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

Abstract

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

   This draft describes the OSPFv2 extensions required for Segment
   Routing.

Requirements Language

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

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
   provisions of BCP 78 and BCP 79.

   Internet-Drafts are working documents of the Internet Engineering
   Task Force (IETF). Note that other groups may also distribute
   working documents as Internet-Drafts. The list of current Internet-
   Drafts is at https://datatracker.ietf.org/drafts/current/.

   Internet-Drafts are draft documents valid for a maximum of six months
   and may be updated, replaced, or obsoleted by other documents at any
   time. It is inappropriate to use Internet-Drafts as reference
   material or to cite them other than as "work in progress."

   This Internet-Draft will expire on June 6, 2019.

Copyright Notice

Table of Contents

1. Introduction

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

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

This draft describes the OSPF extensions required for Segment
Routing.

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

Segment Routing use cases are described in [RFC7855].

2. Segment Routing Identifiers

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

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

2.1. SID/Label Sub-TLV

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

```
 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: 1

      Length: Variable, 3 or 4 octet

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

      The receiving router MUST ignore the SID/Label Sub-TLV if the
      length is other 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]). The TLVs defined below are applicable to
   both OSPFv2 and OSPFv3; see also
   [I-D.ietf-ospf-ospfv3-segment-routing-extensions]

3.1. SR-Algorithm TLV

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

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

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

```
 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: 8

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

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

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

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

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

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

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

3.2. SID/Label Range TLV

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

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

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

```
 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: 9

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

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

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

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

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

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

o The originating router MUST encode each range into a different SID/Label Range TLV.

o The originating router decides the order in which the set of SID/ Label Range TLVs are advertised inside the Router Information Opaque LSA. The originating router MUST ensure the order is the same after a graceful restart (using checkpointing, non-volatile storage, or any other mechanism) in order to assure the SID/label range and SID index correspondence is preserved across graceful restarts.

o The receiving router MUST adhere to the order in which the ranges are advertised when calculating a SID/label from a SID index.

o The originating router MUST NOT advertise overlapping ranges.

o When a router receives multiple overlapping ranges, it MUST conform to the procedures defined in [I-D.ietf-spring-segment-routing-mpls].

The following example illustrates the advertisement of multiple ranges:

The originating router advertises the following ranges:

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

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

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

The indexes span multiple ranges:

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

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

3.3. SR Local Block TLV

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

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

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

```
 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: 14

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

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

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

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

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

The originating router MUST NOT advertise overlapping ranges.

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

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

A router advertising the SRLB TLV MAY also have other label ranges, outside of the SRLB, used for its local allocation purposes which are not advertised in the SRLB TLV. For example, it is possible that an Adjacency-SID is allocated using a local label that is not part of the SRLB.
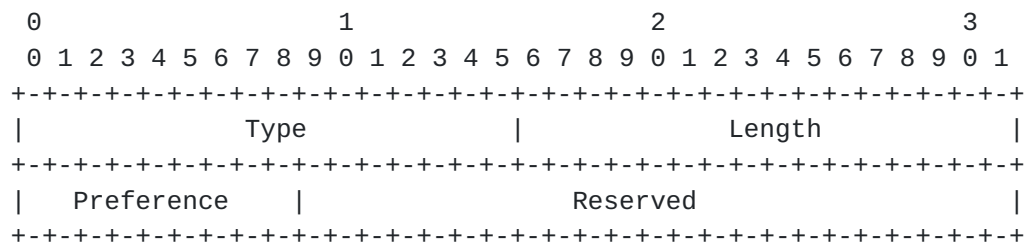
The RI LSA can be advertised at any of the defined flooding scopes (link, area, or autonomous system (AS)). For the purpose of SRLB TLV advertisement, area-scoped flooding is REQUIRED.

3.4. SRMS Preference TLV

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

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

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

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Preference  |                  Reserved                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

   Type: 15

   Length: 4 octets

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

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

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

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

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

4. OSPF Extended Prefix Range TLV

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

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

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

```
 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: 2

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

Prefix length: Length of prefix in bits.

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

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

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

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

where:

> IA-Flag: Inter-Area flag. If set, advertisement is of inter-
> area type. An ABR that is advertising the OSPF Extended Prefix
> Range TLV between areas MUST set this bit.
>
> This bit is used to prevent redundant flooding of Prefix Range
> TLVs between areas as follows:
>
>> An ABR only propagates an inter-area Prefix Range
>> advertisement from the backbone area to connected non-
>> backbone areas if the advertisement is considered to be the
>> best one. The following rules are used to select the best
>> range from the set of advertisements for the same Prefix
>> Range:
>>
>>> An ABR always prefers intra-area Prefix Range
>>> advertisements over inter-area advertisements.
>>>
>>> An ABR does not consider inter-area Prefix Range
>>> advertisements coming from non-backbone areas.

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

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

5. Prefix SID Sub-TLV

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

```
 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: 2

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

    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.ietf-spring-segment-routing-ldp-interop].

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

If the NP-flag is set then:

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

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

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

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

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

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

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

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

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

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

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

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

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

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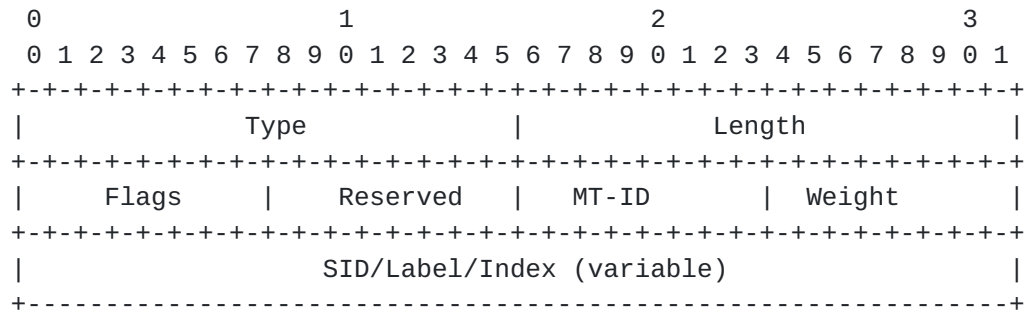   192.0.2.24/30, Prefix-SID: Index 57

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

6. Adjacency Segment Identifier (Adj-SID)

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

6.1. Adj-SID Sub-TLV

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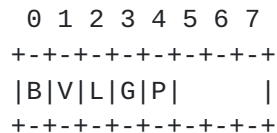   The Adj-SID Sub-TLV has the following format:

```
 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: 2

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

      Flags: Single octet field containing the following flags:

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

   where:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.2. LAN Adj-SID Sub-TLV

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

```
 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: 3

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

   Flags: same as in Section 6.1

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

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

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

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

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

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

7. Elements of Procedure

7.1. Intra-area Segment routing in OSPFv2

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

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

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

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

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

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

7.2. Inter-area Segment routing in OSPFv2

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

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

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

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

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

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

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

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

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

7.3. Segment Routing for External Prefixes

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

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

7.4. Advertisement of Adj-SID

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

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

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

7.4.2. Adjacency SID on Broadcast or NBMA Interfaces

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

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

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

8. IANA Considerations

   This specification updates several existing OSPF registries.

8.1. OSPF Router Information (RI) TLVs Registry

   o 8 (IANA Preallocated) - SR-Algorithm TLV

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

   o 14 - SR Local Block TLV

   o 15 - SRMS Preference TLV

8.2. OSPFv2 Extended Prefix Opaque LSA TLVs Registry

   Following values are allocated:

   o 2 - OSPF Extended Prefix Range TLV

8.3. OSPFv2 Extended Prefix TLV Sub-TLVs Registry

   Following values are allocated:

   o 1 - SID/Label Sub-TLV

   o 2 - Prefix SID Sub-TLV

8.4. OSPFv2 Extended Link TLV Sub-TLVs Registry

   Following initial values are allocated:

   o 1 - SID/Label Sub-TLV

   o 2 - Adj-SID Sub-TLV

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

8.5. IGP Algorithm Type Registry

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

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

   The initial values in the IGP Algorithm Type registry are:

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

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

9. Implementation Status

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

   This section will be removed before publication as an RFC.

   Responses from Nokia (former Alcatel-Lucent):

   Link to a web page describing the implementation:
   https://infoproducts.alcatel-lucent.com/cgi-bin/dbaccessfilename.cgi/
   3HE10799AAAATQZZA01_V1_7450%20ESS%207750%20SR%20and%207950%20XRS%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:

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

   The implementation's level of maturity: Production.

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

   Licensing: Part of a commercial software package.

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

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

Contact information: ppsenak@cisco.com

Responses from Juniper:

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

Feature name is OSPF SPRING

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

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

Licensing: JUNOS Licensing needed.

Implementation experience: NA

Contact information: shraddha@juniper.net

10. Security Considerations

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

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

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

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

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

11. Contributors

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

12. Acknowledgements

We would like to thank Anton Smirnov for his contribution.

Thanks to Acee Lindem for the detail review of the draft,
corrections, as well as discussion about details of the encoding.

13. References

13.1. Normative References

[I-D.ietf-spring-segment-routing]
          Filsfils, C., Previdi, S., Ginsberg, L., Decraene, B.,
          Litkowski, S., and R. Shakir, "Segment Routing
          Architecture", draft-ietf-spring-segment-routing-15 (work
          in progress), January 2018.

[I-D.ietf-spring-segment-routing-ldp-interop]
          Bashandy, A., Filsfils, C., Previdi, S., Decraene, B., and
          S. Litkowski, "Segment Routing interworking with LDP",
          draft-ietf-spring-segment-routing-ldp-interop-15 (work in
          progress), September 2018.

[I-D.ietf-spring-segment-routing-mpls]
          Bashandy, A., Filsfils, C., Previdi, S., Decraene, B.,
          Litkowski, S., and R. Shakir, "Segment Routing with MPLS
          data plane", draft-ietf-spring-segment-routing-mpls-15
          (work in progress), October 2018.

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

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

   [RFC3101] Murphy, P., "The OSPF Not-So-Stubby Area (NSSA) Option",
              RFC 3101, DOI 10.17487/RFC3101, January 2003,
              <https://www.rfc-editor.org/info/rfc3101>.

   [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,
              <https://www.rfc-editor.org/info/rfc4915>.

   [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,
              <https://www.rfc-editor.org/info/rfc6845>.

   [RFC7120] Cotton, M., "Early IANA Allocation of Standards Track Code
              Points", BCP 100, RFC 7120, DOI 10.17487/RFC7120, January
              2014, <https://www.rfc-editor.org/info/rfc7120>.

   [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, <https://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, <https://www.rfc-editor.org/info/rfc7770>.

   [RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for
              Writing an IANA Considerations Section in RFCs", BCP 26,
              RFC 8126, DOI 10.17487/RFC8126, June 2017,
              <https://www.rfc-editor.org/info/rfc8126>.

13.2. Informative References

   [I-D.ietf-ospf-ospfv3-segment-routing-extensions]
              Psenak, P. and S. Previdi, "OSPFv3 Extensions for Segment
              Routing", draft-ietf-ospf-ospfv3-segment-routing-
              extensions-18 (work in progress), November 2018.

   [RFC7474] Bhatia, M., Hartman, S., Zhang, D., and A. Lindem, Ed.,
              "Security Extension for OSPFv2 When Using Manual Key
              Management", RFC 7474, DOI 10.17487/RFC7474, April 2015,
              <https://www.rfc-editor.org/info/rfc7474>.

   [RFC7855] Previdi, S., Ed., Filsfils, C., Ed., Decraene, B.,
              Litkowski, S., Horneffer, M., and R. Shakir, "Source
              Packet Routing in Networking (SPRING) Problem Statement
              and Requirements", RFC 7855, DOI 10.17487/RFC7855, May
              2016, <https://www.rfc-editor.org/info/rfc7855>.

Authors' Addresses

   Peter Psenak (editor)
   Cisco Systems, Inc.
   Apollo Business Center
   Mlynske nivy 43
   Bratislava 821 09
   Slovakia

   Email: ppsenak@cisco.com

   Stefano Previdi (editor)
   Cisco Systems, Inc.
   Via Del Serafico, 200
   Rome 00142
   Italy

   Email: stefano@previdi.net

   Clarence Filsfils
   Cisco Systems, Inc.
   Brussels
   Belgium

   Email: cfilsfil@cisco.com

   Hannes Gredler
   RtBrick Inc.

   Email: hannes@rtbrick.com

   Rob Shakir
   Google, Inc.
   1600 Amphitheatre Parkway
   Mountain View, CA 94043
   US

   Email: robjs@google.com

Wim Henderickx
Nokia
Copernicuslaan 50
Antwerp 2018
BE

Email: wim.henderickx@nokia.com

Jeff Tantsura
Apstra, Inc.

Email: jefftant.ietf@gmail.com