                  Segment Routing interworking with LDP
               draft-ietf-spring-segment-routing-ldp-interop-14

Abstract

   A Segment Routing (SR) node steers a packet through a controlled set
   of instructions, called segments, by prepending the packet with an SR
   header. A segment can represent any instruction, topological or
   service-based. SR allows to enforce a flow through any topological
   path while maintaining per-flow state only at the ingress node to the
   SR domain.

   The Segment Routing architecture can be directly applied to the MPLS
   data plane with no change in the forwarding plane. This document
   describes how Segment Routing operates in a network where LDP is
   deployed and in the case where SR-capable and non-SR-capable nodes
   coexist.

Requirements Language

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
   document are to be interpreted as described in RFC 2119 [RFC2119].

Status of This Memo

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1. Introduction

   Segment Routing, as described in [I-D.ietf-spring-segment-routing],
   can be used on top of the MPLS data plane without any modification as
   described in [I-D.ietf-spring-segment-routing-mpls].

   Segment Routing control plane can co-exist with current label
   distribution protocols such as LDP ([RFC5036]).

   This document outlines the mechanisms through which SR interworks
   with LDP in cases where a mix of SR-capable and non-SR-capable
   routers co-exist within the same network and more precisely in the
   same routing domain.

   Section 2 describes the co-existence of SR with other MPLS Control
   Plane protocols. Section 3 documents the interworking between SR and
   LDP in the case of non-homogeneous deployment. Section 4 describes
   how a partial SR deployment can be used to provide SR benefits to
   LDP-based traffic including a possible application of SR in the
   context of inter-domain MPLS use-cases. Appendix A documents a
   method to migrate from LDP to SR-based MPLS tunneling.

   Typically, an implementation will allow an operator to select
   (through configuration) which of the described modes of SR and LDP
   co-existence to use.

2. SR/LDP Ships-in-the-night coexistence

   "MPLS Control Plane Client (MCC)" refers to any control plane
   protocol installing forwarding entries in the MPLS data plane. SR,
   LDP [RFC5036], RSVP-TE [RFC3209], BGP [RFC8277], etc are examples of
   MCCs.

   An MCC, operating at node N, must ensure that the incoming label it
   installs in the MPLS data plane of Node N has been uniquely allocated
   to himself.

   Segment Routing makes use of the Segment Routing Global Block (SRGB,
   as defined in [I-D.ietf-spring-segment-routing]) for the label
   allocation. The use of the SRGB allows SR to co-exist with any other
   MCC.

   This is clearly the case for the adjacency segment: it is a local
   label allocated by the label manager, as for any MCC.

This is clearly the case for the prefix segment: the label manager
allocates the SRGB set of labels to the SR MCC client and the
operator ensures the unique allocation of each global prefix segment/
label within the allocated SRGB set.

Note that this static label allocation capability of the label
manager has existed for many years across several vendors and hence
is not new. Furthermore, note that the label-manager ability's to
statically allocate a range of labels to a specific application is
not new either. This is required for MPLS-TP operation. In this
case, the range is reserved by the label manager and it is the MPLS-
TP ([RFC5960]) NMS (acting as an MCC) that ensures the unique
allocation of any label within the allocated range and the creation
of the related MPLS forwarding entry.

Let us illustrate an example of ship-in-the-night (SIN) coexistence.

```
                    PE2            PE4
                     \            /
               PE1----A----B---C---PE3
```
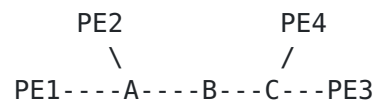
Figure 1: SIN coexistence

The EVEN VPN service is supported by PE2 and PE4 while the ODD VPN
service is supported by PE1 and PE3. The operator wants to tunnel
the ODD service via LDP and the EVEN service via SR.

This can be achieved in the following manner:

   The operator configures PE1, PE2, PE3, PE4 with respective
   loopbacks 192.0.2.201/32, 192.0.2.202/32, 192.0.2.203/32,
   192.0.2.204/32. These PE's advertised their VPN routes with next-
   hop set on their respective loopback address.

   The operator configures A, B, C with respective loopbacks
   192.0.2.1/32, 192.0.2.2/32, 192.0.2.3/32.

   The operator configures PE2, A, B, C and PE4 with SRGB [100, 300].

   The operator attaches the respective Node Segment Identifiers
   (Node-SID's, as defined in [I-D.ietf-spring-segment-routing]):
   202, 101, 102, 103 and 204 to the loopbacks of nodes PE2, A, B, C
   and PE4. The Node-SID's are configured to request penultimate-
   hop-popping.

   PE1, A, B, C and PE3 are LDP capable.

PE1 and PE3 are not SR capable.

PE3 sends an ODD VPN route to PE1 with next-hop 192.0.2.203 and VPN label 10001.

From an LDP viewpoint: PE1 received an LDP label binding (1037) for a forwarding equivalence class (FEC) 192.0.2.203/32 from its next-hop A. A received an LDP label binding (2048) for that FEC from its next-hop B. B received an LDP label binding (3059) for that FEC from its next-hop C. C received implicit-null LDP binding from its next-hop PE3.

As a result, PE1 sends its traffic to the ODD service route advertised by PE3 to next-hop A with two labels: the top label is 1037 and the bottom label is 10001. Node A swaps 1037 with 2048 and forwards to B. B swaps 2048 with 3059 and forwards to C. C pops 3059 and forwards to PE3.

PE4 sends an EVEN VPN route to PE2 with next-hop 192.0.2.204 and VPN label 10002.

From an SR viewpoint: PE2 maps the IGP route 192.0.2.204/32 onto Node-SID 204; node A swaps 204 with 204 and forwards to B; B swaps 204 with 204 and forwards to C; C pops 204 and forwards to PE4.

As a result, PE2 sends its traffic to the VPN service route advertised by PE4 to next-hop A with two labels: the top label is 204 and the bottom label is 10002. Node A swaps 204 with 204 and forwards to B. B swaps 204 with 204 and forwards to C. C pops 204 and forwards to PE4.

The two modes of MPLS tunneling co-exist.

   The ODD service is tunneled from PE1 to PE3 through a continuous LDP LSP traversing A, B and C.

   The EVEN service is tunneled from PE2 to PE4 through a continuous SR node segment traversing A, B and C.

2.1. MPLS2MPLS, MPLS2IP and IP2MPLS co-existence

MPLS2MPLS refers to the forwarding behavior where a router receives a labeled packet and switches it out as a labeled packet. Several MPLS2MPLS entries may be installed in the data plane for the same prefix.

Let us examine A's MPLS forwarding table as an example:

```
Incoming label: 1037

    - outgoing label: 2048
    - outgoing next-hop: B
    Note: this entry is programmed by LDP for 192.0.2.203/32

Incoming label: 203

    - outgoing label: 203
    - outgoing next-hop: B
    Note: this entry is programmed by SR for 192.0.2.203/32
```

These two entries can co-exist because their incoming label is
unique. The uniqueness is guaranteed by the label manager allocation
rules.

The same applies for the MPLS2IP forwarding entries. MPLS2IP is the
forwarding behavior where a router receives a label IPv4/IPv6 packet
with one label only, pops the label, and switches the packet out as
IPv4/IPv6. For IP2MPLS coexistence, refer to Section 6.1.

3. SR and LDP Interworking

This section analyzes the case where SR is available in one part of
the network and LDP is available in another part. It describes how a
continuous MPLS tunnel can be built throughout the network.

```
                    PE2              PE4
                     \              /
               PE1----P5--P6--P7--P8---PE3
```

                     Figure 2: SR and LDP Interworking
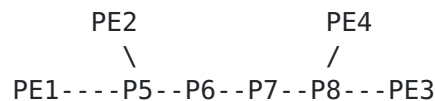
Let us analyze the following example:

   P6, P7, P8, PE4 and PE3 are LDP capable.

   PE1, PE2, P5 and P6 are SR capable. PE1, PE2, P5 and P6 are
   configured with SRGB (100, 200) and respectively with node
   segments 101, 102, 105 and 106.

   A service flow must be tunneled from PE1 to PE3 over a continuous
   MPLS tunnel encapsulation and hence SR and LDP need to interwork.

3.1. LDP to SR

   In this section, a right-to-left traffic flow is analyzed.

   PE3 has learned a service route whose next-hop is PE1. PE3 has an
   LDP label binding from the next-hop P8 for the FEC "PE1". Hence PE3
   sends its service packet to P8 as per classic LDP behavior.

   P8 has an LDP label binding from its next-hop P7 for the FEC "PE1"
   and hence P8 forwards to P7 as per classic LDP behavior.

   P7 has an LDP label binding from its next-hop P6 for the FEC "PE1"
   and hence P7 forwards to P6 as per classic LDP behavior.

   P6 does not have an LDP binding from its next-hop P5 for the FEC
   "PE1". However P6 has an SR node segment to the IGP route "PE1".
   Hence, P6 forwards the packet to P5 and swaps its local LDP-label for
   FEC "PE1" by the equivalent node segment (i.e. 101).

   P5 pops 101 (assuming PE1 advertised its node segment 101 with the
   penultimate-pop flag set) and forwards to PE1.

   PE1 receives the tunneled packet and processes the service label.

   The end-to-end MPLS tunnel is built from an LDP LSP from PE3 to P6
   and the related node segment from P6 to PE1.

3.1.1. LDP to SR Behavior

   It has to be noted that no additional signaling or state is required
   in order to provide interworking in the direction LDP to SR.

   A SR node having LDP neighbors MUST create LDP bindings for each
   Prefix-SID learned in the SR domain by treating SR learned labels as
   if they were learned through an LDP neighbot. In addition for each
   FEC, the SR node stitches the incoming LDP label to the outgoing SR
   label. This has to be done in both LDP independent and ordered label
   distribution control modes as defined in [RFC5036].

3.2. SR to LDP

   In this section, the left-to-right traffic flow is analyzed.

   This section defines the Segment Routing Mapping Server (SRMS). The
   SRMS is a IGP node advertising mapping between Segment Identifiers
   (SID) and prefixes advertised by other IGP nodes. The SRMS uses a
   dedicated IGP extension (IS-IS, OSPFv2 and OSPFv3) which is protocol
   specific and defined in [I-D.ietf-isis-segment-routing-extensions],

[I-D.ietf-ospf-segment-routing-extensions], and
[I-D.ietf-ospf-ospfv3-segment-routing-extensions].

The SRMS function of a SR capable router allows distribution of
mappings for prefixes not locally attached to the advertising router
and therefore allows advertisement of mappings on behalf of non-SR
capable routers.

The SRMS is a control plane only function which may be located
anywhere in the IGP flooding scope. At least one SRMS server MUST
exist in a routing domain to advertise prefix-SIDs on behalf non-SR
nodes, thereby allowing non-LDP routers to send and receive labeled
traffic from LDP-only routers. Multiple SRMSs may be present in the
same network (for redundancy). This implies that there are multiple
ways a prefix-to-SID mapping can be advertised. Conflicts resulting
from inconsistent advertisements are addressed by
[I-D.ietf-spring-segment-routing-mpls].

The example diagram depicted in Figure 2 assumes that the operator
configures P5 to act as a Segment Routing Mapping Server (SRMS) and
advertises the following mappings: (P7, 107), (P8, 108), (PE3, 103)
and (PE4, 104).

The mappings advertised by one or more SRMSs result from local policy
information configured by the operator.

If PE3 had been SR capable, the operator would have configured PE3
with node segment 103. Instead, as PE3 is not SR capable, the
operator configures that policy at the SRMS and it is the latter
which advertises the mapping.

The mapping server advertisements are only understood by SR capable
routers. The SR capable routers install the related node segments in
the MPLS data plane exactly like the node segments had been
advertised by the nodes themselves.

For example, PE1 installs the node segment 103 with next-hop P5
exactly as if PE3 had advertised node segment 103.

PE1 has a service route whose next-hop is PE3. PE1 has a node
segment for that IGP route: 103 with next-hop P5. Hence PE1 sends
its service packet to P5 with two labels: the bottom label is the
service label and the top label is 103.

P5 swaps 103 for 103 and forwards to P6.

P6's next-hop for the IGP route "PE3" is not SR capable (P7 does not
advertise the SR capability). However, P6 has an LDP label binding

from that next-hop for the same FEC (e.g. LDP label 1037). Hence, P6 swaps 103 for 1037 and forwards to P7.

P7 swaps this label with the LDP-label received from P8 and forwards to P8.

P8 pops the LDP label and forwards to PE3.

PE3 receives the tunneled packet and processes the service label.

The end-to-end MPLS tunnel is built from an SR node segment from PE1 to P6 and an LDP LSP from P6 to PE3.

SR mapping advertisement for a given prefix provides no information about the Penultimate Hop Popping. Other mechanisms, such as IGP specific mechanisms ([I-D.ietf-isis-segment-routing-extensions], [I-D.ietf-ospf-segment-routing-extensions] and [I-D.ietf-ospf-ospfv3-segment-routing-extensions]), MAY be used to determine the Penultimate Hop Popping in such case.

Note: In the previous example, Penultimate Hop Popping is not performed at the SR/LDP border for segment 103 (PE3), because none of the routers in the SR domain is Penultimate Hop for segment 103. In this case P6 requires the presence of the segment 103 such as to map it to the LDP label 1037.

3.2.1. Segment Routing Mapping Server (SRMS)

This section specifies the concept and externally visible functionality of a segment routing mapping server (SRMS).

The purpose of a SRMS functionality is to support the advertisement of prefix-SIDs to a prefix without the need to explicitly advertise such assignment within a prefix reachability advertisment. Examples of explicit prefix-SID advertisment are the prefix-SID sub-TLVs defined in ([I-D.ietf-isis-segment-routing-extensions], [I-D.ietf-ospf-segment-routing-extensions], and [I-D.ietf-ospf-ospfv3-segment-routing-extensions]).

The SRMS functionality allows assigning of prefix-SIDs to prefixes owned by non-SR-capable routers as well as to prefixes owned by SR capable nodes. It is the former capability which is essential to the SR-LDP interworking described later in this section

The SRMS functionality consists of two functional blocks: the Mapping Server (MS) and Mapping Client (MC).

A MS is a node that advertises an SR mappings. Advertisements sent
by an MS define the assignment of a prefix-SID to a prefix
independent of the advertisment of reachability to the prefix itself.
An MS MAY advertise SR mappings for any prefix whether or not it
advertises reachability for the prefix and irrespective of whether
that prefix is advertised by or even reachable through any router in
the network.

An MC is a node that receives and uses the MS mapping advertisments.
Note that a node may be both an MS and an MC. An MC interprets the
SR mapping advertisment as an assignment of a prefix-SID to a prefix.
For a given prefix, if an MC receives an SR mapping advertisement
from a mapping server and also has received a prefix-SID
advertisement for that same prefix in a prefix reachability
advertisement, then the MC MUST prefer the SID advertised in the
prefix reachability advertisement over the mapping server
advertisement i.e., the mapping server advertisment MUST be ignored
for that prefix. Hence assigning a prefix-SID to a prefix using the
SRMS functionality does not preclude assigning the same or different
prefix-SID(s) to the same prefix using explicit prefix-SID
advertisement such as the aforementioned prefix-SID sub-TLVs.

For example consider an IPv4 prefix advertisement received by an IS-
IS router in the extended IP reachability TLV (TLV 135). Suppose TLV
135 contained the prefix-SID sub-TLV. If the router that receives
TLV 135 with the prefix-SID sub-TLV also received an SR mapping
advertisement for the same prefix through the SID/label binding TLV,
then the receiving router must prefer the prefix-SID sub-TLV over the
SID/label binding TLV for that prefix. Refer to
([I-D.ietf-isis-segment-routing-extensions], for details about the
prefix-SID sub-TLV and SID/label binding TLV.

3.2.2. SR to LDP Behavior

SR to LDP interworking requires a SRMS as defined above.

Each SR capable router installs in the MPLS data plane Node-SIDs
learned from the SRMS exactly like if these SIDs had been advertised
by the nodes themselves.

A SR node having LDP neighbors MUST stitch the incoming SR label
(whose SID is advertised by the SRMS) to the outgoing LDP label.

It has to be noted that the SR to LDP behavior does not propagate the
status of the LDP FEC which was signaled if LDP was configured to use
the ordered mode.

It has to be noted that in the case of SR to LDP, the label binding is equivalent to the independent LDP Label Distribution Control Mode ([RFC5036]) where a label in bound to a FEC independently from the received binding for the same FEC.

3.2.3. Interoperability of Multiple SRMSes and Prefix-SID advertisements

In the case of SR/LDP interoperability through the use of a SRMS, mappings are advertised by one or more SRMS.

SRMS function is implemented in the link-state protocol (such as IS-IS and OSPF). Link-state protocols allow propagation of updates across area boundaries and therefore SRMS advertisements are propagated through the usual inter-area advertisement procedures in link-state protocols.

Multiple SRMSs can be provisioned in a network for redundancy. Moreover, a preference mechanism may also be used among SRMSs so to deploy a primary/secondary SRMS scheme allowing controlled modification or migration of SIDs.

The content of SRMS advertisement (i.e.: mappings) are a matter of local policy determined by the operator. When multiple SRMSs are active, it is necessary that the information (mappings) advertised by the different SRMSs is aligned and consistent. The following mechanism is applied to determine the preference of SRMS advertisements:

If a node acts as an SRMS, it MAY advertise a preference to be associated with all SRMS SID advertisements sent by that node. The means of advertising the preference is defined in the protocol specific drafts e.g.,[I-D.ietf-isis-segment-routing-extensions] , [I-D.ietf-ospf-segment-routing-extensions], and [I-D.ietf-ospf-ospfv3-segment-routing-extensions]. The preference value is an unsigned 8 bit integer with the following properties:

   0 - Reserved value indicating advertisements from that node MUST NOT be used.

   1 - 255 Preference value (255 is most preferred)

Advertisement of a preference value is optional. Nodes which do not advertise a preference value are assigned a preference value of 128.

A MCC on a node receiving one or more SRMS mapping advertisements applies them as follows

- For any prefix for which it did not receive a prefix-SID advertisement, the MCC applies the SRMS mapping advertisments with the highest preference. The mechanism by which a prefix-SID is advertised for a given prefix is defined in the protocol specification , [I-D.ietf-isis-segment-routing-extensions], [I-D.ietf-ospf-segment-routing-extensions] and [I-D.ietf-ospf-ospfv3-segment-routing-extensions]

- If there is an incoming label collision as specified in [I-D.ietf-spring-segment-routing-mpls] , apply the steps specified in [I-D.ietf-spring-segment-routing-mpls] to resolve the collision.

When the SRMS advertise mappings, an implementation should provide a mechanism through which the operator determines which of the IP2MPLS mappings are preferred among the one advertised by the SRMS and the ones advertised by LDP.

4. SR/LDP Interworking Use Cases

SR can be deployed such as to enhance LDP transport. The SR deployment can be limited to the network region where the SR benefits are most desired.

4.1. SR Protection of LDP-based Traffic

In Figure 4, let us assume:

All link costs are 10 except FG which is 30.

All routers are LDP capable.

X, Y and Z are PE's participating to an important service S.

The operator requires 50msec link-based Fast Reroute (FRR) for service S.

A, B, C, D, E, F and G are SR capable.

X, Y, Z are not SR capable, e.g. as part of a staged migration from LDP to SR, the operator deploys SR first in a sub-part of the network and then everywhere.

```
                        X
                        |
                  Y--A---B---E--Z
                  |   |    \
                  D---C--F--G
                           30
```
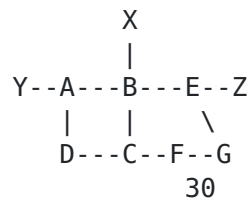
                Figure 3: SR/LDP interworking example

   The operator would like to resolve the following issues:

      To protect the link BA along the shortest-path of the important
      flow XY, B requires a Remote Loop-Free alternate (RLFA, [RFC7490])
      repair tunnel to D and hence a targeted LDP session from B to D.
      Typically, network operators prefer avoiding these dynamically
      established multi-hop LDP sessions in order to reduce the number
      of protocols running in the network and hence simplify network
      operations.

      There is no LFA/RLFA solution to protect the link BE along the
      shortest path of the important flow XZ. The operator wants a
      guaranteed link-based FRR solution.

   The operator can meet these objectives by deploying SR only on A, B,
   C, D, E, F and G:

      The operator configures A, B, C, D, E, F and G with SRGB [100,
      200] and respective node segments 101, 102, 103, 104, 105, 106 and
      107.

      The operator configures D as an SR Mapping Server with the
      following policy mapping: (X, 201), (Y, 202), (Z, 203).

      Each SR node automatically advertises local adjacency segment for
      its IGP adjacencies. Specifically, F advertises adjacency segment
      9001 for its adjacency FG.

   A, B, C, D, E, F and G keep their LDP capability and hence the flows
   XY and XZ are transported over end-to-end LDP LSP's.

   For example, LDP at B installs the following MPLS data plane entries:

   Incoming label: local LDP label bound by B for FEC Y
      Outgoing label: LDP label bound by A for FEC Y
      Outgoing next-hop: A

   Incoming label: local LDP label bound by B for FEC Z
      Outgoing label: LDP label bound by E for FEC Z

       Outgoing next-hop: E

   The novelty comes from how the backup chains are computed for these
   LDP-based entries. While LDP labels are used for the primary next-
   hop and outgoing labels, SR information is used for the FRR
   construction. In steady state, the traffic is transported over LDP
   LSP. In transient FRR state, the traffic is backup thanks to the SR
   enhanced capabilities.

   The RLFA paths are dynamically pre-computed as defined in [RFC7490].
   Typically, implementations allow to enable RLFA mechanism through a
   simple configuration command that triggers both the pre-computation
   and installation of the repair path. The details on how RLFA
   mechanisms are implemented and configured is outside the scope of
   this document and not relevant to the aspects of SR/LDP interwork
   explained in this document.

   This helps meet the requirements of the operator:

       Eliminate targeted LDP session.

       Guaranteed FRR coverage.

       Keep the traffic over LDP LSP in steady state.

       Partial SR deployment only where needed.

4.2. Eliminating Targeted LDP Session

   B's MPLS entry to Y becomes:

   - Incoming label: local LDP label bound by B for FEC Y
       Outgoing label: LDP label bound by A for FEC Y
       Backup outgoing label: SR node segment for Y {202}
       Outgoing next-hop: A
       Backup next-hop: repair tunnel: node segment to D {104}
        with outgoing next-hop: C

   It has to be noted that D is selected as Remote Loop-Free Alternate
   (RLFA) as defined in [RFC7490].

   In steady-state, X sends its Y-destined traffic to B with a top label
   which is the LDP label bound by B for FEC Y. B swaps that top label
   for the LDP label bound by A for FEC Y and forwards to A. A pops the
   LDP label and forwards to Y.

   Upon failure of the link BA, B swaps the incoming top-label with the
   node segment for Y (202) and sends the packet onto a repair tunnel to

D (node segment 104). Thus, B sends the packet to C with the label
stack {104, 202}. C pops the node segment 104 and forwards to D. D
swaps 202 for 202 and forwards to A. A's next-hop to Y is not SR
capable and hence node A swaps the incoming node segment 202 to the
LDP label announced by its next-hop (in this case, implicit null).

After IGP convergence, B's MPLS entry to Y will become:

- Incoming label: local LDP label bound by B for FEC Y
    Outgoing label: LDP label bound by C for FEC Y
    Outgoing next-hop: C

And the traffic XY travels again over the LDP LSP.

Conclusion: the operator has eliminated the need for targeted LDP
sessions (no longer required) and the steady-state traffic is still
transported over LDP. The SR deployment is confined to the area
where these benefits are required.

Despite that in general, an implementation would not require a manual
configuration of LDP Targeted sessions however, it is always a gain
if the operator is able to reduce the set of protocol sessions
running on the network infrastructure.

4.3. Guaranteed FRR coverage

As mentioned in Section 4.1 above, in the example topology described
in Figure 4, there is no RLFA-based solution for protecting the
traffic flow YZ against the failure of link BE because there is no
intersection between the extended P-space and Q-space (see [RFC7490]
for details). However:

- G belongs to the Q space of Z.

- G can be reached from B via a "repair SR path" {106, 9001} that is
   not affected by failure of link BE (The method by which G and the
   repair tunnel to it from B are identified are out of scope of this
   document.)

B's MPLS entry to Z becomes:

    - Incoming label: local LDP label bound by B for FEC Z
        Outgoing label: LDP label bound by E for FEC Z
        Backup outgoing label: SR node segment for Z {203}
        Outgoing next-hop: E
        Backup next-hop: repair tunnel to G: {106, 9001}

            G is reachable from B via the combination of a
            node segment to F {106} and an adjacency segment
            FG {9001}

            Note that {106, 107} would have equally work.
            Indeed, in many case, P's shortest path to Q is
            over the link PQ. The adjacency segment from P to
            Q is required only in very rare topologies where
            the shortest-path from P to Q is not via the link
            PQ.

   In steady-state, X sends its Z-destined traffic to B with a top label
   which is the LDP label bound by B for FEC Z. B swaps that top label
   for the LDP label bound by E for FEC Z and forwards to E. E pops the
   LDP label and forwards to Z.

   Upon failure of the link BE, B swaps the incoming top-label with the
   node segment for Z (203) and sends the packet onto a repair tunnel to
   G (node segment 106 followed by adjacency segment 9001). Thus, B
   sends the packet to C with the label stack {106, 9001, 203}. C pops
   the node segment 106 and forwards to F. F pops the adjacency segment
   9001 and forwards to G. G swaps 203 for 203 and forwards to E. E's
   next-hop to Z is not SR capable and hence E swaps the incoming node
   segment 203 for the LDP label announced by its next-hop (in this
   case, implicit null).

   After IGP convergence, B's MPLS entry to Z will become:

   - Incoming label: local LDP label bound by B for FEC Z
       Outgoing label: LDP label bound by C for FEC Z
       Outgoing next-hop: C

   And the traffic XZ travels again over the LDP LSP.

   Conclusions:

   -   the operator has eliminated its second problem: guaranteed FRR
       coverage is provided. The steady-state traffic is still
       transported over LDP. The SR deployment is confined to the area
       where these benefits are required.

- FRR coverage has been achieved without any signaling for setting
  up the repair LSP and without setting up a targeted LDP session
  between B and G.

4.4. Inter-AS Option C, Carrier's Carrier

In inter-AS Option C [RFC4364], two interconnected ASes sets up
inter-AS MPLS connectivity. SR may be independently deployed in each
AS.

```
                PE1---R1---B1---B2---R2---PE2
                <----------->   <----------->
                     AS1             AS2
```
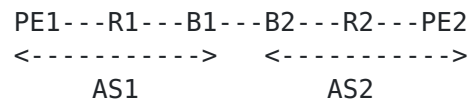
Figure 4: Inter-AS Option C

In Inter-AS Option C, B2 advertises to B1 a labeled BGP route
[RFC8277] for PE2 and B1 reflects it to its internal peers, such as
PE1. PE1 learns from a service route reflector a service route whose
next-hop is PE2. PE1 resolves that service route on the labeled BGP
route to PE2. That labeled BGP route to PE2 is itself resolved on
the AS1 IGP route to B1.

If AS1 operates SR, then the tunnel from PE1 to B1 is provided by the
node segment from PE1 to B1.

PE1 sends a service packet with three labels: the top one is the node
segment to B1, the next-one is the label in the labeled BGP route
provided by B1 for the route "PE2" and the bottom one is the service
label allocated by PE2.

5. IANA Considerations

This document does not introduce any new codepoint.

6. Manageability Considerations

6.1. SR and LDP co-existence

When both SR and LDP co-exist, the following applies:

- If both SR and LDP propose an IP2MPLS entry for the same IP
  prefix, then by default the LDP route SHOULD be selected. This is
  because it is expected that SR is introduced into network that
  contain routers that do not support SR. Hence by having a
  behavior that prefers LDP over SR, traffic flow is unlikely to be
  disrupted

   - A local policy on a router MUST allow to prefer the SR-provided
      IP2MPLS entry.

   - Note that this policy MAY be locally defined. There is no
      requirement that all routers use the same policy.

6.2. Dataplane Verification

   When Label switch paths (LSPs) are defined by stitching LDP LSPs with
   SR LSPs, it is necessary to have mechanisms allowing the verification
   of the LSP connectivity as well as validation of the path. These
   mechanisms are described in [RFC8287].

7. Security Considerations

   This document does not introduce any change to the MPLS dataplane
   [RFC3031] and therefore no additional security of the MPLS dataplane
   is required.

   This document introduces another form of label binding
   advertisements. The security associated with these advertisements is
   part of the security applied to routing protocols such as IS-IS
   [RFC5304] and OSPF [RFC5709] which both optionally make use of
   cryptographic authentication mechanisms. This form of advertisement
   is more centralized, on behalf of the node advertising the IP
   reachability, which presents a different risk profile. This document
   also specifies a mechanism by which the ill effects of advertising
   conflicting label bindings can be mitigated. In particular,
   advertisements from the node advertising the IP reachability is more
   preferred than the centralized one.

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   document.

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10. References

10.1. Normative References

[I-D.ietf-spring-segment-routing]
          Filsfils, C., Previdi, S., Decraene, B., Litkowski, S.,
          and R. Shakir, "Segment Routing Architecture", January
          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-13
          (work in progress), April 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>.

   [RFC5036] Andersson, L., Ed., Minei, I., Ed., and B. Thomas, Ed.,
              "LDP Specification", RFC 5036, DOI 10.17487/RFC5036,
              October 2007, <https://www.rfc-editor.org/info/rfc5036>.

10.2. Informative References

   [I-D.ietf-isis-segment-routing-extensions]
              Previdi, S., Ginsberg, L., Filsfils, C., Bashandy, A.,
              Gredler, H., Litkowski, S., Decraene, B., and J. Tantsura,
              "IS-IS Extensions for Segment Routing", draft-ietf-isis-
              segment-routing-extensions-18 (work in progress), June
              2018.

   [I-D.ietf-ospf-ospfv3-segment-routing-extensions]
              Psenak, P., Filsfils, C., Previdi, S., Gredler, H.,
              Shakir, R., Henderickx, W., and J. Tantsura, "OSPFv3
              Extensions for Segment Routing", draft-ietf-ospf-ospfv3-
              segment-routing-extensions-11 (work in progress), January
              2018.

   [I-D.ietf-ospf-segment-routing-extensions]
              Psenak, P., Previdi, S., Filsfils, C., Gredler, H.,
              Shakir, R., Henderickx, W., and J. Tantsura, "OSPF
              Extensions for Segment Routing", draft-ietf-ospf-segment-
              routing-extensions-24 (work in progress), December 2017.

   [RFC3031] Rosen, E., Viswanathan, A., and R. Callon, "Multiprotocol
              Label Switching Architecture", RFC 3031,
              DOI 10.17487/RFC3031, January 2001,
              <https://www.rfc-editor.org/info/rfc3031>.

   [RFC3209] Awduche, D., Berger, L., Gan, G., Li, T., Srinivasan, V.,
              and G. Srinivasan, "RSVP-TE: Extensions to RSVP for LSP
              Tunnels", December 2001.

   [RFC4364] Rosen, E. and Y. Rekhter, "BGP/MPLS IP Virtual Private
              Networks (VPNs)", RFC 4364, DOI 10.17487/RFC4364, February
              2006, <https://www.rfc-editor.org/info/rfc4364>.

   [RFC5304] Li, T. and R. Atkinson, "IS-IS Cryptographic
              Authentication", RFC 5304, DOI 10.17487/RFC5304, October
              2008, <https://www.rfc-editor.org/info/rfc5304>.

   [RFC5709] Bhatia, M., Manral, V., Fanto, M., White, R., Barnes, M.,
              Li, T., and R. Atkinson, "OSPFv2 HMAC-SHA Cryptographic
              Authentication", RFC 5709, DOI 10.17487/RFC5709, October
              2009, <https://www.rfc-editor.org/info/rfc5709>.

   [RFC5960] Frost, D., Ed., Bryant, S., Ed., and M. Bocci, Ed., "MPLS
              Transport Profile Data Plane Architecture", RFC 5960,
              DOI 10.17487/RFC5960, August 2010,
              <https://www.rfc-editor.org/info/rfc5960>.

   [RFC7490] Bryant, S., Filsfils, C., Previdi, S., Shand, M., and N.
              So, "Remote Loop-Free Alternate (LFA) Fast Reroute (FRR)",
              RFC 7490, DOI 10.17487/RFC7490, April 2015,
              <https://www.rfc-editor.org/info/rfc7490>.

   [RFC8277] Rosen, E., "Using BGP to Bind MPLS Labels to Address
              Prefixes", October 2017.

   [RFC8287] Kumar, N., Pignataro, C., Swallow, G., Akiya, N., Kini,
              S., and M. Chen, "Label Switched Path (LSP) Ping/
              Traceroute for Segment Routing (SR) IGP-Prefix and IGP-
              Adjacency Segment Identifiers (SIDs) with MPLS Data
              Planes", December 2017.

   [RFC8355] Filsfils, C., Previdi, S., Decraene, B., and R. Shakir,
              "Resiliency Use Cases in Source Packet Routing in
              Networking (SPRING) Networks", March 2018.

Appendix A. Migration from LDP to SR

```
                    PE2           PE4
                      \           /
                PE1----P5--P6--P7---PE3
```
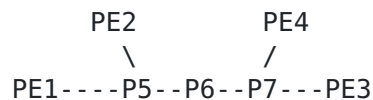
Figure 5: Migration

   Several migration techniques are possible. The technique described
   here is inspired by the commonly used method to migrate from one IGP
   to another.

   At time T0, all the routers run LDP. Any service is tunneled from an
   ingress PE to an egress PE over a continuous LDP LSP.

   At time T1, all the routers are upgraded to SR. They are configured
   with the SRGB range [100, 300]. PE1, PE2, PE3, PE4, P5, P6 and P7
   are respectively configured with the node segments 101, 102, 103,
   104, 105, 106 and 107 (attached to their service-recursing loopback).

   At this time, the service traffic is still tunneled over LDP LSP.
   For example, PE1 has an SR node segment to PE3 and an LDP LSP to
   PE3 but by default, as seen earlier, the LDP IP2MPLS encapsulation
   is preferred. However, it has to be noted that the SR
   infrastructure is usable, e.g. for Fast Reroute (FRR) or IGP Loop
   Free Convergence to protect existing IP and LDP traffic. FRR
   mechanisms are described in and [RFC8355].

   At time T2, the operator enables the local policy at PE1 to prefer SR
   IP2MPLS encapsulation over LDP IP2MPLS.

   The service from PE1 to any other PE is now riding over SR. All
   other service traffic is still transported over LDP LSP.

   At time T3, gradually, the operator enables the preference for SR
   IP2MPLS encapsulation across all the edge routers.

   All the service traffic is now transported over SR. LDP is still
   operational and services could be reverted to LDP.

   At time T4, LDP is unconfigured from all routers.

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