OSPF 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 OSPF 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 RFC 2119 [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. For example, 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 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
   [I-D.filsfils-spring-segment-routing-use-cases].

2. Segment Routing Identifiers

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

   For the purpose of the advertisements of various SID values, new
   Opaque LSAs [RFC5250] are defined in [RFC7684]. These LSAs are
   generic containers that can be used to advertise any additional
   attributes associated with a prefix or link. These Opaque LSAs are

complementary to the existing LSAs and are not aimed to replace any
of the existing LSAs.

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 TLV has
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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      SID/Label (variable)                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

   Type: TBD, suggested value 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 SID/Label Sub-TLV if the length
   is other then 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]).

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 Sub-TLV is optional. It MAY only be advertised once
in the Router Information Opaque LSA. If the SID/Label Range TLV, as
defined in Section 3.2, is advertised, then the SR-Algorithm TLV MUST

also be advertised. If the SR-Algorithm TLV is not advertised by the
node, such node is considered as not being segment routing capable.

An SR Router may 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:

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Algorithm 1 | Algorithm...  |   Algorithm n |               |
+-                                                             -+
|                                                               |
+                                                               +
```

where:

   Type: TBD, suggested value 8

   Length: variable

   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 Sub-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.

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 scope flooding is required.

3.2. **SID/Label Range TLV**

   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:

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Range Size                 |    Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Sub-TLVs (variable)                      |
+-                                                             -+
|                                                               |
+                                                               +
```
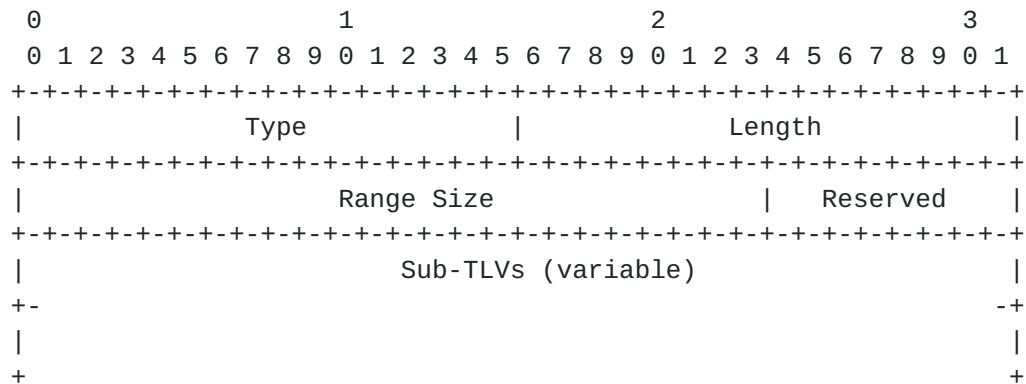
   where:

      Type: TBD, suggested value 9

      Length: variable

      Range Size: 3 octets of the SID/label range

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

   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.

The following example illustrates the advertisement of multiple
ranges:

    The originating router advertises following ranges:
        Range 1: [100, 199]
        Range 2: [1000, 1099]
        Range 3: [500, 599]

    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 scope flooding is required.

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.filsfils-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 new 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:

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Prefix Length |      AF       |          Range Size           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags      |              Reserved                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Address Prefix (variable)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Sub-TLVs (variable)                       |
+-                                                             -+
|                                                               |
```

where:

   Type: TBD, suggested value 2.

   Length: Variable

   Prefix length: Length of the prefix

   AF: 0 - IPv4 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 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. The 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 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.

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.

Address Prefix: The prefix, encoded as an even multiple of 32-bit
words, padded with zero bits as necessary. This encoding consumes
((PrefixLength + 31) / 32) 32-bit words. The Address Prefix
represents the first prefix in the prefix range.

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:

```
 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    |     MT-ID     |   Algorithm   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   SID/Index/Label (variable)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

Type: TBD, suggested value 2.

Length: Variable

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

```
  0  1  2  3  4  5  6  7
+--+--+--+--+--+--+--+--+
|  |NP|M |E |V |L |  |  |
+--+--+--+--+--+--+--+--+
```

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.filsfils-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.

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.

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

A 32-bit index defining the offset in the SID/Label space
advertised by this router.

A 24-bit label where the 20 rightmost bits are used for
encoding the label value.

If multiple Prefix-SIDs are advertised for the same prefix, the
receiving router MUST use the first encoded SID and MAY use the
subsequent SIDs.

When propagating Prefix-SIDs between areas, if multiple prefix-SIDs
are advertised for a prefix, an implementation SHOULD preserve the
original order when advertising prefix-SIDs to other areas. This
allows implementations that only support a single Prefix-SID to have
a consistent view across areas.

When calculating the outgoing label for the prefix, the router MUST take into account the E and P 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 for Prefix-SIDs allocated to inter-area prefixes that are originated by the ABR based on intra-area or inter-area reachability between areas. When the inter-area prefix is generated based on a prefix which is directly attached to the ABR, the NP-Flag SHOULD NOT be set.

The NP-Flag (No-PHP) MUST be be set for the Prefix-SIDs allocated to redistributed prefixes, unless the redistributed prefix is directly attached to the ASBR, in which case the NP-flag SHOULD NOT be set.

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. In such case, MPLS EXP bits of the Prefix-SID are not preserved for the final destination (the Prefix-SID being removed). 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 must 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 may safely 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 the 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 the 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 Prefix SID Sub-TLV is interpreted as a starting SID 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:

```
        10.1.1/24, Prefix-SID: Index 51
        10.1.2/24, Prefix-SID: Index 52
        10.1.3/24, Prefix-SID: Index 53
        10.1.4/24, Prefix-SID: Index 54
        10.1.5/24, Prefix-SID: Index 55
        10.1.6/24, Prefix-SID: Index 56
        10.1.7/24, Prefix-SID: Index 57
```

then the Prefix field in the Extended Prefix Range TLV would be set to 10.1.1.0, Prefix Length would be set to 24, Range Size would be 7, and the Index value in the Prefix-SID Sub-TLV would be set to 51.

6. SID/Label Binding Sub-TLV

   The SID/Label Binding Sub-TLV is used to advertise a SID/Label
   mapping for a path to the prefix.

   The SID/Label Binding Sub-TLV MAY be originated by any router in an
   OSPF domain. The router may advertise a SID/Label binding to a FEC
   along with at least a single 'nexthop style' anchor. The protocol
   supports more than one 'nexthop style' anchor to be attached to a
   SID/Label binding, which results in a simple path description
   language. In analogy to RSVP, the terminology for this is called an
   'Explicit Route Object' (ERO). Since ERO style path notation allows
   anchoring SID/label bindings to both link and node IP addresses, any
   Label Switched Path (LSP) can be described. Additionally, SID/Label
   Bindings from external protocols can be easily re-advertised.

   The SID/Label Binding Sub-TLV may be used for advertising SID/Label
   Bindings and their associated Primary and Backup paths. In a single
   TLV, a primary ERO Path, backup ERO Path, or both can be advertised.
   If a router wants to advertise multiple parallel paths, then it can
   generate several TLVs for the same Prefix/FEC. Each occurrence of a
   Binding TLV for a given FEC Prefix will add a new path.

   The SID/Label Binding 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. Multiple SID/Label Binding TLVs can be
   present in their parent TLV. The SID/Label Binding Sub-TLV has
   following format:
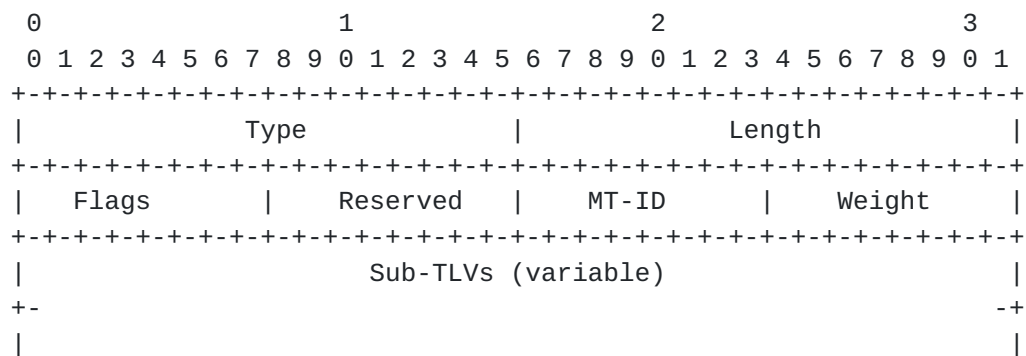
```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type              |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Flags       |   Reserved    |    MT-ID      |    Weight     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Sub-TLVs (variable)                       |
+-                                                             -+
|                                                               |
```

   where:

      Type: TBD, suggested value 3

      Length: Variable

      Flags: Single octet field containing the following flags:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|M|             |
+-+-+-+-+-+-+-+-+
```

where:

M-bit - When the bit is set, the binding represents a mirroring context as defined in [I-D.minto-rsvp-lsp-egress-fast-protection].

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].

The SID/Label Binding Sub-TLV supports the following Sub-TLVs:

SID/Label Sub-TLV as described in Section 2.1. This Sub-TLV MUST appear in the SID/Label Binding Sub-TLV and it SHOULD only appear once. If the SID/Label Sub-TLV is not included in the SID/Label Binding Sub-TLV, the SID/Label Binding Sub-TLV MUST be ignored. If the SID/Label Sub-TLV appears in the SID/Label Binding Sub-TLV more than once, instances other than the first will be ignored and the condition SHOULD be logged for possible action by the network operator.

ERO Metric Sub-TLV as defined in Section 6.1.

ERO Sub-TLVs as defined in Section 6.2.

6.1. ERO Metric Sub-TLV

The ERO Metric Sub-TLV is a Sub-TLV of the SID/Label Binding TLV.

The ERO Metric Sub-TLV advertises the cost of an ERO path. It is used to compare the cost of a given source/destination path. A router SHOULD advertise the ERO Metric Sub-TLV in an advertised ERO TLV. The cost of the ERO Metric Sub-TLV SHOULD be set to the cumulative IGP or TE path cost of the advertised ERO. Since manipulation of the Metric field may attract or repel traffic to and from the advertised segment, it MAY be manually overridden.

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Metric (4 octets)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                        ERO Metric Sub-TLV format

   where:

      Type: TBD, suggested value 8

      Length: Always 4

      Metric: A 4-octet metric representing the aggregate IGP or TE path
      cost.

6.2. ERO Sub-TLVs

   All ERO information represents an ordered set which describes the
   segments of a path. The first ERO Sub-TLV describes the first
   segment of a path. Similiarly, the last ERO Sub-TLV describes the
   segment closest to the egress point. If a router extends or stitches
   a path, it MUST prepend the new segment's path information to the ERO
   list. This applies equally to advertised backup EROs.

   All ERO Sub-TLVs must immediately follow the SID/Label Sub-TLV.

   All Backup ERO Sub-TLVs must immediately follow the last ERO Sub-TLV.

6.2.1. IPv4 ERO Sub-TLV

   The IPv4 ERO Sub-TLV is a Sub-TLV of the SID/Label Binding Sub-TLV.

   The IPv4 ERO Sub-TLV describes a path segment using IPv4 Address
   style encoding. Its semantics have been borrowed from [RFC3209].

```
 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                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    IPv4 Address (4 octets)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                     IPv4 ERO Sub-TLV format
```

where:

   Type: TBD, suggested value 4

   Length: 8 octets

   Flags: Single octet field containing the following flags:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|L|             |
+-+-+-+-+-+-+-+-+
```

   where:

      L-bit - If the L-bit is set, then the segment path is
      designated as 'loose'. Otherwise, the segment path is
      designated as 'strict'. The terms 'loose' and 'strict' are
      defined for RSVP subobjects in [RFC3209].

   IPv4 Address - The address of the explicit route hop.

6.2.2. Unnumbered Interface ID ERO Sub-TLV

The Unnumbered Interface ID ERO Sub-TLV is a Sub-TLV of the SID/Label
Binding Sub-TLV.

The appearance and semantics of the 'Unnumbered Interface ID' have
been borrowed from [RFC3477].

The Unnumbered Interface-ID ERO Sub-TLV describes a path segment that
includes an unnumbered interface. Unnumbered interfaces are
referenced using the interface index. Interface indices are assigned
local to the router and therefore are not unique within a domain.
All elements in an ERO path need to be unique within a domain and
hence need to be disambiguated using a domain unique Router-ID.

```
 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                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Router ID                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Interface ID                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
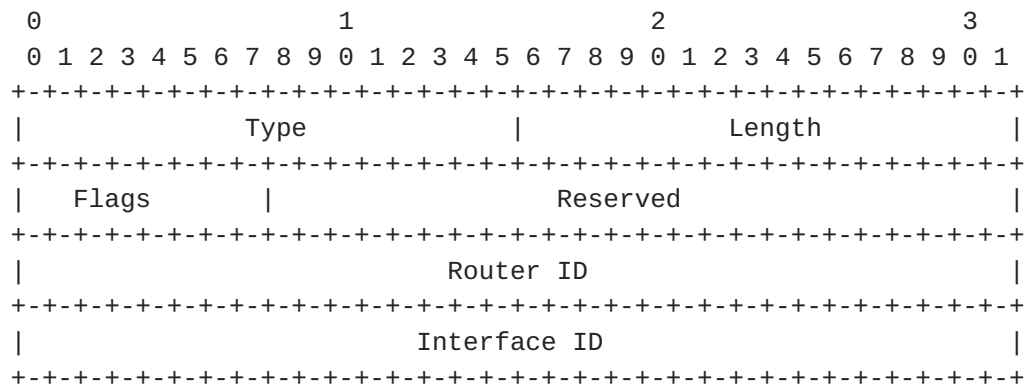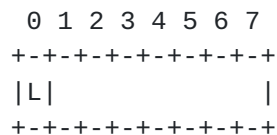
where:

              Unnumbered Interface ID ERO Sub-TLV format

   Type: TBD, suggested value 5

   Length: 12 octets

   Flags: Single octet field containing the following flags:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|L|             |
+-+-+-+-+-+-+-+-+
```

where:

      L-bit - If the L-bit is set, then the segment path is
      designated as 'loose'. Otherwise, the segment path is
      designated as 'strict'. The terms 'loose' and 'strict' are
      defined for RSVP subobjects in [RFC3209]

   Router-ID: Router-ID of the next-hop.

   Interface ID: The identifier assigned to the link by the router
   specified by the Router-ID.

6.2.3. IPv4 Backup ERO Sub-TLV

   IPv4 Prefix Backup ERO Sub-TLV is a Sub-TLV of the SID/Label Binding
   Sub-TLV.

   The IPv4 Backup ERO Sub-TLV describes a path segment using IPv4
   Address style of encoding. Its semantics have been borrowed from
   [RFC3209].

```
     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                          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                   IPv4 Address (4 octets)                     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                    IPv4 Backup ERO Sub-TLV format

   where:

      Type: TBD, suggested value 6

      Length: 8 octets

      Flags: Single octet field containing the following flags:

```
    0 1 2 3 4 5 6 7
   +-+-+-+-+-+-+-+-+
   |L|             |
   +-+-+-+-+-+-+-+-+
```

      where:

         L-bit - If the L-bit is set, then the segment path is
         designated as 'loose'. Otherwise, the segment path is
         designated as 'strict'. The terms 'loose' and 'strict' are
         defined for RSVP subobjects in [RFC3209]

      IPv4 Address - The address of the explicit route hop.

6.2.4. Unnumbered Interface ID Backup ERO Sub-TLV

   The Unnumbered Interface ID Backup ERO Sub-TLV is a Sub-TLV of the
   SID/Label Binding Sub-TLV.

   The appearance and semantics of the 'Unnumbered Interface ID' have
   been borrowed from [RFC3477].

   The Unnumbered Interface-ID Backup ERO Sub-TLV describes a path
   segment that includes an unnumbered interface. Unnumbered interfaces
   are referenced using the interface index. Interface indices are
   assigned local to the router and are therefore not unique within a
   domain. All elements in an ERO path need to be unique within a

domain and hence need to be disambiguated with specification of the
domain unique Router-ID.

```
 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                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Router ID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Interface ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

          Unnumbered Interface ID Backup ERO Sub-TLV format

   where:

      Type: TBD, suggested value 7

      Length: 12 octets

      Flags: Single octet field containing the following flags:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|L|             |
+-+-+-+-+-+-+-+-+
```

      where:

         L-bit - If the L-bit is set, then the segment path is
         designated as 'loose'. Otherwise, the segment path is
         designated as 'strict'.

      Router-ID: Router-ID of the next-hop.

      Interface ID: The identifier assigned to the link by the router
      specified by the Router-ID.

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

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.
Examples where more than one Adj-SID may be used per neighbor are
described in section 4 of
[I-D.filsfils-spring-segment-routing-use-cases]. The Adj-SID 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Flags     |    Reserved   |    MT-ID      |    Weight     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    SID/Label/Index (variable)                |
+---------------------------------------------------------------+
```

where:

   Type: TBD, suggested value 2.

   Length: Variable.

   Flags: Single octet field containing the following flags:

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

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).

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

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: According to the V and L flags, it contains
either:

A 32-bit index defining the offset in the SID/Label space
advertised by this router.

A 24-bit label where the 20 rightmost bits are used for
encoding the label value.

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].

7.2. 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.

```
 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   |     MT-ID     |    Weight     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Neighbor ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     SID/Label/Index (variable)                |
+---------------------------------------------------------------+
```

where:

Type: TBD, suggested value 3.

      Length: Variable.

      Flags: Single octet field containing the following flags:

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

      where:

            B-Flag: Backup-flag. If set, the LAN-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 Prefix-SID
            carries an absolute value. If not set, then the Prefix-SID
            carries an index.

            The 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.

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

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

      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: According to the V and L flags, it contains
      either:

         A 32-bit index defining the offset in the SID/Label space
         advertised by this router.

         A 24-bit label where the 20 rightmost bits are used for
         encoding the label value.

8. Elements of Procedure

8.1. 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).

If multiple routers advertise a Prefix-SID for the same prefix, then the Prefix-SID MUST be the same. This is required in order to allow traffic load-balancing when multiple equal cost paths to the destination exist in the OSPFv2 routing domain.

Prefix-SID can also be advertised by the SR Mapping Servers (as described in [I-D.filsfils-spring-segment-routing-ldp-interop]). The 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.

The SR Mapping Server MUST use 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 the SR Mapping Server.

Area-scoped OSPF Extended Prefix Range TLV 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.

If the Prefix-SID that is advertised in a Prefix SID Sub-TLV is also covered by the OSPF Extended Prefix Range TLV, the Prefix-SID advertised in Prefix SID Sub-TLV MUST be preferred.

8.2. 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-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-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.

8.3. SID 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-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 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.

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 then 2-Way, then the Adj-SID advertisement MUST be
removed from the area.

8.4.2. Adjacency SID on Broadcast or NBMA Interfaces

Broadcast, NBMA or 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 or NBMA
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 an 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 OSPF registries.

9.1. OSPF OSPF Router Information (RI) TLVs Registry

   o 8 (IANA Preallocated) - SR-Algorithm TLV

   o 9 (IANA Preallocated) - SID/Label Range TLV

9.2. OSPF Extended Prefix LSA TLV Registry

   Following values are allocated:

   o 2 - OSPF Extended Prefix Range TLV

9.3. OSPF Extended Prefix LSA Sub-TLV Registry

   Following values are allocated:

   o 1 - SID/Label Sub-TLV

   o 2 - Prefix SID Sub-TLV

   o 3 - SID/Label Binding Sub-TLV

   o 4 - IPv4 ERO Sub-TLV

   o 5 - Unnumbered Interface ID ERO Sub-TLV

   o 6 - IPv4 Backup ERO Sub-TLV

   o 7 - Unnumbered Interface ID Backup ERO Sub-TLV

   o 8 - ERO Metric Sub-TLV

9.4. OSPF Extended Link LSA Sub-TLV 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

[10]. 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 two 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.

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%20Un
icast%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 inter-
operability 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:

www.segment-routing.net/home/tutorial

The implementation's level of maturity: Production.

Coverage: All sections, except the section 6 (SID/Label Binding Sub-
TLV) 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

11. Security Considerations

Implementations must assure that malformed TLV and Sub-TLV
permutations do not result in errors which cause hard OSPF failures.

12. 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.

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corrections, as well as discussion about details of the encoding.

14. References

14.1. Normative References

[RFC2119]   Bradner, S., "Key words for use in RFCs to Indicate
            Requirement Levels", BCP 14, RFC 2119,
            DOI 10.17487/RFC2119, March 1997,
            <http://www.rfc-editor.org/info/rfc2119>.

[RFC2328]   Moy, J., "OSPF Version 2", STD 54, RFC 2328,
            DOI 10.17487/RFC2328, April 1998,
            <http://www.rfc-editor.org/info/rfc2328>.

[RFC3209]   Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V.,
            and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP
            Tunnels", RFC 3209, DOI 10.17487/RFC3209, December 2001,
            <http://www.rfc-editor.org/info/rfc3209>.

[RFC3477]   Kompella, K. and Y. Rekhter, "Signalling Unnumbered Links
            in Resource ReSerVation Protocol - Traffic Engineering
            (RSVP-TE)", RFC 3477, DOI 10.17487/RFC3477, January 2003,
            <http://www.rfc-editor.org/info/rfc3477>.

[RFC3630]   Katz, D., Kompella, K., and D. Yeung, "Traffic Engineering
            (TE) Extensions to OSPF Version 2", RFC 3630,
            DOI 10.17487/RFC3630, September 2003,
            <http://www.rfc-editor.org/info/rfc3630>.

[RFC4915]   Psenak, P., Mirtorabi, S., Roy, A., Nguyen, L., and P.
            Pillay-Esnault, "Multi-Topology (MT) Routing in OSPF",
            RFC 4915, DOI 10.17487/RFC4915, June 2007,
            <http://www.rfc-editor.org/info/rfc4915>.

[RFC5250]   Berger, L., Bryskin, I., Zinin, A., and R. Coltun, "The
            OSPF Opaque LSA Option", RFC 5250, DOI 10.17487/RFC5250,
            July 2008, <http://www.rfc-editor.org/info/rfc5250>.

[RFC6845]   Sheth, N., Wang, L., and J. Zhang, "OSPF Hybrid Broadcast
            and Point-to-Multipoint Interface Type", RFC 6845,
            DOI 10.17487/RFC6845, January 2013,
            <http://www.rfc-editor.org/info/rfc6845>.

[RFC7684]   Psenak, P., Gredler, H., Shakir, R., Henderickx, W.,
            Tantsura, J., and A. Lindem, "OSPFv2 Prefix/Link Attribute
            Advertisement", RFC 7684, DOI 10.17487/RFC7684, November
            2015, <http://www.rfc-editor.org/info/rfc7684>.

   [RFC7770]   Lindem, A., Ed., Shen, N., Vasseur, JP., Aggarwal, R., and
               S. Shaffer, "Extensions to OSPF for Advertising Optional
               Router Capabilities", RFC 7770, DOI 10.17487/RFC7770,
               February 2016, <http://www.rfc-editor.org/info/rfc7770>.

14.2. Informative References

   [I-D.filsfils-spring-segment-routing-ldp-interop]
               Filsfils, C., Previdi, S., Bashandy, A., Decraene, B.,
               Litkowski, S., Horneffer, M., Milojevic, I., Shakir, R.,
               Ytti, S., Henderickx, W., Tantsura, J., and E. Crabbe,
               "Segment Routing interoperability with LDP", draft-
               filsfils-spring-segment-routing-ldp-interop-02 (work in
               progress), September 2014.

   [I-D.filsfils-spring-segment-routing-use-cases]
               Filsfils, C., Francois, P., Previdi, S., Decraene, B.,
               Litkowski, S., Horneffer, M., Milojevic, I., Shakir, R.,
               Ytti, S., Henderickx, W., Tantsura, J., Kini, S., and E.
               Crabbe, "Segment Routing Use Cases", draft-filsfils-
               spring-segment-routing-use-cases-01 (work in progress),
               October 2014.

   [I-D.gredler-ospf-label-advertisement]
               Gredler, H., Amante, S., Scholl, T., and L. Jalil,
               "Advertising MPLS labels in OSPF", draft-gredler-ospf-
               label-advertisement-03 (work in progress), May 2013.

   [I-D.ietf-spring-segment-routing]
               Filsfils, C., Previdi, S., Bashandy, A., Decraene, B.,
               Litkowski, S., Horneffer, M., Shakir, R., Tantsura, J.,
               and E. Crabbe, "Segment Routing Architecture", draft-ietf-
               spring-segment-routing-00 (work in progress), December
               2014.

   [I-D.minto-rsvp-lsp-egress-fast-protection]
               Jeganathan, J., Gredler, H., and Y. Shen, "RSVP-TE LSP
               egress fast-protection", draft-minto-rsvp-lsp-egress-fast-
               protection-03 (work in progress), November 2013.

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