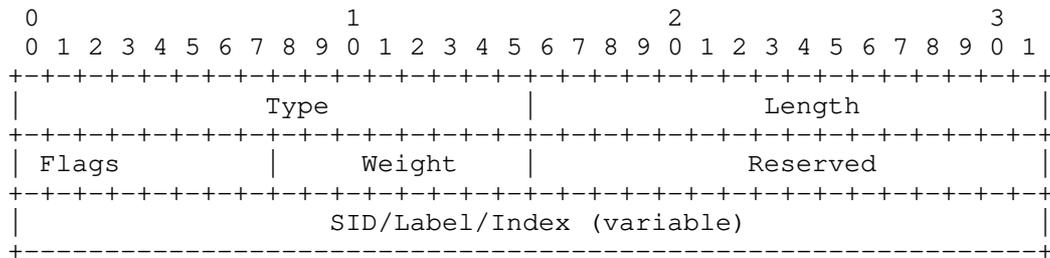
then the Prefix field in the OSPFv3 Extended Prefix Range TLV would be set to 2001:DB8:1::0, the Prefix Length would be set to 120, the Range Size would be set to 7, and the Index value in the Prefix-SID Sub-TLV would be set to 51.

7. Adjacency Segment Identifier (Adj-SID)

An Adjacency Segment Identifier (Adj-SID) represents a router adjacency in Segment Routing.

7.1. Adj-SID Sub-TLV

The Adj-SID Sub-TLV is an optional Sub-TLV of the Router-Link TLV as defined in [RFC8362]. It MAY appear multiple times in the Router-Link TLV. The Adj-SID Sub-TLV has the following format:



where:

Type: 5

Length: 7 or 8 octets, dependent on the V flag.

Flags: Single octet field containing the following flags:

```

0 1 2 3 4 5 6 7
+---+---+---+---+
|B|V|L|G|P|   |
+---+---+---+---+

```

where:

B-Flag: Backup Flag. If set, the Adj-SID refers to an adjacency that is eligible for protection (e.g., using IPFRR or MPLS-FRR) as described in section 3.5 of [RFC8402].

The V-Flag: Value/Index Flag. If set, then the Adj-SID carries an absolute value. If not set, then the Adj-SID carries an index.

The L-Flag: Local/Global Flag. If set, then the value/index carried by the Adj-SID has local significance. If not set, then the value/index carried by this Sub-TLV has global significance.

The G-Flag: Group Flag. When set, the G-Flag indicates that the Adj-SID refers to a group of adjacencies (and therefore MAY be assigned to other adjacencies as well).

P-Flag. Persistent flag. When set, the P-Flag indicates that the Adj-SID is persistently allocated, i.e., the Adj-SID value remains the same across router restart and/or interface flap.

Other bits: Reserved. These MUST be zero when sent and are ignored when received.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Weight: Weight used for load-balancing purposes. The use of the weight is defined in [RFC8402].

SID/Index/Label: as described in Section 6.

An SR-capable router MAY allocate an Adj-SID for each of its adjacencies and set the B-Flag when the adjacency is eligible for protection by an FRR mechanism (IP or MPLS) as described in [RFC8402].

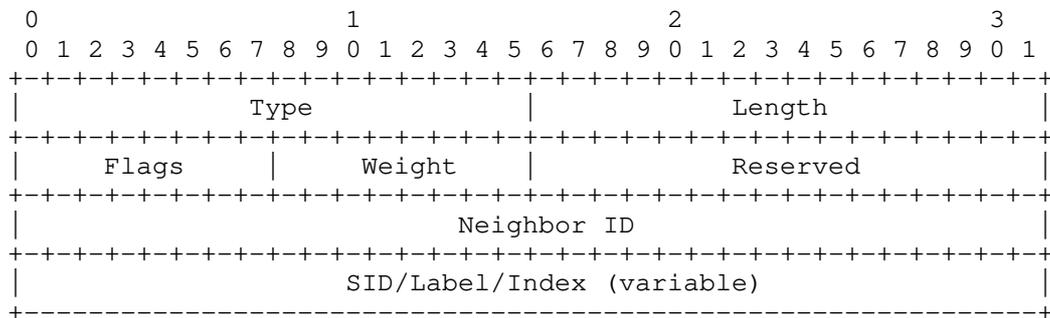
An SR-capable router MAY allocate more than one Adj-SID to an adjacency.

An SR-capable router MAY allocate the same Adj-SID to different adjacencies.

When the P-flag is not set, the Adj-SID MAY be persistent. When the P-flag is set, the Adj-SID MUST be persistent.

7.2. LAN Adj-SID Sub-TLV

The LAN Adj-SID Sub-TLV is an optional Sub-TLV of the Router-Link TLV. It MAY appear multiple times in the Router-Link TLV. It is used to advertise a SID/Label for an adjacency to a non-DR router on a broadcast, NBMA, or hybrid [RFC6845] network.



where:

Type: 6

Length: 11 or 12 octets, dependent on V-flag.

Flags: same as in Section 7.1

Weight: Weight used for load-balancing purposes. The use of the weight is defined in [RFC8402].

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Neighbor ID: The Router ID of the neighbor for which the LAN-Adj-SID is advertised.

SID/Index/Label: as described in Section 6.

When the P-flag is not set, the LAN Adj-SID MAY be persistent.

When the P-flag is set, the LAN Adj-SID MUST be persistent.

8. Elements of Procedure

8.1. Intra-area Segment routing in OSPFv3

An OSPFv3 router that supports segment routing MAY advertise Prefix-SIDs for any prefix to which it is advertising reachability (e.g., a loopback IP address as described in Section 6).

A Prefix-SID can also be advertised by SR Mapping Servers (as described in [I-D.ietf-spring-segment-routing-ldp-interop]). A Mapping Server advertises Prefix-SIDs for remote prefixes that exist in the OSPFv3 routing domain. Multiple Mapping Servers can advertise Prefix-SIDs for the same prefix, in which case the same Prefix-SID MUST be advertised by all of them. The SR Mapping Server could use either area flooding scope or autonomous system flooding scope when advertising Prefix SIDs for prefixes, based on the configuration of the SR Mapping Server. Depending on the flooding scope used, the SR Mapping Server chooses the OSPFv3 LSA type that will be used. If the area flooding scope is needed, an E-Intra-Area-Prefix-LSA [RFC8362] is used. If autonomous system flooding scope is needed, an E-AS-External-LSA [RFC8362] is used.

When a Prefix-SID is advertised by the Mapping Server, which is indicated by the M-flag in the Prefix-SID Sub-TLV (Section 6), the route type as implied by the LSA type is ignored and the Prefix-SID is bound to the corresponding prefix independent of the route type.

Advertisement of the Prefix-SID by the Mapping Server using an Inter-Area Prefix TLV, External-Prefix TLV, or Intra-Area-Prefix TLV [RFC8362] does not itself contribute to the prefix reachability. The NU-bit [RFC5340] MUST be set in the PrefixOptions field of the LSA which is used by the Mapping Server to advertise SID or SID Range, which prevents the advertisement from contributing to prefix reachability.

An SR Mapping Server MUST use the OSPFv3 Extended Prefix Range TLVs when advertising SIDs for prefixes. Prefixes of different route-types can be combined in a single OSPFv3 Extended Prefix Range TLV advertised by an SR Mapping Server.

Area-scoped OSPFv3 Extended Prefix Range TLVs are propagated between areas, similar to propagation of prefixes between areas. Same rules that are used for propagating prefixes between areas [RFC5340] are used for the propagation of the prefix ranges.

8.2. Inter-area Segment routing in OSPFv3

In order to support SR in a multi-area environment, OSPFv3 MUST propagate Prefix-SID information between areas. The following procedure is used to propagate Prefix SIDs between areas.

When an OSPFv3 ABR advertises an Inter-Area-Prefix-LSA from an intra-area prefix to all its connected areas, it will also include the Prefix-SID Sub-TLV, as described in Section 6. The Prefix-SID value will be set as follows:

The ABR will look at its best path to the prefix in the source area and find the advertising router associated with the best path to that prefix.

The ABR will then determine if such router advertised a Prefix-SID for the prefix and use it when advertising the Prefix-SID to other connected areas.

If no Prefix-SID was advertised for the prefix in the source area by the router that contributes to the best path to the prefix, the originating ABR will use the Prefix-SID advertised by any other router when propagating the Prefix-SID for the prefix to other areas.

When an OSPFv3 ABR advertises Inter-Area-Prefix-LSA LSAs from an inter-area route to all its connected areas, it will also include the Prefix-SID Sub-TLV, as described in Section 6. The Prefix-SID value will be set as follows:

The ABR will look at its best path to the prefix in the backbone area and find the advertising router associated with the best path to that prefix.

The ABR will then determine if such router advertised a Prefix-SID for the prefix and use it when advertising the Prefix-SID to other connected areas.

If no Prefix-SID was advertised for the prefix in the backbone area by the ABR that contributes to the best path to the prefix, the originating ABR will use the Prefix-SID advertised by any other router when propagating the Prefix-SID for the prefix to other areas.

8.3. Segment Routing for External Prefixes

AS-External-LSAs are flooded domain wide. When an ASBR, which supports SR, originates an E-AS-External-LSA, it SHOULD also include a Prefix-SID Sub-TLV, as described in Section 6. The Prefix-SID value will be set to the SID that has been reserved for that prefix.

When an NSSA [RFC3101] ABR translates an E-NSSA-LSA into an E-AS-External-LSA, it SHOULD also advertise the Prefix-SID for the prefix. The NSSA ABR determines its best path to the prefix advertised in the translated E-NSSA-LSA and finds the advertising router associated with that path. If the advertising router has advertised a Prefix-SID for the prefix, then the NSSA ABR uses it when advertising the Prefix-SID for the E-AS-External-LSA. Otherwise, the Prefix-SID advertised by any other router will be used.

8.4. Advertisement of Adj-SID

The Adjacency Segment Routing Identifier (Adj-SID) is advertised using the Adj-SID Sub-TLV as described in Section 7.

8.4.1. Advertisement of Adj-SID on Point-to-Point Links

An Adj-SID MAY be advertised for any adjacency on a P2P link that is in neighbor state 2-Way or higher. If the adjacency on a P2P link transitions from the FULL state, then the Adj-SID for that adjacency MAY be removed from the area. If the adjacency transitions to a state lower than 2-Way, then the Adj-SID advertisement MUST be withdrawn from the area.

8.4.2. Adjacency SID on Broadcast or NBMA Interfaces

Broadcast, NBMA, or hybrid [RFC6845] networks in OSPFv3 are represented by a star topology where the DR is the central point to which all other routers on the broadcast, NBMA, or hybrid network connect. As a result, routers on the broadcast, NBMA, or hybrid network advertise only their adjacency to the DR. Routers that do not act as DR do not form or advertise adjacencies with each other. They do, however, maintain 2-Way adjacency state with each other and are directly reachable.

When Segment Routing is used, each router on the broadcast, NBMA, or hybrid network MAY advertise the Adj-SID for its adjacency to the DR using the Adj-SID Sub-TLV as described in Section 7.1.

SR-capable routers MAY also advertise a LAN-Adj-SID for other neighbors (e.g., BDR, DR-OTHER) on the broadcast, NBMA, or hybrid network using the LAN-Adj-SID Sub-TLV as described in Section 7.2.

9. IANA Considerations

This specification updates several existing OSPFv3 registries.

9.1. OSPFv3 Extended-LSA TLV Registry

Following values are allocated:

- o 9 - OSPFv3 Extended Prefix Range TLV

9.2. OSPFv3 Extended-LSA Sub-TLV registry

- o 4 - Prefix SID Sub-TLV
- o 5 - Adj-SID Sub-TLV
- o 6 - LAN Adj-SID Sub-TLV
- o 7 - SID/Label Sub-TLV

10. Security Considerations

With the OSPFv3 segment routing extensions defined herein, OSPFv3 will now program the MPLS data plane [RFC3031]. Previously, LDP [RFC5036] or another label distribution mechanism was required to advertise MPLS labels and program the MPLS data plane.

In general, the same types of attacks that can be carried out on the IP control plane can be carried out on the MPLS control plane resulting in traffic being misrouted in the respective data planes. However, the latter can be more difficult to detect and isolate.

Existing security extensions as described in [RFC5340] and [RFC8362] apply to these segment routing extensions. While OSPFv3 is under a single administrative domain, there can be deployments where potential attackers have access to one or more networks in the OSPFv3 routing domain. In these deployments, stronger authentication mechanisms such as those specified in [RFC4552] or [RFC7166] SHOULD be used.

Implementations MUST assure that malformed TLV and Sub-TLV defined in this document are detected and do not provide a vulnerability for attackers to crash the OSPFv3 router or routing process. Reception of a malformed TLV or Sub-TLV SHOULD be counted and/or logged for further analysis. Logging of malformed TLVs and Sub-TLVs SHOULD be rate-limited to prevent a Denial of Service (DoS) attack (distributed or otherwise) from overloading the OSPFv3 control plane.

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OSPF Extensions for Segment Routing
draft-ietf-ospf-segment-routing-extensions-27

Abstract

Segment Routing (SR) allows a flexible definition of end-to-end paths within IGP topologies by encoding paths as sequences of topological sub-paths, called "segments". These segments are advertised by the link-state routing protocols (IS-IS and OSPF).

This draft describes the OSPFv2 extensions required for Segment Routing.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

Status of This Memo

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1. Introduction

Segment Routing (SR) allows a flexible definition of end-to-end paths within IGP topologies by encoding paths as sequences of topological sub-paths, called "segments". These segments are advertised by the link-state routing protocols (IS-IS and OSPF). Prefix segments represent an ECMP-aware shortest-path to a prefix (or a node), as per the state of the IGP topology. Adjacency segments represent a hop over a specific adjacency between two nodes in the IGP. A prefix segment is typically a multi-hop path while an adjacency segment, in most cases, is a one-hop path. SR's control-plane can be applied to both IPv6 and MPLS data-planes, and does not require any additional signalling (other than IGP extensions). The IPv6 data plane is out of the scope of this specification - it is not applicable to OSPFv2 which only supports the IPv4 address-family. When used in MPLS networks, SR paths do not require any LDP or RSVP-TE signalling. However, SR can interoperate in the presence of LSPs established with RSVP or LDP.

There are additional segment types, e.g., Binding SID defined in [I-D.ietf-spring-segment-routing].

This draft describes the OSPF extensions required for Segment Routing.

Segment Routing architecture is described in [I-D.ietf-spring-segment-routing].

Segment Routing use cases are described in [RFC7855].

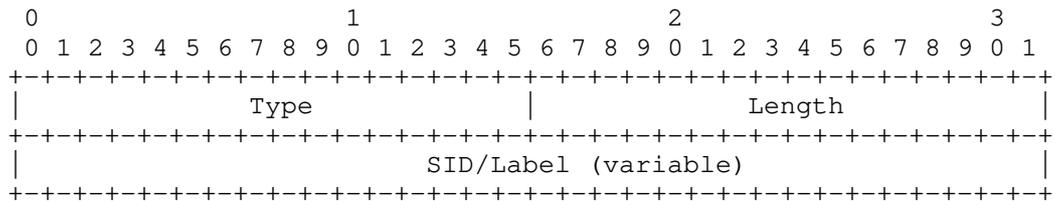
2. Segment Routing Identifiers

Segment Routing defines various types of Segment Identifiers (SIDs): Prefix-SID, Adjacency-SID, LAN Adjacency SID, and Binding SID.

Extended Prefix/Link Opaque LSAs defined in [RFC7684] are used for advertisements of the various SID types.

2.1. SID/Label Sub-TLV

The SID/Label Sub-TLV appears in multiple TLVs or Sub-TLVs defined later in this document. It is used to advertise the SID or label associated with a prefix or adjacency. The SID/Label Sub-TLV has following format:



where:

Type: 1

Length: Variable, 3 or 4 octet

SID/Label: If length is set to 3, then the 20 rightmost bits represent a label. If length is set to 4, then the value represents a 32-bit SID.

The receiving router MUST ignore the SID/Label Sub-TLV if the length is other than 3 or 4.

3. Segment Routing Capabilities

Segment Routing requires some additional router capabilities to be advertised to other routers in the area.

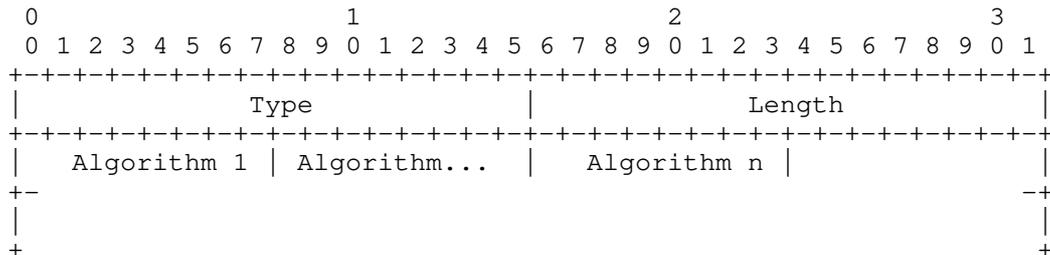
These SR capabilities are advertised in the Router Information Opaque LSA (defined in [RFC7770]). The TLVs defined below are applicable to both OSPFv2 and OSPFv3; see also [I-D.ietf-ospf-ospfv3-segment-routing-extensions]

3.1. SR-Algorithm TLV

The SR-Algorithm TLV is a top-level TLV of the Router Information Opaque LSA (defined in [RFC7770]).

The SR-Algorithm TLV is optional. It SHOULD only be advertised once in the Router Information Opaque LSA. If the SR-Algorithm TLV is not advertised by the node, such node is considered as not being segment routing capable.

An SR Router can use various algorithms when calculating reachability to OSPF routers or prefixes in an OSPF area. Examples of these algorithms are metric based Shortest Path First (SPF), various flavors of Constrained SPF, etc. The SR-Algorithm TLV allows a router to advertise the algorithms currently used by the router to other routers in an OSPF area. The SR-Algorithm TLV has following format:



where:

Type: 8

Variable, in octets, dependent on number of algorithms advertised.

Algorithm: Single octet identifying the algorithm. The following values are defined by this document:

0: Shortest Path First (SPF) algorithm based on link metric. This is the standard shortest path algorithm as computed by the OSPF protocol. Consistent with the deployed practice for link-state protocols, Algorithm 0 permits any node to overwrite the SPF path with a different path based on its local policy. If the SR-Algorithm TLV is advertised, Algorithm 0 MUST be included.

1: Strict Shortest Path First (SPF) algorithm based on link metric. The algorithm is identical to Algorithm 0 but Algorithm 1 requires that all nodes along the path will honor the SPF routing decision. Local policy at the node claiming support for Algorithm 1 MUST NOT alter the SPF paths computed by Algorithm 1.

When multiple SR-Algorithm TLVs are received from a given router, the receiver MUST use the first occurrence of the TLV in the Router Information LSA. If the SR-Algorithm TLV appears in multiple Router Information LSAs that have different flooding scopes, the SR-Algorithm TLV in the Router Information LSA with the area-scoped flooding scope MUST be used. If the SR-Algorithm TLV appears in

multiple Router Information LSAs that have the same flooding scope, the SR-Algorithm TLV in the Router Information (RI) LSA with the numerically smallest Instance ID MUST be used and subsequent instances of the SR-Algorithm TLV MUST be ignored.

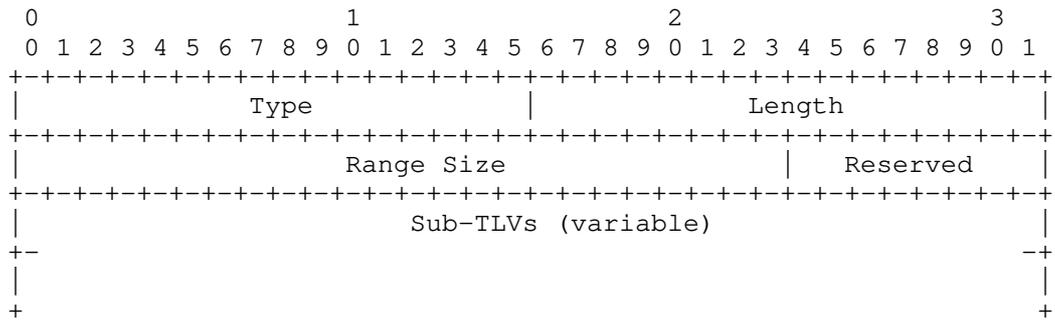
The RI LSA can be advertised at any of the defined opaque flooding scopes (link, area, or Autonomous System (AS)). For the purpose of SR-Algorithm TLV advertisement, area-scoped flooding is REQUIRED.

3.2. SID/Label Range TLV

Prefix SIDs MAY be advertised in a form of an index as described in Section 5. Such index defines the offset in the SID/Label space advertised by the router. The SID/Label Range TLV is used to advertise such SID/Label space.

The SID/Label Range TLV is a top-level TLV of the Router Information Opaque LSA (defined in [RFC7770]).

The SID/Label Range TLV MAY appear multiple times and has the following format:



where:

Type: 9

Length: Variable, in octets, dependent on Sub-TLVs.

Range Size: 3-octet SID/label range size (i.e., the number of SIDs or labels in the range including the first SID/label). It MUST be greater than 0.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Initially, the only supported Sub-TLV is the SID/Label Sub-TLV as defined in Section 2.1. The SID/Label Sub-TLV MUST be included in the SID/Label Range TLV. The SID/Label advertised in the SID/Label Sub-TLV represents the first SID/Label in the advertised range.

Only a single SID/Label Sub-TLV MAY be advertised in SID/Label Range TLV. If more than one SID/Label Sub-TLVs are present, the SID/Label Range TLV MUST be ignored.

Multiple occurrences of the SID/Label Range TLV MAY be advertised, in order to advertise multiple ranges. In such case:

- o The originating router MUST encode each range into a different SID/Label Range TLV.
- o The originating router decides the order in which the set of SID/Label Range TLVs are advertised inside the Router Information Opaque LSA. The originating router MUST ensure the order is the same after a graceful restart (using checkpointing, non-volatile storage, or any other mechanism) in order to assure the SID/label range and SID index correspondence is preserved across graceful restarts.
- o The receiving router MUST adhere to the order in which the ranges are advertised when calculating a SID/label from a SID index.
- o The originating router MUST NOT advertise overlapping ranges.
- o When a router receives multiple overlapping ranges, it MUST conform to the procedures defined in [I-D.ietf-spring-segment-routing-mps].

The following example illustrates the advertisement of multiple ranges:

The originating router advertises the following ranges:

```
Range 1: Range Size: 100   SID/Label Sub-TLV: 100
Range 1: Range Size: 100   SID/Label Sub-TLV: 1000
Range 1: Range Size: 100   SID/Label Sub-TLV: 500
```

The receiving routers concatenate the ranges and build the Segment Routing Global Block (SRGB) as follows:

```
SRGB = [100, 199]
       [1000, 1099]
       [500, 599]
```

The indexes span multiple ranges:

```
index=0 means label 100
...
index 99 means label 199
index 100 means label 1000
index 199 means label 1099
...
index 200 means label 500
...
```

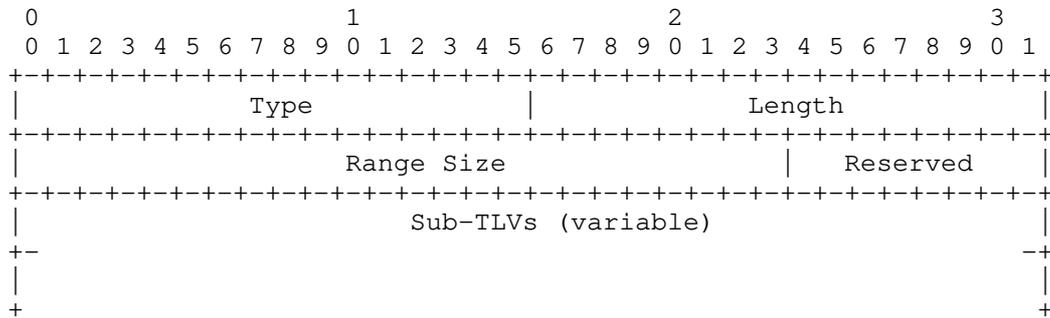
The RI LSA can be advertised at any of the defined flooding scopes (link, area, or autonomous system (AS)). For the purpose of SID/Label Range TLV advertisement, area-scoped flooding is REQUIRED.

3.3. SR Local Block TLV

The SR Local Block TLV (SRLB TLV) contains the range of labels the node has reserved for local SIDs. SIDs from the SRLB MAY be used for Adjacency-SIDs, but also by components other than the OSPF protocol. As an example, an application or a controller can instruct the router to allocate a specific local SID. Some controllers or applications can use the control plane to discover the available set of local SIDs on a particular router. In such cases, the SRLB is advertised in the control plane. The requirement to advertise the SRLB is further described in [I-D.ietf-spring-segment-routing-mpls]. The SRLB TLV is used to advertise the SRLB.

The SRLB TLV is a top-level TLV of the Router Information Opaque LSA (defined in [RFC7770]).

The SRLB TLV MAY appear multiple times in the Router Information Opaque LSA and has the following format:



where:

Type: 14

Length: Variable, in octets, dependent on Sub-TLVs.

Range Size: 3-octet SID/label range size (i.e., the number of SIDs or labels in the range including the first SID/label). It MUST be greater than 0.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Initially, the only supported Sub-TLV is the SID/Label Sub-TLV as defined in Section 2.1. The SID/Label Sub-TLV MUST be included in the SRLB TLV. The SID/Label advertised in the SID/Label Sub-TLV represents the first SID/Label in the advertised range.

Only a single SID/Label Sub-TLV MAY be advertised in the SRLB TLV. If more than one SID/Label Sub-TLVs are present, the SRLB TLV MUST be ignored.

The originating router MUST NOT advertise overlapping ranges.

Each time a SID from the SRLB is allocated, it SHOULD also be reported to all components (e.g., controller or applications) in order for these components to have an up-to-date view of the current SRLB allocation. This is required to avoid collisions between allocation instructions.

Within the context of OSPF, the reporting of local SIDs is done through OSPF Sub-TLVs such as the Adjacency-SID (Section 6). However, the reporting of allocated local SIDs can also be done through other means and protocols which are outside the scope of this document.

A router advertising the SRLB TLV MAY also have other label ranges, outside of the SRLB, used for its local allocation purposes which are not advertised in the SRLB TLV. For example, it is possible that an Adjacency-SID is allocated using a local label that is not part of the SRLB.

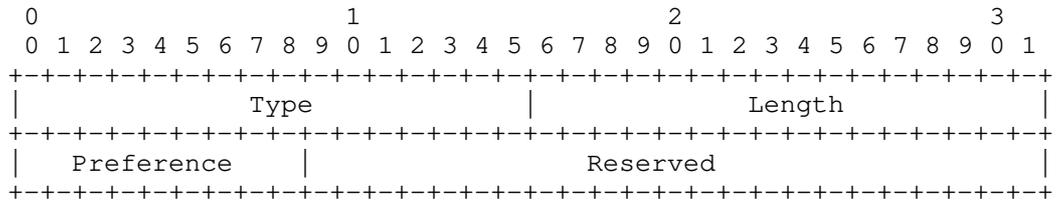
The RI LSA can be advertised at any of the defined flooding scopes (link, area, or autonomous system (AS)). For the purpose of SRLB TLV advertisement, area-scoped flooding is REQUIRED.

3.4. SRMS Preference TLV

The Segment Routing Mapping Server Preference TLV (SRMS Preference TLV) is used to advertise a preference associated with the node that acts as an SR Mapping Server. The role of an SRMS is described in [I-D.ietf-spring-segment-routing-ldp-interop]. SRMS preference is defined in [I-D.ietf-spring-segment-routing-ldp-interop].

The SRMS Preference TLV is a top-level TLV of the Router Information Opaque LSA (defined in [RFC7770]).

The SRMS Preference TLV MAY only be advertised once in the Router Information Opaque LSA and has the following format:



where:

Type: 15

Length: 4 octets

Preference: 1 octet. SRMS preference value from 0 to 255.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

When multiple SRMS Preference TLVs are received from a given router, the receiver MUST use the first occurrence of the TLV in the Router Information LSA. If the SRMS Preference TLV appears in multiple Router Information LSAs that have different flooding scopes, the SRMS Preference TLV in the Router Information LSA with the narrowest

flooding scope MUST be used. If the SRMS Preference TLV appears in multiple Router Information LSAs that have the same flooding scope, the SRMS Preference TLV in the Router Information LSA with the numerically smallest Instance ID MUST be used and subsequent instances of the SRMS Preference TLV MUST be ignored.

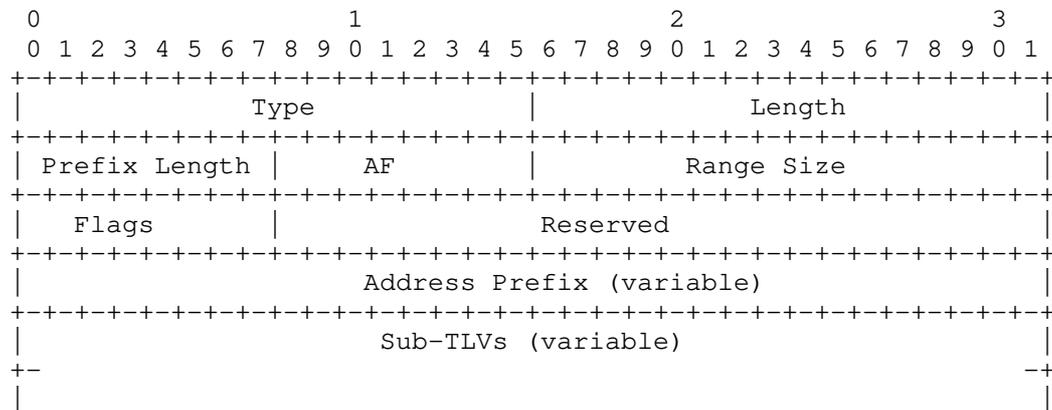
The RI LSA can be advertised at any of the defined flooding scopes (link, area, or autonomous system (AS)). For the purpose of the SRMS Preference TLV advertisement, AS-scoped flooding SHOULD be used. This is because SRMS servers can be located in a different area than consumers of the SRMS advertisements. If the SRMS advertisements from the SRMS server are only used inside the SRMS server's area, area-scoped flooding MAY be used.

4. OSPF Extended Prefix Range TLV

In some cases it is useful to advertise attributes for a range of prefixes. The Segment Routing Mapping Server, which is described in [I-D.ietf-spring-segment-routing-ldp-interop], is an example where we need a single advertisement to advertise SIDs for multiple prefixes from a contiguous address range.

The OSPF Extended Prefix Range TLV, which is a top level TLV of the Extended Prefix LSA described in [RFC7684] is defined for this purpose.

Multiple OSPF Extended Prefix Range TLVs MAY be advertised in each OSPF Extended Prefix Opaque LSA, but all prefix ranges included in a single OSPF Extended Prefix Opaque LSA MUST have the same flooding scope. The OSPF Extended Prefix Range TLV has the following format:



where:

Type: 2

Length: Variable, in octets, dependent on Sub-TLVs.

Prefix length: Length of prefix in bits.

AF: Address family for the prefix. Currently, the only supported value is 0 for IPv4 unicast. The inclusion of address family in this TLV allows for future extension.

Range size: Represents the number of prefixes that are covered by the advertisement. The Range Size MUST NOT exceed the number of prefixes that could be satisfied by the prefix length without including the IPv4 multicast address range (224.0.0.0/3).

Flags: Single octet field. The following flags are defined:

```

  0  1  2  3  4  5  6  7
+---+---+---+---+---+---+---+---+
| IA |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+

```

where:

IA-Flag: Inter-Area flag. If set, advertisement is of inter-area type. An ABR that is advertising the OSPF Extended Prefix Range TLV between areas MUST set this bit.

This bit is used to prevent redundant flooding of Prefix Range TLVs between areas as follows:

An ABR only propagates an inter-area Prefix Range advertisement from the backbone area to connected non-backbone areas if the advertisement is considered to be the best one. The following rules are used to select the best range from the set of advertisements for the same Prefix Range:

An ABR always prefers intra-area Prefix Range advertisements over inter-area advertisements.

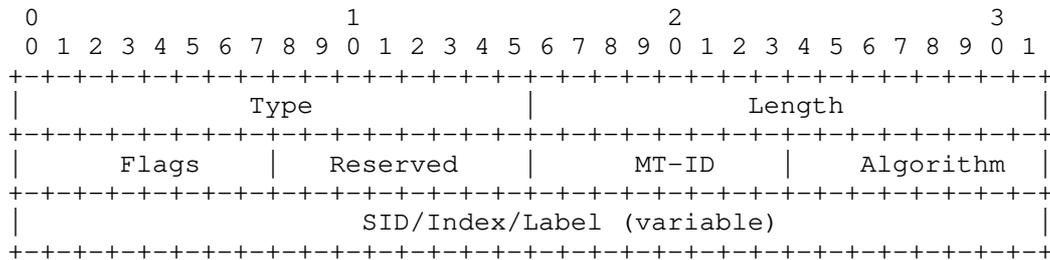
An ABR does not consider inter-area Prefix Range advertisements coming from non-backbone areas.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

Address Prefix: For the address family IPv4 unicast, the prefix itself is encoded as a 32-bit value. The default route is represented by a prefix of length 0. Prefix encoding for other address families is beyond the scope of this specification.

5. Prefix SID Sub-TLV

The Prefix SID Sub-TLV is a Sub-TLV of the OSPF Extended Prefix TLV described in [RFC7684] and the OSPF Extended Prefix Range TLV described in Section 4. It MAY appear more than once in the parent TLV and has the following format:

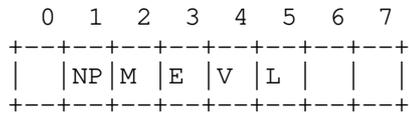


where:

Type: 2

Length: 7 or 8 octets, dependent on the V-flag

Flags: Single octet field. The following flags are defined:



where:

NP-Flag: No-PHP flag. If set, then the penultimate hop MUST NOT pop the Prefix-SID before delivering packets to the node that advertised the Prefix-SID.

M-Flag: Mapping Server Flag. If set, the SID was advertised by a Segment Routing Mapping Server as described in [I-D.ietf-spring-segment-routing-ldp-interop].

E-Flag: Explicit-Null Flag. If set, any upstream neighbor of the Prefix-SID originator MUST replace the Prefix-SID with the Explicit-NULL label (0 for IPv4) before forwarding the packet.

V-Flag: Value/Index Flag. If set, then the Prefix-SID carries an absolute value. If not set, then the Prefix-SID carries an index.

L-Flag: Local/Global Flag. If set, then the value/index carried by the Prefix-SID has local significance. If not set, then the value/index carried by this Sub-TLV has global significance.

Other bits: Reserved. These MUST be zero when sent and are ignored when received.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

MT-ID: Multi-Topology ID (as defined in [RFC4915]).

Algorithm: Single octet identifying the algorithm the Prefix-SID is associated with as defined in Section 3.1.

A router receiving a Prefix-SID from a remote node and with an algorithm value that such remote node has not advertised in the SR-Algorithm Sub-TLV (Section 3.1) MUST ignore the Prefix-SID Sub-TLV.

SID/Index/Label: According to the V and L flags, it contains:

V-flag is set to 0 and L-flag is set to 0: The SID/Index/Label field is a 4 octet index defining the offset in the SID/Label space advertised by this router

V-flag is set to 1 and L-flag is set to 1: The SID/Index/Label field is a 3 octet local label where the 20 rightmost bits are used for encoding the label value.

All other combinations of V-flag and L-flag are invalid and any SID advertisement received with an invalid setting for V and L flags MUST be ignored.

If an OSPF router advertises multiple Prefix-SIDs for the same prefix, topology and algorithm, all of them MUST be ignored.

When calculating the outgoing label for the prefix, the router MUST take into account, as described below, the E, NP and M flags

advertised by the next-hop router if that router advertised the SID for the prefix. This MUST be done regardless of whether the next-hop router contributes to the best path to the prefix.

The NP-Flag (No-PHP) MUST be set and the E-flag MUST be clear for Prefix-SIDs allocated to inter-area prefixes that are originated by the ABR based on intra-area or inter-area reachability between areas, unless the advertised prefix is directly attached to the ABR.

The NP-Flag (No-PHP) MUST be set and the E-flag MUST be clear for Prefix-SIDs allocated to redistributed prefixes, unless the redistributed prefix is directly attached to the ASBR.

If the NP-Flag is not set, then any upstream neighbor of the Prefix-SID originator MUST pop the Prefix-SID. This is equivalent to the penultimate hop popping mechanism used in the MPLS dataplane. If the NP-flag is not set, then the received E-flag is ignored.

If the NP-flag is set then:

If the E-flag is not set, then any upstream neighbor of the Prefix-SID originator MUST keep the Prefix-SID on top of the stack. This is useful when the originator of the Prefix-SID need to stitch the incoming packet into a continuing MPLS LSP to the final destination. This could occur at an Area Border Router (prefix propagation from one area to another) or at an AS Boundary Router (prefix propagation from one domain to another).

If the E-flag is set, then any upstream neighbor of the Prefix-SID originator MUST replace the Prefix-SID with an Explicit-NULL label. This is useful, e.g., when the originator of the Prefix-SID is the final destination for the related prefix and the originator wishes to receive the packet with the original EXP bits.

When the M-Flag is set, the NP-flag and the E-flag MUST be ignored at reception.

As the Mapping Server does not specify the originator of a prefix advertisement, it is not possible to determine PHP behavior solely based on the Mapping Server advertisement. However, PHP behavior SHOULD be done in following cases:

The Prefix is intra-area type and the downstream neighbor is the originator of the prefix.

The Prefix is inter-area type and downstream neighbor is an ABR, which is advertising prefix reachability and is also generating

the Extended Prefix TLV with the A-flag set for this prefix as described in section 2.1 of [RFC7684].

The Prefix is external type and downstream neighbor is an ASBR, which is advertising prefix reachability and is also generating the Extended Prefix TLV with the A-flag set for this prefix as described in section 2.1 of [RFC7684].

When a Prefix-SID is advertised in an Extended Prefix Range TLV, then the value advertised in the Prefix SID Sub-TLV is interpreted as a starting SID/Label value.

Example 1: If the following router addresses (loopback addresses) need to be mapped into the corresponding Prefix SID indexes:

```
Router-A: 192.0.2.1/32, Prefix-SID: Index 1
Router-B: 192.0.2.2/32, Prefix-SID: Index 2
Router-C: 192.0.2.3/32, Prefix-SID: Index 3
Router-D: 192.0.2.4/32, Prefix-SID: Index 4
```

then the Prefix field in the Extended Prefix Range TLV would be set to 192.0.2.1, Prefix Length would be set to 32, Range Size would be set to 4, and the Index value in the Prefix-SID Sub-TLV would be set to 1.

Example 2: If the following prefixes need to be mapped into the corresponding Prefix-SID indexes:

```
192.0.2.0/30, Prefix-SID: Index 51
192.0.2.4/30, Prefix-SID: Index 52
192.0.2.8/30, Prefix-SID: Index 53
192.0.2.12/30, Prefix-SID: Index 54
192.0.2.16/30, Prefix-SID: Index 55
192.0.2.20/30, Prefix-SID: Index 56
192.0.2.24/30, Prefix-SID: Index 57
```

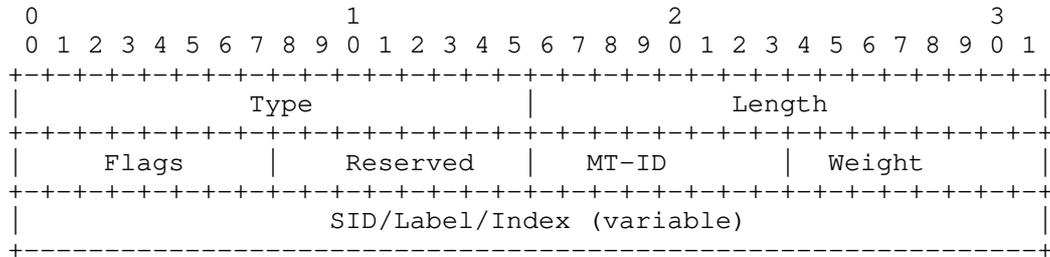
then the Prefix field in the Extended Prefix Range TLV would be set to 192.0.2.0, Prefix Length would be set to 30, Range Size would be 7, and the Index value in the Prefix-SID Sub-TLV would be set to 51.

6. Adjacency Segment Identifier (Adj-SID)

An Adjacency Segment Identifier (Adj-SID) represents a router adjacency in Segment Routing.

6.1. Adj-SID Sub-TLV

Adj-SID is an optional Sub-TLV of the Extended Link TLV defined in [RFC7684]. It MAY appear multiple times in the Extended Link TLV. The Adj-SID Sub-TLV has the following format:

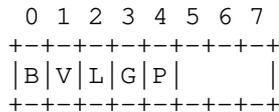


where:

Type: 2

Length: 7 or 8 octets, dependent on the V flag.

Flags: Single octet field containing the following flags:



where:

B-Flag: Backup Flag. If set, the Adj-SID refers to an adjacency that is eligible for protection (e.g., using IPFRR or MPLS-FRR) as described in section 3.5 of [I-D.ietf-spring-segment-routing].

The V-Flag: Value/Index Flag. If set, then the Adj-SID carries an absolute value. If not set, then the Adj-SID carries an index.

The L-Flag: Local/Global Flag. If set, then the value/index carried by the Adj-SID has local significance. If not set, then the value/index carried by this Sub-TLV has global significance.

The G-Flag: Group Flag. When set, the G-Flag indicates that the Adj-SID refers to a group of adjacencies (and therefore MAY be assigned to other adjacencies as well).

P-Flag. Persistent flag. When set, the P-Flag indicates that the Adj-SID is persistently allocated, i.e., the Adj-SID value remains consistent across router restart and/or interface flap.

Other bits: Reserved. These MUST be zero when sent and are ignored when received.

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

MT-ID: Multi-Topology ID (as defined in [RFC4915]).

Weight: Weight used for load-balancing purposes. The use of the weight is defined in [I-D.ietf-spring-segment-routing].

SID/Index/Label: as described in Section 5.

An SR capable router MAY allocate an Adj-SID for each of its adjacencies and set the B-Flag when the adjacency is eligible for protection by an FRR mechanism (IP or MPLS) as described in section 3.5 of [I-D.ietf-spring-segment-routing].

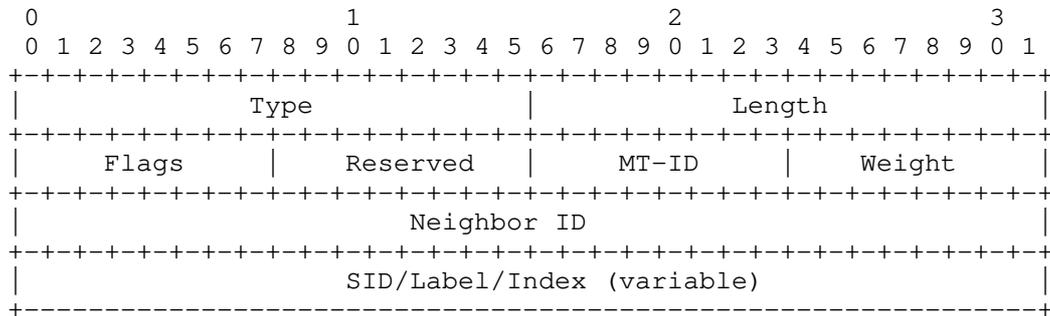
An SR capable router MAY allocate more than one Adj-SID to an adjacency

An SR capable router MAY allocate the same Adj-SID to different adjacencies

When the P-flag is not set, the Adj-SID MAY be persistent. When the P-flag is set, the Adj-SID MUST be persistent.

6.2. LAN Adj-SID Sub-TLV

LAN Adj-SID is an optional Sub-TLV of the Extended Link TLV defined in [RFC7684]. It MAY appear multiple times in the Extended-Link TLV. It is used to advertise a SID/Label for an adjacency to a non-DR router on a broadcast, NBMA, or hybrid [RFC6845] network.



where:

Type: 3

Length: 11 or 12 octets, dependent on V-flag.

Flags: same as in Section 6.1

Reserved: SHOULD be set to 0 on transmission and MUST be ignored on reception.

MT-ID: Multi-Topology ID (as defined in [RFC4915]).

Weight: Weight used for load-balancing purposes. The use of the weight is defined in [I-D.ietf-spring-segment-routing].

Neighbor ID: The Router ID of the neighbor for which the LAN-Adj-SID is advertised.

SID/Index/Label: as described in Section 5.

When the P-flag is not set, the Adj-SID MAY be persistent. When the P-flag is set, the Adj-SID MUST be persistent.

7. Elements of Procedure

7.1. Intra-area Segment routing in OSPFv2

An OSPFv2 router that supports segment routing MAY advertise Prefix-SIDs for any prefix to which it is advertising reachability (e.g., a loopback IP address as described in Section 5).

A Prefix-SID can also be advertised by the SR Mapping Servers (as described in [I-D.ietf-spring-segment-routing-ldp-interop]). A Mapping Server advertises Prefix-SIDs for remote prefixes that exist in the OSPFv2 routing domain. Multiple Mapping Servers can advertise

Prefix-SIDs for the same prefix, in which case the same Prefix-SID MUST be advertised by all of them. The flooding scope of the OSPF Extended Prefix Opaque LSA that is generated by the SR Mapping Server could be either area-scoped or AS-scoped and is determined based on the configuration of the SR Mapping Server.

An SR Mapping Server MUST use the OSPF Extended Prefix Range TLV when advertising SIDs for prefixes. Prefixes of different route-types can be combined in a single OSPF Extended Prefix Range TLV advertised by an SR Mapping Server. Because the OSPF Extended Prefix Range TLV doesn't include a Route-Type field, as in the OSPF Extended Prefix TLV, it is possible to include adjacent prefixes from different Route-Types in the OSPF Extended Prefix Range TLV.

Area-scoped OSPF Extended Prefix Range TLVs are propagated between areas. Similar to propagation of prefixes between areas, an ABR only propagates the OSPF Extended Prefix Range TLV that it considers to be the best from the set it received. The rules used to pick the best OSPF Extended Prefix Range TLV are described in Section 4.

When propagating an OSPF Extended Prefix Range TLV between areas, ABRs MUST set the IA-Flag, that is used to prevent redundant flooding of the OSPF Extended Prefix Range TLV between areas as described in Section 4.

7.2. Inter-area Segment routing in OSPFv2

In order to support SR in a multi-area environment, OSPFv2 MUST propagate Prefix-SID information between areas. The following procedure is used to propagate Prefix SIDs between areas.

When an OSPF ABR advertises a Type-3 Summary LSA from an intra-area prefix to all its connected areas, it will also originate an Extended Prefix Opaque LSA, as described in [RFC7684]. The flooding scope of the Extended Prefix Opaque LSA type will be set to area-local scope. The route-type in the OSPF Extended Prefix TLV is set to inter-area. The Prefix-SID Sub-TLV will be included in this LSA and the Prefix-SID value will be set as follows:

The ABR will look at its best path to the prefix in the source area and find the advertising router associated with the best path to that prefix.

The ABR will then determine if such router advertised a Prefix-SID for the prefix and use it when advertising the Prefix-SID to other connected areas.

If no Prefix-SID was advertised for the prefix in the source area by the router that contributes to the best path to the prefix, the originating ABR will use the Prefix-SID advertised by any other router when propagating the Prefix-SID for the prefix to other areas.

When an OSPF ABR advertises Type-3 Summary LSAs from an inter-area route to all its connected areas, it will also originate an Extended Prefix Opaque LSA, as described in [RFC7684]. The flooding scope of the Extended Prefix Opaque LSA type will be set to area-local scope. The route-type in OSPF Extended Prefix TLV is set to inter-area. The Prefix-SID Sub-TLV will be included in this LSA and the Prefix-SID will be set as follows:

The ABR will look at its best path to the prefix in the backbone area and find the advertising router associated with the best path to that prefix.

The ABR will then determine if such router advertised a Prefix-SID for the prefix and use it when advertising the Prefix-SID to other connected areas.

If no Prefix-SID was advertised for the prefix in the backbone area by the ABR that contributes to the best path to the prefix, the originating ABR will use the Prefix-SID advertised by any other router when propagating the Prefix-SID for the prefix to other areas.

7.3. Segment Routing for External Prefixes

Type-5 LSAs are flooded domain wide. When an ASBR, which supports SR, generates Type-5 LSAs, it SHOULD also originate Extended Prefix Opaque LSAs, as described in [RFC7684]. The flooding scope of the Extended Prefix Opaque LSA type is set to AS-wide scope. The route-type in the OSPF Extended Prefix TLV is set to external. The Prefix-SID Sub-TLV is included in this LSA and the Prefix-SID value will be set to the SID that has been reserved for that prefix.

When an NSSA [RFC3101] ABR translates Type-7 LSAs into Type-5 LSAs, it SHOULD also advertise the Prefix-SID for the prefix. The NSSA ABR determines its best path to the prefix advertised in the translated Type-7 LSA and finds the advertising router associated with that path. If the advertising router has advertised a Prefix-SID for the prefix, then the NSSA ABR uses it when advertising the Prefix-SID for the Type-5 prefix. Otherwise, the Prefix-SID advertised by any other router will be used.

7.4. Advertisement of Adj-SID

The Adjacency Segment Routing Identifier (Adj-SID) is advertised using the Adj-SID Sub-TLV as described in Section 6.

7.4.1. Advertisement of Adj-SID on Point-to-Point Links

An Adj-SID MAY be advertised for any adjacency on a P2P link that is in neighbor state 2-Way or higher. If the adjacency on a P2P link transitions from the FULL state, then the Adj-SID for that adjacency MAY be removed from the area. If the adjacency transitions to a state lower than 2-Way, then the Adj-SID advertisement MUST be withdrawn from the area.

7.4.2. Adjacency SID on Broadcast or NBMA Interfaces

Broadcast, NBMA, or hybrid [RFC6845] networks in OSPF are represented by a star topology where the Designated Router (DR) is the central point to which all other routers on the broadcast, NBMA, or hybrid network connect. As a result, routers on the broadcast, NBMA, or hybrid network advertise only their adjacency to the DR. Routers that do not act as DR do not form or advertise adjacencies with each other. They do, however, maintain 2-Way adjacency state with each other and are directly reachable.

When Segment Routing is used, each router on the broadcast, NBMA, or hybrid network MAY advertise the Adj-SID for its adjacency to the DR using the Adj-SID Sub-TLV as described in Section 6.1.

SR capable routers MAY also advertise a LAN-Adj-SID for other neighbors (e.g., BDR, DR-OTHER) on the broadcast, NBMA, or hybrid network using the LAN-ADJ-SID Sub-TLV as described in Section 6.2.

8. IANA Considerations

This specification updates several existing OSPF registries.

8.1. OSPF Router Information (RI) TLVs Registry

- o 8 (IANA Preallocated) - SR-Algorithm TLV
- o 9 (IANA Preallocated) - SID/Label Range TLV
- o 14 - SR Local Block TLV
- o 15 - SRMS Preference TLV

8.2. OSPFv2 Extended Prefix Opaque LSA TLVs Registry

Following values are allocated:

- o 2 - OSPF Extended Prefix Range TLV

8.3. OSPFv2 Extended Prefix TLV Sub-TLVs Registry

Following values are allocated:

- o 1 - SID/Label Sub-TLV
- o 2 - Prefix SID Sub-TLV

8.4. OSPFv2 Extended Link TLV Sub-TLVs Registry

Following initial values are allocated:

- o 1 - SID/Label Sub-TLV
- o 2 - Adj-SID Sub-TLV
- o 3 - LAN Adj-SID/Label Sub-TLV

8.5. IGP Algorithm Type Registry

IANA is requested to set up a registry called "IGP Algorithm Type" under a new category of "Interior Gateway Protocol (IGP) Parameters" IANA registries. The registration policy for this registry is "Standards Action" ([RFC8126] and [RFC7120]).

Values in this registry come from the range 0-255.

The initial values in the IGP Algorithm Type registry are:

0: Shortest Path First (SPF) algorithm based on link metric. This is the standard shortest path algorithm as computed by the IGP protocol. Consistent with the deployed practice for link-state protocols, Algorithm 0 permits any node to overwrite the SPF path with a different path based on its local policy.

1: Strict Shortest Path First (SPF) algorithm based on link metric. The algorithm is identical to Algorithm 0 but Algorithm 1 requires that all nodes along the path will honor the SPF routing decision. Local policy at the node claiming support for Algorithm 1 MUST NOT alter the SPF paths computed by Algorithm 1.

9. Implementation Status

An implementation survey with seven questions related to the implementer's support of OSPFv2 Segment Routing was sent to the OSPF WG list and several known implementers. This section contains responses from three implementers who completed the survey. No external means were used to verify the accuracy of the information submitted by the respondents. The respondents are considered experts on the products they reported on. Additionally, responses were omitted from implementers who indicated that they have not implemented the function yet.

This section will be removed before publication as an RFC.

Responses from Nokia (former Alcatel-Lucent):

Link to a web page describing the implementation:

https://infoproducts.alcatel-lucent.com/cgi-bin/dbaccessfilename.cgi/3HE10799AAAATQZZA01_V1_7450%20ESS%207750%20SR%20and%207950%20XRS%20Unicast%20Routing%20Protocols%20Guide%20R14.0.R1.pdf

The implementation's level of maturity: Production.

Coverage: We have implemented all sections and have support for the latest draft.

Licensing: Part of the software package that needs to be purchased.

Implementation experience: Great spec. We also performed interoperability testing with Cisco's OSPF Segment Routing implementation.

Contact information: wim.henderickx@nokia.com

Responses from Cisco Systems:

Link to a web page describing the implementation:

<http://www.segment-routing.net/home/tutorial>

The implementation's level of maturity: Production.

Coverage: All sections have been implemented according to the latest draft.

Licensing: Part of a commercial software package.

Implementation experience: Many aspects of the draft are result of the actual implementation experience, as the draft evolved from its

initial version to the current one. Interoperability testing with Alcatel-Lucent was performed, which confirmed the draft's ability to serve as a reference for the implementors.

Contact information: ppsenak@cisco.com

Responses from Juniper:

The implementation's name and/or a link to a web page describing the implementation:

Feature name is OSPF SPRING

The implementation's level of maturity: To be released in 16.2 (second half of 2016)

Coverage: All sections implemented except Sections 4, and 6.

Licensing: JUNOS Licensing needed.

Implementation experience: NA

Contact information: shraddha@juniper.net

10. Security Considerations

With the OSPFv2 segment routing extensions defined herein, OSPFv2 will now program the MPLS data plane [RFC3031] in addition to the IP data plane. Previously, LDP [RFC5036] or another label distribution mechanism was required to advertise MPLS labels and program the MPLS data plane.

In general, the same types of attacks that can be carried out on the IP control plane can be carried out on the MPLS control plane resulting in traffic being misrouted in the respective data planes. However, the latter can be more difficult to detect and isolate.

Existing security extensions as described in [RFC2328] and [RFC7684] apply to these segment routing extensions. While OSPF is under a single administrative domain, there can be deployments where potential attackers have access to one or more networks in the OSPF routing domain. In these deployments, stronger authentication mechanisms such as those specified in [RFC7474] SHOULD be used.

Implementations MUST assure that malformed TLV and Sub-TLV defined in this document are detected and do not provide a vulnerability for attackers to crash the OSPFv2 router or routing process. Reception of malformed TLV or Sub-TLV SHOULD be counted and/or logged for

further analysis. Logging of malformed TLVs and Sub-TLVs SHOULD be rate-limited to prevent a Denial of Service (DoS) attack (distributed or otherwise) from overloading the OSPF control plane.

11. Contributors

The following people gave a substantial contribution to the content of this document: Acee Lindem, Ahmed Bashandy, Martin Horneffer, Bruno Decraene, Stephane Litkowski, Igor Milojevic, Rob Shakir and Saku Ytti.

12. Acknowledgements

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YANG Data Model for OSPF Protocol
draft-ietf-ospf-yang-29

Abstract

This document defines a YANG data model that can be used to configure and manage OSPF. The model is based on YANG1.1 as defined in RFC 7950 and conforms to the Network Management Datastore Architecture (NMDA) as described in RFC 8342.

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1. Overview

YANG [RFC6020][RFC7950] is a data definition language used to define the contents of a conceptual data store that allows networked devices to be managed using NETCONF [RFC6241], RESTCONF [RFC8040], and other Network Management protocols. Furthermore, YANG data models can be used as the basis for implementation of other interfaces, such as CLI and programmatic APIs.

This document defines a YANG data model that can be used to configure and manage OSPF and it is an augmentation to the core routing data model. It fully conforms to the Network Management Datastore Architecture (NMDA) [RFC8342]. A core routing data model is defined in [RFC8349], and it provides the basis for the development of data models for routing protocols. The interface data model is defined in [RFC8343] and is used for referencing interfaces from the routing

protocol. The key-chain data model used for OSPF authentication is defined in [RFC8177] and provides both a reference to configured key-chains and an enumeration of cryptographic algorithms.

Both OSPFv2 [RFC2328] and OSPFv3 [RFC5340] are supported. In addition to the core OSPF protocol, features described in other OSPF RFCs are also supported. These includes demand circuit [RFC1793], traffic engineering [RFC3630], multiple address family [RFC5838], graceful restart [RFC3623] [RFC5187], NSSA [RFC3101], and OSPFv2 or OSPFv3 as a PE-CE Protocol [RFC4577], [RFC6565]. These non-core features are optional in the OSPF data model.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.2. Tree Diagrams

This document uses the graphical representation of data models defined in [RFC8340].

2. Design of Data Model

Although the basis of OSPF configuration elements like routers, areas, and interfaces remains the same, the detailed configuration model varies among router vendors. Differences are observed in terms of how the protocol instance is tied to the routing domain and how multiple protocol instances are be instantiated among others.

The goal of this document is to define a data model that provides a common user interface to the OSPFv2 and OSPFv3 protocols. There is very little information that is designated as "mandatory", providing freedom for vendors to adapt this data model to their respective product implementations.

2.1. OSPF Operational State

The OSPF operational state is included in the same tree as OSPF configuration consistent with the Network Management Datastore Architecture [RFC8342]. Consequently, only the routing container in the ietf-routing model [RFC8349] is augmented. The routing-state container is not augmented.

2.2. Overview

The OSPF YANG module defined in this document has all the common building blocks for the OSPF protocol.

The OSPF YANG module augments the /routing/control-plane-protocols/control-plane-protocol path defined in the ietf-routing module. The ietf-ospf model defines a single instance of OSPF which may be instantiated as an OSPFv2 or OSPFv3 instance. Multiple instances are instantiated as multiple control-plane protocols instances.

```

module: ietf-ospf
  augment /rt:routing/rt:control-plane-protocols/
    rt:control-plane-protocol:
      +--rw ospf
         .
         .
         +--rw af?                               identityref
            .
            .
            +--rw areas
               +--rw area* [area-id]
                  +--rw area-id                 area-id-type
                     .
                     .
                     +--rw virtual-links
                        +--rw virtual-link* [transit-area-id router-id]
                           .
                           .
                           +--rw sham-links {pe-ce-protocol}?
                              +--rw sham-link* [local-id remote-id]
                                 .
                                 .
                                 +--rw interfaces
                                    +--rw interface* [name]
                                       .
                                       .
            +--rw topologies {multi-topology}?
               +--rw topology* [name]
                  .
                  .

```

The ospf container includes one OSPF protocol instance. The instance includes OSPF router level configuration and operational state. Each OSPF instance maps to a control-plane-protcol instance as defined in [RFC8349].

The area and area/interface containers define the OSPF configuration and operational state for OSPF areas and interfaces respectively.

The topologies container defines the OSPF configuration and operational state for OSPF topologies when the multi-topology feature is supported.

2.3. OSPFv2 and OSPFv3

The data model defined herein supports both OSPFv2 and OSPFv3.

The field 'version' is used to indicate the OSPF version and is mandatory. Based on the configured version, the data model varies to accommodate the differences between OSPFv2 and OSPFv3.

2.4. Optional Features

Optional features are beyond the basic OSPF configuration and it is the responsibility of each vendor to decide whether to support a given feature on a particular device.

This model defines the following optional features:

1. multi-topology: Support Multi-Topology Routing (MTR) [RFC4915].
2. multi-area-adj: Support OSPF multi-area adjacency [RFC5185].
3. explicit-router-id: Support explicit per-instance Router-ID specification.
4. demand-circuit: Support OSPF demand circuits [RFC1793].
5. mtu-ignore: Support disabling OSPF Database Description packet MTU mismatch checking specified in section 10.6 of [RFC2328].
6. lls: Support OSPF link-local signaling (LLS) [RFC5613].
7. prefix-suppression: Support OSPF prefix advertisement suppression [RFC6860].
8. ttl-security: Support OSPF Time to Live (TTL) security check support [RFC5082].
9. nsr: Support OSPF Non-Stop Routing (NSR). The OSPF NSR feature allows a router with redundant control-plane capability (e.g., dual Route-Processor (RP) cards) to maintain its state and adjacencies during planned and unplanned control-plane processing restarts. It differs from graceful-restart or Non-

Stop Forwarding (NSF) in that no protocol signaling or assistance from adjacent OSPF neighbors is required to recover control-plane state.

10. graceful-restart: Support Graceful OSPF Restart [RFC3623], [RFC5187].
11. auto-cost: Support OSPF interface cost calculation according to reference bandwidth [RFC2328].
12. max-ecmp: Support configuration of the maximum number of Equal-Cost Multi-Path (ECMP) paths.
13. max-lsa: Support configuration of the maximum number of LSAs the OSPF instance will accept [RFC1765].
14. te-rid: Support configuration of the Traffic Engineering (TE) Router-ID, i.e., the Router Address described in Section 2.4.1 of [RFC3630] or the Router IPv6 Address TLV described in Section 3 of [RFC5329].
15. ldp-igp-sync: Support LDP IGP synchronization [RFC5443].
16. ospfv2-authentication-trailer: Support OSPFv2 Authentication trailer as specified in [RFC5709] or [RFC7474].
17. ospfv3-authentication-ipsec: Support IPsec for OSPFv3 authentication [RFC4552].
18. ospfv3-authentication-trailer: Support OSPFv3 Authentication trailer as specified in [RFC7166].
19. fast-reroute: Support IP Fast Reroute (IP-FRR) [RFC5714].
20. node-flag: Support node-flag for OSPF prefixes. [RFC7684].
21. node-tag: Support node admin tag for OSPF instances [RFC7777].
22. lfa: Support Loop-Free Alternates (LFAs) [RFC5286].
23. remote-lfa: Support Remote Loop-Free Alternates (R-LFA) [RFC7490].
24. stub-router: Support RFC 6987 OSPF Stub Router advertisement [RFC6987].
25. pe-ce-protocol: Support OSPF as a PE-CE protocol [RFC4577], [RFC6565].

26. ietf-spf-delay: Support IETF SPF delay algorithm [RFC8405].
27. bfd: Support BFD detection of OSPF neighbor reachability [RFC5880], [RFC5881], and [I-D.ietf-bfd-yang].
28. hybrid-interface: Support OSPF Hybrid Broadcast and Point-to-Point Interfaces [RFC6845].

It is expected that vendors will support additional features through vendor-specific augmentations.

2.5. OSPF Router Configuration/Operational State

The ospf container is the top-level container in this data model. It represents an OSPF protocol instance and contains the router level configuration and operational state. The operational state includes the instance statistics, IETF SPF delay statistics, AS-Scoped Link State Database, local RIB, SPF Log, and the LSA log.

```

module: ietf-ospf
  augment /rt:routing/rt:control-plane-protocols/
    rt:control-plane-protocol:
      +--rw ospf
      .
      .
      +--rw af iana-rt-types:address-family
      +--rw enable? boolean
      +--rw explicit-router-id? rt-types:router-id
      | {explicit-router-id}?
      +--rw preference
      | +--rw (scope)?
      | | +--:(single-value)
      | | | +--rw all? uint8
      | | +--:(multi-values)
      | | +--rw (granularity)?
      | | | +--:(detail)
      | | | | +--rw intra-area? uint8
      | | | | +--rw inter-area? uint8
      | | | +--:(coarse)
      | | | | +--rw internal? uint8
      | | | +--rw external? uint8
      +--rw nsr {nsr}?
      | +--rw enable? boolean
      +--rw graceful-restart {graceful-restart}?
      | +--rw enable? boolean
      | +--rw helper-enable? boolean
      | +--rw restart-interval? uint16
      | +--rw helper-strict-lsa-checking? boolean
  
```

```

+--rw auto-cost {auto-cost}?
|   +--rw enable?                boolean
|   +--rw reference-bandwidth?   uint32
+--rw spf-control
|   +--rw paths?                  uint16 {max-ecmp}?
|   +--rw ietf-spf-delay {ietf-spf-delay}?
|       +--rw initial-delay?     uint16
|       +--rw short-delay?       uint16
|       +--rw long-delay?        uint16
|       +--rw hold-down?         uint16
|       +--rw time-to-learn?     uint16
|       +--ro current-state?     enumeration
|       +--ro remaining-time-to-learn? uint16
|       +--ro remaining-hold-down? uint16
|       +--ro last-event-received? yang:timestamp
|       +--ro next-spf-time?     yang:timestamp
|       +--ro last-spf-time?     yang:timestamp
+--rw database-control
|   +--rw max-lsa?               uint32 {max-lsa}?
+--rw stub-router {stub-router}?
|   +--rw (trigger)?
|       +--:(always)
|           +--rw always!
+--rw mpls
|   +--rw te-rid {te-rid}?
|       |   +--rw ipv4-router-id?   inet:ipv4-address
|       |   +--rw ipv6-router-id?   inet:ipv6-address
|       +--rw ldp
|           +--rw igp-sync?         boolean {ldp-igp-sync}?
+--rw fast-reroute {fast-reroute}?
|   +--rw lfa {lfa}?
+--ro protected-routes
|   +--ro af-stats* [af prefix alternate]
|       +--ro af                    iana-rt-types:address-family
|       +--ro prefix                  string
|       +--ro alternate                string
|       +--ro alternate-type?         enumeration
|       +--ro best?                    boolean
|       +--ro non-best-reason?        string
|       +--ro protection-available?   bits
|       +--ro alternate-metric1?      uint32
|       +--ro alternate-metric2?      uint32
|       +--ro alternate-metric3?      uint32
+--ro unprotected-routes
|   +--ro af-stats* [af prefix]
|       +--ro af                    iana-rt-types:address-family
|       +--ro prefix                  string
+--ro protection-statistics* [frr-protection-method]

```

```

|   +--ro frr-protection-method string
|   +--ro af-stats* [af]
|       +--ro af                               iana-rt-types:address-family
|       +--ro total-routes?                    uint32
|       +--ro unprotected-routes?             uint32
|       +--ro protected-routes?               uint32
|       +--ro linkprotected-routes?           uint32
|       +--ro nodeprotected-routes?           uint32
+--rw node-tags {node-tag}?
|   +--rw node-tag* [tag]
|       +--rw tag                               uint32
+--ro router-id?
+--ro local-rib
|   +--ro route* [prefix]
|       +--ro prefix                            inet:ip-prefix
|       +--ro next-hops
|           +--ro next-hop* [next-hop]
|               +--ro outgoing-interface?     if:interface-ref
|               +--ro next-hop                 inet:ip-address
|       +--ro metric?                          uint32
|       +--ro route-type?                      route-type
|       +--ro route-tag?                      uint32
+--ro statistics
|   +--ro discontinuity-time                    yang:date-and-time
|   +--ro originate-new-lsa-count?            yang:counter32
|   +--ro rx-new-lsas-count?                  yang:counter32
|   +--ro as-scope-lsa-count?                 yang:gauge32
|   +--ro as-scope-lsa-chksum-sum?           uint32
|   +--ro database
|       +--ro as-scope-lsa-type*
|           +--ro lsa-type?                    uint16
|           +--ro lsa-count?                   yang:gauge32
|           +--ro lsa-cksum-sum?              int32
+--ro database
|   +--ro as-scope-lsa-type* [lsa-type]
|   +--ro as-scope-lsas
|       +--ro as-scope-lsa* [lsa-id adv-router]
|           +--ro lsa-id                        union
|           +--ro adv-router                    inet:ipv4-address
|           +--ro decoded-completed?           boolean
|           +--ro raw-data?                    yang:hex-string
|           +--ro (version)?
|               +--:(ospfv2)
|                   | +--ro ospfv2
|                   .
|                   .
|               +--:(ospfv3)
|                   +--ro ospfv3

```

```

.
.
+--ro spf-log
|   +--ro event* [id]
|   |   +--ro id                uint32
|   |   +--ro spf-type?         enumeration
|   |   +--ro schedule-timestamp? yang:timestamp
|   |   +--ro start-timestamp?  yang:timestamp
|   |   +--ro end-timestamp?    yang:timestamp
|   |   +--ro trigger-lsa*
|   |   |   +--ro area-id?      area-id-type
|   |   |   +--ro link-id?     union
|   |   |   +--ro type?        uint16
|   |   |   +--ro lsa-id?      yang:dotted-quad
|   |   |   +--ro adv-router?  yang:dotted-quad
|   |   |   +--ro seq-num?     uint32
+--ro lsa-log
|   +--ro event* [id]
|   |   +--ro id                uint32
|   |   +--ro lsa
|   |   |   +--ro area-id?      area-id-type
|   |   |   +--ro link-id?     union
|   |   |   +--ro type?        uint16
|   |   |   +--ro lsa-id?      yang:dotted-quad
|   |   |   +--ro adv-router?  yang:dotted-quad
|   |   |   +--ro seq-num?     uint32
|   |   +--ro received-timestamp? yang:timestamp
|   |   +--ro reason?          identityref
.
.

```

2.6. OSPF Area Configuration/Operational State

The area container contains OSPF area configuration and the list of interface containers representing all the OSPF interfaces in the area. The area operational state includes the area statistics and the Area Link State Database (LSDB).

```

module: ietf-ospf
  augment /rt:routing/rt:control-plane-protocols/
    rt:control-plane-protocol:
      +--rw ospf
      .
      .
      +--rw areas
      |   +--rw area* [area-id]
      |   |   +--rw area-id                area-id-type
      |   |   +--rw area-type?            identityref

```



```

+--rw virtual-link* [transit-area-id router-id]
  +--rw transit-area-id      -> ../../../../
                             area/area-id
  +--rw router-id            rt-types:router-id
  +--rw hello-interval?     uint16
  +--rw dead-interval?      uint32
  +--rw retransmit-interval? uint16
  +--rw transmit-delay?     uint16
  +--rw lls?                 boolean {lls}?
  +--rw ttl-security {ttl-security}?
  |   +--rw enable?         boolean
  |   +--rw hops?           uint8
  +--rw enable?              boolean
  +--rw authentication
  |   +--rw (auth-type-selection)?
  |   |   +--:(ospfv2-auth)
  |   |   |   +--rw ospfv2-auth-trailer-rfc?
  |   |   |   |   ospfv2-auth-trailer-rfc-version
  |   |   |   |   {ospfv2-authentication-trailer}?
  |   |   |   +--rw (ospfv2-auth-specification)?
  |   |   |   |   +--:(auth-key-chain) {key-chain}?
  |   |   |   |   |   +--rw ospfv2-key-chain?
  |   |   |   |   |   |   key-chain:key-chain-ref
  |   |   |   |   |   +--:(auth-key-explicit)
  |   |   |   |   |   |   +--rw ospfv2-key-id?         uint32
  |   |   |   |   |   |   +--rw ospfv2-key?           string
  |   |   |   |   |   |   +--rw ospfv2-crypto-algorithm?
  |   |   |   |   |   |   |   identityref
  |   |   |   +--:(ospfv3-auth-ipsec)
  |   |   |   |   {ospfv3-authentication-ipsec}?
  |   |   |   |   +--rw sa?                             string
  |   |   |   +--:(ospfv3-auth-trailer)
  |   |   |   |   {ospfv3-authentication-trailer}?
  |   |   |   +--rw (ospfv3-auth-specification)?
  |   |   |   |   +--:(auth-key-chain) {key-chain}?
  |   |   |   |   |   +--rw ospfv3-key-chain?
  |   |   |   |   |   |   key-chain:key-chain-ref
  |   |   |   |   |   +--:(auth-key-explicit)
  |   |   |   |   |   |   +--rw ospfv3-sa-id?           uint16
  |   |   |   |   |   |   +--rw ospfv3-key?           string
  |   |   |   |   |   |   +--rw ospfv3-crypto-algorithm?
  |   |   |   |   |   |   |   identityref
  +--ro cost?                uint16
  +--ro state?               if-state-type
  +--ro hello-timer?         rt-types:
  |                           rtimer-value-seconds16
  +--ro wait-timer?         rt-types:
  |                           rtimer-value-seconds16
  |

```



```

+--rw lls?                               boolean {lls}?
+--rw ttl-security {ttl-security}?
|   +--rw enable?    boolean
|   +--rw hops?     uint8
+--rw enable?                boolean
+--rw authentication
|   +--rw (auth-type-selection)?
|   |   +--:(ospfv2-auth)
|   |   |   +--rw ospfv2-auth-trailer-rfc?
|   |   |   |   ospfv2-auth-trailer-rfc-version
|   |   |   |   {ospfv2-authentication-trailer}?
|   |   |   +--rw (ospfv2-auth-specification)?
|   |   |   |   +--:(auth-key-chain) {key-chain}?
|   |   |   |   |   +--rw ospfv2-key-chain?
|   |   |   |   |   |   key-chain:key-chain-ref
|   |   |   |   |   +--:(auth-key-explicit)
|   |   |   |   |   |   +--rw ospfv2-key-id?    uint32
|   |   |   |   |   |   +--rw ospfv2-key?      string
|   |   |   |   |   |   +--rw ospfv2-crypto-algorithm?
|   |   |   |   |   |   |   identityref
|   |   |   +--:(ospfv3-auth-ipsec)
|   |   |   |   {ospfv3-authentication-ipsec}?
|   |   |   |   +--rw sa?                        string
|   |   |   +--:(ospfv3-auth-trailer)
|   |   |   |   {ospfv3-authentication-trailer}?
|   |   |   +--rw (ospfv3-auth-specification)?
|   |   |   |   +--:(auth-key-chain) {key-chain}?
|   |   |   |   |   +--rw ospfv3-key-chain?
|   |   |   |   |   |   key-chain:key-chain-ref
|   |   |   |   |   +--:(auth-key-explicit)
|   |   |   |   |   |   +--rw ospfv3-sa-id?      uint16
|   |   |   |   |   |   +--rw ospfv3-key?        string
|   |   |   |   |   |   +--rw ospfv3-crypto-algorithm?
|   |   |   |   |   |   |   identityref
|   |   |   +--rw cost?                          uint16
|   |   +--rw mtu-ignore?                          boolean
|   |   |   {mtu-ignore}?
|   +--rw prefix-suppression? boolean
|   |   {prefix-suppression}?
|   +--ro state?                                   if-state-type
|   +--ro hello-timer?                            rt-types:
|   |   rtimer-value-seconds16
|   +--ro wait-timer?                             rt-types:
|   |   rtimer-value-seconds16
|   +--ro dr-router-id?                           rt-types:router-id
|   +--ro dr-ip-addr?                              inet:ip-address
|   +--ro bdr-router-id?                          rt-types:router-id
|   +--ro bdr-ip-addr?                            inet:ip-address

```

```

+--ro statistics
  +--ro discontinuity-time      yang:date-and-time
  +--ro if-event-count?        yang:counter32
  +--ro link-scope-lsa-count?  yang:gauge32
  +--ro link-scope-lsa-cksum-sum?
                                uint32
  +--ro database
    +--ro link-scope-lsa-type*
      +--ro lsa-type?          uint16
      +--ro lsa-count?        yang:gauge32
      +--ro lsa-cksum-sum?    int32
+--ro neighbors
  +--ro neighbor* [neighbor-router-id]
    +--ro neighbor-router-id
                                rt-types:router-id
  +--ro address?               inet:ip-address
  +--ro dr-router-id?          rt-types:router-id
  +--ro dr-ip-addr?            inet:ip-address
  +--ro bdr-router-id?        rt-types:router-id
  +--ro bdr-ip-addr?           inet:ip-address
  +--ro state?                 nbr-state-type
  +--ro cost?                  uint32
  +--ro dead-timer?            rt-types:
    |                           rtimer-value-seconds16
+--ro statistics
  +--ro nbr-event-count?       yang:counter32
  +--ro nbr-retrans-qlen?     yang:gauge32
+--ro database
  +--ro link-scope-lsa-type* [lsa-type]
    +--ro lsa-type             uint16
  +--ro link-scope-lsas
:
:

```

2.7. OSPF Interface Configuration/Operational State

The interface container contains OSPF interface configuration and operational state. The interface operational state includes the statistics, list of neighbors, and Link-Local Link State Database (LSDB).

```

module: ietf-ospf
  augment /rt:routing/rt:control-plane-protocols/
    rt:control-plane-protocol:
      +--rw ospf
      .

```

```

.
+--rw areas
  +--rw area* [area-id]
    .
    .
    +--rw interfaces
      +--rw interface* [name]
        +--rw name if:interface-ref
        +--rw interface-type? enumeration
        +--rw passive? boolean
        +--rw demand-circuit? boolean
        +--rw priority? uint8
        +--rw multi-areas {multi-area-adj}?
          +--rw multi-area* [multi-area-id]
            +--rw multi-area-id area-id-type
            +--rw cost? uint16
        +--rw static-neighbors
          +--rw neighbor* [identifier]
            +--rw identifier inet:ip-address
            +--rw cost? uint16
            +--rw poll-interval? uint16
            +--rw priority? uint8
        +--rw node-flag? boolean
          {node-flag}?
        +--rw bfd {bfd}?
          +--rw enable? boolean
        +--rw fast-reroute {fast-reroute}?
          +--rw lfa {lfa}?
            +--rw candidate-enable? boolean
            +--rw enable? boolean
            +--rw remote-lfa {remote-lfa}?
              +--rw enable? boolean
        +--rw hello-interval? uint16
        +--rw dead-interval? uint32
        +--rw retransmit-interval? uint16
        +--rw transmit-delay? uint16
        +--rw lls? boolean {lls}?
        +--rw ttl-security {ttl-security}?
          +--rw enable? boolean
          +--rw hops? uint8
        +--rw enable? boolean
        +--rw authentication
          +--rw (auth-type-selection)?
            +--:(ospfv2-auth)
              +--rw ospfv2-auth-trailer-rfc?
                ospfv2-auth-trailer-rfc-version
                {ospfv2-authentication-trailer}?

```

```

    +--rw (ospfv2-auth-specification)?
      +--:(auth-key-chain) {key-chain}?
        |   +--rw ospfv2-key-chain?
        |       key-chain:key-chain-ref
        +--:(auth-key-explicit)
          +--rw ospfv2-key-id?      uint32
          +--rw ospfv2-key?        string
          +--rw ospfv2-crypto-algorithm?
              identityref
+--:(ospfv3-auth-ipsec)
  |   {ospfv3-authentication-ipsec}?
  |   +--rw sa?                    string
+--:(ospfv3-auth-trailer)
  |   {ospfv3-authentication-trailer}?
  +--rw (ospfv3-auth-specification)?
    +--:(auth-key-chain) {key-chain}?
      |   +--rw ospfv3-key-chain?
      |       key-chain:key-chain-ref
    +--:(auth-key-explicit)
      +--rw ospfv3-sa-id?          uint16
      +--rw ospfv3-key?            string
      +--rw ospfv3-crypto-algorithm?
          identityref
+--rw cost?                        uint16
+--rw mtu-ignore?                  boolean
  |   {mtu-ignore}?
+--rw prefix-suppression?         boolean
  |   {prefix-suppression}?
+--ro state?                       if-state-type
+--ro hello-timer?                rt-types:
  |   rtimer-value-seconds16
+--ro wait-timer?                 rt-types:
  |   rtimer-value-seconds16
+--ro dr-router-id?               rt-types:router-id
+--ro dr-ip-addr?                 inet:ip-address
+--ro bdr-router-id?              rt-types:router-id
+--ro bdr-ip-addr?                inet:ip-address
+--ro statistics
  |   +--ro if-event-count?         yang:counter32
  |   +--ro link-scope-lsa-count?  yang:gauge32
  |   +--ro link-scope-lsa-cksum-sum?
  |       uint32
  +--ro database
    +--ro link-scope-lsa-type*
      +--ro lsa-type?              uint16
      +--ro lsa-count?             yang:gauge32
      +--ro lsa-cksum-sum?        int32
+--ro neighbors

```

```

+--ro neighbor* [neighbor-router-id]
  +--ro neighbor-router-id
    rt-types:router-id
  +--ro address?      inet:ip-address
  +--ro dr-router-id? rt-types:router-id
  +--ro dr-ip-addr?   inet:ip-address
  +--ro bdr-router-id? rt-types:router-id
  +--ro bdr-ip-addr?  inet:ip-address
  +--ro state?        nbr-state-type
  +--ro dead-timer?   rt-types:
  |                   rtimer-value-seconds16
+--ro statistics
  +--ro nbr-event-count?
  |                   yang:counter32
  +--ro nbr-retrans-qlen?
  |                   yang:gauge32
+--ro database
  . +--ro link-scope-lsa-type* [lsa-type]
  .   +--ro lsa-type      uint16
  .   +--ro link-scope-lsas
  .
  .
+--rw topologies {ospf:multi-topology}?
  +--rw topology* [name]
  |   +--rw name -> ../../../../../../../../../../
  |   |                   ../../../../../../rt:ribs/rib/name
  |   +--rw cost? uint32
+--rw instance-id?      uint8

```

2.8. OSPF Notifications

This YANG model defines a list of notifications that inform YANG clients of important events detected during protocol operation. The defined notifications cover the common set of traps from the OSPFv2 MIB [RFC4750] and OSPFv3 MIB [RFC5643].

```

notifications:
  +---n if-state-change
  |   +--ro routing-protocol-name?
  |   +   -> /rt:routing/control-plane-protocols/
  |   +   control-plane-protocol/name
  |   +--ro af?
  |   +   -> /rt:routing/control-plane-protocols/
  |   +   control-plane-protocol
  |   +   [rt:name=current()/../routing-protocol-name]/
  |   +   ospf:ospf/af

```

```

+--ro (if-link-type-selection)?
  +--:(interface)
  |   +--ro interface
  |       +--ro interface?   if:interface-ref
  +--:(virtual-link)
  |   +--ro virtual-link
  |       +--ro transit-area-id?   area-id-type
  |       +--ro neighbor-router-id?   rt-types:router-id
  +--:(sham-link)
  |   +--ro sham-link
  |       +--ro area-id?   area-id-type
  |       +--ro local-ip-addr?   inet:ip-address
  |       +--ro remote-ip-addr?   inet:ip-address
+--ro state?   if-state-type
+---n if-config-error
+--ro routing-protocol-name?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol/name
+--ro af?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol
+   [rt:name=current()/../routing-protocol-name]/
+   ospf:ospf/af
+--ro (if-link-type-selection)?
  +--:(interface)
  |   +--ro interface
  |       +--ro interface?   if:interface-ref
  +--:(virtual-link)
  |   +--ro virtual-link
  |       +--ro transit-area-id?   area-id-type
  |       +--ro neighbor-router-id?   rt-types:router-id
  +--:(sham-link)
  |   +--ro sham-link
  |       +--ro area-id?   area-id-type
  |       +--ro local-ip-addr?   inet:ip-address
  |       +--ro remote-ip-addr?   inet:ip-address
+--ro packet-source?   yang:dotted-quad
+--ro packet-type?   packet-type
+--ro error?   enumeration
+---n nbr-state-change
+--ro routing-protocol-name?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol/name
+--ro af?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol
+   [rt:name=current()/../routing-protocol-name]/
+   ospf:ospf/af

```

```

+---ro (if-link-type-selection)?
  +---:(interface)
  |   +---ro interface
  |       +---ro interface?   if:interface-ref
  +---:(virtual-link)
  |   +---ro virtual-link
  |       +---ro transit-area-id?   area-id-type
  |       +---ro neighbor-router-id? rt-types:router-id
  +---:(sham-link)
  |   +---ro sham-link
  |       +---ro area-id?   area-id-type
  |       +---ro local-ip-addr?   inet:ip-address
  |       +---ro remote-ip-addr?   inet:ip-address
+---ro neighbor-router-id?   rt-types:router-id
+---ro neighbor-ip-addr?   yang:dotted-quad
+---ro state?   nbr-state-type
+---n nbr-restart-helper-status-change
+---ro routing-protocol-name?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol/name
+---ro af?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol
+   [rt:name=current()/../routing-protocol-name]/
+   ospf:ospf/af
+---ro (if-link-type-selection)?
  +---:(interface)
  |   +---ro interface
  |       +---ro interface?   if:interface-ref
  +---:(virtual-link)
  |   +---ro virtual-link
  |       +---ro transit-area-id?   area-id-type
  |       +---ro neighbor-router-id? rt-types:router-id
  +---:(sham-link)
  |   +---ro sham-link
  |       +---ro area-id?   area-id-type
  |       +---ro local-ip-addr?   inet:ip-address
  |       +---ro remote-ip-addr?   inet:ip-address
+---ro neighbor-router-id?   rt-types:router-id
+---ro neighbor-ip-addr?   yang:dotted-quad
+---ro status?   restart-helper-status-type
+---ro age?   uint32
+---ro exit-reason?   restart-exit-reason-type
+---n if-rx-bad-packet
+---ro routing-protocol-name?
+   -> /rt:routing/control-plane-protocols/
+   control-plane-protocol/name
+---ro af?

```

```

+     -> /rt:routing/control-plane-protocols/
+     control-plane-protocol
+     [rt:name=current()/../routing-protocol-name]/
+     ospf:ospf/af
+---ro (if-link-type-selection)?
|   +---:(interface)
|   |   +---ro interface
|   |   |   +---ro interface?    if:interface-ref
|   |   +---:(virtual-link)
|   |   |   +---ro virtual-link
|   |   |   |   +---ro transit-area-id?    area-id-type
|   |   |   |   +---ro neighbor-router-id?  rt-types:router-id
|   |   +---:(sham-link)
|   |   |   +---ro sham-link
|   |   |   |   +---ro area-id?            area-id-type
|   |   |   |   +---ro local-ip-addr?     inet:ip-address
|   |   |   |   +---ro remote-ip-addr?    inet:ip-address
|   +---ro packet-source?                yang:dotted-quad
|   +---ro packet-type?                  packet-type
+---n lsdb-approaching-overflow
|   +---ro routing-protocol-name?
|   +     -> /rt:routing/control-plane-protocols/
|   +     control-plane-protocol/name
|   +---ro af?
|   +     -> /rt:routing/control-plane-protocols/
|   +     control-plane-protocol
|   +     [rt:name=current()/../routing-protocol-name]/
|   +     ospf:ospf/af
|   +---ro ext-lsdb-limit?                uint32
+---n lsdb-overflow
|   +---ro routing-protocol-name?
|   +     -> /rt:routing/control-plane-protocols/
|   +     control-plane-protocol/name
|   +---ro af?
|   +     -> /rt:routing/control-plane-protocols/
|   +     control-plane-protocol
|   +     [rt:name=current()/../routing-protocol-name]/
|   +     ospf:ospf/af
|   +---ro ext-lsdb-limit?                uint32
+---n nssa-translator-status-change
|   +---ro routing-protocol-name?
|   +     -> /rt:routing/control-plane-protocols/
|   +     control-plane-protocol/name
|   +---ro af?
|   +     -> /rt:routing/control-plane-protocols/
|   +     control-plane-protocol
|   +     [rt:name=current()/../routing-protocol-name]/
|   +     ospf:ospf/af

```

```

|   +--ro area-id?                area-id-type
|   +--ro status?                 nssa-translator-state-type
+---n restart-status-change
|   +--ro routing-protocol-name?
|   +   -> /rt:routing/control-plane-protocols/
|   +   control-plane-protocol/name
|   +--ro af?
|   +   -> /rt:routing/control-plane-protocols/
|   +   control-plane-protocol
|   +   [rt:name=current()/../routing-protocol-name]/
|   +   ospf:ospf/af
+---ro status?                   restart-status-type
+---ro restart-interval?        uint16
+---ro exit-reason?            restart-exit-reason-type

```

2.9. OSPF RPC Operations

The "ietf-ospf" module defines two RPC operations:

- o clear-database: reset the content of a particular OSPF Link State Database.
- o clear-neighbor: Reset a particular OSPF neighbor or group of neighbors associated with an OSPF interface.

```

rpcs:
+---x clear-neighbor
|   +---w input
|   |   +---w routing-protocol-name
|   |   +   -> /rt:routing/control-plane-protocols/
|   |   +   control-plane-protocol/name
|   |   +---w interface?           if:interface-ref
+---x clear-database
|   +---w input
|   |   +---w routing-protocol-name
|   |   -> /rt:routing/control-plane-protocols/
|   |   control-plane-protocol/name

```

3. OSPF YANG Module

The following RFCs and drafts are not referenced in the document text but are referenced in the ietf-ospf.yang module: [RFC0905], [RFC4576], [RFC4973], [RFC5250], [RFC5309], [RFC5642], [RFC5881], [RFC6991], [RFC7770], [RFC7884], [RFC8294], and [RFC8476].

```

<CODE BEGINS> file "ietf-ospf@2019-10-17.yang"
module ietf-ospf {
  yang-version 1.1;

```

```
namespace "urn:ietf:params:xml:ns:yang:ietf-ospf";

prefix ospf;

import ietf-inet-types {
  prefix "inet";
  reference "RFC 6991: Common YANG Data Types";
}

import ietf-yang-types {
  prefix "yang";
  reference "RFC 6991: Common YANG Data Types";
}

import ietf-interfaces {
  prefix "if";
  reference "RFC 8343: A YANG Data Model for Interface
            Management (NMDA Version)";
}

import ietf-routing-types {
  prefix "rt-types";
  reference "RFC 8294: Common YANG Data Types for the
            Routing Area";
}

import iana-routing-types {
  prefix "iana-rt-types";
  reference "RFC 8294: Common YANG Data Types for the
            Routing Area";
}

import ietf-routing {
  prefix "rt";
  reference "RFC 8349: A YANG Data Model for Routing
            Management (NMDA Version)";
}

import ietf-key-chain {
  prefix "key-chain";
  reference "RFC 8177: YANG Data Model for Key Chains";
}

import ietf-bfd-types {
  prefix "bfd-types";
  reference "RFC YYYY: YANG Data Model for Bidirectional
            Forwarding Detection (BFD). Please replace YYYY with
            published RFC number for draft-ietf-bfd-yang.";
```

```
}  
  
organization  
  "IETF LSR - Link State Routing Working Group";  
  
contact  
  "WG Web: <https://datatracker.ietf.org/group/lsr/>  
  WG List: <mailto:lsr@ietf.org>  
  
  Editor: Derek Yeung  
  <mailto:derek@arrcus.com>  
  Author: Acee Lindem  
  <mailto:acee@cisco.com>  
  Author: Yingzhen Qu  
  <mailto:yingzhen.qu@futurewei.com>  
  Author: Salih K A  
  <mailto:salih@juniper.net>  
  Author: Ing-Wher Chen  
  <mailto:ingwherchen@mitre.org>";  
  
description  
  "This YANG module defines the generic configuration and  
  operational state for the OSPF protocol common to all  
  vendor implementations. It is intended that the module  
  will be extended by vendors to define vendor-specific  
  OSPF configuration parameters and policies,  
  for example, route maps or route policies.  
  
  This YANG model conforms to the Network Management  
  Datastore Architecture (NMDA) as described in RFC 8242.  
  
  Copyright (c) 2018 IETF Trust and the persons identified as  
  authors of the code. All rights reserved.  
  
  Redistribution and use in source and binary forms, with or  
  without modification, is permitted pursuant to, and subject to  
  the license terms contained in, the Simplified BSD License set  
  forth in Section 4.c of the IETF Trust's Legal Provisions  
  Relating to IETF Documents  
  (https://trustee.ietf.org/license-info).  
  
  This version of this YANG module is part of RFC XXXX  
  (https://www.rfc-editor.org/info/rfcXXXX); see the RFC itself  
  for full legal notices.  
  
  The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL', 'SHALL  
  NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'NOT RECOMMENDED',  
  'MAY', and 'OPTIONAL' in this document are to be interpreted as
```

described in BCP 14 (RFC 2119) (RFC 8174) when, and only when, they appear in all capitals, as shown here.

This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices.";

```
revision 2019-10-17 {
  description
    "Initial revision.";
  reference
    "RFC XXXX: A YANG Data Model for OSPF.";
}

feature multi-topology {
  description
    "Support Multiple-Topology Routing (MTR).";
  reference "RFC 4915: Multi-Topology Routing";
}

feature multi-area-adj {
  description
    "OSPF multi-area adjacency support as in RFC 5185.";
  reference "RFC 5185: Multi-Area Adjacency";
}

feature explicit-router-id {
  description
    "Set Router-ID per instance explicitly.";
}

feature demand-circuit {
  description
    "OSPF demand circuit support as in RFC 1793.";
  reference "RFC 1793: OSPF Demand Circuits";
}

feature mtu-ignore {
  description
    "Disable OSPF Database Description packet MTU
     mismatch checking specified in the OSPF
     protocol specification.";
  reference "RFC 2328: OSPF Version 2, section 10.6";
}

feature lls {
  description
    "OSPF link-local signaling (LLS) as in RFC 5613.";
  reference "RFC 5613: OSPF Link-Local Signaling";
}
```

```
feature prefix-suppression {
  description
    "OSPF prefix suppression support as in RFC 6860.";
  reference "RFC 6860: Hide Transit-Only Networks in OSPF";
}

feature ttl-security {
  description
    "OSPF Time to Live (TTL) security check support.";
  reference "RFC 5082: The Generalized TTL Security
            Mechanism (GTSM)";
}

feature nsr {
  description
    "Non-Stop-Routing (NSR) support. The OSPF NSR feature
     allows a router with redundant control-plane capability
     (e.g., dual Route-Processor (RP) cards) to maintain its
     state and adjacencies during planned and unplanned
     OSPF instance restarts. It differs from graceful-restart
     or Non-Stop Forwarding (NSF) in that no protocol signaling
     or assistance from adjacent OSPF neighbors is required to
     recover control-plane state.";
}

feature graceful-restart {
  description
    "Graceful OSPF Restart as defined in RFC 3623 and
     RFC 5187.";
  reference "RFC 3623: Graceful OSPF Restart
            RFC 5187: OSPFv3 Graceful Restart";
}

feature auto-cost {
  description
    "Calculate OSPF interface cost according to
     reference bandwidth.";
  reference "RFC 2328: OSPF Version 2";
}

feature max-ecmp {
  description
    "Setting maximum number of ECMP paths.";
}

feature max-lsa {
  description
    "Setting the maximum number of LSAs the OSPF instance
```

```
        will accept.";
        reference "RFC 1765: OSPF Database Overload";
    }

    feature te-rid {
        description
            "Support configuration of the Traffic Engineering (TE)
            Router-ID, i.e., the Router Address described in Section
            2.4.1 of RFC3630 or the Router IPv6 Address TLV described
            in Section 3 of RFC5329.";
        reference "RFC 3630: Traffic Engineering (TE) Extensions
            to OSPF Version 2
            RFC 5329: Traffic Engineering (TE) Extensions
            to OSPF Version 3";
    }

    feature ldp-igp-sync {
        description
            "LDP IGP synchronization.";
        reference "RFC 5443: LDP IGP Synchronization";
    }

    feature ospfv2-authentication-trailer {
        description
            "Support OSPFv2 authentication trailer for OSPFv2
            authentication.";
        reference "RFC 5709: Supporting Authentication
            Trailer for OSPFv2
            RFC 7474: Security Extension for OSPFv2 When
            Using Manual Key Management";
    }

    feature ospfv3-authentication-ipsec {
        description
            "Support IPsec for OSPFv3 authentication.";
        reference "RFC 4552: Authentication/Confidentiality
            for OSPFv3";
    }

    feature ospfv3-authentication-trailer {
        description
            "Support OSPFv3 authentication trailer for OSPFv3
            authentication.";
        reference "RFC 7166: Supporting Authentication
            Trailer for OSPFv3";
    }

    feature fast-reroute {
```

```
description
  "Support for IP Fast Reroute (IP-FRR).";
reference "RFC 5714: IP Fast Reroute Framework";
}

feature key-chain {
  description
    "Support of keychain for authentication.";
reference "RFC8177: YANG Data Model for Key Chains";
}

feature node-flag {
  description
    "Support for node-flag for OSPF prefixes.";
reference "RFC 7684: OSPFv2 Prefix/Link Advertisement";
}

feature node-tag {
  description
    "Support for node admin tag for OSPF routing instances.";
reference "RFC 7777: Advertising Node Administrative
          Tags in OSPF";
}

feature lfa {
  description
    "Support for Loop-Free Alternates (LFAs).";
reference "RFC 5286: Basic Specification for IP Fast
          Reroute: Loop-Free Alternates";
}

feature remote-lfa {
  description
    "Support for Remote Loop-Free Alternates (R-LFA).";
reference "RFC 7490: Remote Loop-Free Alternate (LFA)
          Fast Reroute (FRR)";
}

feature stub-router {
  description
    "Support for RFC 6987 OSPF Stub Router Advertisement.";
reference "RFC 6987: OSPF Stub Router Advertisement";
}

feature pe-ce-protocol {
  description
    "Support for OSPF as a PE-CE protocol";
reference "RFC 4577: OSPF as the Provider/Customer Edge
```

```
        Protocol for BGP/MPLS IP Virtual Private
        Networks (VPNs)
        RFC 6565: OSPFv3 as a Provider Edge to Customer
        Edge (PE-CE) Routing Protocol";
    }

    feature ietf-spf-delay {
        description
            "Support for IETF SPF delay algorithm.";
        reference "RFC 8405: SPF Back-off algorithm for link
            state IGP";
    }

    feature bfd {
        description
            "Support for BFD detection of OSPF neighbor reachability.";
        reference "RFC 5880: Bidirectional Forwarding Detection (BFD)
            RFC 5881: Bidirectional Forwarding Detection
            (BFD) for IPv4 and IPv6 (Single Hop)";
    }

    feature hybrid-interface {
        description
            "Support for OSPF Hybrid interface type.";
        reference "RFC 6845: OSPF Hybrid Broadcast and
            Point-to-Multipoint Interface Type";
    }

    identity ospf {
        base "rt:routing-protocol";
        description "Any OSPF protocol version";
    }

    identity ospfv2 {
        base "ospf";
        description "OSPFv2 protocol";
    }

    identity ospfv3 {
        base "ospf";
        description "OSPFv3 protocol";
    }

    identity area-type {
        description "Base identity for OSPF area type.";
    }

    identity normal-area {
```

```
    base area-type;
    description "OSPF normal area.";
}

identity stub-nssa-area {
    base area-type;
    description "OSPF stub or NSSA area.";
}

identity stub-area {
    base stub-nssa-area;
    description "OSPF stub area.";
}

identity nssa-area {
    base stub-nssa-area;
    description "OSPF Not-So-Stubby Area (NSSA).";
    reference "RFC 3101: The OSPF Not-So-Stubby Area
              (NSSA) Option";
}

identity ospf-lsa-type {
    description
        "Base identity for OSPFv2 and OSPFv3
         Link State Advertisement (LSA) types";
}

identity ospfv2-lsa-type {
    base ospf-lsa-type;
    description
        "OSPFv2 LSA types";
}

identity ospfv2-router-lsa {
    base ospfv2-lsa-type;
    description
        "OSPFv2 Router LSA - Type 1";
}

identity ospfv2-network-lsa {
    base ospfv2-lsa-type;
    description
        "OSPFv2 Network LSA - Type 2";
}

identity ospfv2-summary-lsa-type {
    base ospfv2-lsa-type;
    description
```

```
    "OSPFv2 Summary LSA types";
}

identity ospfv2-network-summary-lsa {
  base ospfv2-summary-lsa-type;
  description
    "OSPFv2 Network Summary LSA - Type 3";
}

identity ospfv2-asbr-summary-lsa {
  base ospfv2-summary-lsa-type;
  description
    "OSPFv2 AS Boundary Router (ASBR) Summary LSA - Type 4";
}

identity ospfv2-external-lsa-type {
  base ospfv2-lsa-type;
  description
    "OSPFv2 External LSA types";
}

identity ospfv2-as-external-lsa {
  base ospfv2-external-lsa-type;
  description
    "OSPFv2 AS External LSA - Type 5";
}

identity ospfv2-nssa-lsa {
  base ospfv2-external-lsa-type;
  description
    "OSPFv2 Not-So-Stubby-Area (NSSA) LSA - Type 7";
}

identity ospfv2-opaque-lsa-type {
  base ospfv2-lsa-type;
  description
    "OSPFv2 Opaque LSA types";
}

identity ospfv2-link-scope-opaque-lsa {
  base ospfv2-opaque-lsa-type;
  description
    "OSPFv2 Link-Scoped Opaque LSA - Type 9";
}

identity ospfv2-area-scope-opaque-lsa {
  base ospfv2-opaque-lsa-type;
  description
```

```
        "OSPFv2 Area-Scoped Opaque LSA - Type 10";
    }

    identity ospfv2-as-scope-opaque-lsa {
        base ospfv2-opaque-lsa-type;
        description
            "OSPFv2 AS-Scoped Opaque LSA - Type 11";
    }

    identity ospfv2-unknown-lsa-type {
        base ospfv2-lsa-type;
        description
            "OSPFv2 Unknown LSA type";
    }

    identity ospfv3-lsa-type {
        base ospf-lsa-type;
        description
            "OSPFv3 LSA types.";
    }

    identity ospfv3-router-lsa {
        base ospfv3-lsa-type;
        description
            "OSPFv3 Router LSA - Type 0x2001";
    }

    identity ospfv3-network-lsa {
        base ospfv3-lsa-type;
        description
            "OSPFv3 Network LSA - Type 0x2002";
    }

    identity ospfv3-summary-lsa-type {
        base ospfv3-lsa-type;
        description
            "OSPFv3 Summary LSA types";
    }

    identity ospfv3-inter-area-prefix-lsa {
        base ospfv3-summary-lsa-type;
        description
            "OSPFv3 Inter-area Prefix LSA - Type 0x2003";
    }

    identity ospfv3-inter-area-router-lsa {
        base ospfv3-summary-lsa-type;
        description
```

```
    "OSPFv3 Inter-area Router LSA - Type 0x2004";
}

identity ospfv3-external-lsa-type {
  base ospfv3-lsa-type;
  description
    "OSPFv3 External LSA types";
}

identity ospfv3-as-external-lsa {
  base ospfv3-external-lsa-type;
  description
    "OSPFv3 AS-External LSA - Type 0x4005";
}

identity ospfv3-nssa-lsa {
  base ospfv3-external-lsa-type;
  description
    "OSPFv3 Not-So-Stubby-Area (NSSA) LSA - Type 0x2007";
}

identity ospfv3-link-lsa {
  base ospfv3-lsa-type;
  description
    "OSPFv3 Link LSA - Type 0x0008";
}

identity ospfv3-intra-area-prefix-lsa {
  base ospfv3-lsa-type;
  description
    "OSPFv3 Intra-area Prefix LSA - Type 0x2009";
}

identity ospfv3-router-information-lsa {
  base ospfv3-lsa-type;
  description
    "OSPFv3 Router Information LSA - Types 0x800C,
    0xA00C, and 0xC00C";
}

identity ospfv3-unknown-lsa-type {
  base ospfv3-lsa-type;
  description
    "OSPFv3 Unknown LSA type";
}

identity lsa-log-reason {
  description
```

```
    "Base identity for an LSA log reason.";
}

identity lsa-refresh {
  base lsa-log-reason;
  description
    "Identity used when the LSA is logged
     as a result of receiving a refresh LSA.";
}

identity lsa-content-change {
  base lsa-log-reason;
  description
    "Identity used when the LSA is logged
     as a result of a change in the content
     of the LSA.";
}

identity lsa-purge {
  base lsa-log-reason;
  description
    "Identity used when the LSA is logged
     as a result of being purged.";
}

identity informational-capability {
  description
    "Base identity for router informational capabilities.";
}

identity graceful-restart {
  base informational-capability;
  description
    "When set, the router is capable of restarting
     gracefully.";
  reference "RFC 3623: Graceful OSPF Restart
            RFC 5187: OSPFv3 Graceful Restart";
}

identity graceful-restart-helper {
  base informational-capability;
  description
    "When set, the router is capable of acting as
     a graceful restart helper.";
  reference "RFC 3623: Graceful OSPF Restart
            RFC 5187: OSPFv3 Graceful Restart";
}
```

```
identity stub-router {
  base informational-capability;
  description
    "When set, the router is capable of acting as
    an OSPF Stub Router.";
  reference "RFC 6987: OSPF Stub Router Advertisement";
}

identity traffic-engineering {
  base informational-capability;
  description
    "When set, the router is capable of OSPF traffic
    engineering.";
  reference "RFC 3630: Traffic Engineering (TE) Extensions
    to OSPF Version 2
    RFC 5329: Traffic Engineering (TE) Extensions
    to OSPF Version 3";
}

identity p2p-over-lan {
  base informational-capability;
  description
    "When set, the router is capable of OSPF Point-to-Point
    over LAN.";
  reference "RFC 5309: Point-to-Point Operation over LAN
    in Link State Routing Protocols";
}

identity experimental-te {
  base informational-capability;
  description
    "When set, the router is capable of OSPF experimental
    traffic engineering.";
  reference
    "RFC 4973: OSPF-xTE OSPF Experimental Traffic
    Engineering";
}

identity router-lsa-bit {
  description
    "Base identity for Router-LSA bits.";
}

identity vlink-end-bit {
  base router-lsa-bit;
  description
    "V bit, when set, the router is an endpoint of one or
    more virtual links.";
```

```
    }

    identity asbr-bit {
      base router-lsa-bit;
      description
        "E bit, when set, the router is an AS Boundary
         Router (ASBR).";
    }

    identity abr-bit {
      base router-lsa-bit;
      description
        "B bit, when set, the router is an Area Border
         Router (ABR).";
    }

    identity nssa-bit {
      base router-lsa-bit;
      description
        "Nt bit, when set, the router is an NSSA border router
         that is unconditionally translating NSSA LSAs into
         AS-external LSAs.";
    }

    identity ospfv3-lsa-option {
      description
        "Base identity for OSPF LSA options flags.";
    }

    identity af-bit {
      base ospfv3-lsa-option;
      description
        "AF bit, when set, the router supports OSPFv3 Address
         Families as in RFC5838.";
    }

    identity dc-bit {
      base ospfv3-lsa-option;
      description
        "DC bit, when set, the router supports demand circuits.";
    }

    identity r-bit {
      base ospfv3-lsa-option;
      description
        "R bit, when set, the originator is an active router.";
    }
  }
```

```
identity n-bit {
  base ospfv3-lsa-option;
  description
    "N bit, when set, the router is attached to an NSSA";
}

identity e-bit {
  base ospfv3-lsa-option;
  description
    "E bit, this bit describes the way AS-external LSAs
    are flooded";
}

identity v6-bit {
  base ospfv3-lsa-option;
  description
    "V6 bit, if clear, the router/link should be excluded
    from IPv6 routing calculation";
}

identity ospfv3-prefix-option {
  description
    "Base identity for OSPFv3 Prefix Options.";
}

identity nu-bit {
  base ospfv3-prefix-option;
  description
    "NU Bit, when set, the prefix should be excluded
    from IPv6 unicast calculations.";
}

identity la-bit {
  base ospfv3-prefix-option;
  description
    "LA bit, when set, the prefix is actually an IPv6
    interface address of the Advertising Router.";
}

identity p-bit {
  base ospfv3-prefix-option;
  description
    "P bit, when set, the NSSA area prefix should be
    translated to an AS External LSA and advertised
    by the translating NSSA Border Router.";
}

identity dn-bit {
```

```
    base ospfv3-prefix-option;
    description
      "DN bit, when set, the inter-area-prefix LSA or
      AS-external LSA prefix has been advertised as an
      L3VPN prefix.";
  }

  identity ospfv2-lsa-option {
    description
      "Base identity for OSPFv2 LSA option flags.";
  }

  identity mt-bit {
    base ospfv2-lsa-option;
    description
      "MT bit, When set, the router supports multi-topology as
      in RFC 4915.";
  }

  identity v2-dc-bit {
    base ospfv2-lsa-option;
    description
      "DC bit, When set, the router supports demand circuits.";
  }

  identity v2-p-bit {
    base ospfv2-lsa-option;
    description
      "P bit, wnlly used in type-7 LSA. When set, an NSSA
      border router should translate the type-7 LSA
      to a type-5 LSA.";
  }

  identity mc-flag {
    base ospfv2-lsa-option;
    description
      "MC Bit, when set, the router supports MOSPF.";
  }

  identity v2-e-flag {
    base ospfv2-lsa-option;
    description
      "E Bit, this bit describes the way AS-external LSAs
      are flooded.";
  }

  identity o-bit {
    base ospfv2-lsa-option;
```

```
    description
      "O bit, when set, the router is opaque-capable as in
       RFC 5250.";
  }

  identity v2-dn-bit {
    base ospfv2-lsa-option;
    description
      "DN bit, when a type 3, 5 or 7 LSA is sent from a PE
       to a CE, the DN bit must be set. See RFC 4576.";
  }

  identity ospfv2-extended-prefix-flag {
    description
      "Base identity for extended prefix TLV flag.";
  }

  identity a-flag {
    base ospfv2-extended-prefix-flag;
    description
      "Attach flag, when set it indicates that the prefix
       corresponds and a route what is directly connected to
       the advertising router..";
  }

  identity node-flag {
    base ospfv2-extended-prefix-flag;
    description
      "Node flag, when set, it indicates that the prefix is
       used to represent the advertising node, e.g., a loopback
       address.";
  }

  typedef ospf-metric {
    type uint32 {
      range "0 .. 16777215";
    }
    description
      "OSPF Metric - 24-bit unsigned integer.";
  }

  typedef ospf-link-metric {
    type uint16 {
      range "0 .. 65535";
    }
    description
      "OSPF Link Metric - 16-bit unsigned integer.";
  }
}
```

```
typedef opaque-id {
  type uint32 {
    range "0 .. 16777215";
  }
  description
    "Opaque ID - 24-bit unsigned integer.";
}

typedef area-id-type {
  type yang:dotted-quad;
  description
    "Area ID type.";
}

typedef route-type {
  type enumeration {
    enum intra-area {
      description "OSPF intra-area route.";
    }
    enum inter-area {
      description "OSPF inter-area route.";
    }
    enum external-1 {
      description "OSPF type 1 external route.";
    }
    enum external-2 {
      description "OSPF type 2 external route.";
    }
    enum nssa-1 {
      description "OSPF type 1 NSSA route.";
    }
    enum nssa-2 {
      description "OSPF type 2 NSSA route.";
    }
  }
  description "OSPF route type.";
}

typedef if-state-type {
  type enumeration {
    enum down {
      value "1";
      description
        "Interface down state.";
    }
    enum loopback {
      value "2";
      description

```

```
        "Interface loopback state.";
    }
    enum waiting {
        value "3";
        description
            "Interface waiting state.";
    }
    enum point-to-point {
        value "4";
        description
            "Interface point-to-point state.";
    }
    enum dr {
        value "5";
        description
            "Interface Designated Router (DR) state.";
    }
    enum bdr {
        value "6";
        description
            "Interface Backup Designated Router (BDR) state.";
    }
    enum dr-other {
        value "7";
        description
            "Interface Other Designated Router state.";
    }
}
description
    "OSPF interface state type.";
}

typedef router-link-type {
    type enumeration {
        enum point-to-point-link {
            value "1";
            description
                "Point-to-Point link to Router";
        }
        enum transit-network-link {
            value "2";
            description
                "Link to transit network identified by
                Designated-Router (DR)";
        }
        enum stub-network-link {
            value "3";
            description

```

```
        "Link to stub network identified by subnet";
    }
    enum virtual-link {
        value "4";
        description
            "Virtual link across transit area";
    }
}
description
    "OSPF Router Link Type.";
}

typedef nbr-state-type {
    type enumeration {
        enum down {
            value "1";
            description
                "Neighbor down state.";
        }
        enum attempt {
            value "2";
            description
                "Neighbor attempt state.";
        }
        enum init {
            value "3";
            description
                "Neighbor init state.";
        }
        enum 2-way {
            value "4";
            description
                "Neighbor 2-Way state.";
        }
        enum exstart {
            value "5";
            description
                "Neighbor exchange start state.";
        }
        enum exchange {
            value "6";
            description
                "Neighbor exchange state.";
        }
        enum loading {
            value "7";
            description
                "Neighbor loading state.";
        }
    }
}
```

```
    }
    enum full {
      value "8";
      description
        "Neighbor full state.";
    }
  }
  description
    "OSPF neighbor state type.";
}

typedef restart-helper-status-type {
  type enumeration {
    enum not-helping {
      value "1";
      description
        "Restart helper status not helping.";
    }
    enum helping {
      value "2";
      description
        "Restart helper status helping.";
    }
  }
  description
    "Restart helper status type.";
}

typedef restart-exit-reason-type {
  type enumeration {
    enum none {
      value "1";
      description
        "Restart not attempted.";
    }
    enum in-progress {
      value "2";
      description
        "Restart in progress.";
    }
    enum completed {
      value "3";
      description
        "Restart successfully completed.";
    }
    enum timed-out {
      value "4";
      description

```

```
        "Restart timed out.";
    }
    enum topology-changed {
        value "5";
        description
            "Restart aborted due to topology change.";
    }
}
description
    "Describes the outcome of the last attempt at a
    graceful restart, either by itself or acting
    as a helper.";
}

typedef packet-type {
    type enumeration {
        enum hello {
            value "1";
            description
                "OSPF Hello packet.";
        }
        enum database-description {
            value "2";
            description
                "OSPF Database Description packet.";
        }
        enum link-state-request {
            value "3";
            description
                "OSPF Link State Request packet.";
        }
        enum link-state-update {
            value "4";
            description
                "OSPF Link State Update packet.";
        }
        enum link-state-ack {
            value "5";
            description
                "OSPF Link State Acknowledgement packet.";
        }
    }
    description
        "OSPF packet type.";
}

typedef nssa-translator-state-type {
    type enumeration {
```

```
    enum enabled {
      value "1";
      description
        "NSSA translator enabled state.";
    }
    enum elected {
      value "2";
      description
        "NSSA translator elected state.";
    }
    enum disabled {
      value "3";
      description
        "NSSA translator disabled state.";
    }
  }
  description
    "OSPF NSSA translator state type.";
}

typedef restart-status-type {
  type enumeration {
    enum not-restarting {
      value "1";
      description
        "Router is not restarting.";
    }
    enum planned-restart {
      value "2";
      description
        "Router is going through planned restart.";
    }
    enum unplanned-restart {
      value "3";
      description
        "Router is going through unplanned restart.";
    }
  }
  description
    "OSPF graceful restart status type.";
}

typedef fletcher-checksum16-type {
  type string {
    pattern '(0x)?[0-9a-fA-F]{4}';
  }
  description
    "Fletcher 16-bit checksum in hex-string format 0xXXXX.";
```

```
        reference "RFC 905: ISO Transport Protocol specification
                ISO DP 8073";
    }

typedef ospfv2-auth-trailer-rfc-version {
    type enumeration {
        enum rfc5709 {
            description
                "Support OSPF Authentication Trailer as
                described in RFC 5709";
            reference "RFC 5709: OSPFv2 HMAC-SHA Cryptographic
                    Authentication";
        }

        enum rfc7474 {
            description
                "Support OSPF Authentication Trailer as
                described in RFC 7474";
            reference
                "RFC 7474: Security Extension for OSPFv2
                When Using Manual Key Management Authentication";
        }
    }
    description
        "OSPFv2 Authentication Trailer Support";
}

grouping tlv {
    description
        "Type-Length-Value (TLV)";
    leaf type {
        type uint16;
        description "TLV type.";
    }
    leaf length {
        type uint16;
        description "TLV length (octets).";
    }
    leaf value {
        type yang:hex-string;
        description "TLV value.";
    }
}

grouping unknown-tlvs {
    description
        "Unknown TLVs grouping - Used for unknown TLVs or
```

```
        unknown sub-TLVs.";
    container unknown-tlvs {
        description "All unknown TLVs.";
        list unknown-tlv {
            description "Unknown TLV.";
            uses tlv;
        }
    }
}

grouping node-tag-tlv {
    description "OSPF Node Admin Tag TLV grouping.";
    list node-tag {
        leaf tag {
            type uint32;
            description
                "Node admin tag value.";
        }
        description
            "List of tags.";
    }
}

grouping router-capabilities-tlv {
    description "OSPF Router Capabilities TLV grouping.";
    reference "RFC 7770: OSPF Router Capabilities";
    container router-informational-capabilities {
        leaf-list informational-capabilities {
            type identityref {
                base informational-capability;
            }
            description
                "Informational capability list. This list will
                contains the identities for the informational
                capabilities supported by router.";
        }
        description
            "OSPF Router Informational Flag Definitions.";
    }
    list informational-capabilities-flags {
        leaf informational-flag {
            type uint32;
            description
                "Individual informational capability flag.";
        }
        description
            "List of informational capability flags. This will
            return all the 32-bit informational flags irrespective
```

```
        of whether or not they are known to the device.";
    }
    list functional-capabilities {
        leaf functional-flag {
            type uint32;
            description
                "Individual functional capability flag.";
        }
        description
            "List of functional capability flags. This will
            return all the 32-bit functional flags irrespective
            of whether or not they are known to the device.";
    }
}

grouping dynamic-hostname-tlv {
    description "Dynamic Hostname TLV";
    reference "RFC 5642: Dynamic Hostnames for OSPF";
    leaf hostname {
        type string {
            length "1..255";
        }
        description "Dynamic Hostname";
    }
}

grouping sbfd-discriminator-tlv {
    description "Seamless BFD Discriminator TLV";
    reference "RFC 7884: S-BFD Discriminators in OSPF";
    list sbfd-discriminators {
        leaf sbfd-discriminator {
            type uint32;
            description "Individual S-BFD Discriminator.";
        }
        description
            "List of S-BFD Discriminators";
    }
}

grouping maximum-sid-depth-tlv {
    description "Maximum SID Depth (MSD) TLV";
    reference
        "RFC 8476: Signaling Maximum Segment Depth (MSD)
        using OSPF";
    list msd-type {
        leaf msd-type {
            type uint8;
            description "Maximum Segment Depth (MSD) type";
        }
    }
}
```

```
    }
    leaf msd-value {
      type uint8;
      description
        "Maximum Segment Depth (MSD) value for the type";
    }
  }
  description
    "List of Maximum Segment Depth (MSD) tuples";
}

grouping ospf-router-lsa-bits {
  container router-bits {
    leaf-list rtr-lsa-bits {
      type identityref {
        base router-lsa-bit;
      }
      description
        "Router LSA bits list. This list will contain
        identities for the bits which are set in the
        Router-LSA bits.";
    }
    description "Router LSA Bits.";
  }
  description
    "Router LSA Bits - Currently common for OSPFv2 and
    OSPFv3 but it may diverge with future augmentations.";
}

grouping ospfv2-router-link {
  description "OSPFv2 router link.";
  leaf link-id {
    type union {
      type inet:ipv4-address;
      type yang:dotted-quad;
    }
    description "Router-LSA Link ID";
  }
  leaf link-data {
    type union {
      type inet:ipv4-address;
      type uint32;
    }
    description "Router-LSA Link data.";
  }
  leaf type {
    type router-link-type;
    description "Router-LSA Link type.";
  }
}
```

```
    }
  }

  grouping ospfv2-lsa-body {
    description "OSPFv2 LSA body.";
    container router {
      when "derived-from-or-self(..../header/type, "
        + "'ospfv2-router-lsa')" {
        description
          "Only applies to Router-LSAs.";
      }
      description
        "Router LSA.";
      uses ospf-router-lsa-bits;
      leaf num-of-links {
        type uint16;
        description "Number of links in Router LSA.";
      }
      container links {
        description "All router Links.";
        list link {
          description "Router LSA link.";
          uses ospfv2-router-link;
          container topologies {
            description "All topologies for the link.";
            list topology {
              description
                "Topology specific information.";
              leaf mt-id {
                type uint8;
                description
                  "The MT-ID for the topology enabled on
                  the link.";
              }
              leaf metric {
                type uint16;
                description "Metric for the topology.";
              }
            }
          }
        }
      }
    }
  }
}

container network {
  when "derived-from-or-self(..../header/type, "
    + "'ospfv2-network-lsa')" {
    description
      "Only applies to Network LSAs.";
  }
}
```

```
    }
  description
    "Network LSA.";
  leaf network-mask {
    type yang:dotted-quad;
    description
      "The IP address mask for the network.";
  }
  container attached-routers {
    description "All attached routers.";
    leaf-list attached-router {
      type inet:ipv4-address;
      description
        "List of the routers attached to the network.";
    }
  }
}
container summary {
  when "derived-from(..../header/type, "
    + "'ospfv2-summary-lsa-type')" {
    description
      "Only applies to Summary LSAs.";
  }
  description
    "Summary LSA.";
  leaf network-mask {
    type inet:ipv4-address;
    description
      "The IP address mask for the network";
  }
  container topologies {
    description "All topologies for the summary LSA.";
    list topology {
      description
        "Topology specific information.";
      leaf mt-id {
        type uint8;
        description
          "The MT-ID for the topology enabled for
            the summary.";
      }
      leaf metric {
        type ospf-metric;
        description "Metric for the topology.";
      }
    }
  }
}
```

```
container external {
  when "derived-from ../../header/type, "
    + "'ospfv2-external-lsa-type'" {
    description
      "Only applies to AS-external LSAs and NSSA LSAs.";
  }
  description
    "External LSA.";
  leaf network-mask {
    type inet:ipv4-address;
    description
      "The IP address mask for the network";
  }
  container topologies {
    description "All topologies for the external.";
    list topology {
      description
        "Topology specific information.";
      leaf mt-id {
        type uint8;
        description
          "The MT-ID for the topology enabled for the
            external or NSSA prefix.";
      }
      leaf flags {
        type bits {
          bit E {
            description
              "When set, the metric specified is a Type 2
                external metric.";
          }
        }
        description "Flags.";
      }
      leaf metric {
        type ospf-metric;
        description "Metric for the topology.";
      }
      leaf forwarding-address {
        type inet:ipv4-address;
        description
          "Forwarding address.";
      }
      leaf external-route-tag {
        type uint32;
        description
          "Route tag for the topology.";
      }
    }
  }
}
```

```
    }
  }
}
container opaque {
  when "derived-from(..../header/type, "
    + "'ospfv2-opaque-lsa-type')" {
    description
      "Only applies to Opaque LSAs.";
  }
  description
    "Opaque LSA.";

  container ri-opaque {
    description "OSPF Router Information (RI) opaque LSA.";
    reference "RFC 7770: OSPF Router Capabilities";

    container router-capabilities-tlv {
      description
        "Informational and functional router capabilities";
      uses router-capabilities-tlv;
    }

    container node-tag-tlvs {
      description
        "All node tag TLVs.";
      list node-tag-tlv {
        description
          "Node tag TLV.";
        uses node-tag-tlv;
      }
    }

    container dynamic-hostname-tlv {
      description "OSPF Dynamic Hostname";
      uses dynamic-hostname-tlv;
    }

    container sbfd-discriminator-tlv {
      description "OSPF S-BFD Discriminators";
      uses sbfd-discriminator-tlv;
    }

    container maximum-sid-depth-tlv {
      description "OSPF Maximum SID Depth (MSD) values";
      uses maximum-sid-depth-tlv;
    }
  }
  uses unknown-tlvs;
}
```

```
container te-opaque {
  description "OSPFv2 Traffic Engineering (TE) opaque LSA.";
  reference "RFC 3630: Traffic Engineering (TE)
            Extensions to OSPFv2";

  container router-address-tlv {
    description
      "Router address TLV.";
    leaf router-address {
      type inet:ipv4-address;
      description
        "Router address.";
    }
  }
}

container link-tlv {
  description "Describes a single link, and it is constructed
of a set of Sub-TLVs.";
  leaf link-type {
    type router-link-type;
    mandatory true;
    description "Link type.";
  }
  leaf link-id {
    type union {
      type inet:ipv4-address;
      type yang:dotted-quad;
    }
    mandatory true;
    description "Link ID.";
  }
  container local-if-ipv4-addr {
    description "All local interface IPv4 addresses.";
    leaf-list local-if-ipv4-addr {
      type inet:ipv4-address;
      description
        "List of local interface IPv4 addresses.";
    }
  }
  container remote-if-ipv4-addr {
    description "All remote interface IPv4 addresses.";
    leaf-list remote-if-ipv4-addr {
      type inet:ipv4-address;
      description
        "List of remote interface IPv4 addresses.";
    }
  }
  leaf te-metric {
```

```
        type uint32;
        description "TE metric.";
    }
    leaf max-bandwidth {
        type rt-types:bandwidth-ieee-float32;
        description "Maximum bandwidth.";
    }
    leaf max-reservable-bandwidth {
        type rt-types:bandwidth-ieee-float32;
        description "Maximum reservable bandwidth.";
    }
    container unreserved-bandwidths {
        description "All unreserved bandwidths.";
        list unreserved-bandwidth {
            leaf priority {
                type uint8 {
                    range "0 .. 7";
                }
                description "Priority from 0 to 7.";
            }
            leaf unreserved-bandwidth {
                type rt-types:bandwidth-ieee-float32;
                description "Unreserved bandwidth.";
            }
        }
        description
            "List of unreserved bandwidths for different
            priorities.";
    }
}
leaf admin-group {
    type uint32;
    description
        "Administrative group/Resource Class/Color.";
}
uses unknown-tlvs;
}
}

container extended-prefix-opaque {
    description "All extended prefix TLVs in the LSA.";
    list extended-prefix-tlv {
        description "Extended prefix TLV.";
        leaf route-type {
            type enumeration {
                enum unspecified {
                    value "0";
                    description "Unspecified.";
                }
            }
        }
    }
}
```

```
enum intra-area {
  value "1";
  description "OSPF intra-area route.";
}
enum inter-area {
  value "3";
  description "OSPF inter-area route.";
}
enum external {
  value "5";
  description "OSPF External route.";
}
enum nssa {
  value "7";
  description "OSPF NSSA external route.";
}
}
description "Route type.";
}
container flags {
  leaf-list extended-prefix-flags {
    type identityref {
      base ospfv2-extended-prefix-flag;
    }
    description
      "Extended prefix TLV flags list. This list will
       contain identities for the prefix flags that
       are set in the extended prefix flags.";
  }
  description "Prefix Flags.";
}
leaf prefix {
  type inet:ip-prefix;
  description "Address prefix.";
}
uses unknown-tlvs;
}
}

container extended-link-opaque {
  description "All extended link TLVs in the LSA.";
  container extended-link-tlv {
    description "Extended link TLV.";
    uses ospfv2-router-link;
    container maximum-sid-depth-tlv {
      description "OSPF Maximum SID Depth (MSD) values";
      uses maximum-sid-depth-tlv;
    }
  }
}
```

```
        uses unknown-tlvs;
    }
}
}

grouping ospfv3-lsa-options {
    description "OSPFv3 LSA options";
    container lsa-options {
        leaf-list lsa-options {
            type identityref {
                base ospfv3-lsa-option;
            }
            description
                "OSPFv3 LSA Option flags list. This list will contain
                the identities for the OSPFv3 LSA options that are
                set for the LSA.";
        }
        description "OSPFv3 LSA options.";
    }
}

grouping ospfv3-lsa-prefix {
    description
        "OSPFv3 LSA prefix.";

    leaf prefix {
        type inet:ip-prefix;
        description
            "LSA Prefix.";
    }
    container prefix-options {
        leaf-list prefix-options {
            type identityref {
                base ospfv3-prefix-option;
            }
            description
                "OSPFv3 prefix option flag list. This list will
                contain the identities for the OSPFv3 options
                that are set for the OSPFv3 prefix.";
        }
        description "Prefix options.";
    }
}

grouping ospfv3-lsa-external {
    description
        "AS-External and NSSA LSA.";
```

```
leaf metric {
  type ospf-metric;
  description "Metric";
}
leaf flags {
  type bits {
    bit E {
      description
        "When set, the metric specified is a Type 2
        external metric.";
    }
    bit F {
      description
        "When set, a Forwarding Address is included
        in the LSA.";
    }
    bit T {
      description
        "When set, an External Route Tag is included
        in the LSA.";
    }
  }
  description "Flags.";
}

leaf referenced-ls-type {
  type identityref {
    base ospfv3-lsa-type;
  }
  description "Referenced Link State type.";
}
leaf unknown-referenced-ls-type {
  type uint16;
  description
    "Value for an unknown Referenced Link State type.";
}

uses ospfv3-lsa-prefix;

leaf forwarding-address {
  type inet:ipv6-address;
  description
    "Forwarding address.";
}

leaf external-route-tag {
  type uint32;
  description
```

```
        "Route tag.";
    }
    leaf referenced-link-state-id {
        type uint32;
        description
            "Referenced Link State ID.";
    }
}

grouping ospfv3-lsa-body {
    description "OSPFv3 LSA body.";
    container router {
        when "derived-from-or-self(..../header/type, "
            + "'ospfv3-router-lsa')" {
            description
                "Only applies to Router LSAs.";
        }
        description "Router LSA.";
        uses ospf-router-lsa-bits;
        uses ospfv3-lsa-options;

        container links {
            description "All router link.";
            list link {
                description "Router LSA link.";
                leaf interface-id {
                    type uint32;
                    description "Interface ID for link.";
                }
                leaf neighbor-interface-id {
                    type uint32;
                    description "Neighbor's Interface ID for link.";
                }
                leaf neighbor-router-id {
                    type rt-types:router-id;
                    description "Neighbor's Router ID for link.";
                }
                leaf type {
                    type router-link-type;
                    description "Link type: 1 - Point-to-Point Link
                                2 - Transit Network Link
                                3 - Stub Network Link
                                4 - Virtual Link";
                }
                leaf metric {
                    type uint16;
                    description "Link Metric.";
                }
            }
        }
    }
}
```

```
    }
  }
}
container network {
  when "derived-from-or-self(..../header/type, "
    + "'ospfv3-network-lsa')" {
    description
      "Only applies to Network LSAs.";
  }
  description "Network LSA.";

  uses ospfv3-lsa-options;

  container attached-routers {
    description "All attached routers.";
    leaf-list attached-router {
      type rt-types:router-id;
      description
        "List of the routers attached to the network.";
    }
  }
}
container inter-area-prefix {
  when "derived-from-or-self(..../header/type, "
    + "'ospfv3-inter-area-prefix-lsa')" {
    description
      "Only applies to Inter-Area-Prefix LSAs.";
  }
  leaf metric {
    type ospf-metric;
    description "Inter-Area Prefix Metric";
  }
  uses ospfv3-lsa-prefix;
  description "Prefix LSA.";
}
container inter-area-router {
  when "derived-from-or-self(..../header/type, "
    + "'ospfv3-inter-area-router-lsa')" {
    description
      "Only applies to Inter-Area-Router LSAs.";
  }
  uses ospfv3-lsa-options;
  leaf metric {
    type ospf-metric;
    description "AS Boundary Router (ASBR) Metric.";
  }
  leaf destination-router-id {
    type rt-types:router-id;
  }
}
```

```
        description
            "The Router ID of the ASBR described by the LSA.";
    }
    description "Inter-Area-Router LSA.";
}
container as-external {
    when "derived-from-or-self(..../header/type, "
        + "'ospfv3-as-external-lsa')" {
        description
            "Only applies to AS-external LSAs.";
    }

    uses ospfv3-lsa-external;

    description "AS-External LSA.";
}
container nssa {
    when "derived-from-or-self(..../header/type, "
        + "'ospfv3-nssa-lsa')" {
        description
            "Only applies to NSSA LSAs.";
    }
    uses ospfv3-lsa-external;

    description "NSSA LSA.";
}
container link {
    when "derived-from-or-self(..../header/type, "
        + "'ospfv3-link-lsa')" {
        description
            "Only applies to Link LSAs.";
    }
}
leaf rtr-priority {
    type uint8;
    description
        "Router priority for DR election. A router with a
        higher priority will be preferred in the election
        and a value of 0 indicates the router is not
        eligible to become Designated Router or Backup
        Designated Router (BDR).";
}
uses ospfv3-lsa-options;

leaf link-local-interface-address {
    type inet:ipv6-address;
    description
        "The originating router's link-local
        interface address for the link.";
```

```
    }

    leaf num-of-prefixes {
      type uint32;
      description "Number of prefixes.";
    }

    container prefixes {
      description "All prefixes for the link.";
      list prefix {
        description
          "List of prefixes associated with the link.";
        uses ospfv3-lsa-prefix;
      }
    }
    description "Link LSA.";
  }
  container intra-area-prefix {
    when "derived-from-or-self(..../header/type, "
      + "'ospfv3-intra-area-prefix-lsa')"{
      description
        "Only applies to Intra-Area-Prefix LSAs.";
    }
    description "Intra-Area-Prefix LSA.";

    leaf referenced-ls-type {
      type identityref {
        base ospfv3-lsa-type;
      }
      description "Referenced Link State type.";
    }
    leaf unknown-referenced-ls-type {
      type uint16;
      description
        "Value for an unknown Referenced Link State type.";
    }
    leaf referenced-link-state-id {
      type uint32;
      description
        "Referenced Link State ID.";
    }
    leaf referenced-adv-router {
      type rt-types:router-id;
      description
        "Referenced Advertising Router.";
    }
  }

  leaf num-of-prefixes {
```

```
        type uint16;
        description "Number of prefixes.";
    }
    container prefixes {
        description "All prefixes in this LSA.";
        list prefix {
            description "List of prefixes in this LSA.";
            uses ospfv3-lsa-prefix;
            leaf metric {
                type ospf-metric;
                description "Prefix Metric.";
            }
        }
    }
}
container router-information {
    when "derived-from-or-self(..../header/type, "
        + "'ospfv3-router-information-lsa')" {
        description
            "Only applies to Router Information LSAs (RFC7770).";
    }
    container router-capabilities-tlv {
        description
            "Informational and functional router capabilities";
        uses router-capabilities-tlv;
    }
    container node-tag-tlvs {
        description
            "All node tag tlvs.";
        list node-tag-tlv {
            description
                "Node tag tlv.";
            uses node-tag-tlv;
        }
    }
    container dynamic-hostname-tlv {
        description "OSPF Dynamic Hostname";
        uses dynamic-hostname-tlv;
    }
    container sbfd-discriminator-tlv {
        description "OSPF S-BFD Discriminators";
        uses sbfd-discriminator-tlv;
    }
    description "Router Information LSA.";
    reference "RFC 7770: Extensions for Advertising Router
        Capabilities";
}
}
```

```
grouping lsa-header {
  description
    "Common LSA for OSPFv2 and OSPFv3";
  leaf age {
    type uint16;
    mandatory true;
    description "LSA age.";
  }
  leaf type {
    type identityref {
      base ospf-lsa-type;
    }
    mandatory true;
    description "LSA type";
  }
  leaf adv-router {
    type rt-types:router-id;
    mandatory true;
    description "LSA advertising router.";
  }
  leaf seq-num {
    type uint32;
    mandatory true;
    description "LSA sequence number.";
  }
  leaf checksum {
    type fletcher-checksum16-type;
    mandatory true;
    description "LSA checksum.";
  }
  leaf length {
    type uint16;
    mandatory true;
    description "LSA length including the header.";
  }
}

grouping ospfv2-lsa {
  description
    "OSPFv2 LSA - LSAs are uniquely identified by
    the <LSA Type, Link-State ID, Advertising Router>
    tuple with the sequence number differentiating
    LSA instances.";
  container header {
    must "(derived-from(type, "
      + "'ospfv2-opaque-lsa-type') and "
      + "opaque-id and opaque-type) or "
      + "(not(derived-from(type, "
```

```
        + "'ospfv2-opaque-lsa-type') "
        + "and not(opaque-id) and not(opaque-type))" {
    description
        "Opaque type and ID only apply to Opaque LSAs.";
    }
    description
        "Decoded OSPFv2 LSA header data.";

    container lsa-options {
        leaf-list lsa-options {
            type identityref {
                base ospfv2-lsa-option;
            }
            description
                "LSA option flags list. This list will contain
                 the identities for the identities for the OSPFv2
                 LSA options that are set.";
        }
        description
            "LSA options.";
    }

    leaf lsa-id {
        type yang:dotted-quad;
        mandatory true;
        description "Link-State ID.";
    }

    leaf opaque-type {
        type uint8;
        description "Opaque type.";
    }

    leaf opaque-id {
        type opaque-id;
        description "Opaque ID.";
    }

    uses lsa-header;
    }
    container body {
        description
            "Decoded OSPFv2 LSA body data.";
        uses ospfv2-lsa-body;
    }
    }

    grouping ospfv3-lsa {
```

```
description
    "Decoded OSPFv3 LSA.";
container header {
    description
        "Decoded OSPFv3 LSA header data.";
    leaf lsa-id {
        type uint32;
        mandatory true;
        description "OSPFv3 LSA ID.";
    }
    uses lsa-header;
}
container body {
    description
        "Decoded OSPF LSA body data.";
    uses ospfv3-lsa-body;
}
}
grouping lsa-common {
    description
        "Common fields for OSPF LSA representation.";
    leaf decode-completed {
        type boolean;
        description
            "The OSPF LSA body was successfully decoded other than
            unknown TLVs. Unknown LSAs types and OSPFv2 unknown
            opaque LSA types are not decoded. Additionally,
            malformed LSAs are generally not accepted and will
            not be in the Link State Database.";
    }
    leaf raw-data {
        type yang:hex-string;
        description
            "The complete LSA in network byte
            order hexadecimal as received or originated.";
    }
}
}

grouping lsa {
    description
        "OSPF LSA.";
    uses lsa-common;
    choice version {
        description
            "OSPFv2 or OSPFv3 LSA body.";
        container ospfv2 {
            description "OSPFv2 LSA";
            uses ospfv2-lsa;
        }
    }
}
```

```
    }
    container ospfv3 {
      description "OSPFv3 LSA";
      uses ospfv3-lsa;
    }
  }
}

grouping lsa-key {
  description
    "OSPF LSA key - the database key for each LSA of a given
    type in the Link State DataBase (LSDB).";
  leaf lsa-id {
    type union {
      type yang:dotted-quad;
      type uint32;
    }
    description
      "Link-State ID.";
  }
  leaf adv-router {
    type rt-types:router-id;
    description
      "Advertising router.";
  }
}

grouping instance-stat {
  description "Per-instance statistics";
  leaf discontinuity-time {
    type yang:date-and-time;
    description
      "The time on the most recent occasion at which any one or
      more of this OSPF instance's counters suffered a
      discontinuity. If no such discontinuities have occurred
      since the OSPF instance was last re-initialized, then
      this node contains the time the OSPF instance was
      re-initialized which normally occurs when it was
      created.";
  }
  leaf originate-new-lsa-count {
    type yang:counter32;
    description
      "The number of new LSAs originated. Discontinuities in the
      value of this counter can occur when the OSPF instance is
      re-initialized.";
  }
  leaf rx-new-lsas-count {
```

```
    type yang:counter32;
    description
      "The number of new LSAs received. Discontinuities in the
       value of this counter can occur when the OSPF instance is
       re-initialized.";
  }
  leaf as-scope-lsa-count {
    type yang:gauge32;
    description "The number of AS-scope LSAs.";
  }
  leaf as-scope-lsa-chksum-sum {
    type uint32;
    description
      "The module 2**32 sum of the LSA checksums
       for AS-scope LSAs. The value should be treated as
       unsigned when comparing two sums of checksums. While
       differing checksums indicate a different combination
       of LSAs, equivalent checksums don't guarantee that the
       LSAs are the same given that multiple combinations of
       LSAs can result in the same checksum.";
  }
}
container database {
  description "Container for per AS-scope LSA statistics.";
  list as-scope-lsa-type {
    description "List of AS-scope LSA statistics";
    leaf lsa-type {
      type uint16;
      description "AS-Scope LSA type.";
    }
    leaf lsa-count {
      type yang:gauge32;
      description "The number of LSAs of the LSA type.";
    }
  }
  leaf lsa-cksum-sum {
    type uint32;
    description
      "The module 2**32 sum of the LSA checksums
       for the LSAs of this type. The value should be
       treated as unsigned when comparing two sums of
       checksums. While differing checksums indicate a
       different combination of LSAs, equivalent checksums
       don't guarantee that the LSAs are the same given that
       multiple combinations of LSAs can result in the same
       checksum.";
  }
}
}
uses instance-fast-reroute-state;
```

```
}  
  
grouping area-stat {  
  description "Per-area statistics.";  
  leaf discontinuity-time {  
    type yang:date-and-time;  
    description  
      "The time on the most recent occasion at which any one or  
      more of this OSPF area's counters suffered a  
      discontinuity. If no such discontinuities have occurred  
      since the OSPF area was last re-initialized, then  
      this node contains the time the OSPF area was  
      re-initialized which normally occurs when it was  
      created.";  
  }  
  leaf spf-runs-count {  
    type yang:counter32;  
    description  
      "The number of times the intra-area SPF has run.  
      Discontinuities in the value of this counter can occur  
      when the OSPF area is re-initialized.";  
  }  
  leaf abr-count {  
    type yang:gauge32;  
    description  
      "The total number of Area Border Routers (ABRs)  
      reachable within this area.";  
  }  
  leaf asbr-count {  
    type yang:gauge32;  
    description  
      "The total number of AS Boundary Routers (ASBRs).";  
  }  
  leaf ar-nssa-translator-event-count {  
    type yang:counter32;  
    description  
      "The number of NSSA translator-state changes.  
      Discontinuities in the value of this counter can occur  
      when the OSPF area is re-initialized.";  
  }  
  leaf area-scope-lsa-count {  
    type yang:gauge32;  
    description  
      "The number of area-scope LSAs in the area.";  
  }  
  leaf area-scope-lsa-cksum-sum {  
    type uint32;  
    description
```

```
    "The module 2**32 sum of the LSA checksums
    for area-scope LSAs. The value should be treated as
    unsigned when comparing two sums of checksums. While
    differing checksums indicate a different combination
    of LSAs, equivalent checksums don't guarantee that the
    LSAs are the same given that multiple combinations of
    LSAs can result in the same checksum.";
  }
  container database {
    description "Container for area-scope LSA type statistics.";
    list area-scope-lsa-type {
      description "List of area-scope LSA statistics";
      leaf lsa-type {
        type uint16;
        description "Area-scope LSA type.";
      }
      leaf lsa-count {
        type yang:gauge32;
        description "The number of LSAs of the LSA type.";
      }
      leaf lsa-cksum-sum {
        type uint32;
        description
          "The module 2**32 sum of the LSA checksums
          for the LSAs of this type. The value should be
          treated as unsigned when comparing two sums of
          checksums. While differing checksums indicate a
          different combination of LSAs, equivalent checksums
          don't guarantee that the LSAs are the same given that
          multiple combinations of LSAs can result in the same
          checksum.";
      }
    }
  }
}

grouping interface-stat {
  description "Per-interface statistics";
  leaf discontinuity-time {
    type yang:date-and-time;
    description
      "The time on the most recent occasion at which any one or
      more of this OSPF interface's counters suffered a
      discontinuity. If no such discontinuities have occurred
      since the OSPF interface was last re-initialized, then
      this node contains the time the OSPF interface was
      re-initialized which normally occurs when it was
      created.";
  }
}
```

```
    }
  leaf if-event-count {
    type yang:counter32;
    description
      "The number of times this interface has changed its
       state or an error has occurred. Discontinuities in the
       value of this counter can occur when the OSPF interface
       is re-initialized.";
  }
  leaf link-scope-lsa-count {
    type yang:gauge32;
    description "The number of link-scope LSAs.";
  }
  leaf link-scope-lsa-cksum-sum {
    type uint32;
    description
      "The module 2**32 sum of the LSA checksums
       for link-scope LSAs. The value should be treated as
       unsigned when comparing two sums of checksums. While
       differing checksums indicate a different combination
       of LSAs, equivalent checksums don't guarantee that the
       LSAs are the same given that multiple combinations of
       LSAs can result in the same checksum.";
  }
  container database {
    description "Container for link-scope LSA type statistics.";
    list link-scope-lsa-type {
      description "List of link-scope LSA statistics";
      leaf lsa-type {
        type uint16;
        description "Link scope LSA type.";
      }
      leaf lsa-count {
        type yang:gauge32;
        description "The number of LSAs of the LSA type.";
      }
      leaf lsa-cksum-sum {
        type uint32;
        description
          "The module 2**32 sum of the LSA checksums
           for the LSAs of this type. The value should be
           treated as unsigned when comparing two sums of
           checksums. While differing checksums indicate a
           different combination of LSAs, equivalent checksums
           don't guarantee that the LSAs are the same given that
           multiple combinations of LSAs can result in the same
           checksum.";
      }
    }
  }
}
```

```
    }
  }
}

grouping neighbor-stat {
  description "Per-neighbor statistics.";
  leaf discontinuity-time {
    type yang:date-and-time;
    description
      "The time on the most recent occasion at which any one or
      more of this OSPF neighbor's counters suffered a
      discontinuity. If no such discontinuities have occurred
      since the OSPF neighbor was last re-initialized, then
      this node contains the time the OSPF neighbor was
      re-initialized which normally occurs when the neighbor
      is dynamically discovered and created.";
  }
  leaf nbr-event-count {
    type yang:counter32;
    description
      "The number of times this neighbor has changed
      state or an error has occurred. Discontinuities in the
      value of this counter can occur when the OSPF neighbor
      is re-initialized.";
  }
  leaf nbr-retrans-qlen {
    type yang:gauge32;
    description
      "The current length of the retransmission queue.";
  }
}

grouping instance-fast-reroute-config {
  description
    "This group defines global configuration of IP
    Fast ReRoute (FRR).";
  container fast-reroute {
    if-feature fast-reroute;
    description
      "This container may be augmented with global
      parameters for IP-FRR.";
    container lfa {
      if-feature lfa;
      description
        "This container may be augmented with
        global parameters for Loop-Free Alternatives (LFA).
        Container creation has no effect on LFA activation.";
    }
  }
}
```

```
    }
  }

  grouping instance-fast-reroute-state {
    description "IP-FRR state data grouping";

    container protected-routes {
      if-feature fast-reroute;
      config false;
      description "Instance protection statistics";

      list address-family-stats {
        key "address-family prefix alternate";
        description
          "Per Address Family protected prefix information";

        leaf address-family {
          type iana-rt-types:address-family;
          description
            "Address-family";
        }
        leaf prefix {
          type inet:ip-prefix;
          description
            "Protected prefix.";
        }
        leaf alternate {
          type inet:ip-address;
          description
            "Alternate next hop for the prefix.";
        }
        leaf alternate-type {
          type enumeration {
            enum equal-cost {
              description
                "ECMP alternate.";
            }
            enum lfa {
              description
                "LFA alternate.";
            }
            enum remote-lfa {
              description
                "Remote LFA alternate.";
            }
            enum tunnel {
              description
                "Tunnel based alternate

```

```
        (like RSVP-TE or GRE).";
    }
    enum ti-lfa {
        description
            "TI-LFA alternate.";
    }
    enum mrt {
        description
            "MRT alternate.";
    }
    enum other {
        description
            "Unknown alternate type.";
    }
}
description
    "Type of alternate.";
}
leaf best {
    type boolean;
    description
        "Indicates that this alternate is preferred.";
}
leaf non-best-reason {
    type string {
        length "1..255";
    }
    description
        "Information field to describe why the alternate
        is not best.";
}
leaf protection-available {
    type bits {
        bit node-protect {
            position 0;
            description
                "Node protection available.";
        }
        bit link-protect {
            position 1;
            description
                "Link protection available.";
        }
        bit srlg-protect {
            position 2;
            description
                "SRLG protection available.";
        }
    }
}
```

```
        bit downstream-protect {
            position 3;
            description
                "Downstream protection available.";
        }
        bit other {
            position 4;
            description
                "Other protection available.";
        }
    }
    description "Protection provided by the alternate.";
}
leaf alternate-metric1 {
    type uint32;
    description
        "Metric from Point of Local Repair (PLR) to
        destination through the alternate path.";
}
leaf alternate-metric2 {
    type uint32;
    description
        "Metric from PLR to the alternate node";
}
leaf alternate-metric3 {
    type uint32;
    description
        "Metric from alternate node to the destination";
}
}
}

container unprotected-routes {
    if-feature fast-reroute;
    config false;
    description "List of prefixes that are not protected";

    list address-family-stats {
        key "address-family prefix";
        description
            "Per Address Family (AF) unprotected prefix statistics.";

        leaf address-family {
            type iana-rt-types:address-family;
            description "Address-family";
        }
        leaf prefix {
            type inet:ip-prefix;
        }
    }
}
```

```
        description "Unprotected prefix.";
    }
}

list protection-statistics {
    key frr-protection-method;
    config false;
    description "List protection method statistics";

    leaf frr-protection-method {
        type string;
        description "Protection method used.";
    }
    list address-family-stats {
        key address-family;
        description "Per Address Family protection statistics.";

        leaf address-family {
            type iana-rt-types:address-family;
            description "Address-family";
        }
        leaf total-routes {
            type uint32;
            description "Total prefixes.";
        }
        leaf unprotected-routes {
            type uint32;
            description
                "Total prefixes that are not protected.";
        }
        leaf protected-routes {
            type uint32;
            description
                "Total prefixes that are protected.";
        }
        leaf linkprotected-routes {
            type uint32;
            description
                "Total prefixes that are link protected.";
        }
        leaf nodeprotected-routes {
            type uint32;
            description
                "Total prefixes that are node protected.";
        }
    }
}
}
```

```
    }

    grouping interface-fast-reroute-config {
      description
        "This group defines interface configuration of IP-FRR.";
      container fast-reroute {
        if-feature fast-reroute;
        container lfa {
          if-feature lfa;
          leaf candidate-enable {
            type boolean;
            default true;
            description
              "Enable the interface to be used as backup.";
          }
          leaf enable {
            type boolean;
            default false;
            description
              "Activates LFA - Per-prefix LFA computation
              is assumed.";
          }
          container remote-lfa {
            if-feature remote-lfa;
            leaf enable {
              type boolean;
              default false;
              description
                "Activates Remote LFA (R-LFA).";
            }
          }
          description
            "Remote LFA configuration.";
        }
        description
          "LFA configuration.";
      }
      description
        "Interface IP Fast-reroute configuration.";
    }
  }

  grouping interface-physical-link-config {
    description
      "Interface cost configuration that only applies to
      physical interfaces (non-virtual) and sham links.";
    leaf cost {
      type ospf-link-metric;
      description

```

```
        "Interface cost.";
    }
    leaf mtu-ignore {
        if-feature mtu-ignore;
        type boolean;
        description
            "Enable/Disable bypassing the MTU mismatch check in
            Database Description packets specified in RFC 2328,
            section 10.6.";
    }
    leaf prefix-suppression {
        if-feature prefix-suppression;
        type boolean;
        description
            "Suppress advertisement of the prefixes associated
            with the interface.";
    }
}

grouping interface-common-config {
    description
        "Common configuration for all types of interfaces,
        including virtual links and sham links.";

    leaf hello-interval {
        type uint16;
        units seconds;
        description
            "Interval between hello packets (seconds). It must
            be the same for all routers on the same network.
            Different networks, implementations, and deployments
            will use different hello-intervals. A sample value
            for a LAN network would be 10 seconds.";
        reference "RFC 2328: OSPF Version 2, Appendix C.3";
    }

    leaf dead-interval {
        type uint16;
        units seconds;
        must "../dead-interval > ../hello-interval" {
            error-message "The dead interval must be "
                + "larger than the hello interval";
        }
        description
            "The value must be greater than the 'hello-interval'.";
    }
    description
        "Interval after which a neighbor is declared down
        (seconds) if hello packets are not received. It is
```

```
        typically 3 or 4 times the hello-interval. A typical
        value for LAN networks is 40 seconds.";
        reference "RFC 2328: OSPF Version 2, Appendix C.3";
    }

    leaf retransmit-interval {
        type uint16 {
            range "1..3600";
        }
        units seconds;
        description
            "Interval between retransmitting unacknowledged Link
            State Advertisements (LSAs) (seconds). This should
            be well over the round-trip transmit delay for
            any two routers on the network. A sample value
            would be 5 seconds.";
        reference "RFC 2328: OSPF Version 2, Appendix C.3";
    }

    leaf transmit-delay {
        type uint16;
        units seconds;
        description
            "Estimated time needed to transmit Link State Update
            (LSU) packets on the interface (seconds). LSAs have
            their age incremented by this amount when advertised
            on the interface. A sample value would be 1 second.";
        reference "RFC 2328: OSPF Version 2, Appendix C.3";
    }

    leaf lls {
        if-feature lls;
        type boolean;
        description
            "Enable/Disable link-local signaling (LLS) support.";
    }

    container ttl-security {
        if-feature ttl-security;
        description "Time to Live (TTL) security check.";
        leaf enable {
            type boolean;
            description
                "Enable/Disable TTL security check.";
        }
        leaf hops {
            type uint8 {
                range "1..254";
            }
        }
    }
}
```

```
    }
    default 1;
    description
      "Maximum number of hops that an OSPF packet may
       have traversed before reception.";
  }
}
leaf enable {
  type boolean;
  default true;
  description
    "Enable/disable OSPF protocol on the interface.";
}

container authentication {
  description "Authentication configuration.";
  choice auth-type-selection {
    description
      "Options for OSPFv2/OSPFv3 authentication
       configuration.";
    case ospfv2-auth {
      when "derived-from-or-self(..../..../..../rt:type, "
        + "'ospfv2')" {
        description "Applied to OSPFv2 only.";
      }
      leaf ospfv2-auth-trailer-rfc {
        if-feature ospfv2-authentication-trailer;
        type ospfv2-auth-trailer-rfc-version;
        description
          "Version of OSFPv2 authentication trailer support -
           RFC 5709 or RFC 7474";
      }
    }
    choice ospfv2-auth-specification {
      description
        "Key chain or explicit key parameter specification";
      case auth-key-chain {
        if-feature key-chain;
        leaf ospfv2-key-chain {
          type key-chain:key-chain-ref;
          description
            "key-chain name.";
        }
      }
    }
    case auth-key-explicit {
      leaf ospfv2-key-id {
        type uint32;
        description
          "Key Identifier";
      }
    }
  }
}
```

```
    }
    leaf ospfv2-key {
      type string;
      description
        "OSPFv2 authentication key. The
         length of the key may be dependent on the
         cryptographic algorithm.";
    }
    leaf ospfv2-crypto-algorithm {
      type identityref {
        base key-chain:crypto-algorithm;
      }
      description
        "Cryptographic algorithm associated with key.";
    }
  }
}
}
case ospfv3-auth-ipsec {
  when "derived-from-or-self(.../.../.../.../.../rt:type, "
    + "'ospfv3')" {
    description "Applied to OSPFv3 only.";
  }
  if-feature ospfv3-authentication-ipsec;
  leaf sa {
    type string;
    description
      "Security Association (SA) name.";
  }
}
case ospfv3-auth-trailer {
  when "derived-from-or-self(.../.../.../.../.../rt:type, "
    + "'ospfv3')" {
    description "Applied to OSPFv3 only.";
  }
  if-feature ospfv3-authentication-trailer;
  choice ospfv3-auth-specification {
    description
      "Key chain or explicit key parameter specification";
    case auth-key-chain {
      if-feature key-chain;
      leaf ospfv3-key-chain {
        type key-chain:key-chain-ref;
        description
          "key-chain name.";
      }
    }
    case auth-key-explicit {
```



```
    enum "hybrid" {
      if-feature hybrid-interface;
      description
        "Specify OSPF hybrid broadcast/P2MP network.";
    }
  }
  description
    "Interface type.";
}

leaf passive {
  type boolean;
  description
    "Enable/Disable passive interface - a passive interface's
    prefix will be advertised but no neighbor adjacencies
    will be formed on the interface.";
}

leaf demand-circuit {
  if-feature demand-circuit;
  type boolean;
  description
    "Enable/Disable demand circuit.";
}

leaf priority {
  type uint8;
  description
    "Configure OSPF router priority. On multi-access network
    this value is for Designated Router (DR) election. The
    priority is ignored on other interface types. A router
    with a higher priority will be preferred in the election
    and a value of 0 indicates the router is not eligible to
    become Designated Router or Backup Designated Router
    (BDR).";
}

container multi-areas {
  if-feature multi-area-adj;
  description "Container for multi-area config.";
  list multi-area {
    key multi-area-id;
    description
      "Configure OSPF multi-area adjacency.";
    leaf multi-area-id {
      type area-id-type;
      description
        "Multi-area adjacency area ID.";
    }
  }
}
```

```
    }
    leaf cost {
      type ospf-link-metric;
      description
        "Interface cost for multi-area adjacency.";
    }
  }
}

container static-neighbors {
  description "Statically configured neighbors.";

  list neighbor {
    key "identifier";
    description
      "Specify a static OSPF neighbor.";

    leaf identifier {
      type inet:ip-address;
      description
        "Neighbor Router ID, IPv4 address, or IPv6 address.";
    }

    leaf cost {
      type ospf-link-metric;
      description
        "Neighbor cost. Different implementations have different
        default costs with some defaulting to a cost inversely
        proportional to the interface speed. Others will
        default to 1 equating the cost to a hop count." ;
    }

    leaf poll-interval {
      type uint16;
      units seconds;
      description
        "Neighbor poll interval (seconds) for sending OSPF
        hello packets to discover the neighbor on NBMA
        networks. This interval dictates the granularity for
        discovery of new neighbors. A sample would be
        120 seconds (2 minutes) for a legacy Packet Data
        Network (PDN) X.25 network.";
      reference "RFC 2328: OSPF Version 2, Appendix C.5";
    }

    leaf priority {
      type uint8;
      description
        "Neighbor priority for DR election. A router with a
        higher priority will be preferred in the election

```

```
        and a value of 0 indicates the router is not
        eligible to become Designated Router or Backup
        Designated Router (BDR).";
    }
}

leaf node-flag {
    if-feature node-flag;
    type boolean;
    default false;
    description
        "Set prefix as identifying the advertising router.";
    reference "RFC 7684: OSPFv2 Prefix/Link Attribute
        Advertisement";
}

container bfd {
    if-feature bfd;
    description "BFD Client Configuration.";
    uses bfd-types:client-cfg-parms;
    reference "RFC YYYY: YANG Data Model for Bidirectional
        Forwarding Detection (BFD). Please replace YYYY with
        published RFC number for draft-ietf-bfd-yang.";
}

uses interface-fast-reroute-config;
uses interface-common-config;
uses interface-physical-link-config;
}

grouping neighbor-state {
    description
        "OSPF neighbor operational state.";

    leaf address {
        type inet:ip-address;
        config false;
        description
            "Neighbor address.";
    }

    leaf dr-router-id {
        type rt-types:router-id;
        config false;
        description "Neighbor's Designated Router (DR) Router ID.";
    }

    leaf dr-ip-addr {
```

```
    type inet:ip-address;
    config false;
    description "Neighbor's Designated Router (DR) IP address.";
  }

  leaf bdr-router-id {
    type rt-types:router-id;
    config false;
    description
      "Neighbor's Backup Designated Router (BDR) Router ID.";
  }

  leaf bdr-ip-addr {
    type inet:ip-address;
    config false;
    description
      "Neighbor's Backup Designated Router (BDR) IP Address.";
  }

  leaf state {
    type nbr-state-type;
    config false;
    description
      "OSPF neighbor state.";
  }

  leaf cost {
    type ospf-link-metric;
    config false;
    description "Cost to reach neighbor for Point-to-Multipoint
      and Hybrid networks";
  }

  leaf dead-timer {
    type rt-types:timer-value-seconds16;
    config false;
    description "This timer tracks the remaining time before
      the neighbor is declared dead.";
  }

  container statistics {
    config false;
    description "Per-neighbor statistics";
    uses neighbor-stat;
  }
}

grouping interface-common-state {
  description
    "OSPF interface common operational state.";
  reference "RFC2328 Section 9: OSPF Version2 -
    The Interface Data Structure";
}
```

```
leaf state {
  type if-state-type;
  config false;
  description "Interface state.";
}

leaf hello-timer {
  type rt-types:timer-value-seconds16;
  config false;
  description "This timer tracks the remaining time before
               the next hello packet is sent on the
               interface.";
}

leaf wait-timer {
  type rt-types:timer-value-seconds16;
  config false;
  description "This timer tracks the remaining time before
               the interface exits the Waiting state.";
}

leaf dr-router-id {
  type rt-types:router-id;
  config false;
  description "Designated Router (DR) Router ID.";
}

leaf dr-ip-addr {
  type inet:ip-address;
  config false;
  description "Designated Router (DR) IP address.";
}

leaf bdr-router-id {
  type rt-types:router-id;
  config false;
  description "Backup Designated Router (BDR) Router ID.";
}

leaf bdr-ip-addr {
  type inet:ip-address;
  config false;
  description "Backup Designated Router (BDR) IP Address.";
}

container statistics {
  config false;
  description "Per-interface statistics";
}
```

```
    uses interface-stat;
  }

  container neighbors {
    config false;
    description "All neighbors for the interface.";
    list neighbor {
      key "neighbor-router-id";
      description
        "List of interface OSPF neighbors.";
      leaf neighbor-router-id {
        type rt-types:router-id;
        description
          "Neighbor Router ID.";
      }
      uses neighbor-state;
    }
  }

  container database {
    config false;
    description "Link-scope Link State Database.";
    list link-scope-lsa-type {
      key "lsa-type";
      description
        "List OSPF link-scope LSAs.";
      leaf lsa-type {
        type uint16;
        description "OSPF link-scope LSA type.";
      }
      container link-scope-lsas {
        description
          "All link-scope LSAs of this LSA type.";
        list link-scope-lsa {
          key "lsa-id adv-router";
          description "List of OSPF link-scope LSAs";
          uses lsa-key;
          uses lsa {
            refine "version/ospfv2/ospfv2" {
              must "derived-from-or-self( "
                + "../../../../../../../../../../../"
                + "rt:type, 'ospfv2')" {
                description "OSPFv2 LSA.";
              }
            }
            refine "version/ospfv3/ospfv3" {
              must "derived-from-or-self( "
                + "../../../../../../../../../../../"
                + "rt:type, 'ospfv3')" {
            }
          }
        }
      }
    }
  }
}
```

```
        description "OSPFv3 LSA.";
    }
}
}
}
}
}
}
}

grouping interface-state {
    description
        "OSPF interface operational state.";
    reference "RFC2328 Section 9: OSPF Version2 -
        The Interface Data Structure";

    uses interface-common-state;
}

grouping virtual-link-config {
    description
        "OSPF virtual link configuration state.";

    uses interface-common-config;
}

grouping virtual-link-state {
    description
        "OSPF virtual link operational state.";

    leaf cost {
        type ospf-link-metric;
        config false;
        description
            "Virtual link interface cost.";
    }
    uses interface-common-state;
}

grouping sham-link-config {
    description
        "OSPF sham link configuration state.";

    uses interface-common-config;
    uses interface-physical-link-config;
}

grouping sham-link-state {
```

```
description
  "OSPF sham link operational state.";
uses interface-common-state;
}

grouping address-family-area-config {
  description
    "OSPF address-family specific area config state.";

  container ranges {
    description "Container for summary ranges";

    list range {
      key "prefix";
      description
        "Summarize routes matching address/mask -
        Applicable to Area Border Routers (ABRs) only.";
      leaf prefix {
        type inet:ip-prefix;
        description
          "IPv4 or IPv6 prefix";
      }
      leaf advertise {
        type boolean;
        description
          "Advertise or hide.";
      }
      leaf cost {
        type ospf-metric;
        description
          "Advertised cost of summary route.";
      }
    }
  }
}

grouping area-common-config {
  description
    "OSPF area common configuration state.";

  leaf summary {
    when "derived-from(..../area-type,'stub-nssa-area')" {
      description
        "Summary advertisement into the stub/NSSA area.";
    }
    type boolean;
    description
      "Enable/Disable summary advertisement into the stub or
```

```
        NSSA area.";
    }
    leaf default-cost {
        when "derived-from(..../area-type,'stub-nssa-area')" {
            description
                "Cost for LSA default route advertised into the
                stub or NSSA area.";
        }
        type ospf-metric;
        description
            "Set the summary default route cost for a
            stub or NSSA area.";
    }
}

grouping area-config {
    description
        "OSPF area configuration state.";

    leaf area-type {
        type identityref {
            base area-type;
        }
        default normal-area;
        description
            "Area type.";
    }

    uses area-common-config;
    uses address-family-area-config;
}

grouping area-state {
    description
        "OSPF area operational state.";

    container statistics {
        config false;
        description "Per-area statistics";
        uses area-stat;
    }

    container database {
        config false;
        description "Area-scope Link State Database.";
        list area-scope-lsa-type {
            key "lsa-type";
            description "List OSPF area-scope LSAs.";
        }
    }
}
```



```
        description "Next hops for the route.";
        list next-hop {
            key "next-hop";
            description "List of next hops for the route";
            leaf outgoing-interface {
                type if:interface-ref;
                description
                    "Name of the outgoing interface.";
            }
            leaf next-hop {
                type inet:ip-address;
                description "Next hop address.";
            }
        }
    }
    leaf metric {
        type uint32;
        description "Metric for this route.";
    }
    leaf route-type {
        type route-type;
        description "Route type for this route.";
    }
    leaf route-tag {
        type uint32;
        description "Route tag for this route.";
    }
}
}
}

grouping ietf-spf-delay {
    leaf initial-delay {
        type uint32;
        units milliseconds;
        description
            "Delay used while in QUIET state (milliseconds).";
    }
    leaf short-delay {
        type uint32;
        units milliseconds;
        description
            "Delay used while in SHORT_WAIT state (milliseconds).";
    }
    leaf long-delay {
        type uint32;
        units milliseconds;
        description

```

```
        "Delay used while in LONG_WAIT state (milliseconds).";
    }
    leaf hold-down {
        type uint32;
        units milliseconds;
        description
            "Timer used to consider an IGP stability period
            (milliseconds).";
    }
    leaf time-to-learn {
        type uint32;
        units milliseconds;
        description
            "Duration used to learn all the IGP events
            related to a single component failure (milliseconds).";
    }
    leaf current-state {
        type enumeration {
            enum "quiet" {
                description "QUIET state";
            }
            enum "short-wait" {
                description "SHORT_WAIT state";
            }
            enum "long-wait" {
                description "LONG_WAIT state";
            }
        }
        config false;
        description
            "Current SPF back-off algorithm state.";
    }
    leaf remaining-time-to-learn {
        type rt-types:timer-value-milliseconds;
        config false;
        description
            "Remaining time until time-to-learn timer fires.";
    }
    leaf remaining-hold-down {
        type rt-types:timer-value-milliseconds;
        config false;
        description
            "Remaining time until hold-down timer fires.";
    }
    leaf last-event-received {
        type yang:timestamp;
        config false;
        description
```

```
        "Time of last SPF triggering event.";
    }
    leaf next-spf-time {
        type yang:timestamp;
        config false;
        description
            "Time when next SPF has been scheduled.";
    }
    leaf last-spf-time {
        type yang:timestamp;
        config false;
        description
            "Time of last SPF computation.";
    }
    description
        "Grouping for IETF SPF delay configuration and state";
}

grouping node-tag-config {
    description
        "OSPF node tag config state.";
    container node-tags {
        if-feature node-tag;
        list node-tag {
            key tag;
            leaf tag {
                type uint32;
                description
                    "Node tag value.";
            }
            description
                "List of tags.";
        }
        description
            "Container for node admin tags.";
    }
}

grouping instance-config {
    description
        "OSPF instance config state.";

    leaf enable {
        type boolean;
        default true;
        description
            "Enable/Disable the protocol.";
    }
}
```

```
leaf explicit-router-id {
  if-feature explicit-router-id;
  type rt-types:router-id;
  description
    "Defined in RFC 2328. A 32-bit number
     that uniquely identifies the router.";
}

container preference {
  description
    "Route preference configuration. In many
     implementations, preference is referred to as
     administrative distance.";
  reference
    "RFC 8349: A YANG Data Model for Routing Management
     (NMDA Version)";
  choice scope {
    description
      "Options for expressing preference
       as single or multiple values.";
    case single-value {
      leaf all {
        type uint8;
        description
          "Preference for intra-area, inter-area, and
           external routes.";
      }
    }
    case multi-values {
      choice granularity {
        description
          "Options for expressing preference
           for intra-area and inter-area routes.";
        case detail {
          leaf intra-area {
            type uint8;
            description
              "Preference for intra-area routes.";
          }
          leaf inter-area {
            type uint8;
            description
              "Preference for inter-area routes.";
          }
        }
        case coarse {
          leaf internal {
            type uint8;
          }
        }
      }
    }
  }
}
```

```
        description
            "Preference for both intra-area and
            inter-area routes.";
    }
}
leaf external {
    type uint8;
    description
        "Preference for AS external routes.";
}
}
}

container nsr {
    if-feature nsr;
    description
        "Non-Stop Routing (NSR) config state.";
    leaf enable {
        type boolean;
        description
            "Enable/Disable NSR.";
    }
}

container graceful-restart {
    if-feature graceful-restart;
    description
        "Graceful restart config state.";
    reference "RFC 3623: OSPF Graceful Restart
        RFC 5187: OSPFv3 Graceful Restart";
    leaf enable {
        type boolean;
        description
            "Enable/Disable graceful restart as defined in RFC 3623
            for OSPFv2 and RFC 5187 for OSPFv3.";
    }
    leaf helper-enable {
        type boolean;
        description
            "Enable graceful restart helper support for restarting
            routers (RFC 3623 Section 3).";
    }
    leaf restart-interval {
        type uint16 {
            range "1..1800";
        }
    }
}
```

```
    units seconds;
    default "120";
    description
        "Interval to attempt graceful restart prior
         to failing (RFC 3623 Section B.1) (seconds)";
}
leaf helper-strict-lsa-checking {
    type boolean;
    description
        "Terminate graceful restart when an LSA topology change
         is detected (RFC 3623 Section B.2).";
}
}

container auto-cost {
    if-feature auto-cost;
    description
        "Interface Auto-cost configuration state.";
    leaf enable {
        type boolean;
        description
            "Enable/Disable interface auto-cost.";
    }
    leaf reference-bandwidth {
        when "../enable = 'true'" {
            description "Only when auto cost is enabled";
        }
        type uint32 {
            range "1..4294967";
        }
        units Mbits;
        description
            "Configure reference bandwidth used to automatically
             determine interface cost (Mbits). The cost is the
             reference bandwidth divided by the interface speed
             with 1 being the minimum cost.";
    }
}

container spf-control {
    leaf paths {
        if-feature max-ecmp;
        type uint16 {
            range "1..65535";
        }
        description
            "Maximum number of Equal-Cost Multi-Path (ECMP) paths.";
    }
}
```

```
    container ietf-spf-delay {
      if-feature ietf-spf-delay;
      uses ietf-spf-delay;
      description
        "IETF SPF delay algorithm configuration.";
    }
  description "SPF calculation control.";
}

container database-control {
  leaf max-lsa {
    if-feature max-lsa;
    type uint32 {
      range "1..4294967294";
    }
    description
      "Maximum number of LSAs OSPF the router will accept.";
  }
  description "Database maintenance control.";
}

container stub-router {
  if-feature stub-router;
  description "Set maximum metric configuration";

  choice trigger {
    description
      "Specific triggers which will enable stub
      router state.";
    container always {
      presence
        "Enables unconditional stub router support";
      description
        "Unconditional stub router state (advertise
        transit links with MaxLinkMetric";
      reference "RFC 6987: OSPF Stub Router
        Advertisement";
    }
  }
}

container mpls {
  description
    "OSPF MPLS config state.";
  container te-rid {
    if-feature te-rid;
    description
      "Stable OSPF Router IP Address used for Traffic
```

```
        Engineering (TE)";
    leaf ipv4-router-id {
        type inet:ipv4-address;
        description
            "Explicitly configure the TE IPv4 Router ID.";
    }
    leaf ipv6-router-id {
        type inet:ipv6-address;
        description
            "Explicitly configure the TE IPv6 Router ID.";
    }
}
container ldp {
    description
        "OSPF MPLS LDP config state.";
    leaf igp-sync {
        if-feature ldp-igp-sync;
        type boolean;
        description
            "Enable LDP IGP synchronization.";
    }
}
}
uses instance-fast-reroute-config;
uses node-tag-config;
}

grouping instance-state {
    description
        "OSPF instance operational state.";

    leaf router-id {
        type rt-types:router-id;
        config false;
        description
            "Defined in RFC 2328. A 32-bit number
            that uniquely identifies the router.";
    }

    uses local-rib;

    container statistics {
        config false;
        description "Per-instance statistics";
        uses instance-stat;
    }

    container database {
```

```

config false;
description "AS-scope Link State Database.";
list as-scope-lsa-type {
  key "lsa-type";
  description "List OSPF AS-scope LSAs.";
  leaf lsa-type {
    type uint16;
    description "OSPF AS scope LSA type.";
  }
  container as-scope-lsas {
    description "All AS-scope of LSA of this LSA type.";
    list as-scope-lsa {
      key "lsa-id adv-router";
      description "List of OSPF AS-scope LSAs";
      uses lsa-key;
      uses lsa {
        refine "version/ospfv2/ospfv2" {
          must "derived-from-or-self( "
            + "../.../.../.../.../.../"
            + "rt:type, 'ospfv2')" {
            description "OSPFv2 LSA.";
          }
        }
        refine "version/ospfv3/ospfv3" {
          must "derived-from-or-self( "
            + "../.../.../.../.../.../"
            + "rt:type, 'ospfv3')" {
            description "OSPFv3 LSA.";
          }
        }
      }
    }
  }
}
uses spf-log;
uses lsa-log;
}

grouping multi-topology-area-common-config {
  description
    "OSPF multi-topology area common configuration state.";
  leaf summary {
    when "derived-from(.../.../.../area-type, 'stub-nssa-area')" {
      description
        "Summary advertisement into the stub/NSSA area.";
    }
    type boolean;
  }
}

```

```
        description
            "Enable/Disable summary advertisement into the
            topology in the stub or NSSA area.";
    }
    leaf default-cost {
        when "derived-from ../../../../area-type, 'stub-nssa-area'" {
            description
                "Cost for LSA default route advertised into the
                topology into the stub or NSSA area.";
        }
        type ospf-metric;
        description
            "Set the summary default route cost for a
            stub or NSSA area.";
    }
}

grouping multi-topology-area-config {
    description
        "OSPF multi-topology area configuration state.";

    uses multi-topology-area-common-config;
    uses address-family-area-config;
}

grouping multi-topology-state {
    description
        "OSPF multi-topology operational state.";

    uses local-rib;
}

grouping multi-topology-interface-config {
    description
        "OSPF multi-topology configuration state.";

    leaf cost {
        type ospf-link-metric;
        description
            "Interface cost for this topology.";
    }
}

grouping ospfv3-interface-config {
    description
        "OSPFv3 interface specific configuration state.";

    leaf instance-id {
```

```
    type uint8 {
      range "0 .. 31";
    }
    description
      "OSPFv3 instance ID.";
  }
}

grouping ospfv3-interface-state {
  description
    "OSPFv3 interface specific operational state.";

  leaf interface-id {
    type uint16;
    config false;
    description
      "OSPFv3 interface ID.";
  }
}

grouping lsa-identifiers {
  description
    "The parameters that uniquely identify an LSA.";
  leaf area-id {
    type area-id-type;
    description
      "Area ID";
  }
  leaf type {
    type uint16;
    description
      "LSA type.";
  }
  leaf lsa-id {
    type union {
      type inet:ipv4-address;
      type yang:dotted-quad;
    }
    description "Link-State ID.";
  }
  leaf adv-router {
    type rt-types:router-id;
    description
      "LSA advertising router.";
  }
  leaf seq-num {
    type uint32;
    description

```

```
        "LSA sequence number.";
    }
}

grouping spf-log {
    description
        "Grouping for SPF log.";
    container spf-log {
        config false;
        description
            "This container lists the SPF log.";
        list event {
            key id;
            description
                "List of SPF log entries represented
                as a wrapping buffer in chronological
                order with the oldest entry returned
                first.";
            leaf id {
                type uint32;
                description
                    "Event identifier - Purely internal value.";
            }
            leaf spf-type {
                type enumeration {
                    enum full {
                        description
                            "SPF computation was a Full SPF.";
                    }
                    enum intra {
                        description
                            "SPF computation was only for intra-area routes.";
                    }
                    enum inter {
                        description
                            "SPF computation was only for inter-area
                            summary routes.";
                    }
                    enum external {
                        description
                            "SPF computation was only for AS external routes.";
                    }
                }
            }
            description
                "The SPF computation type for the SPF log entry.";
        }
        leaf schedule-timestamp {
            type yang:timestamp;
        }
    }
}
```

```
        description
            "This is the timestamp when the computation was
            scheduled.";
    }
    leaf start-timestamp {
        type yang:timestamp;
        description
            "This is the timestamp when the computation was
            started.";
    }
    leaf end-timestamp {
        type yang:timestamp;
        description
            "This the timestamp when the computation was
            completed.";
    }
    list trigger-lsa {
        description
            "The list of LSAs that triggered the computation.";
        uses lsa-identifiers;
    }
}
}
```

```
grouping lsa-log {
    description
        "Grouping for the LSA log.";
    container lsa-log {
        config false;
        description
            "This container lists the LSA log.
            Local LSA modifications are also included
            in the list.";
        list event {
            key id;
            description
                "List of LSA log entries represented
                as a wrapping buffer in chronological order
                with the oldest entries returned first.";
            leaf id {
                type uint32;
                description
                    "Event identifier - purely internal value.";
            }
            container lsa {
                description
                    "This container describes the logged LSA.";
            }
        }
    }
}
```

```
        uses lsa-identifiers;
    }
    leaf received-timestamp {
        type yang:timestamp;
        description
            "This is the timestamp when the LSA was received.
            In case of local LSA update, the timestamp refers
            to the LSA origination time.";
    }
    leaf reason {
        type identityref {
            base lsa-log-reason;
        }
        description
            "This reason for the LSA log entry.";
    }
}
}
}

augment "/rt:routing/rt:control-plane-protocols/"
+ "rt:control-plane-protocol" {
    when "derived-from(rt:type, 'ospf')" {
        description
            "This augmentation is only valid for a routing protocol
            instance of OSPF (type 'ospfv2' or 'ospfv3').";
    }
    description "OSPF protocol ietf-routing module
        control-plane-protocol augmentation.";

    container ospf {
        description
            "OSPF protocol Instance";

        leaf address-family {
            type iana-rt-types:address-family;
            description
                "Address-family of the instance.";
        }

        uses instance-config;
        uses instance-state;

        container areas {
            description "All areas.";
            list area {
                key "area-id";
                description

```

```

    "List of OSPF areas";
  leaf area-id {
    type area-id-type;
    description
      "Area ID";
  }

  uses area-config;
  uses area-state;

  container virtual-links {
    when "derived-from-or-self(..../area-type, 'normal-area') "
      + "and ..../area-id = '0.0.0.0'" {
      description
        "Virtual links must be in backbone area.";
    }
    description "All virtual links.";
    list virtual-link {
      key "transit-area-id router-id";
      description
        "OSPF virtual link";
      leaf transit-area-id {
        type leafref {
          path "..../..../..../area/area-id";
        }
        must "derived-from-or-self("
          + "..../..../..../area[area-id=current()]/area-type, "
          + "'normal-area') and "
          + "..../..../..../area[area-id=current()]/area-id != "
          + "'0.0.0.0'" {
          error-message "Virtual link transit area must "
            + "be non-zero.";
          description
            "Virtual-link transit area must be
              non-zero area.";
        }
        description
          "Virtual link transit area ID.";
      }
      leaf router-id {
        type rt-types:router-id;
        description
          "Virtual Link remote endpoint Router ID.";
      }
    }

    uses virtual-link-config;
    uses virtual-link-state;
  }

```

```

    }
    container sham-links {
      if-feature pe-ce-protocol;
      description "All sham links.";
      list sham-link {
        key "local-id remote-id";
        description
          "OSPF sham link";
        leaf local-id {
          type inet:ip-address;
          description
            "Address of the local sham Link endpoint.";
        }
        leaf remote-id {
          type inet:ip-address;
          description
            "Address of the remote sham Link endpoint.";
        }
        uses sham-link-config;
        uses sham-link-state;
      }
    }
    container interfaces {
      description "All interfaces.";
      list interface {
        key "name";
        description
          "List of OSPF interfaces.";
        leaf name {
          type if:interface-ref;
          description
            "Interface name reference.";
        }
        uses interface-config;
        uses interface-state;
      }
    }
  }
}

augment "/rt:routing/rt:control-plane-protocols/"
  + "rt:control-plane-protocol/ospf" {
  when "derived-from(../rt:type, 'ospf')" {
    description
      "This augmentation is only valid for OSPF
      (type 'ospfv2' or 'ospfv3').";
  }
}

```

```

    }
    if-feature multi-topology;
    description
      "OSPF multi-topology instance configuration
      state augmentation.";
    container topologies {
      description "All topologies.";
      list topology {
        key "name";
        description
          "OSPF topology - The OSPF topology address-family
          must coincide with the routing-instance
          address-family.";
        leaf name {
          type leafref {
            path "../..../..../..../rt:ribs/rt:rib/rt:name";
          }
          description "RIB name corresponding to the OSPF
            topology.";
        }

        uses multi-topology-state;
      }
    }
  }
}

augment "/rt:routing/rt:control-plane-protocols/"
  + "rt:control-plane-protocol/ospf/"
  + "areas/area" {
  when "derived-from-or-self(..../..../rt:type, "
    + "'ospfv2')" {
    description
      "This augmentation is only valid for OSPFv2.";
  }
  if-feature multi-topology;
  description
    "OSPF multi-topology area configuration state
    augmentation.";
  container topologies {
    description "All topologies for the area.";
    list topology {
      key "name";
      description "OSPF area topology.";
      leaf name {
        type leafref {
          path "../..../..../..../..../..../"
            + "rt:ribs/rt:rib/rt:name";
        }
      }
    }
  }
}

```

```

        description
            "Single topology enabled for this area.";
    }

    uses multi-topology-area-config;
}
}

augment "/rt:routing/rt:control-plane-protocols/"
+ "rt:control-plane-protocol/ospf/"
+ "areas/area/interfaces/interface" {
when "derived-from-or-self(..../..../..../rt:type, "
+ "'ospfv2')" {
description
    "This augmentation is only valid for OSPFv2.";
}
if-feature multi-topology;
description
    "OSPF multi-topology interface configuration state
    augmentation.";
container topologies {
description "All topologies for the interface.";
list topology {
key "name";
description "OSPF interface topology.";
leaf name {
type leafref {
path "..../..../..../..../..../..../..../..../"
+ "rt:ribs/rt:rib/rt:name";
}
description
    "Single topology enabled on this interface.";
}
}
uses multi-topology-interface-config;
}
}

augment "/rt:routing/rt:control-plane-protocols/"
+ "rt:control-plane-protocol/ospf/"
+ "areas/area/interfaces/interface" {
when "derived-from-or-self(..../..../..../rt:type, "
+ "'ospfv3')" {
description
    "This augmentation is only valid for OSPFv3.";
}
}

```

```
    description
      "OSPFv3 interface specific configuration state
      augmentation.";
    uses ospfv3-interface-config;
    uses ospfv3-interface-state;
  }

  grouping route-content {
    description
      "This grouping defines OSPF-specific route attributes.";
    leaf metric {
      type uint32;
      description "OSPF route metric.";
    }
    leaf tag {
      type uint32;
      default "0";
      description "OSPF route tag.";
    }
    leaf route-type {
      type route-type;
      description "OSPF route type";
    }
  }

  augment "/rt:routing/rt:ribs/rt:rib/rt:routes/rt:route" {
    when "derived-from(rt:source-protocol, 'ospf')" {
      description
        "This augmentation is only valid for routes whose
        source protocol is OSPF.";
    }
    description
      "OSPF-specific route attributes.";
    uses route-content;
  }

  /*
  * RPCs
  */

  rpc clear-neighbor {
    description
      "This RPC request clears a particular set of OSPF neighbors.
      If the operation fails for OSPF internal reason, then
      error-tag and error-app-tag should be set to a meaningful
      value.";
    input {
      leaf routing-protocol-name {
```

```
    type leafref {
      path "/rt:routing/rt:control-plane-protocols/"
        + "rt:control-plane-protocol/rt:name";
    }
    mandatory "true";
    description
      "OSPF protocol instance which information for neighbors
      are to be cleared.

      If the referenced OSPF instance doesn't exist, then
      this operation SHALL fail with error-tag 'data-missing'
      and error-app-tag
      'routing-protocol-instance-not-found'.";
  }

  leaf interface {
    type if:interface-ref;
    description
      "Name of the OSPF interface for which neighbors are to
      be cleared.

      If the referenced OSPF interface doesn't exist, then
      this operation SHALL fail with error-tag
      'data-missing' and error-app-tag
      'ospf-interface-not-found'.";
  }
}

rpc clear-database {
  description
    "This RPC request clears a particular OSPF Link State
    Database. If the operation fails for OSPF internal reason,
    then error-tag and error-app-tag should be set to a
    meaningful value.";
  input {
    leaf routing-protocol-name {
      type leafref {
        path "/rt:routing/rt:control-plane-protocols/"
          + "rt:control-plane-protocol/rt:name";
      }
      mandatory "true";
      description
        "OSPF protocol instance whose Link State Database is to
        be cleared.

        If the referenced OSPF instance doesn't exist, then
        this operation SHALL fail with error-tag 'data-missing'";
    }
  }
}
```

```
        and error-app-tag
          'routing-protocol-instance-not-found'. ";
      }
    }
  }

/*
 * Notifications
 */

grouping notification-instance-hdr {
  description
    "This grouping describes common instance specific
    data for OSPF notifications.";

  leaf routing-protocol-name {
    type leafref {
      path "/rt:routing/rt:control-plane-protocols/"
        + "rt:control-plane-protocol/rt:name";
    }
    must "derived-from( "
      + "/rt:routing/rt:control-plane-protocols/"
      + "rt:control-plane-protocol[rt:name=current()]/"
      + "rt:type, 'ospf')";
    description
      "OSPF routing protocol instance name.";
  }

  leaf address-family {
    type leafref {
      path "/rt:routing/"
        + "rt:control-plane-protocols/rt:control-plane-protocol"
        + "[rt:name=current()]/../routing-protocol-name]/"
        + "ospf/address-family";
    }
    description
      "Address family of the OSPF instance.";
  }
}

grouping notification-interface {
  description
    "This grouping provides interface information
    for the OSPF interface specific notification.";

  choice if-link-type-selection {
    description
      "Options for link type.";
  }
}
```

```
    container interface {
      description "Normal interface.";
      leaf interface {
        type if:interface-ref;
        description "Interface.";
      }
    }
  container virtual-link {
    description "virtual-link.";
    leaf transit-area-id {
      type area-id-type;
      description "Area ID.";
    }
    leaf neighbor-router-id {
      type rt-types:router-id;
      description "Neighbor Router ID.";
    }
  }
  container sham-link {
    description "sham link.";
    leaf area-id {
      type area-id-type;
      description "Area ID.";
    }
    leaf local-ip-addr {
      type inet:ip-address;
      description "Sham link local address.";
    }
    leaf remote-ip-addr {
      type inet:ip-address;
      description "Sham link remote address.";
    }
  }
}

grouping notification-neighbor {
  description
    "This grouping provides the neighbor information
    for neighbor specific notifications.";

  leaf neighbor-router-id {
    type rt-types:router-id;
    description "Neighbor Router ID.";
  }

  leaf neighbor-ip-addr {
    type inet:ip-address;
  }
}
```

```
        description "Neighbor address.";
    }
}

notification if-state-change {
    uses notification-instance-hdr;
    uses notification-interface;

    leaf state {
        type if-state-type;
        description "Interface state.";
    }
    description
        "This notification is sent when an interface
        state change is detected.";
}

notification if-config-error {
    uses notification-instance-hdr;
    uses notification-interface;

    leaf packet-source {
        type inet:ip-address;
        description "Source address.";
    }

    leaf packet-type {
        type packet-type;
        description "OSPF packet type.";
    }

    leaf error {
        type enumeration {
            enum "bad-version" {
                description "Bad version.";
            }
            enum "area-mismatch" {
                description "Area mismatch.";
            }
            enum "unknown-nbma-nbr" {
                description "Unknown NBMA neighbor.";
            }
            enum "unknown-virtual-nbr" {
                description "Unknown virtual link neighbor.";
            }
            enum "auth-type-mismatch" {
                description "Auth type mismatch.";
            }
        }
    }
}
```

```
    enum "auth-failure" {
      description "Auth failure.";
    }
    enum "net-mask-mismatch" {
      description "Network mask mismatch.";
    }
    enum "hello-interval-mismatch" {
      description "Hello interval mismatch.";
    }
    enum "dead-interval-mismatch" {
      description "Dead interval mismatch.";
    }
    enum "option-mismatch" {
      description "Option mismatch.";
    }
    enum "mtu-mismatch" {
      description "MTU mismatch.";
    }
    enum "duplicate-router-id" {
      description "Duplicate Router ID.";
    }
    enum "no-error" {
      description "No error.";
    }
  }
  description "Error code.";
}
description
  "This notification is sent when an interface
  config error is detected.";
}

notification nbr-state-change {
  uses notification-instance-hdr;
  uses notification-interface;
  uses notification-neighbor;

  leaf state {
    type nbr-state-type;
    description "Neighbor state.";
  }

  description
    "This notification is sent when a neighbor
    state change is detected.";
}

notification nbr-restart-helper-status-change {
```

```
uses notification-instance-hdr;
uses notification-interface;
uses notification-neighbor;

leaf status {
  type restart-helper-status-type;
  description "Restart helper status.";
}

leaf age {
  type rt-types:timer-value-seconds16;
  description
    "Remaining time in current OSPF graceful restart
    interval when the router is acting as a restart
    helper for the neighbor.";
}

leaf exit-reason {
  type restart-exit-reason-type;
  description
    "Restart helper exit reason.";
}
description
  "This notification is sent when a neighbor restart
  helper status change is detected.";
}

notification if-rx-bad-packet {
  uses notification-instance-hdr;
  uses notification-interface;

  leaf packet-source {
    type inet:ip-address;
    description "Source address.";
  }

  leaf packet-type {
    type packet-type;
    description "OSPF packet type.";
  }

  description
    "This notification is sent when an OSPF packet that
    cannot be parsed is received on an OSPF interface.";
}

notification lsdbs-approaching-overflow {
  uses notification-instance-hdr;
```

```
leaf ext-lsdb-limit {
  type uint32;
  description
    "The maximum number of non-default AS-external LSAs
    entries that can be stored in the Link State Database.";
}

description
  "This notification is sent when the number of LSAs
  in the router's Link State Database has exceeded
  ninety percent of the AS-external limit (ext-lsdb-limit).";
}

notification lsdb-overflow {
  uses notification-instance-hdr;

  leaf ext-lsdb-limit {
    type uint32;
    description
      "The maximum number of non-default AS-external LSAs
      entries that can be stored in the Link State Database.";
  }

  description
    "This notification is sent when the number of LSAs
    in the router's Link State Database has exceeded the
    AS-external limit (ext-lsdb-limit).";
}

notification nssa-translator-status-change {
  uses notification-instance-hdr;

  leaf area-id {
    type area-id-type;
    description "Area ID.";
  }

  leaf status {
    type nssa-translator-state-type;
    description
      "NSSA translator status.";
  }

  description
    "This notification is sent when there is a change
    in the router's role in translating OSPF NSSA LSAs
    to OSPF AS-External LSAs.";
}
```

```
notification restart-status-change {
  uses notification-instance-hdr;

  leaf status {
    type restart-status-type;
    description
      "Restart status.";
  }

  leaf restart-interval {
    type uint16 {
      range 1..1800;
    }
    units seconds;
    default "120";
    description
      "Restart interval.";
  }

  leaf exit-reason {
    type restart-exit-reason-type;
    description
      "Restart exit reason.";
  }

  description
    "This notification is sent when the graceful restart
    state for the router has changed.";
}
}
<CODE ENDS>
```

4. Security Considerations

The YANG modules specified in this document define a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a pre-configured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in `ietf-ospf.yang` module that are writable/creatable/deletable (i.e., `config true`, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., `edit-config`) to these data nodes without proper protection can have a negative effect on network operations. Writable data node represent configuration of each instance, area, virtual link, sham-link, and interface. These correspond to the following schema nodes:

```
/ospf
/ospf/areas/
/ospf/areas/area[area-id]
/ospf/virtual-links/
/ospf/virtual-links/virtual-link[transit-area-id router-id]
/ospf/areas/area[area-id]/interfaces
/ospf/areas/area[area-id]/interfaces/interface[name]
/ospf/area/area[area-id]/sham-links
/ospf/area/area[area-id]/sham-links/sham-link[local-id remote-id]
```

For OSPF, the ability to modify OSPF configuration will allow the entire OSPF domain to be compromised including peering with unauthorized routers to misroute traffic or mount a massive Denial-of-Service (DoS) attack. For example, adding OSPF on any unprotected interface could allow an OSPF adjacency to be formed with an unauthorized and malicious neighbor. Once an adjacency is formed, traffic could be hijacked. As a simpler example, a Denial-of-Service attack could be mounted by changing the cost of an OSPF interface to be asymmetric such that a hard routing loop ensues. In general, unauthorized modification of most OSPF features will pose there own set of security risks and the "Security Considerations" in the respective reference RFCs should be consulted.

Some of the readable data nodes in the `ietf-ospf.yang` module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via `get`, `get-config`, or `notification`) to these data nodes. The exposure of the Link State Database (LSDB) will expose the detailed topology of the network. There is a separate Link State Database for each instance, area, virtual link, sham-link, and interface. These correspond to the following schema nodes:

```
/ospf/database
```

```
/ospf/areas/area[area-id]/database
```

```
/ospf/virtual-links/virtual-link[transit-area-id router-id]/database
```

```
/ospf/areas/area[area-id]/interfaces/interface[name]/database
```

```
/ospf/area/area[area-id]/sham-links/sham-link[local-id remote-id]/database
```

Exposure of the Link State Database includes information beyond the scope of the OSPF router and this may be undesirable since exposure may facilitate other attacks. Additionally, in the case of an area LSDB, the complete IP network topology and, if deployed, the traffic engineering topology of the OSPF area can be reconstructed. Network operators may consider their topologies to be sensitive confidential data.

For OSPF authentication, configuration is supported via the specification of key-chains [RFC8177] or the direct specification of key and authentication algorithm. Hence, authentication configuration using the "auth-table-trailer" case in the "authentication" container inherits the security considerations of [RFC8177]. This includes the considerations with respect to the local storage and handling of authentication keys.

Additionally, local specification of OSPF authentication keys and the associated authentication algorithm is supported for legacy implementations that do not support key-chains [RFC8177] It is RECOMMENDED that implementations migrate to key-chains due the seamless support of key and algorithm rollover, as well as, the hexadecimal key specification affording more key entropy, and encryption of keys using the Advanced Encryption Standard (AES) Key Wrap Padding Algorithm [RFC5649].

Some of the RPC operations in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control access to these operations. The OSPF YANG module supports the "clear-neighbor" and "clear-database" RPCs. If access to either of these is compromised, they can result in temporary network outages be employed to mount DoS attacks.

The actual authentication key data (whether locally specified or part of a key-chain) is sensitive and needs to be kept secret from unauthorized parties; compromise of the key data would allow an

attacker to forge OSPF traffic that would be accepted as authentic, potentially compromising the entirety OSPF domain.

5. IANA Considerations

This document registers a URI in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made:

```
URI: urn:ietf:params:xml:ns:yang:ietf-ospf
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.
```

This document registers a YANG module in the YANG Module Names registry [RFC6020].

```
name: ietf-ospf
namespace: urn:ietf:params:xml:ns:yang:ietf-ospf
prefix: ospf
reference: RFC XXXX
```

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Service Distribution using OSPF
draft-pillay-esnault-ospf-service-distribution-03

Abstract

The Open Shortest Path First (OSPF) protocol is used to carry data on behalf of other services using the Opaque Link State Advertisements. The protocol's flooding mechanism is well suited to cover the data propagation requirements of services such as Traffic Engineering. However, the current mechanism cannot scale for a large number of services nor satisfy some of their new set of requirements. This document describes a new mechanism in OSPF to support service and data distribution for a large number of services, computation of preferred service access points and a controlled service data exchange.

Status of This Memo

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1. Introduction

Originally, routing protocols were designed to propagate routing related information only. With the advent of Traffic Engineering, the IGPs started to be used as a transport mechanism. Most of the applications using IGPs as transport are still very much limited and confined to routing applications with similar requirements.

Today, OSPF can carry data for applications using Opaque LSAs. These Opaque LSAs are an integral part of the OSPF database and will be

flooded, synchronized and updated just as any other LSA. However, they do not contribute directly to any routes or trigger an SPF.

Opaque LSAs will need to be flooded across all the OSPF area or domain and neighbor adjacencies to FULL state will depend on successful exchange of these LSAs.

The Link State IGP's are limited on the size of payload information they can carry as it will be flooded and stored in every single router all across their areas or domain regardless whether it is of interest or not.

This document describes a new mechanism in OSPF to support service and data distribution for a large number of services, computation of preferred service access points and controlled distribution of service data.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119] only when they appear in all upper case. They may also appear in lower or mixed case as English words, without any normative meaning.

3. Requirements for service data propagation

Services requirements differ from the traditional routing information dissemination model. The service data may be unrelated to routing or be of interest only to some routers. The new set of requirements for using OSPF as Service Distribution Router (SDR) is as follows

- Scale to a large number of services

- No assumption regarding size, format or nature of the data

- No assumption regarding topology

- Routing and service data separated and independent

- Must support cases where minimal number of routers only may be upgraded

- Must support dynamic events

- Routers only store and process data of interest

Ability to compute the shortest path to a producer or consumer of a service per IGP metrics or service metrics.

There is no assumptions regarding producers and consumers of services, their location or uniqueness.

Secured data may reside only on some routers.

In addition the routing requirements for OSPF as Service data distribution are

Backward compatible with Open Standard OSPF

Minimal/No impact on routing convergence and performance

4. Typical Scenario for Services Distribution Router

A SDR is typically reachable by multiple consumers or producers of data. The router itself may not be connected directly to any other router with Service Distribution Capability. The intermediate routers may have limited storage capability or cannot store the data for security reasons.

The SDR is aware of the topological information of the other service routers and can compute paths to the preferred Producer SDR (PSDR) or the Consumers SDR (CSDR) of a service. The SDR will implement tables of producers and consumers for services.

The SDR ensures that interested subscribers to a service are notified with the latest updates.

Producers or consumers can join or leave a service at any time using APIs. The SDR receiving the notification of "registration" or "de-registration" flood the change of state to all the known SDRs in its topology. Therefore, all SDR have the same view of the producers and consumers in the topology.

5. OSPF Service Distribution Router

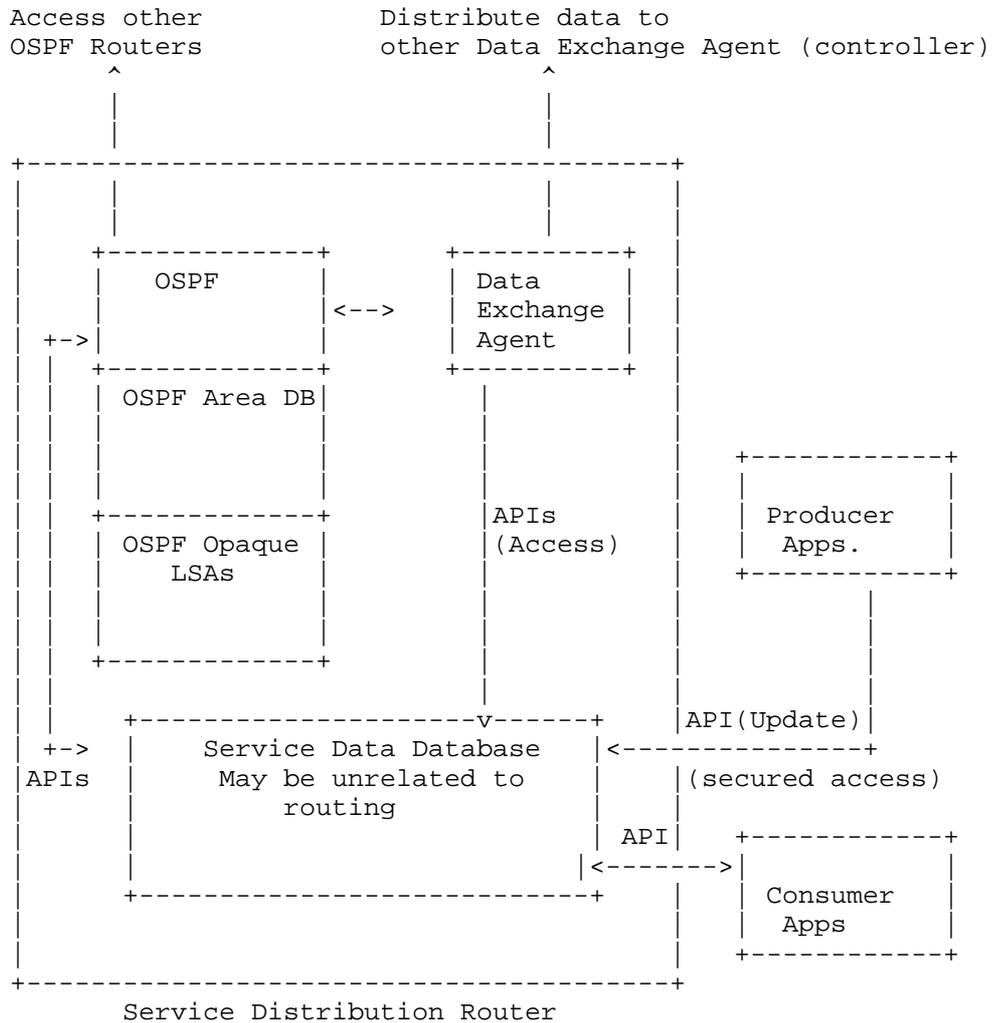
A SDR leverages OSPF's capability to store and flood the topology and other attributes of SDR capable routers. SDRs form an overlay and do not require to be directly connected to each other. SDRs do not need to maintain adjacency between them other than the normal OSPF adjacency for routing purposes. The SDRs rely on the OSPF underlying network for reachability to other SDR routers.

SDRs advertise a directory of producers and consumers of services and are capable to compute preferred producers. The SDRs delegate data

exchange processing to remote SDRs to an external agent. The implementation detail of the agent is outside the scope of this document.

The OSPF Opaque LSAs is used to carry relevant and interesting information for reachability and nature of SDR capable routers.

In order to limit the service data dissemination costs (storage, bandwidth, security, ..), SDRs may store only limited data of interest.



The OSPF Service Distribution Router

The following sections describe the extensions in OSPF protocol to support this capability.

6. Storage Of Service Data

The service data can be stored in an independent Service Data Database(SDD). There is no assumption made here on the size, format or nature of data. The data can be stored on the disk of the router and accessible by APIs to OSPF and other applications for query and

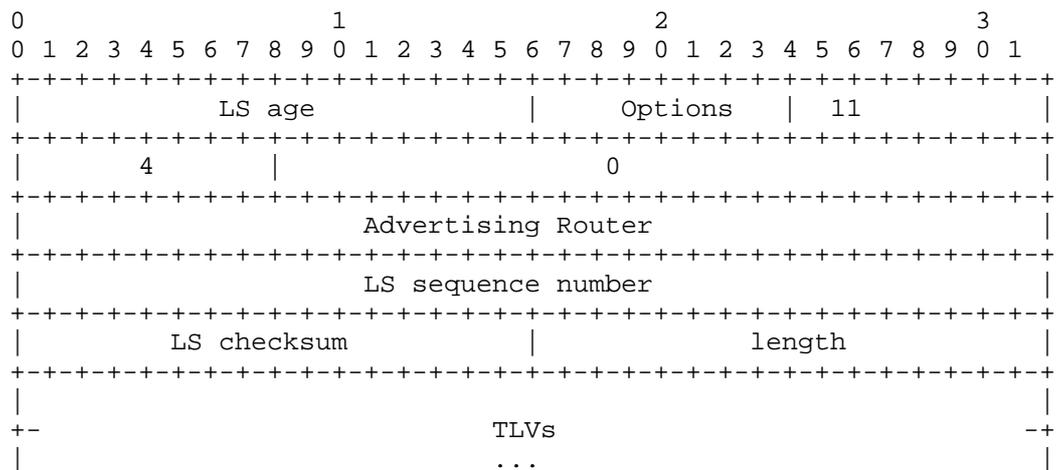
update or an external storage outside the router. A SDD is not part of OSPF and does not participate in the bringing up of adjacencies. The SDD may be accessible through APIs to outside applications such as an SDN controller.

It is desirable that the service data databases have a very flexible format to cater for a broad range of applications. The service data may be secured and encrypted with authenticated access to outside applications as well. The scope of how to implement this database is outside the scope of this document.

7. Mechanics of the OSPF Service Information Distribution Implementation

7.1. Advertising and Signaling of SDR Capability

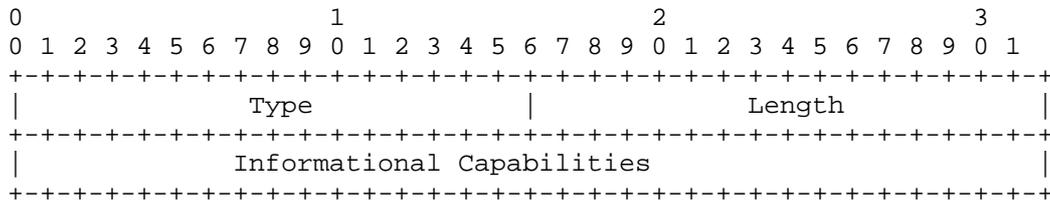
The OSPF SDR router will identify itself to the rest of the domain by advertising its capability and a routable ip address. For example, this address MAY be a loopback interface configured to uniquely identify an OSPF SDR router. A new bit for SDR capability is reserved in the Router Information Capabilities TLV of the Router Information LSA, as defined in section 2.1 of [RFC7770].



The OSPF Router Information LSA

Flooding scope for AS 11

The format of the Router Information Capabilities TLV is defined in sections 2.3, 2.4 and 2.5 of [RFC7770]



The Router Informational Capabilities TLV

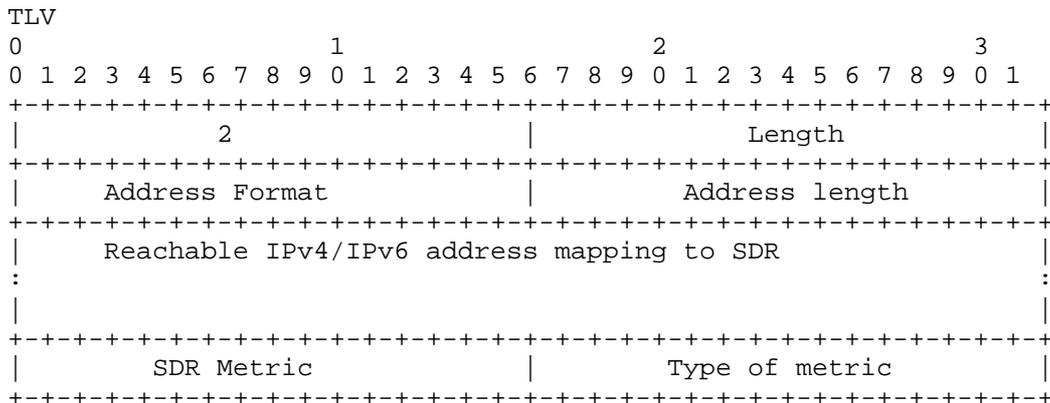
A new informational capability bit is defined for Service Distribution Routers

Bit Capabilities

6 Service Distribution Router Capability

7.2. Advertising the Service Distribution Router and its address mapping

A new TLV is defined in the Router Information LSA is used to advertise a resolvable router ID or routable address to reach the router.



Service router TLV and address Mapping

Type: A 16-bit field set to 2 representing the Service Distribution Router Address Mapping This TLV is applicable both to OSPFv2 and OSPFv3.

Length: A 16-bit field that indicates the length of the value portion in octets.

Address Format: A 16-bit field that indicates the length of the value portion in octets.

Possible values

1 : IPv4 Address

2 : IPv6 Address

Address Length: A 16-bit field that indicates the length of the value portion in octets.

Address : Routable IPv4/IPv6 address mapped to SDR

SDR metric: A 16-bit field that indicates SDR metric greater than 0.

Type of metric:

0 : None defined - Ignore SDR Metric

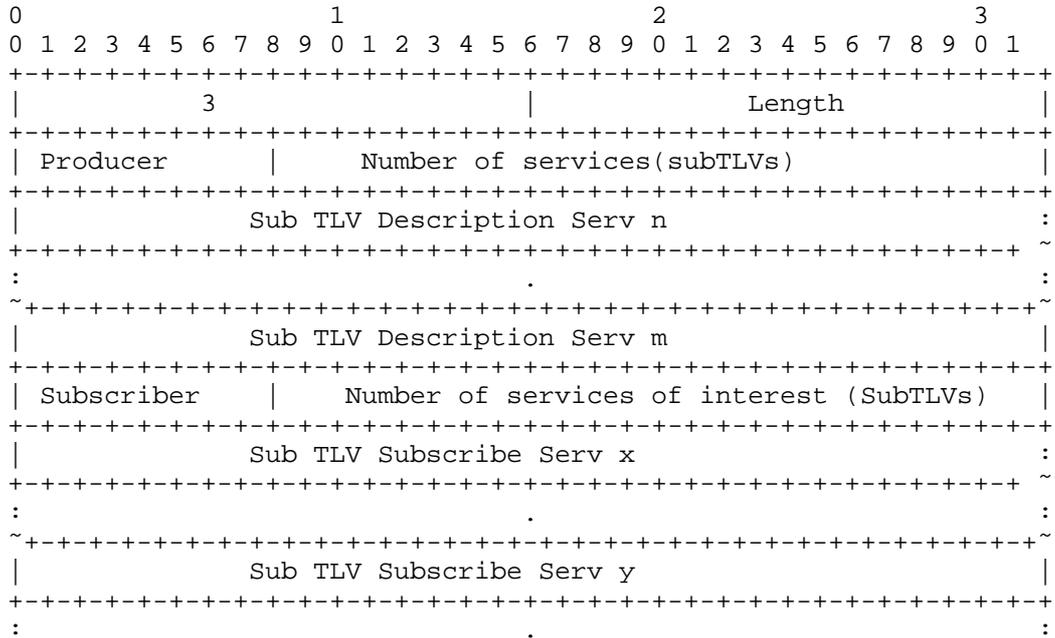
1 : SDR metric overrides the IGP metric

2 : Computed metric is composite of IGP metric + SDR metric

7.3. Advertising the Directory of Producers and Consumers

Opaque LSAs with autonomous system flooding scope as described in [RFC5250], are used to describe the services reachable through this router using TLVs.

Definition of TLV

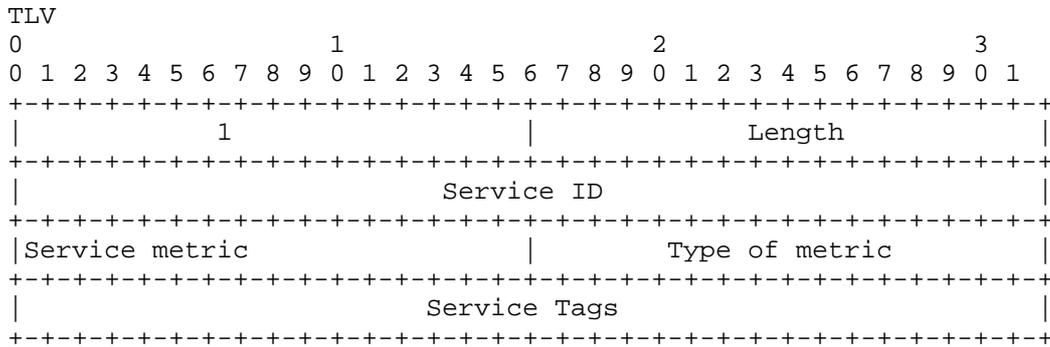


Example of TLV for Directory of Producers and Subscribers

Type: A 16-bit field set to 3 representing the Directory of the Service Distribution Router. This TLV is applicable both to OSPFv2 and OSPFv3.

Length: A 16-bit field that indicates the length of the value portion in octets.

Services are described in a unique sub-TLV. The sub-TLV should contain a Service Identifier which uniquely identifies the service with network wide significance. The sub-TLV format should be flexible and it MAY be used to advertise a preference metric for the service.



Service Description Sub-TLV

Type: A 16-bit field set to 1 representing the Service Description Sub-TLV This TLV is applicable both to OSPFv2 and OSPFv3.

Length: A 16-bit field that indicates the length of the value portion in octets.

Service ID: A 32-bit field representing the Service Identifier. This TLV is applicable both to OSPFv2 and OSPFv3.

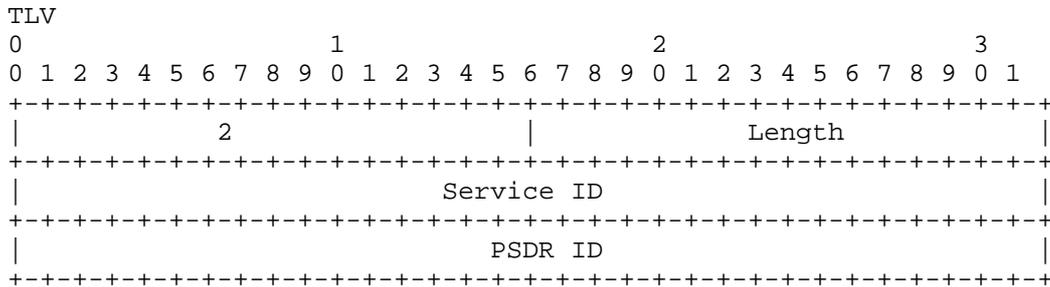
Service Metric: A 16-bit field that indicates the metric associated with the service. A metric of 0 would represent undefined. An unreachable or oversubscribed service has a metric of 0xFFFFFFFF.

Type of metric:

- 0 : None defined - Ignore Service Metric
- 1 : Service metric overrides the IGP/SDR metric
- 2 : Computed metric is composite of IGP metric + SDR metric + Service metric

Service Tags: A 32-bit field representing the Service Tags. Service tags may be used for policy purposes. This TLV is applicable both to OSPFv2 and OSPFv3.

The Services of interest (Consumers exist) are described in a unique sub-TLV. The sub-TLV should contain a Service Identifier which uniquely identifies the service with network wide significance. The sub-TLV format should be flexible and MUST contained the preferred SDR ID. If no producer exists yet for the service then the Preferred SDR ID should be set to 0.



Service Subscription Sub-TLV

Type: A 16-bit field set to 2 representing the Service Subscription Sub-TLV This TLV is applicable both to OSPFv2 and OSPFv3.

Length: A 16-bit field that indicates the length of the value portion in octets.

Service ID: A 32-bit field representing the Service Identifier. A Service Identifier may only be defined in a unique sub-tlv. This TLV is applicable both to OSPFv2 and OSPFv3.

PSDR ID: A 32-bit field that indicates the PSDR for data exchange. Set to 0 if there is no producer for the service.

The topological view and characteristics of the OSPF Overlay Service Distribution Routers can be used to compute preferred producer independent of IGP metrics. It is possible to have multiple LSAs for large directories however a service must be described in a unique sub-tlv for the SDR.

7.4. Service Routing Capable Router Operations

The additional requirements are

- No assumption on topology
- Multiple producers may exists
- Multiple consumers can all have different service interest
- Producers/Consumers may join and leave at anytime
- Consumers and Producers have access to the Service Data database

The SDR capable routers advertise the consumers who subscribe to a service. The producers may connect to the SDR router to update the services/data in the Service Data database. The SDR router then builds the Opaque LSA describing the producer services which are reachable through it as well as the services its consumers are interested in.

When the router has a full neighbor relationship, it now has the topological view of all SDR capable routers in the domain as well as the services they offer and are interested in.

Leveraging the fact that the OSPF has already run its SPF, the reachability of overlay SDR capable routers and services offered. It is possible to calculate the preferred Producer SDR for a service by using a composite of the IGP metric, the SDR metric and the service metric. The list of preferred producers for a service can then be evaluated at each SDR.

The list of Consumer SDRs interested in service can also easily be computed from the directory of consumers.

7.4.1. Operation due to Producer changes

The producer service operations are

- New producer advertises a service

- Existing Producer start advertising a new service

- Existing Producer stops advertising a service.

The router will be notified by the application regarding the new producer and the services offered. The router will then either update or create an Opaque LSA to advertise this new information and flood it to all SR routers.

Upon receiving this information, remote SDR routers can recalculate the preferred PSDR. It may also need to perform some operations if it has consumers for this new service.

7.4.2. Operation due to Consumer changes

The consumer service operations are

- A new consumer join and add subscription

- An existing consumer stops subscriptions

An existing consumer adds subscriptions

The router will be notified by the application regarding the new consumer and the services it is interested in. The router will then either update or create an Opaque LSA to advertise this new information and flood it to all SDR routers.

Upon receipt of the new Opaque LSA the remote SDR routers can then update the list of CSDRs interested in their services per latest information.

8. Calculation of Optimal Producer

Leveraging OSPF capability to store and compute paths on a topology, the same mechanisms can be used to compute the Optimal PSDRs using the SPF for SDR reachable address using IGP metrics, SDR metric and the service metric. The Optimal PSDR is used in the consumer subtlv.

9. Service Router Data Operations

OSPF SDR delegates the task of SDD distribution to the Data Exchange Agent. This text defines an implementation of such an agent and named it the Service Data Distribution Agent (SDDA). OSPF SDR provides SDDA information about which Consumer SDR is interested which service provided by this OSPF (Producer) SDR. The SDDA makes use of such information to setup distribution channel for SDD distribution from this OSPF Producer SDR to other OSPF Consumer SDRs.

For each OSPF Consumer SDR which subscribes to at least one service provided by this OSPF Producer SDR, there will be a different distribution channel created.

The distribution channel is setup when the OSPF Consumer SDR has subscribed to its first service provided by this OSPF Producer SDR. When the OSPF Consumer SDR subscribes to additional service provided by this OSPF Producer SDR, service data for the new service will be carried over the existing distribution channel. In other words, the same distribution channel can carry service data for different services. The services carried are said to be bound to the distribution channel.

When a distribution channel is first setup for a service or a new service is bound to the channel, the SDDA will notify the SDD. In turn, the SDD will send the latest data for that service to the SDDA for distribution over that channel.

On the other hand, whenever the SDD has new version of data for a service, the SDD will send those data to the SDDA, which will

distribute the new data to all the distribution channels which carry the service.

9.1. Implementation of SDDA

The SDDA implementation is beyond the scope of this document.

10. Security Considerations

The new extensions defined in this document do not introduce any new security concerns other than those already defined in Section 6 of [RFC2328] and [RFC5340].

11. IANA Considerations

11.1. Service Distribution Router Capability bit

This draft requests IANA to assign the bit 6 for Service Distribution Router Capability in the OSPF Router Informational Capabilities Bits.

11.2. Service ID Registry

The Service ID registries has been defined

Range	Assignment Policy
0	Reserved (not to be assigned)
1-32767	Unassigned (Standards Action)
32768-65535	Experimentation (No assignments)
65536..	Reserved

Service ID Assignments

12. Contributors

The authors would like to acknowledge the contributions of Mike Dubroskiy, Rashmi Shrivastava and Jean-Michel Esnault in the early draft of this document.

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OSPFv2 Link Traffic Engineering (TE) Attribute Reuse
draft-ppsenak-ospf-te-link-attr-reuse-05.txt

Abstract

Various link attributes have been defined in OSPFv2 in the context of the MPLS Traffic Engineering (TE) and GMPLS. Many of these link attributes can be used for purposes other than MPLS Traffic Engineering or GMPLS. This document defines how to distribute such attributes in OSPFv2 for applications other than MPLS Traffic Engineering or GMPLS purposes.

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1. Introduction

Various link attributes have been defined in OSPFv2 [RFC2328] in the context of the MPLS traffic engineering and GMPLS. All these attributes are distributed by OSPFv2 as sub-TLVs of the Link-TLV advertised in the OSPFv2 TE Opaque LSA [RFC3630].

Many of these link attributes are useful outside of the traditional MPLS Traffic Engineering or GMPLS. This brings its own set of problems, in particular how to distribute these link attributes in OSPFv2 when MPLS TE or GMPLS are not deployed or are deployed in parallel with other applications that use these link attributes.

[RFC7855] discusses use cases/requirements for SR. Included among these use cases is SRTE. If both RSVP-TE and SRTE are deployed in a network, link attribute advertisements can be used by one or both of these applications. As there is no requirement for the link attributes advertised on a given link used by SRTE to be identical to the link attributes advertised on that same link used by RSVP-TE, there is a clear requirement to indicate independently which link attribute advertisements are to be used by each application.

As the number of applications which may wish to utilize link attributes may grow in the future, an additional requirement is that the extensions defined allow the association of additional applications to link attributes without altering the format of the advertisements or introducing new backwards compatibility issues.

Finally, there may still be many cases where a single attribute value can be shared among multiple applications, so the solution should minimize advertising duplicate link/attribute when possible.

1.1. Requirements notation

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Link attributes examples

This section lists some of the link attributes originally defined for MPLS Traffic Engineering that can be used for other purposes in OSPFv2. The list doesn't necessarily contain all the required attributes.

1. Remote Interface IP address [RFC3630] - OSPFv2 currently cannot distinguish between parallel links between two OSPFv2 routers. As a result, the two-way connectivity check performed during SPF

may succeed when the two routers disagree on which of the links to use for data traffic.

2. Link Local/Remote Identifiers - [RFC4203] - Used for the two-way connectivity check for parallel unnumbered links. Also used for identifying adjacencies for unnumbered links in Segment Routing traffic engineering.
 3. Shared Risk Link Group (SRLG) [RFC4203] - In IPFRR, the SRLG is used to compute diverse backup paths [RFC5714].
 4. Unidirectional Link Delay/Loss Metrics [RFC7471] - Could be used for the shortest path first (SPF) computation using alternate metrics within an OSPF area.
3. Advertising Link Attributes

This section outlines possible approaches for advertising link attributes originally defined for MPLS Traffic Engineering purposes or GMPLS when they are used for other applications.

3.1. TE Opaque LSA

One approach for advertising link attributes is to continue to use TE Opaque LSA ([RFC3630]). There are several problems with this approach:

1. Whenever the link is advertised in a TE Opaque LSA, the link becomes a part of the TE topology, which may not match IP routed topology. By making the link part of the TE topology, remote nodes may mistakenly believe that the link is available for MPLS TE or GMPLS, when, in fact, MPLS is not enabled on the link.
2. The TE Opaque LSA carries link attributes that are not used or required by MPLS TE or GMPLS. There is no mechanism in a TE Opaque LSA to indicate which of the link attributes are passed to MPLS TE application and which are used by other applications including OSPFv2 itself.
3. Link attributes used for non-TE purposes are partitioned across multiple LSAs - the TE Opaque LSA and the Extended Link Opaque LSA. This partitioning will require implementations to lookup multiple LSAs to extract link attributes for a single link, bringing needless complexity to OSPFv2 implementations.

The advantage of this approach is that there is no additional standardization requirement to advertise the TE/GMPL attributes for other applications. Additionally, link attributes are only

advertised once when both OSPF TE and other applications are deployed on the same link. This is not expected to be a common deployment scenario.

3.2. Extended Link Opaque LSA

An alternative approach for advertising link attributes is to use Extended Link Opaque LSAs as defined in [RFC7684]. This LSA was defined as a generic container for distribution of the extended link attributes. There are several advantages in using Extended Link LSA:

1. Advertisement of the link attributes does not make the link part of the TE topology. It avoids any conflicts and is fully compatible with the [RFC3630].
2. The TE Opaque LSA remains truly opaque to OSPFv2 as originally defined in [RFC3630]. Its content is not inspected by OSPFv2 and OSPFv2 acts as a pure transport.
3. There is clear distinction between link attributes used by TE and link attributes used by other OSPFv2 applications.
4. All link attributes that are used by OSPFv2 applications are advertised in a single LSA, the Extended Link Opaque LSA.

The disadvantage of this approach is that in rare cases, the same link attribute is advertised in both the TE Opaque and Extended Link Attribute LSAs. Additionally, there will be additional standardization effort. However, this could also be viewed as an advantage as the non-TE use cases for the TE link attributes are documented and validated by the OSPF working group.

3.3. Selected Approach

It is RECOMMENDED to use the Extended Link Opaque LSA ([RFC7684] to advertise any link attributes used for non-TE purposes in OSPFv2, including those that have been originally defined for TE purposes. TE link attributes used for TE purposes continue to use TE Opaque LSA ([RFC3630]).

It is also RECOMMENDED to keep the format of the link attribute TLVs that have been defined for TE purposes unchanged even when they are used for non-TE purposes.

Finally, it is RECOMMENDED to allocate unique code points for link attribute TLVs that have been defined for TE purposes for the OSPFv2 Extended Link TLV Sub-TLV Registry as defined in [RFC7684]. For each

reused TLV, the code point will be defined in an IETF document along with the expected usecase(s).

4. Reused TE link attributes

This section defines the use case and code points for the OSPFv2 Extended Link TLV Sub-TLV Registry for some of the link attributes that have been originally defined for TE or GMPLS purposes.

4.1. Remote interface IP address

The OSPFv2 description of an IP numbered point-to-point adjacency does not include the remote IP address. As described in Section 2, this makes the two-way connectivity check ambiguous in the presence of the parallel point-to-point links between two OSPFv2 routers.

The Remote IP address of the link can also be used for Segment Routing traffic engineering to identify the link in a set of parallel links between two OSPFv2 routers [I-D.ietf-ospf-segment-routing-extensions]. Similarly, the remote IP address is useful in identifying individual parallel OSPF links advertised in BGP Link-State as described in [I-D.ietf-idr-ls-distribution].

To advertise the Remote interface IP address in the OSPFv2 Extended Link TLV, the same format of the sub-TLV as defined in section 2.5.4. of [RFC3630] is used and TLV type TBD1 is used.

4.2. Link Local/Remote Identifiers

The OSPFv2 description of an IP unnumbered point-to-point adjacency does not include the remote link identifier. As described in Section 2, this makes the two-way connectivity check ambiguous in the presence of the parallel point-to-point IP unnumbered links between two OSPFv2 routers.

The local and remote link identifiers can also be used for Segment Routing traffic engineering to identify the link in a set of parallel IP unnumbered links between two OSPFv2 routers [I-D.ietf-ospf-segment-routing-extensions]. Similarly, these identifiers are useful in identifying individual parallel OSPF links advertised in BGP Link-State as described in [I-D.ietf-idr-ls-distribution].

To advertise the link Local/Remote identifiers in the OSPFv2 Extended Link TLV, the same format of the sub-TLV as defined in section 1.1. of [RFC4203] is used and TLV type TBD2 is used.

4.3. Shared Risk Link Group (SRLG)

The SRLG of a link can be used in IPFRR to compute a backup path that does not share any SRLG group with the protected link.

To advertise the SRLG of the link in the OSPFv2 Extended Link TLV, the same format of the sub-TLV as defined in section 1.3. of [RFC4203] is used and TLV type TBD3 is used.

4.4. Extended Metrics

[RFC3630] defines several link bandwidth types. [RFC7471] defines extended link metrics that are based on link bandwidth, delay and loss characteristics. All these can be used to compute best paths within an OSPF area to satisfy requirements for bandwidth, delay (nominal or worst case) or loss.

To advertise extended link metrics in the OSPFv2 Extended Link TLV, the same format of the sub-TLVs as defined in [RFC7471] is used with following TLV types:

- TBD4 - Unidirectional Link Delay
- TBD5 - Min/Max Unidirectional Link Delay
- TBD6 - Unidirectional Delay Variation
- TBD7 - Unidirectional Link Loss
- TBD8 - Unidirectional Residual Bandwidth
- TBD9 - Unidirectional Available Bandwidth
- TBD10 - Unidirectional Utilized Bandwidth

5. Advertisement of Application Specific Values

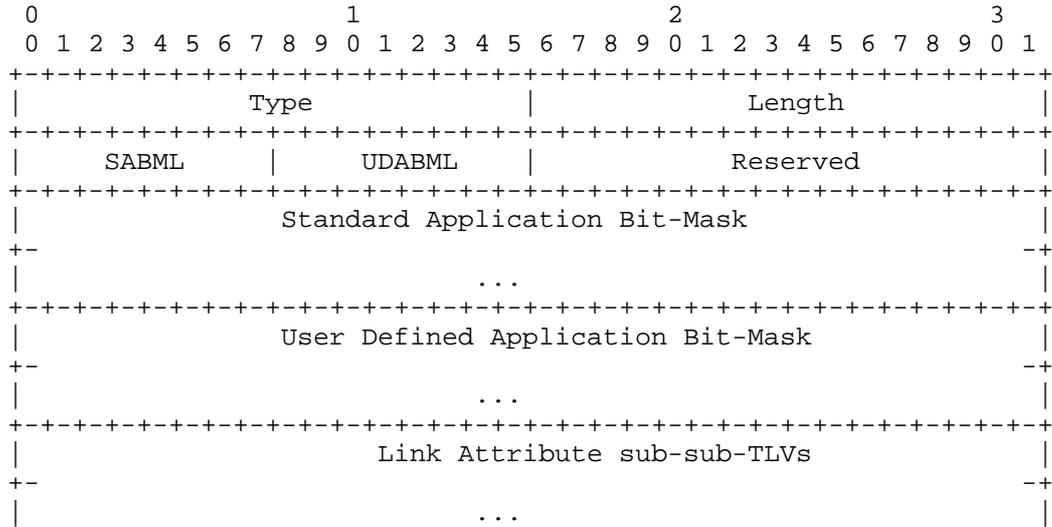
Multiple applications can utilize link attributes that are flooded by OSPFv2. Some examples of applications using the link attributes are Segment Routing Traffic Engineering and LFA [RFC5286].

In some cases the link attribute only has a single value that is applicable to all applications. An example is a Remote interface IP address [Section 4.1] or Link Local/Remote Identifiers [Section 4.2].

In some cases the link attribute MAY have different values for different applications. An example could be SRLG [Section 4.3],

where values used by LFA could be different then the values used by Segment Routing Traffic Engineering.

To allow advertisement of the application specific values of the link attribute, a new Extended Link Attribute sub-TLV of the Extended Link TLV [RFC7471] is defined. The Extended Link Attribute sub-TLV is an optional sub-TLV and can appear multiple times in the Extended Link TLV. It has following format:



where:

Type: TBD11, suggested value 14

Length: variable

SABML: Standard Application Bit-Mask Length. If the Standard Application Bit-Mask is not present, the Standard Application Bit-Mask Length MUST be set to 0.

UDABML: User Defined Application Bit-Mask Length. If the User Defined Application Bit-Mask is not present, the User Defined Application Bit-Mask Length MUST be set to 0.

Standard Application Bit-Mask: Optional set of bits, where each bit represents a single standard application. The following bits are defined by this document:

Bit-0: RSVP Traffic Engineering

Bit-1: Segment Routing Traffic Engineering

Bit-2: Loop Free Alternate (LFA). Includes all LFA types.

User Defined Application Bit-Mask: Optional set of bits, where each bit represents a single user defined application.

Standard Application Bits are defined/sent starting with Bit 0. Additional bit definitions that may be defined in the future SHOULD be assigned in ascending bit order so as to minimize the number of octets that will need to be transmitted.

User Defined Application bits have no relationship to Standard Application bits and are NOT managed by IANA or any other standards body. It is recommended that bits are used starting with Bit 0 so as to minimize the number of octets required to advertise all of them.

Undefined bits in both Bit-Masks MUST be transmitted as 0 and MUST be ignored on receipt. Bits that are NOT transmitted MUST be treated as if they are set to 0 on receipt.

If the link attribute advertisement is limited to be used by a specific set of applications, corresponding Bit-Masks MUST be present and application specific bit(s) MUST be set for all applications that use the link attributes advertised in the Extended Link Attribute sub-TLV.

Application Bit-Masks apply to all link attributes that support application specific values and are advertised in the Extended Link Attribute sub-TLV.

The advantage of not making the Application Bit-Masks part of the attribute advertisement itself is that we can keep the format of the link attributes that have been defined previously and reuse the same format when advertising them in the Extended Link Attribute sub-TLV.

If the link attribute is advertised and there is no Application Bit-Mask present in the Extended Link Attribute Sub-TLV, the link attribute advertisement MAY be used by any application. If, however, another advertisement of the same link attribute includes any Application Bit-Mask in the Extended Link Attribute sub-TLV, applications that are listed in the Application Bit-Masks of such Extended Link Attribute sub-TLV SHOULD use the attribute advertisement which has the application specific bit set in the Application Bit-Masks.

If the same application is listed in the Application Bit-Masks of more than one Extended Link Attribute sub-TLV, the application SHOULD

use the first advertisement and ignore any subsequent advertisements of the same attribute. This situation SHOULD be logged as an error.

This document defines the set of link attributes for which the Application Bit-Masks may be advertised. If any of the Application Bit-Masks is included in the Extended Link Attribute sub-TLV that advertises any link attribute(s) NOT listed below, the Application Bit-Masks MUST NOT be used for such link attribute(s). It MUST be used for those attribute(s) that support application specific values. Documents which define new link attributes MUST state whether the new attributes support application specific values. The link attributes to which the Application Bit-Masks may apply are:

- Shared Risk Link Group
- Unidirectional Link Delay
- Min/Max Unidirectional Link Delay
- Unidirectional Delay Variation
- Unidirectional Link Loss
- Unidirectional Residual Bandwidth
- Unidirectional Available Bandwidth
- Unidirectional Utilized Bandwidth

6. Deployment Considerations

If link attributes are advertised associated with zero length application bit masks for both standard applications and user defined applications, then that set of link attributes MAY be used by any application. If support for a new application is introduced on any node in a network in the presence of such advertisements, these advertisements MAY be used by the new application. If this is not what is intended, then existing advertisements MUST be readvertised with an explicit set of applications specified before a new application is introduced.

7. Attribute Advertisements and Enablement

This document defines extensions to support the advertisement of application specific link attributes. The presence or absence of link attribute advertisements for a given application on a link does NOT indicate the state of enablement of that application on that

link. Enablement of an application on a link is controlled by other means.

For some applications, the concept of enablement is implicit. For example, SRTE implicitly is enabled on all links which are part of the Segment Routing enabled topology. Advertisement of link attributes supports constraints which may be applied when specifying an explicit path through that topology.

For other applications enablement is controlled by local configuration. For example, use of a link as an LFA can be controlled by local enablement/disablement and/or the use of administrative tags.

It is an application specific policy as to whether a given link can be used by that application even in the absence of any application specific link attributes.

8. Backward Compatibility

Link attributes may be concurrently advertised in both the TE Opaque LSA [RFC3630] and the Extended Link Opaque LSA [RFC7684].

In fact, there is at least one OSPF implementation that utilizes the link attributes advertised in TE Opaque LSAs [RFC3630] for Non-RSVP TE applications. For example, this implementation of LFA and remote LFA utilizes links attributes such as Shared Risk Link Groups (SRLG) [RFC4203] and Admin Group [[RFC3630]advertised in TE Opaque LSAs. These applications are described in [RFC5286], [RFC7490], [I-D.ietf-rtgwg-lfa-manageability] and [I-D.psarkar-rtgwg-rlfa-node-protection].

When an OSPF routing domain includes routers using link attributes from TE Opaque LSAs for Non-RSVP TE applications such as LFA, OSPF routers in that domain should continue to advertise such TE Opaque LSAs. If there are also OSPF routers using the link attributes described herein for any application, OSPF routers in the routing domain will also need to advertise these attributes in OSPF Extended Link Attributes LSAs [RFC7684]. In such a deployment, the advertised attributes SHOULD be the same and Non-RSVP application access to link attributes is a matter of local policy.

9. Security Considerations

Implementations must assure that malformed TLV and Sub-TLV permutations do not result in errors that cause hard OSPFv2 failures.

10. IANA Considerations

OSPFv2 Extended Link TLV Sub-TLVs registry [RFC7684] defines sub-TLVs at any level of nesting for OSPFv2 Extended Link TLVs. This specification updates OSPFv2 Extended Link TLV sub-TLVs registry with the following TLV types:

- TBD1 (4 Recommended) - Remote interface IP address
- TBD2 (5 Recommended) - Link Local/Remote Identifiers
- TBD3 (6 Recommended) - Shared Risk Link Group
- TBD4 (7 Recommended) - Unidirectional Link Delay
- TBD5 (8 Recommended) - Min/Max Unidirectional Link Delay
- TBD6 (9 Recommended) - Unidirectional Delay Variation
- TBD7 (10 Recommended) - Unidirectional Link Loss
- TBD8 (11 Recommended) - Unidirectional Residual Bandwidth
- TBD9 (12 Recommended) - Unidirectional Available Bandwidth
- TBD10 (13 Recommended) - Unidirectional Utilized Bandwidth
- TBD11 (14 Recommended) - Extended Link Attribute

This specification defines a new Link-Attribute-Applicability Application Bits registry and defines following bits:

- Bit-0 - Segment Routing Traffic Engineering
- Bit-1 - LFA

11. Acknowledgments

Thanks to Chris Bowers for his review and comments.

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OSPF Routing with Cross-Address Family MPLS Traffic Engineering Tunnels
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Abstract

When using Traffic Engineering (TE) in a dual-stack IPv4/IPv6 network the Multiprotocol Label Switching (MPLS) TE Label Switched Paths (LSP) infrastructure may be duplicated, even if the destination IPv4 and IPv6 addresses belong to the same remote router. In order to achieve an integrated MPLS TE LSP infrastructure, OSPF routes must be computed over MPLS TE tunnels created using information propagated in another OSPF instance. This is solved by advertising cross-address family (X-AF) OSPF TE information.

This document describes an update to RFC5786 that allows for the easy identification of a router's local X-AF IP addresses.

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1. Introduction

TE Extensions to OSPFv2 [RFC3630] and to OSPFv3 [RFC5329] have been described to support intra-area TE in IPv4 and IPv6 networks, respectively. In both cases the TE database provides a tight coupling between the routed protocol and TE signaling information in it. In other words, any use of the TE link state database is limited to IPv4 for OSPFv2 [RFC2328] and IPv6 for OSPFv3 [RFC5340].

In a dual stack network it may be desirable to set up common MPLS TE LSPs to carry traffic destined to addresses from different address families on a router. The use of common LSPs eases potential scalability and management concerns by halving the number of LSPs in the network. Besides, it allows operators to group traffic based on business characteristics and/or applications or class of service, not constrained by the network protocol which carries it.

For example, an LSP created based on MPLS TE information propagated by OSPFv2 instance can be defined to carry both IPv4 and IPv6 traffic, instead of having both OSPFv2 and OSPFv3 to provision a separate LSP for each address family. Even if in some cases the address family-specific traffic is to be separated, the calculation from a common database may prove operationally beneficial.

A requirement when creating a common MPLS TE infrastructure is the ability to reliably map the X-AF family addresses to the

corresponding advertising tail-end router. This mapping is a challenge because the LSAs containing the routing information are carried in one OSPF instance while the TE calculation may be done using a TE database from a different instance.

A simple solution to this problem is to rely on the Router ID to identify a node in the corresponding OSPFv2 and OSPFv3 databases. This solution would mandate both instances on the same router to be configured with the same Router ID. However, relying on the correctness of the configuration puts additional burden on network management and adds cost to the operation of the network. The network becomes even more difficult to manage if OSPFv2 and OSPFv3 topologies do not match exactly, for example if area borders are drawn differently in the two protocols. Also, if the routing processes do fall out of sync (having different Router IDs, even if for local administrative reasons), there is no defined way for other routers to discover such misalignment and to take any corrective measures (such as to avoid routing through affected TE tunnels or issuing warning to network management). The use of misaligned router IDs may result in delivering the traffic to the wrong tail-end router, which could lead to suboptimal routing or even traffic loops.

This document describes an update to [RFC5786] that allows for the easy identification of a router's local X-AF IP addresses. Routers using the Node Attribute TLV [RFC5786] can include non-TE enabled interface addresses in their OSPF TE advertisements, and also use the same sub-TLVs to carry X-AF information, facilitating the mapping mentioned above.

The method described in this document can also be used to compute X-AF mapping of egress LSR for sub-LSPs of a Point-to-Multipoint LSP (see [RFC4461]). Considerations of using Point-to-Multipoint MPLS TE for X-AF traffic forwarding is outside the scope of this specification.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Operation

[RFC5786] defined the Node IPv4 Local Address and Node IPv6 Local Address sub-TLVs of the Node Attribute TLV for a router to advertise additional local IPv4 and IPv6 addresses. To solve the problem outlined in [RFC5786] OSPFv2 would advertise and use only IPv4 addresses and OSPFv3 would advertise and use only IPv6 addresses.

This document updates [RFC5786] so that a router can also announce one or more local X-AF addresses using the corresponding Local Address sub-TLV. In other words, to implement the X-AF routing technique proposed in this document, OSPFv2 will advertise the Node IPv6 Local Address sub-TLV and OSPFv3 will advertise the Node IPv4 Local Address sub-TLV, possibly in addition to advertising other IP addresses as documented by [RFC5786].

A node that implements X-AF routing SHOULD advertise in the corresponding Node Local Address sub-TLV all X-AF IP addresses local to the router that can be used by Constrained SPF (CSPF) to calculate MPLS TE LSPs. In general, OSPF SHOULD advertise the IP address listed in the Router Address TLV of the X-AF instance maintaining MPLS TE database plus any additional local addresses advertised by the X-AF OSPF instance in its Node Local Address sub-TLV. Implementation MAY advertise other local X-AF addresses.

If the Node Attribute TLV carries both the Node IPv4 Local Address sub-TLV and the Node IPv6 Local Address sub-TLV, then the X-AF component must be considered for the consolidated calculation of MPLS TE LSPs. Both instances may carry the required information, it is left to local configuration to determine which database is used.

On Area Border Routers (ABR), each advertised X-AF IP address MUST be advertised into at most one area. If OSPFv2 and OSPFv3 area borders match (i.e. for each interface area number for OSPFv2 and OSPFv3 instances is numerically equal), then the X-AF addresses MUST be advertised into the same area in both instances. This allows other ABRs connected to the same set of areas to know with which area to associate MPLS TE tunnels.

During the X-AF routing calculation, X-AF IP addresses are used to map locally created LSPs to tail-end routers in the LSDB. The mapping algorithm can be described as:

Walk the list of all MPLS TE tunnels for which the computing router is a head-end. For each MPLS TE tunnel T:

1. If T's destination IP address is from the same address family as the computing OSPF instance, then the tunnel must have been signaled based on MPLS TE information propagated in the same OSPF instance. Process the tunnel as per [RFC3630] or [RFC5329].
2. Otherwise it is a X-AF MPLS TE tunnel. Note tunnel's destination IP address.
3. Walk the X-AF IP addresses in the LSDBs of all connected areas. If a matching IP address is found, advertised by router R in area

A, then mark the tunnel T as belonging to area A and terminating on tail-end router R. Assign an intra-area SPF cost to reach router R within area A as the IGP cost of tunnel T.

After completing this calculation, each TE tunnel is associated with an area and tail-end router in terms of the routing LSDB of the computing OSPF instance and has a metric.

Note that for clarity of description the mapping algorithm is specified as a single calculation. Actual implementations for the efficiency may choose to support equivalent mapping functionality without implementing the algorithm exactly as it is described.

As an example lets consider a router in dual-stack network running OSPFv2 and OSPFv3 for IPv4 and IPv6 routing correspondingly. Suppose OSPFv2 instance is used to propagate MPLS TE information and the router is configured to accept TE LSPs terminating at local addresses 198.51.100.1 and 198.51.100.2. Then the router will advertise into OSPFv2 instance IPv4 address 198.51.100.1 in the Router Address TLV, additional local IPv4 address 198.51.100.2 in the Node IPv4 Local Address sub-TLV, plus other Traffic Engineering TLVs as required by [RFC3630]. If OSPFv3 instance in the network is enabled for X-AF TE routing (that is, to use for IPv6 routing MPLS TE LSPs computed by OSPFv2), then the OSPFv3 instance of the router will advertise the Node IPv4 Local Address sub-TLV listing local IPv4 addresses 198.51.100.1 and 198.51.100.2. Other routers in the OSPFv3 network will use this information to reliably identify this router as egress LSR for MPLS TE LSPs terminating at either 198.51.100.1 or 198.51.100.2.

4. Backward Compatibility

Node Attribute TLV and Node Local Address sub-TLVs and their usage are defined in [RFC5786] and updated by [RFC6827]. Way of using these TLVs as specified in this document is fully backward compatible with previous standard documents.

An implementation processing Node Attribute TLV MUST interpret its content as follows:

- o If the Node Attribute TLV contains Local TE Router ID sub-TLV then this Node Attribute TLV MUST be treated as carrying routing information for ASON (Automatically Switched Optical Network) and processed as specified in [RFC6827].
- o Otherwise Node Attribute TLV contains one or more instance(s) of Node IPv4 Local Address and/or Node IPv6 Local Address sub-TLVs.

Meaning of each Local Address sub-TLV has to be identified separately.

- * If Node Local Address sub-TLV belongs to the same address family as instance of OSPF protocol advertising it then address carried in the sub-TLV MUST be treated as described in [RFC5786].
- * Otherwise the address is used for X-AF tunnel tail-end mapping as defined by this document.

5. Security Considerations

This document introduces no new security concerns. Security considerations of using Node Attribute TLV are discussed in [RFC5786].

6. IANA Considerations

This document has no IANA actions.

7. Acknowledgements

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8. References

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