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OSPFv3 Extensions for SRv6
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Abstract

The Segment Routing (SR) architecture allows a flexible definition of the end-to-end path by encoding it as a sequence of topological elements called "segments". It can be implemented over an MPLS or IPv6 data plane. This document describes the OSPFv3 extensions required to support Segment Routing over the IPv6 data plane (SRv6).

Table of Contents

1. Introduction

Segment Routing (SR) architecture [RFC8402] specifies how a node can steer a packet through an ordered list of instructions, called segments. These segments are identified through Segment Identifiers (SIDs).

Segment Routing can be instantiated on the IPv6 data plane through the use of the Segment Routing Header (SRH) defined in [RFC8754]. SRv6 refers to this SR instantiation on the IPv6 dataplane.

The network programming paradigm for SRv6 is specified in [RFC8986]. It describes how any behavior can be bound to a SID and how any network program can be expressed as a combination of SIDs. It also describes several well-known behaviors that can be bound to SRv6 SIDs.

This document specifies OSPFv3 extensions to support SRv6 as defined in [RFC8986]. The extensions include advertisement of an OSPFv3 router's SRv6 capabilities, SRv6 Locators, and required SRv6 SIDs along with their supported endpoint behaviors. Familiarity with [RFC8986] is necessary to understand the extensions specified in this document.

At a high level, the extensions to OSPFv3 are comprised of the following:

1. An SRv6 Capabilities TLV to advertise the SRv6 features and SRH operations supported by an OSPFv3 router

2. Several new sub-TLVs are defined to advertise various SRv6 Maximum SID Depths.

3. An SRv6 Locator TLV to advertise the SRv6 Locator - a form of summary address for the algorithm-specific SIDs instantiated on an OSPFv3 router

4. TLVs and Sub-TLVs to advertise the SRv6 SIDs instantiated on an OSPFv3 router along with their endpoint behaviors

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.

2. SRv6 Capabilities TLV

The SRv6 Capabilities TLV is used by an OSPFv3 router to advertise its support for the SR Segment Endpoint Node [RFC8754] functionality along with its SRv6-related capabilities. This is an optional top level TLV of the OSPFv3 Router Information LSA [RFC7770] which MUST be advertised by an SRv6-enabled router.

This TLV SHOULD be advertised only once in the OSPFv3 Router Information LSA. When multiple SRv6 Capabilities TLVs are received from a given router, the receiver MUST use the first occurrence of the TLV in the OSPFv3 Router Information LSA. If the SRv6 Capabilities TLV appears in multiple OSPFv3 Router Information LSAs that have different flooding scopes, the TLV in the OSPFv3 Router Information LSA with the area-scoped flooding scope MUST be used. If the SRv6 Capabilities TLV appears in multiple OSPFv3 Router Information LSAs that have the same flooding scope, the TLV in the OSPFv3 Router Information LSA with the numerically smallest Instance ID MUST be used and subsequent instances of the TLV MUST be ignored.

The OSPFv3 Router Information LSA can be advertised at any of the defined flooding scopes (link, area, or Autonomous System (AS)). For the purpose of SRv6 Capabilities TLV advertisement, area-scoped flooding is REQUIRED.

The format of OSPFv3 SRv6 Capabilities TLV is shown below:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |               Type            |          Length               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |             Flags             |           Reserved            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Sub-TLVs...
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: SRv6 Capabilities TLV

Where:

- o Type: 2-octet field. The value for this type is 20.

- o Length: 2-octet field. The total length (in octets) of the value portion of the TLV including nested Sub-TLVs.

- o Reserved: 2-octet field. It MUST be set to 0 on transmission and MUST be ignored on receipt.

- o Flags: 2-octet field. The flags are defined as follows:

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| |O|                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

* O-flag: If set, then the router is capable of supporting the O-bit in the SRH flags, as specified in [RFC9259].

* Other flags are not defined and reserved for future use. They MUST be set to 0 on transmission and MUST be ignored on receipt.

The SRv6 Capabilities TLV may contain optional Sub-TLVs. No Sub-TLVs are defined in this specification.

3. Advertisement of Supported Algorithms

An SRv6-enabled OSPFv3 router advertises its algorithm support using the SR Algorithm TLV defined in [RFC8665] as described in [RFC8666].

4. Advertisement of SRH Operation Limits

An SRv6-enabled router may have different capabilities and limits when it comes to SRH processing and this needs to be advertised to other OSPFv3 routers in the SRv6 domain.

[RFC8476] defines the means to advertise node and link specific values for Maximum SID Depth (MSD) types. Node MSDs are advertised using the Node MSD TLV in the OSPFv3 Router Information LSA [RFC7770] while Link MSDs are advertised using the Link MSD Sub-TLV of the Router-Link TLV [RFC8362]. The format of the MSD types for OSPFv3 is defined in [RFC8476].

The MSD types for SRv6 that are defined in section 4 of [I-D.ietf-lsr-isis-srv6-extensions] for IS-IS are also used by OSPFv3. These MSD Types are allocated under the IGP MSD Types registry maintained by IANA that are shared by IS-IS and OSPF. They are described below:

4.1. Maximum Segments Left MSD Type

The Maximum Segments Left MSD Type signals the maximum value of the "Segments Left" field of the SRH of a received packet before applying the Endpoint behavior associated with a SID. If no value is advertised, the supported value is assumed to be 0.

4.2. Maximum End Pop MSD Type

The Maximum End Pop MSD Type signals the maximum number of SIDs in the SRH to which the router can apply "Penultimate Segment Pop (PSP) of the SRH" or "Ultimate Segment Pop (USP) of the SRH", as defined in [RFC8986] flavors. If the advertised value is zero or no value is advertised, then the router cannot apply PSP or USP flavors.

4.3. Maximum H.Encaps MSD Type

The Maximum H.Encaps MSD Type signals the maximum number of SIDs that can be added as part of the "H.Encaps" behavior as defined in [RFC8986]. If the advertised value is zero or no value is advertised then the headend can apply an SR Policy that only contains one segment, without inserting any SRH. A non-zero SRH Max H.encaps MSD indicates that the headend can insert an SRH with SIDs up to the advertised value.

4.4. Maximum End D MSD Type

The Maximum End D MSD Type specifies the maximum number of SIDs present in an SRH when performing decapsulation. These includes, but not limited to, End.DX6, End.DT4, End.DT46, End with USD, End.X with USD as defined in [RFC8986]. If the advertised value is zero or no value is advertised, then the router cannot apply any behavior that results in decapsulation and forwarding of the inner packet when the outer IPv6 header contains an SRH.

5. SRv6 SIDs and Reachability

An SRv6 Segment Identifier (SID) is 128 bits and consists of Locator, Function, and Argument parts as described in [RFC8986].

An OSPFv3 router is provisioned with algorithm-specific locators for each algorithm supported by that router. Each locator is a covering prefix for all SIDs provisioned on that router which have the matching algorithm.

Locators MUST be advertised in the SRv6 Locator TLV (see Section 6.1). Forwarding entries for the locators advertised in the SRv6 Locator TLV MUST be installed in the forwarding plane of receiving SRv6-capable routers when the associated algorithm is supported by the receiving OSPFv3 router. Locators can be of different route types similar to existing OSPFv3 route types - Intra-Area, Inter-Area, External, and NSSA. The processing of the prefix advertised in the SRv6 Locator TLV, the calculation of its reachability, and the installation in the forwarding plane follows the OSPFv3 [RFC5340] specifications for the respective route types.

Locators associated with algorithms 0 and 1 SHOULD be advertised using the respective OSPFv3 Extended LSA types with extended TLVs [RFC8362] so that routers that do not support SRv6 will install a forwarding entry for SRv6 traffic matching those locators. When operating in Extended LSA sparse-mode [RFC8362], these locators SHOULD be also advertised using the respective legacy OSPFv3 LSAs [RFC5340].

In cases where a locator advertisement is received both in a prefix reachability advertisement (i.e., via legacy OSPFv3 LSAs and/or Extended Prefix TLVs using OSPFv3 Extended LSAs) and an SRv6 Locator TLV, the prefix reachability advertisement in the OSPFv3 legacy LSA or Extended LSA MUST be preferred over the advertisement in the SRv6 Locator TLV when installing entries in the forwarding plane. This is to prevent inconsistent forwarding entries between SRv6 capable and SRv6 incapable OSPFv3 routers. Such preference of prefix reachability advertisement does not have any impact on the rest of the data advertised in the SRv6 Locator TLV.

SRv6 SIDs are advertised as Sub-TLVs in the SRv6 Locator TLV except for SRv6 End.X SIDs/LAN End.X SIDs which are associated with a specific Neighbor/Link and are therefore advertised as Sub-TLVs of E-Router-Link TLV.

SRv6 SIDs received from other OSFPv3 routers are not directly routable and MUST NOT be installed in the forwarding plane. Reachability to SRv6 SIDs depends upon the existence of a covering locator.

Adherence to the rules defined in this section will assure that SRv6 SIDs associated with a supported algorithm will be forwarded correctly, while SRv6 SIDs associated with an unsupported algorithm will be dropped. NOTE: The drop behavior depends on the absence of a default/summary route matching the locator prefix.

For forwarding to work correctly, the locator associated with SRv6 SID advertisements must be the longest prefix match installed in the forwarding plane for those SIDs. To ensure correct forwarding, network operators should take steps to make sure that this requirement is not compromised. For example, the following situations should be avoided:

- Another locator associated with a different topology/algorithm is the longest prefix match

- Another prefix advertised via OSPFv3 legacy or Extended LSA advertisement is the longest prefix match

5.1. SRv6 Flexible Algorithm

[I-D.ietf-lsr-flex-algo] specifies IGP Flexible Algorithm mechanisms for OSPFv3. Section 14.2 of [I-D.ietf-lsr-flex-algo] explains SRv6 forwarding for Flex-Algorithm and the same applies to supporting SRv6 Flex-Algorithm using OSPFv3. When the algorithm value that is advertised in the SRv6 Locator TLV (refer to Section 6.1) represents a Flex-Algorithm, the procedures described in section 14.2 of [I-D.ietf-lsr-flex-algo] are followed for the programming of those specific SRv6 Locators. Locators associated with Flexible Algorithms SHOULD NOT be advertised in the base OSPFv3 prefix reachability advertisements. Advertising the Flexible Algorithm locator in a regular prefix reachability advertisement would make them available for non-Flex-Algo forwarding (i.e., algorithm 0).

The procedures for OSPFv3 Flex-Algorithm for SR-MPLS, as specified in [I-D.ietf-lsr-flex-algo], like ASBR reachability, inter-area, external, and NSSA prefix advertisements and their use in Flex-Algorithm route computation also apply for SRv6.

6. SRv6 Locator LSA

The SRv6 Locator LSA has a function code of TBD while the S1/S2 bits are dependent on the desired flooding scope for the LSA. The flooding scope of the SRv6 Locator LSA depends on the scope of the advertised SRv6 Locator and is under the control of the advertising router. The U bit will be set indicating that the LSA should be flooded even if it is not understood.

Multiple SRv6 Locator LSAs can be advertised by an OSPFv3 router and they are distinguished by their Link State IDs (which are chosen arbitrarily by the originating router).

The format of SRv6 Locator LSA is shown below:

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            LS age             |1|S12|   Function Code         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       Link State ID                           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       Advertising Router                      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       LS sequence number                      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |        LS checksum            |             Length            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                               |
    +-                            TLVs                             -+
    |                             ...                               |
```

Figure 2: SRv6 Locator LSA

The format of the TLVs within the body of the SRv6 Locator LSA is the same as the format used by [RFC3630]. The variable TLV section consists of one or more nested TLV tuples. Nested TLVs are also referred to as Sub-TLVs. The format of each TLV is:

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |              Type             |             Length            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                            Value                              |
                                   o
                                   o
                                   o
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: SRv6 Locator LSA TLV Format

The Length field defines the length of the value portion in octets (thus, a TLV with no value portion would have a length of 0). The TLV is padded to 4-octet alignment; padding is not included in the Length field (so a 3-octet value would have a length of 3, but the total size of the TLV would be 8 octets). Nested TLVs are also 32-bit aligned. For example, a 1-byte value would have the Length field set to 1 and 3 octets of padding would be added to the end of the value portion of the TLV. The padding is composed of zeros.

6.1. SRv6 Locator TLV

The SRv6 Locator TLV is a top-level TLV of the SRv6 Locator LSA that is used to advertise an SRv6 Locator, its attributes, and SIDs associated with it. Multiple SRv6 Locator TLVs MAY be advertised in each SRv6 Locator LSA. However, since the S12 bits define the flooding scope, the LSA flooding scope MUST satisfy the application-specific requirements for all the locators included in a single SRv6 Locator LSA.

When multiple SRv6 Locator TLVs are received from a given router in an SRv6 Locator LSA for the same Locator, the receiver MUST use the first occurrence of the TLV in the LSA. If the SRv6 Locator TLV for the same Locator appears in multiple SRv6 Locator LSAs that have different flooding scopes, the TLV in the SRv6 Locator LSA with the area-scoped flooding scope MUST be used. If the SRv6 Locator TLV for the same Locator appears in multiple SRv6 Locator LSAs that have the same flooding scope, the TLV in the SRv6 Locator LSA with the numerically smallest Link-State ID MUST be used and subsequent instances of the TLV MUST be ignored.

The format of SRv6 Locator TLV is shown below:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |              Type             |              Length           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Route Type   |  Algorithm    | Locator Length|    Flags      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                              Metric                           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Locator (128 bits) ...                                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Locator continued ...                                       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Locator continued ...                                       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Locator continued ...                                       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      Sub-TLVs (variable)                      |
 +-                                                             -+
 |                             ...                               |
```

Figure 4: SRv6 Locator TLV

Where:

Type: 2-octet field. The value for this type is 1.

Length: 2-octet field. The total length (in octets) of the value portion of the TLV including nested Sub-TLVs.

Route Type: 1-octet field. The type of the locator route. The only supported types are the ones listed below and the SRv6 Locator TLV MUST be ignored on receipt of any other type.

```
1 - Intra-Area
2 - Inter-Area
3 - AS External Type 1
4 - AS External Type 2
5 - NSSA External Type 1
6 - NSSA External Type 2
```

Algorithm: 1-octet field. The algorithm associated with the SRv6 Locator. Algorithm values are defined in the IGP Algorithm Type registry.

Locator Length: 1-octet field. Carries the length of the Locator prefix as the number of locator bits from the range (1-128).

Flags: 1-octet field. The flags are defined as follows:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|N|A| Reserved  |
+-+-+-+-+-+-+-+-+
```

* N-flag: When the locator uniquely identifies a router node in the network (i.e., it is provisioned on one and only one router), the N bit MUST be set. Otherwise, this bit MUST be clear.

* A-flag: When the Locator is configured as anycast, the A bit SHOULD be set. Otherwise, this bit MUST be clear. If both the N and A bits are set, then receiving routers MUST ignore the N bit (i.e., consider it as not set).

* Other flags are not defined and reserved for future use. They MUST be set to 0 on transmission and MUST be ignored on receipt.

Metric: 4-octet field. The metric value associated with the SRv6 Locator.

Locator: 16-octet field. This field encodes the advertised SRv6 Locator.

Sub-TLVs: Used to advertise Sub-TLVs that provide additional attributes for the given SRv6 Locator and SRv6 SIDs associated with the SRv6 Locator.

7. Advertisement of SRv6 End SIDs

The SRv6 End SID Sub-TLV is a Sub-TLV of the SRv6 Locator TLV in the SRv6 Locator LSA (defined in Section 6). It is used to advertise the SRv6 SIDs belonging to the router along with their associated endpoint behaviors. SIDs associated with adjacencies are advertised as described in Section 8. Every SRv6-enabled OSPFv3 router SHOULD advertise at least one SRv6 SID associated with an END behavior for itself as specified in [RFC8986].

SRv6 End SIDs inherit the algorithm from the parent locator. The SRv6 End SID MUST be allocated from its associated locator. SRv6 End SIDs that are NOT allocated from the associated locator MUST be ignored.

The router MAY advertise multiple instances of the SRv6 End SID Sub-TLV within the SRv6 Locator TLV - one for each of the SRv6 SIDs to be advertised. When multiple SRv6 End SID Sub-TLVs are received in the SRv6 Locator TLV from a given router for the same SRv6 SID value, the receiver MUST use the first occurrence of the Sub-TLV in the SRv6 Locator TLV.

The format of SRv6 End SID Sub-TLV is shown below

```
      0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |               Type            |          Length               |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |     Flags     |   Reserved    |        Endpoint Behavior      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |   SID (128 bits) ...                                          |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |   SID continued ...                                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |   SID continued ...                                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |   SID continued ...                                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |   Sub-TLVs (variable) . . .
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: SRv6 End SID Sub-TLV

Where:

Type: 2-octet field. The value for this type is 1.

Length: 2-octet field. The total length (in octets) of the value portion of the Sub-TLV including its further nested Sub-TLVs.

Reserved: 1-octet field. It MUST be set to 0 on transmission and MUST be ignored on receipt.

Flags: 1-octet field. It carries the flags associated with the SID. No flags are currently defined and this field MUST be set to 0 on transmission and MUST be ignored on receipt.

Endpoint Behavior: 2 octets field. The endpoint behavior code point for this SRv6 SID as defined in [RFC8986]. Supported behavior values for this sub-TLV are defined in Section 10 of this document. Unsupported or unrecognized behavior values are ignored by the receiver.

SID: 16-octet field. This field encodes the advertised SRv6 SID.

Sub-TLVs: Used to advertise Sub-TLVs that provide additional attributes for the given SRv6 SID.

8. Advertisement of SRv6 SIDs Associated with Adjacencies

The SRv6 endpoint behaviors defined in [RFC8986] include certain behaviors that are specific to links or adjacencies. The most basic of these which is critical for link-state routing protocols like OSPFv3 is the End.X behavior that is an instruction to forward to a specific neighbor on a specific link. These SRv6 SIDs and others that are defined in [RFC8986] which are specific to links or adjacencies need to be advertised to OSPFv3 routers within an area to steer SRv6 traffic over a specific link or adjacency.

The advertisement of SRv6 SIDs that are specific to a particular neighbor is accomplished via two different optional Sub-TLVs of the E-Router-Link TLV defined in [RFC8362]:

- o SRv6 End.X SID Sub-TLV: Used for OSPFv3 adjacencies over point-to-point or point-to-multipoint links and for the adjacency to the Designated Router (DR) over broadcast and Non-Broadcast-Multi-Access (NBMA) links.

- o SRv6 LAN End.X SID Sub-TLV: Used for OSPFv3 adjacencies on broadcast and NBMA links to the Backup DR and DR-Other neighbors. This Sub-TLV includes the OSPFv3 Router-ID of the neighbor and thus allows for an instance of this Sub-TLV for each neighbor to be explicitly advertised as a Sub-TLV of the E-Router-Link TLV for the same link.

Every SRv6 enabled OSPFv3 router SHOULD instantiate at least one unique SRv6 End.X SID corresponding to each of its neighbors. A router MAY instantiate more than one SRv6 End.X SID for a single neighbor. The same SRv6 End.X SID MAY be advertised for more than one neighbor. Thus multiple instances of the SRv6 End.X SID and SRv6 LAN End.X SID Sub-TLVs MAY be advertised within the E-Router-Link TLV for a single link.

All End.X and LAN End.X SIDs MUST be subsumed by the subnet of a Locator with the matching algorithm which is advertised by the same OSPFv3 router in an SRv6 Locator TLV. End.X SIDs which do not meet this requirement MUST be ignored. This ensures that the OSPFv3 router advertising the End.X or LAN End.X SID is also advertising its corresponding Locator with the algorithm that will be used for computing paths destined to the SID.

8.1. SRv6 End.X SID Sub-TLV

The format of the SRv6 End.X SID Sub-TLV is shown below

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Type            |          Length               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Endpoint Behavior      |     Flags     |   Reserved1   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Algorithm   |    Weight     |            Reserved2          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID (128 bits) ...                                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID continued ...                                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID continued ...                                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID continued ...                                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Sub-TLVs (variable) . . .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: SRv6 End.X SID Sub-TLV

Where:

Type: 2-octet field. The value for this type is 31.

Length: 2-octet field. The total length (in octets) of the value portion of the Sub-TLV including its further nested Sub-TLVs.

Endpoint Behavior: 2-octet field. The endpoint behavior code point for this SRv6 SID as defined in [RFC8986]. Supported behavior values for this sub-TLV are defined in Section 10 of this document. Unsupported or unrecognized behavior values are ignored by the receiver.

Flags: 1-octet field. The flags are defined as follows:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|B|S|P| Reserved|
+-+-+-+-+-+-+-+-+
```

* B-Flag: Backup Flag. If set, the SID refers to a path that is eligible for protection.

* S-Flag: Set Flag. When set, the S-Flag indicates that the End.X SID refers to a set of adjacencies (and therefore MAY be assigned to other adjacencies as well).

* P-Flag: Persistent Flag: If set, the SID is persistently allocated, i.e., the SID value remains consistent across router restart and session/interface flap.

* Other flags are not defined and reserved for future use. They MUST be set to 0 on transmission and MUST be ignored on receipt.

Reserved1: 1-octet field. It MUST be set to 0 on transmission and MUST be ignored on receipt.

Algorithm: 1-octet field. The algorithm associated with the SRv6 Locator from which the SID is allocated. Algorithm values are defined in the IGP Algorithm Type registry.

Weight: 1-octet field. Its value represents the weight of the End.X SID for load-balancing. The use of the weight is defined in [RFC8402].

Reserved2: 2-octet field. It MUST be set to 0 on transmission and MUST be ignored on receipt.

SID: 16-octet field. This field encodes the advertised SRv6 SID.

Sub-TLVs: Used to advertise Sub-TLVs that provide additional attributes for the given SRv6 End.X SID.

8.2. SRv6 LAN End.X SID Sub-TLV

The format of the SRv6 LAN End.X SID Sub-TLV is as shown below:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Type            |          Length               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Endpoint Behavior        |     Flags     |   Reserved1   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Algorithm   |    Weight     |           Reserved2           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    OSPFv3 Router-ID of neighbor                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID (128 bits) ...                                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID continued ...                                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID continued ...                                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   SID continued ...                                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Sub-TLVs (variable) . . .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7: SRv6 LAN End.X SID Sub-TLV

Where:

o Type: 2-octet field. The value for this type is 32.

o Length: 2-octet field. The total length (in octets) of the value portion of the Sub-TLV including its further nested Sub-TLVs.

o Endpoint Behavior: 2-octet field. The code point for the endpoint behavior for this SRv6 SID as defined in section 9.2 of [RFC8986].

o Flags: 1-octet field. The flags are defined as follows:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|B|S|P| Reserved|
+-+-+-+-+-+-+-+-+
```

* B-Flag: Backup Flag. If set, the SID refers to a path that is eligible for protection.

  * S-Flag: Set Flag. When set, the S-Flag indicates that the End.X SID refers to a set of adjacencies (and therefore MAY be assigned to other adjacencies as well).

  * P-Flag: Persistent Flag: If set, the SID is persistently allocated, i.e., the SID value remains consistent across router restart and session/interface flap.

  * Other flags are not defined and reserved for future use. They MUST be set to 0 on transmission and MUST be ignored on receipt.

o Reserved1: 1-octet field. It MUST be set to 0 on transmission and MUST be ignored on receipt.

o Algorithm: 1-octet field. The algorithm associated with the SRv6 Locator from which the SID is allocated. Algorithm values are defined in the IGP Algorithm Type registry.

o Weight: 1-octet field. Its value represents the weight of the End.X SID for load balancing. The use of the weight is defined in [RFC8402].

o Reserved2: 2-octet field. It MUST be set to 0 on transmission and MUST be ignored on receipt.

o Neighbor ID: 4-octet field. It carries the OSPFv3 Router-id of the neighbor.

o SID: 16-octet field. This field encodes the advertised SRv6 SID.

o Sub-TLVs: Used to advertise Sub-TLVs that provide additional attributes for the given SRv6 SID.

9. SRv6 SID Structure Sub-TLV

SRv6 SID Structure Sub-TLV is used to advertise the structure of the SRv6 SID as defined in [RFC8986]. It is used as an optional Sub-TLV of the following:

o SRv6 End SID Sub-TLV (refer to Section 7)

o SRv6 End.X SID Sub-TLV (refer to Section 8.1)

o SRv6 LAN End.X SID Sub-TLV (refer to Section 8.2)

The Sub-TLV has the following format:

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |               Type            |          Length               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    LB Length  |  LN Length    | Fun. Length   |  Arg. Length  |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 8: SRv6 SID Structure Sub-TLV

Where:

Type: 2-octet field. The value for this type is 30.

Length: 2-octet field. It carries the value of 4.

LB Length: 1-octet field. SRv6 SID Locator Block length in bits.

LN Length: 1-octet bit field. SRv6 SID Locator Node length in bits.

Function Length: 1-octet field. SRv6 SID Function length in bits.

Argument Length: 1-octet field. SRv6 SID Argument length in bits.

The SRv6 SID Structure Sub-TLV MUST NOT appear more than once in its parent Sub-TLV. If it appears more than once in its parent Sub-TLV, the parent Sub-TLV MUST be ignored by the receiver.

The sum of all four sizes advertised in SRv6 SID Structure Sub-TLV MUST be less than or equal to 128 bits. If the sum of all four sizes advertised in the SRv6 SID Structure Sub-TLV is larger than 128 bits, the parent TLV/Sub-TLV MUST be ignored by the receiver.

The SRv6 SID Structure Sub-TLV is intended for informational use by the control and management planes. It MUST NOT be used at a transit node (as defined in [RFC8754]) for forwarding packets. As an example, this information could be used for:

o validation of SRv6 SIDs being instantiated in the network and advertised via OSPFv3. These can be learned by controllers via BGP-LS and then be monitored for conformance to the SRv6 SID allocation scheme chosen by the operator as described in Section 3.2 of [RFC8986].

- o verification and the automation for securing the SRv6 domain by provisioning filtering rules at SR domain boundaries as described in Section 5 of [RFC8754].

The details of these potential applications are outside the scope of this document.

10. Advertising Endpoint Behaviors

Endpoint behaviors are defined in [RFC8986]. The codepoints for the Endpoint behaviors are defined in the "SRv6 Endpoint Behaviors" registry of [RFC8986]. This section lists the Endpoint behaviors and their codepoints, which MAY be advertised by OSPFv3 and the Sub-TLVs in which each type MAY appear.

Endpoint Behavior	Endpoint Behavior Codepoint	End SID	End.X SID	LAN End.X SID
End (PSP, USP, USD)	1-4, 28-31	Y	N	N
End.X (PSP, USP, USD)	5-8, 32-35	N	Y	Y
End.DX6	16	N	Y	Y
End.DX4	17	N	Y	Y
End.DT6	18	Y	N	N
End.DT4	19	Y	N	N
End.DT64	20	Y	N	N

Figure 9: SRv6 Endpoint Behaviors in OSPFv3

11. Security Considerations

Existing security extensions as described in [RFC5340] and [RFC8362] apply to these SRv6 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 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.

This document describes the OSPFv3 extensions required to support Segment Routing over an IPv6 data plane. The security considerations for Segment Routing are discussed in [RFC8402]. [RFC8986] defines the SRv6 Network Programming concept and specifies the main Segment Routing behaviors to enable the creation of interoperable overlays; the security considerations from that document apply too.

The advertisement for an incorrect MSD value may have negative consequences, see [RFC8476] for additional considerations.

Security concerns associated with the setting of the O-flag are described in [RFC9259].

Security concerns associated with the usage of Flex-Algorithms are described in [I-D.ietf-lsr-flex-algo].

12. IANA Considerations

This document requests IANA to perform allocations from OSPF and OSPFv3 related registries as well as creating of new registries as follows.

12.1. OSPF Router Information TLVs

IANA has allocated a code point via early allocation process in the "OSPF Router Information (RI) TLVs" registry under the "OSPF Parameters" registry for the new TLV below that needs to be made permanent:

Type 20: SRv6-Capabilities TLV: Refer to Section 2.

12.2. OSPFv3 LSA Function Codes

IANA has allocated a code point via early allocation process in the "OSPFv3 LSA Function Codes" registry under the "OSPFv3 Parameters" registry for the new LSA below that needs to be made permanent:

- o Type 42: SRv6 Locator LSA: Refer to Section 6.

12.3. OSPFv3 Extended-LSA Sub-TLVs

IANA has allocated the following code points in via early allocation process in the "OSPFv3 Extended-LSA Sub-TLVs" registry under the "OSPFv3 Parameters" registry for the new Sub-TLVs below that need to be made permanent:

- Type 30: SRv6 SID Structure Sub-TLV: Refer to Section 9.
- Type 31: SRv6 End.X SID Sub-TLV: Refer to Section 8.1.
- Type 32: SRv6 LAN End.X SID Sub-TLV: Refer to Section 8.2.

12.4. OSPFv3 Locator LSA TLVs

This document requests the creation of an "OSPFv3 Locator LSA TLVs" registry, that defines top-level TLVs for the OSPFv3 SRv6 Locator LSA, under the "OSPFv3 Parameters" registry. The initial code-points assignment is as below:

- Type 0: Reserved.
- Type 1: SRv6 Locator TLV: Refer to Section 6.1.

Types in the range 2-32767 are allocated via IETF Review or IESG Approval [RFC8126].

Types in the range 32768-33023 are Reserved for Experimental Use; these will not be registered with IANA and MUST NOT be mentioned by RFCs.

Types in the range 33024-45055 are to be assigned on a First Come First Served (FCFS) basis.

Types in the range 45056-65535 are not to be assigned at this time. Before any assignments can be made in the 33024-65535 range, there MUST be an IETF specification that specifies IANA Considerations that cover the range being assigned.

12.5. OSPFv3 Locator LSA Sub-TLVs

This document requests the creation of an "OSPFv3 Locator LSA Sub-TLVs" registry, that defines Sub-TLVs at any level of nesting for the SRv6 Locator LSA, to be added under the "OSPFv3 Parameters" registry. The initial code-points assignment is as below:

- Type 0: Reserved.

o Type 1: SRv6 End SID Sub-TLV: Refer to Section 7.

o Type 10: SRv6 SID Structure Sub-TLV: Refer to Section 9.

Types in the range 2-9 and 11-32767 are allocated via IETF Review or IESG Approval [RFC8126].

Types in the range 32768-33023 are Reserved for Experimental Use; these will not be registered with IANA and MUST NOT be mentioned by RFCs.

Types in the range 33024-45055 are to be assigned on a First Come First Served (FCFS) basis.

Types in the range 45056-65535 are not to be assigned at this time. Before any assignments can be made in the 33024-65535 range, there MUST be an IETF specification that specifies IANA Considerations that cover the range being assigned.

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