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OSPF Extensions for Segment Routing
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Abstract

   Segment Routing (SR) allows for 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

   This Internet-Draft will expire on September 22, 2016.

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1. Introduction

   Segment Routing (SR) allows for 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). 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
   [I-D.ietf-ospf-prefix-link-attr]. These new LSAs are defined as
   generic containers that can be used to advertise any additional
   attributes associated with a prefix or link. These new 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 bytes

   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 [RFC4970]).

3.1. SR-Algorithm TLV

The SR-Algorithm TLV is a top-level TLV of the Router Information
Opaque LSA (defined in [RFC4970]).

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 SR-Algorithm TLV MUST
also be advertised.

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 that the router is currently using
   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
         the support of Algorithm 1 MUST NOT alter the forwarding
         decision 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
   the SR-Algorithm TLV propagation, 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 [RFC4970]).

   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)                    |
+-                                                            -+
|                                                               |
+                                                               +
```
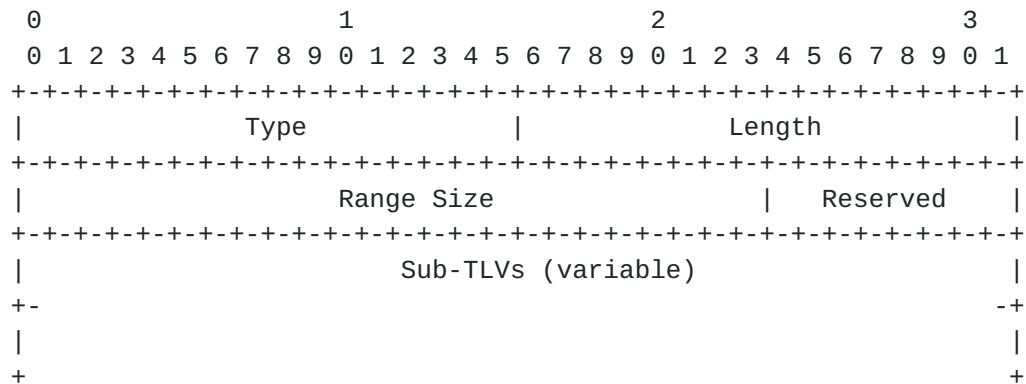
   where:

      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 occurrence 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 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) is 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 purposes of the
   SID/Label Range TLV propagation, area scope flooding is required.

[4]. OSPF Extended Prefix Range TLV

   In some cases it is useful to advertise attributes for the range of
   prefixes. 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.

   OSPF Extended Prefix Range TLV, which is a new top level TLV of the
   Extended Prefix LSA described in [I-D.ietf-ospf-prefix-link-attr] 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: 1 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. 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 advertisement over inter-area one.

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

An ABR propagates inter-area Prefix Range advertisement from backbone area to connected non backbone areas only if such advertisement is considered to be the best one.

Address Prefix: the prefix, encoded as an even multiple of 32-bit words, padded with zeroed 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 [I-D.ietf-ospf-prefix-link-attr] 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: 1 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 the packet to the node
that advertised the Prefix-SID.

M-Flag: Mapping Server Flag. If set, the SID is advertised
from the Segment Routing Mapping Server functionality 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 a
Prefix-SID having an Explicit-NULL value (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: one 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 E and P flags advertised by the next-hop router, if
next-hop 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 on the 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 the prefix which is directly attached to
the ABR, NP-Flag SHOULD NOT be set

The NP-Flag (No-PHP) MUST be be set on the Prefix-SIDs allocated to
redistributed prefixes, unless the redistributed prefix is directly
attached to 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
clear 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 inter-area border router
   (prefix propagation from one area to another) or at an inter-
   domain border 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 a Prefix-SID having an
   Explicit-NULL value. 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 M-Flag is set, NP-flag and 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:

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

Prefix is of inter-area type and downstream neighbor is an ABR,
which is advertising the prefix reachability and is also
generating the Extended Prefix TLV with A-flag set for this prefix
as described in section 2.1 of [I-D.ietf-ospf-prefix-link-attr].

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

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 [I-D.ietf-ospf-prefix-link-attr] 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: 1 octet field of following flags:

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

where:

    M-bit - When the bit is set the binding represents the
    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 MUST only appear
once.

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

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 bytes

   Flags: 1 octet field of 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'.

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 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 bytes

Flags: 1 octet field of 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: is 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 bytes

Flags: 1 octet field of 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'.

 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 bytes

Flags: 1 octet field of 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: is 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
[I-D.ietf-ospf-prefix-link-attr]. 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. 1 octet field of following flags:

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

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 S-Flag. Set Flag. When set, the S-Flag indicates that the
Adj-SID refers to a set 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].

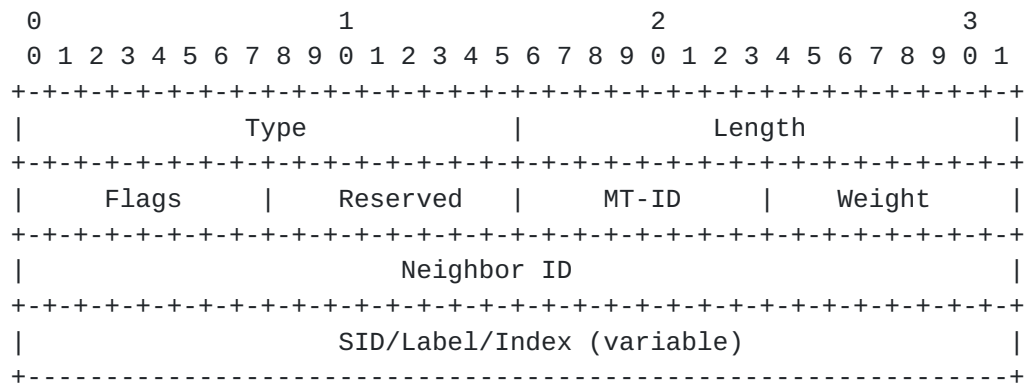SID/Index/Label: according to the V and L flags, it contains
either:

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 [I-D.ietf-ospf-prefix-link-attr]. 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 node on a broadcast or NBMA network.
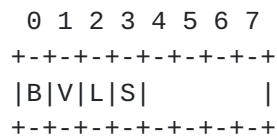
```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type              |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Flags     |    Reserved   |     MT-ID     |     Weight    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Neighbor ID                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     SID/Label/Index (variable)                |
+---------------------------------------------------------------+
```

where:

   Type: TBD, suggested value 3.

   Length: variable.

   Flags. 1 octet field of following flags:

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

where:

      B-Flag: Backup-flag: set if the LAN-Adj-SID refer 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 S-Flag. Set Flag. When set, the S-Flag indicates that the
Adj-SID refers to a set 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 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 network.

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.

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, 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 is described in Section 4.

When propagating OSPF Extended Prefix Range TLV between areas, ABR
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 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 in order 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 [I-D.ietf-ospf-prefix-link-attr].
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 [I-D.ietf-ospf-prefix-link-attr].
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 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 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 an Extended
Prefix Opaque LSAs, as described in [I-D.ietf-ospf-prefix-link-attr].
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 or NBMA 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 or NBMA network connect. As a result, routers on the broadcast or NBMA 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 Adj-SID Sub-TLV as described in Section 7.1.

SR capable routers MAY also advertise an Adj-SID for other neighbors (e.g. BDR, DR-OTHER) on the broadcast or NBMA 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. Security Considerations

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

11. Contributors

The following people gave a substantial contribution to the content
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Bruno Decraene, Stephane Litkowski, Igor Milojevic, Rob Shakir and
Saku Ytti.

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TLV" in [I-D.gredler-ospf-label-advertisement].

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

13. References

13.1. 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>.

   [RFC4970]   Lindem, A., Ed., Shen, N., Vasseur, JP., Aggarwal, R., and
               S. Shaffer, "Extensions to OSPF for Advertising Optional
               Router Capabilities", RFC 4970, DOI 10.17487/RFC4970, July
               2007, <http://www.rfc-editor.org/info/rfc4970>.

   [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>.

13.2. 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-ospf-prefix-link-attr]
            Psenak, P., Gredler, H., rjs@rob.sh, r., Henderickx, W.,
            Tantsura, J., and A. Lindem, "OSPFv2 Prefix/Link Attribute
            Advertisement", draft-ietf-ospf-prefix-link-attr-13 (work
            in progress), August 2015.

   [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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