SPRING Working Group   W. Cheng
Internet-Draft   China Mobile
Intended status: Standards Track   Z. Li
Expires: March 14, 2021   C. Li
                                                  Huawei Technologies
                                                           C. Xie
                                                           C. Li
                                                     China Telecom
                                                           H. Tian
                                                           F. Zhao
                                                            CAICT
                                                 September 10, 2020

                    Generalized SRv6 Network Programming
                    draft-cl-spring-generalized-srv6-np-02

Abstract

   As the deployment of SRv6, some new requirements are proposed, such
   as SRv6 compression, transporting over SR-MPLS/MPLS and IPv4 domains.
   Therefore, it is necessary to consider other types of segments or
   sub-paths in the end-to-end SRv6 network programming.

   This document proposes Generalized Segment Routing over IPv6 (G-SRv6)
   Networking Programming, which supports to encode multiple types of
   Segments in a SRH, called Generalized SRH (G-SRH). These Segments
   can be called Generalized Segment, and the ID can be Generalized
   Segment Identifier (G-SID), which may include an SRv6 SID(128 bits),
   C-SIDs, MPLS labels, or IPv4 tunnel information.

   This document also defines the mechanisms of Generalized SRv6
   Networking Programming and the requirements of related protocol
   extensions of control plane and data plane.

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 March 14, 2021.

Table of Contents

1. Introduction

   Segment routing (SR) [RFC8402] is a source routing paradigm that
   explicitly indicates the forwarding path for packets at the ingress
   node by inserting an ordered list of instructions, called segments.

   When segment routing is deployed on the IPv6 data plane, it is called
   SRv6 [I-D.ietf-6man-segment-routing-header]. For support of SR, a
   new routing header called Segment Routing Header (SRH), which
   contains a list of SIDs and other information, has been defined in
   [I-D.ietf-6man-segment-routing-header]. In use cases like Traffic
   Engineering, an ordered SID List with multiple SIDs is inserted into
   the SRH to steer packets along an explicit path.

   As the deployment of SRv6, some new requirements are proposed, such
   as SRv6 compression, transporting over SR-MPLS/MPLS and IPv4 domains.
   Therefore, it is necessary to consider other types of segments or
   sub-paths in the end-to-end SRv6 network programming.

   This document proposes Generalized Segment Routing over IPv6 (G-SRv6)
   Networking Programming, which supports to encode multiple types of
   Segments in a SRH, called Generalized SRH (G-SRH). These Segments
   can be called Generalized Segment, and the ID can be Generalized

Segment Identifier (G-SID), which may include an SRv6 SID(128 bits), C-SIDs, MPLS labels, or IPv4 tunnel information.

This document also defines the mechanisms of Generalized SRv6 Networking Programming and the requirements of related protocol extensions of control plane and data plane.

2. Terminology

This document makes use of the terms defined in [I-D.ietf-6man-segment-routing-header], [RFC8402] and [RFC8200], and the reader is assumed to be familiar with that terminology. This document introduces the following terms:

SRv6 SID: The 128-bit segment identifier is introduced in [I-D.ietf-spring-srv6-network-programming]. It is always composed by locator, function and/or arguments.

C-SRv6: Compressed SRv6 Network Programming

Compressable SID: It is the 128-bit SRv6 SID which can be compressed. It is composed by Common Prefix and Compressed Segment Identifier (C-SID) and optional arguments.

Common Prefix: It is the same prefix shared by multiple Compressable SIDs.

C-SID: Compressed Segment Identifier [I-D.li-spring-compressed-srv6-np]. It is the remaining part of Compressable SID removing Common Prefix and arguments. The recommended length of C-SIDs is 32 bits.

C-SRH: Compressed Segment Routing Header. It is the enhanced SRH used for C-SRv6.

G-SRv6: Generalized SRv6 Network Programming

G-SID: Generalized Segment Identifier.

G-SRH: Generalized Segment Routing Header. It is the enhanced SRH used for G-SRv6.

Compression G-SID: It is the G-SID for encapsulating C-SIDs.

MPLS G-SID: It is the G-SID for encapsulating MPLS label stack encapsulation information.

IPv4 G-SID: It is the G-SID for encapsulating IPv4 tunnel
information.

SRv6 Compression Sub-path: It is the path for crossing the SRv6
compression domain in the end-to-end G-SRv6 path.

SR-MPLS Sub-path: It is the path for crossing the SR-MPLS domain in
the end-to-end G-SRv6 path.

IPv4 Tunnel Sub-path: It is the IPv4 tunnel path for crossing the
IPv4 domain in the end-to-end G-SRv6 path.

2.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and
"OPTIONAL" in this document are to be interpreted as described in BCP
14 [RFC2119] [RFC8174] when, and only when, they appear in all
capitals, as shown here.

3. Requirements

This section describes the requirements of G-SRv6.

3.1. Crossing C-SRv6 Domains

The overhead of SIDs (16 bytes per SID) in SRH proposes challenges
for packet processing and payload efficiency. For addressing this
problem, some solutions are proposed. For example,
[I-D.li-spring-compressed-srv6-np] proposes Compressed SRv6 Network
programming(C-SRv6).

In an SRv6 domain, the SIDs will be allocated from an address block,
called SID space. For routing within an SRv6 domain, the SIDs may
have the same prefix (Common Prefix).
[I-D.li-spring-compressed-srv6-np] defines a compressed SID (C-SID)
to carry the different part of the original SRv6 SID in the SRH. The
format of a compressable SRv6 SID with 32 bit C-SID is shown in
Figure 1. The argument part is specified by use cases, and it is
zero by default. It is shared by the compressable SRv6 SIDs in a
C-SRv6 sub-path

```
    0           Variable Length          32 bits            128 bits
    +----------------------------------------------------------------+
    |            Common Prefix  | C-SID      | Argument      |
    +----------------------------------------------------------------+
    |-------- Locator ---------------->|<-FuncID->|<--Argument -->|
                                |<--->|
                                   |
                        Different part of Locator
```
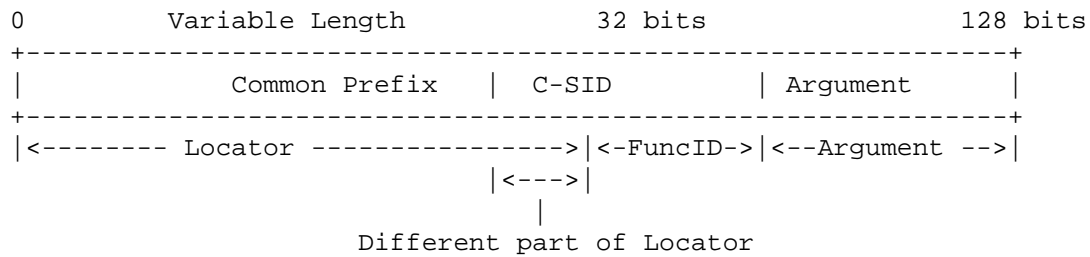
                Figure 1. 32 bits C-SID in Compressable SRv6 SID

In C-SRv6, the common prefix can be carried by the first SID in the
IPv6 destination address, while only the C-SIDs of the original SIDs
are carried in the C-SRH. In this way, the overhead of SRv6 can be
reduced.

C-SRv6 can reduce the overhead of SRH. But the C-SRv6 requires that
all the SIDs of the SRv6 path to be the compressable SRv6 SID. The
limitation causes that it does not work in the following scenarios:

Scenario 1-1:

In a single domain owing to the incremental deployment there will be
the scenario in which some nodes can support C-SRv6 while others only
support SRv6. This causes that the end-to-end SRv6 path may be
composed by both SRv6 SIDs and Compressable SRv6 SIDs. In this case
C-SRv6 cannot work and SRH has to be used for the SRv6 path.

For example, as illustrated in Figure 2, a packet is forwarded along
the path A1->A2->A3->A4->A5->A6->A7, and the SRv6 SID list is
[A::1:1, A::2:1, A::3:1, A::4:1, A::5:1, A6::6:1, A::7:10]. All the
nodes along the path support compression except A6. In this case,
the SID list can not be compressed due to A6 does not support
compression.

```
             (A::3:1)  A3------A4  (A::4:1)
                        |       |
             (A::2:1)  A2       A5  (A::5:1)
                        |       |
   Tenant10   CE1-----A0---A1------A6---A7-----CE3  Tenant10 with
               (A::1:1)(A6::6:1) (A::7:10)       IPv4 20/8
```
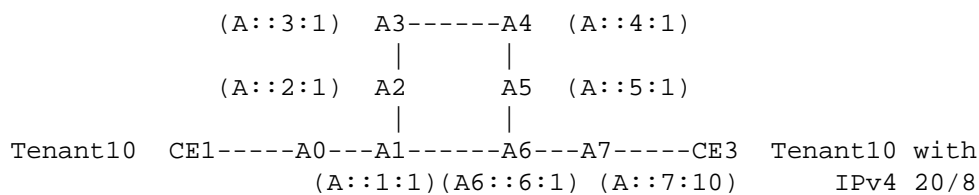
       Figure 2. SRv6 Path with SRv6 SIDs and Compressable SIDs

   Scenario 1-2:

In C-SRv6, Common Prefix must be designed for the Compressable SRv6
SIDs. But in the scenario of crossing multiple SRv6 domains, it is
very difficult to design the unified Common Prefix. It can be easy
to design its own Common Prefix in a single domain. Thus an SRv6
path crossing multiple domains may be composed by different groups of
Compressable SRv6 SIDs with different Common Prefixes, and they can
not be encoded in a single C-SRH.

For example, as illustrated in Figure 3, , a packet is forwarded
along the path A1->A2->A3->A4->B1->B2->B3->B4, and the SRv6 SID list
is [A::1:1, A::2:1, A::3:1, A:4:1, B::1:1, B::2:1, B::3:1, B:4:1].
The Common Prefix of the sub-path A1->A2->A3->A4 is A and the Common
Prefix of the sub-path B1->B2->B3->B4 is B. But the end-to-end SRv6
path cannot be compressed in a single C-SRH.

```
                 A2-----A3    B2-----B3
                  |      |     |      |
                  |      |     |      |
                  |      |     |      |
 Tenant10  CE1---A0----A1-----A4----B1-----B4-----B0---CE3  Tenant10 with
                                                            IPv4 20/8
```
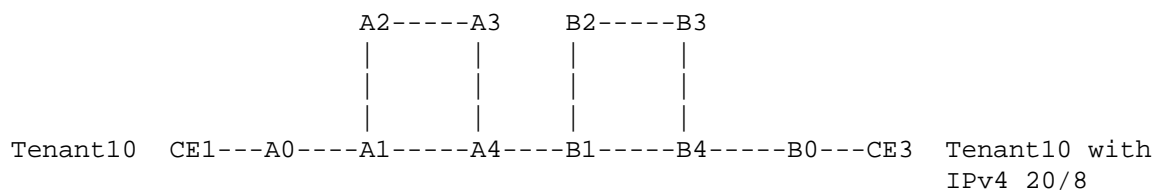
Figure 3. SRv6 Path Crossing Multiple SRv6 Compression Domains

For addressing above problems, a mechanism of encoding SRv6 SIDs and
SRv6 C-SIDs in any order in an SRH should be provided, which does not
require all the nodes along the path to support SRv6 compression.

3.2. Crossing SR-MPLS Domains

In SRv6, END.BM SID can be used for indicating an SR-MPLS Policy.
Therefore, when an SRv6 packet needs to travel an SR-MPLS path, the
associated END.BM SID should be encoded in the SID list. When the
packet arrives at the ingress node of the SR-MPLS path, an MPLS label
stack will be encapsulated to the packet according to the END.BM, and
the packet will be forwarded in the SR-MPLS domain based on the MPLS
labels.

End.BM hides the details of the SR-MPLS path, which brings benefits
on security and privacy. But it brings more network states to the
intermediate nodes of the SRv6 path. Also, when operators can manage
both the SRv6 networks and SR-MPLS networks, it can program an end-
to-end path under specific SLA assurance. If the existing SR-MPLS
path associated with END.BM can not meet the SLA requirement, then a
new END.BM SID should be configured and advertised among the
networks. This procedure increases the complexities of deploying
services.

For example, as illustrated in Figure 4, when a packet is sent from
CE1 to CE3, it may choose several paths in SR-MPLS domain, which
provide different SLA assurance. Therefore, state of multiple SR-
MPLS paths should be maintained at the node A1 and A2.

- SR-MPLS Path 1: A1->A4->A5

- SR-MPLS Path 2: A1->A2->A3->A6

- SR-MPLS Path 3: A1->A2->A3->A6->A5

- SR-MPLS Path 4: A2->A3->A6

- SR-MPLS Path 5: A2->A1->A4->A5

- SR-MPLS Path 6: A2->A1->A4->A5->A6

There will be more states of path should be maintained when the scale
of SR-MPLS domain is large.

```
                B2-------A2----A3-----A6-------B3
                 |  SRv6  |   SR-MPLS  |  SRv6  |
                 | Domain |   Domain   | Domain |
                 |        |            |        |
  Tenant10  CE1---B1-------A1----A4-----A5-------B4---CE3  Tenant10 with
                                                             IPv4 20/8
```
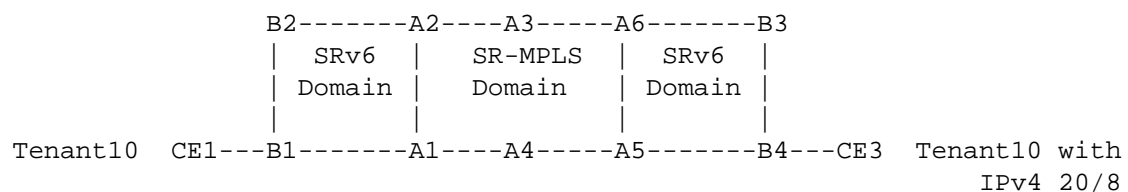
                Figure 4. SRv6 Path Crossing SR-MPLS Domains

In order to program SR-MPLS sub-path more flexible and reduce the
states on the intermediate nodes, a mechanism for encoding SRv6 SID
and MPLS labels should be provided. In this way, the ingress node of
the path can program the end-to-end path including the SRv6 sub-path
and the SR-MPLS sub-path, and no state of MPLS sub-path will be
maintained.

3.3. Crossing IPv4 Domains

In some scenarios such as SD-WAN an SRv6 packet may cross an IPv4
domain, and the SRv6 packets will be transported by the IPv6 over
IPv4 tunnel. Similar to SR-MPLS, there can be two options for
indicating the IPv4 tunnel.

o Option A: the IPv4 tunnel binding SID in SRH

o Option B: the IPv4 tunnel parameters in SRH

For IPv4 tunnel binding SID, the ingress node of IPv4 tunnel should
maintain the states of this tunnel.

For example, as illustrated in Figure 5, when a packet is sent from
CE1 to CE3, it may choose several paths in the IPv4 domain.
Therefore, state of multiple IPv4 tunnels should be maintained at the
node A1 and A2.

- IPv4 Tunnel 1: Source Address A1, Destination Address A5

- IPv4 Tunnel 2: Source Address A1, Destination Address A6

- IPv4 Tunnel 3: Source Address A2, Destination Address A5

- IPv4 Tunnel 4: Source Address A2, Destination Address A6

There will be more states of IPv4 tunnels should be maintained when
the scale of the IPv4 domain is large.

```
              B2-------A2----A3-----A6-------B3
              |  SRv6  |   IPv4   |  SRv6  |
              | Domain |  Domain  | Domain |
              |        |          |        |
   Tenant10  CE1---B1-------A1----A4-----A5-------B4---CE3  Tenant10 with
                                                           IPv4 20/8
```
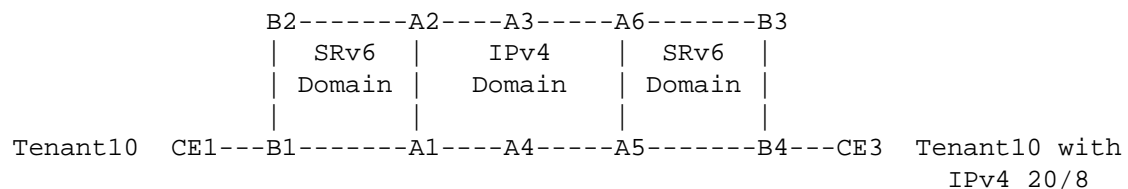
               Figure 5. SRv6 Path Crossing IPv4 Domains

The second option can be adopted to carry the IPv4 tunnel information
explicitly in the SRH. At the ingress of the IPv4 tunnel, an IPv4
tunnel header will be encapsulated to the packet according to the
IPv4 tunnel information in the SRH. In order to support encoding
IPv4 tunnel information in SRH, new mechanisms are required.

4. Concept of Generalized SRv6

According to the requirements described above, this document proposes
Generalized SRv6, which supports to encode multiple types of Segment
ID in a single SRH for an end-to-end Generalized SRv6 path that
travels multiple types of networks, such as SRv6 domains, Compressed
SRv6 domains, SR-MPLS domains and IPv4 domains.

In order to support G-SRv6, this document proposes some enhancements
of SRH. This enhanced SRH is called Generalized SRH (G-SRH). The
Segments encoded in a G-SRH is called General Segments and its ID is
called Generalized SID (G-SID). A G-SID is a 128 bits value, and it
may contain:

   o an SRv6 SID

   o a compression G-SID

   o an MPLS G-SID

   o an IPv4 G-SID

4.1. SRv6 G-SID

   SRv6 SID is a type of G-SID. A G-SID contains a single SRv6 SID, and
   does not change anything of SRv6 SID.

4.2. Compression G-SID

   As per [I-D.li-spring-compressed-srv6-np], a C-SID is a sub-set of a
   compressable SRv6 SID, which can be used for routing the packets in
   compressed SRv6 network programming.

   A compression G-SID shown in Figure 6 may contains several C-SIDs and
   optional padding. When C-SID is a 32 bits value, a compression G-SID
   can consist of 4 C-SIDs. If the length of C-SIDs in a G-SID is less
   than 128 bits, then padding is required.

```
  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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           C-SID 0                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           C-SID 1                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           C-SID 2                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           C-SID 3                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                              (a)

  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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           Padding                            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           Padding                            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           C-SID 0                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           C-SID 1                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                              (b)
```

Figure 6. Compression G-SID

4.3. MPLS G-SID

   An MPLS G-SID shown in Figure 7 may contains 4 MPLS Label
   Encapsulations, if number of MPLS Label Encapsulations is less than
   4, then padding is required in G-SID for aligning with 128 bits.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Label 0                   | TC  |S|    TTL     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Label 1                   | TC  |S|    TTL     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Label 2                   | TC  |S|    TTL     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Label 3                   | TC  |S|    TTL     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                              (a)

 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Padding                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Padding                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Label 0                   | TC  |1|    TTL     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Label 1                   | TC  |S|    TTL     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                              (b)
```
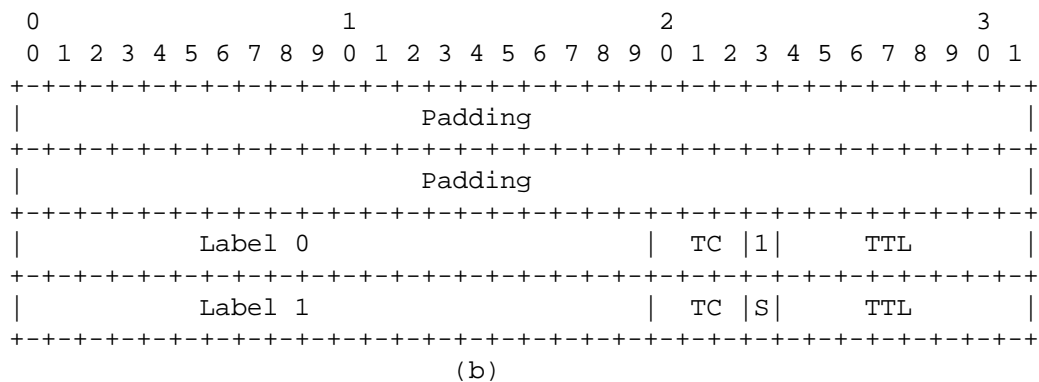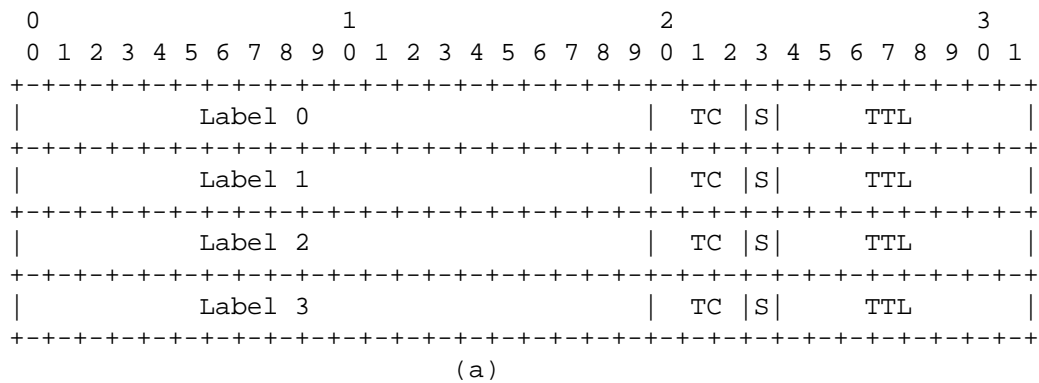
Figure 7. MPLS G-SID

   In order to indicate the MPLS G-SID, this document proposes a END.M
   (End function with SR-MPLS path instantiation), this will be
   described in section 6.

   An MPLS G-SID appears after the END.M SID, and it can not be the last
   G-SID in the G-SID list.

4.4. IPv4 G-SID

   An IPv4 G-SID shown in Figure 8 contains 128 bits IPv4 tunnel related
   information. The format of IPv4 G-SID is shown below.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Type  |               Tunnel Parameters                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      IPv4 Src Address                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      IPv4 Dest Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Tunnel Parameters                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
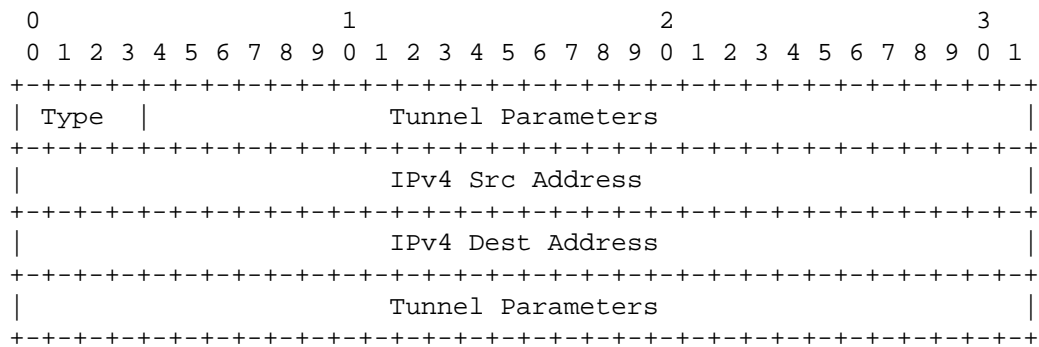
                        Figure 8. IPv4 G-SID

   In order to indicate the IPv4 G-SID, this document proposes a END.4
   (End function with IPv4 tunnel instantiation), this will be described
   in section 7. The detailed encoding of IPv4 tunnel G-SID is also
   described in section 7.

   An IPv4 G-SID appears after the End.4 SID, and it can not be the last
   G-SID in the G-SID list.

5. G-SRv6 for Crossing SRv6 Compression Domains

   This section describes the mechanism of G-SRv6 for crossing SRv6
   Compression Domains.

5.1. Mechanisms

   The path for crossing SRv6 Compression Domain is called Compressed
   SRv6 sub-path. It should be encoded in any location of a G-SRH.
   There are following aspects should be considered in this mechanism:

   o Compression SID indication

   o C-SID length indication

   o Start of C-SIDs indication

   o End of C-SIDs indication

5.1.1. Compressable SID Indication

   A new flavor can be introduced to indicate that an SRv6 SID is
   compressable. There are two options for the definition of the
   flavor:

   o Option A: If the Compressable flavor is set for a specific SRv6
      SID, it means that the SRv6 SID can be used as normal SRv6 SID and
      also can be used as Compressable SRv6 SID.

   o Option B: If the Compressable flavor is set for a specific SRv6
      SID, it means that the SRv6 SID can only be used as Compressable
      SRv6 SID. In this option, if an SRv6 SID is already allocated and
      the compression requirement is proposed, a new SRv6 SID has to be
      allocated as the Compressable SRv6 SID for the same function.

   Though the Option B may use more SRv6 SIDs for the purpose of
   compression, it has much advantages in the incremental deployment.
   This document recommends the Option B.

5.1.2. C-SID Length Indication

   Compresable SRv6 SID can be represented as Common Prefix +
   C-SID+(Optional) Argument. There can be multiple options for the
   length of C-SID as follows:

   o Option A: a variable length in bytes

   o Option B: optional length such as 16/32/64 bits

   o Option C: only one option, 32 bits

   Though the length of C-SID can be configured locally or advertised by
   protocol extensions, the different length of C-SID will increase the
   complexity of process of control plane and data plane which is not
   necessary. This document recommends Option C which is a ideal
   tradeoff between the compression and the enough space for node ID and
   SRv6 Function.

5.1.3. Start of Compression Indication

   In G-SRv6, if the SID list of an SRv6 sub-path consists of a list of
   compressable SIDs, it can be programmed as follows: the first
   compressable SID indicates the start of C-SRv6 sub-path, followed by
   compressable G-SIDs, which includes C-SIDs and padding if the number
   of (32 bits) C-SIDs is less than 4 in a G-SID. The format of
   programmed SRv6 compression sub-path is shown in Figure 9.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   .                              ...                              .
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Compression G-SID 1                     |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Compression G-SID 2                     |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Compressable SRv6 SID                   |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
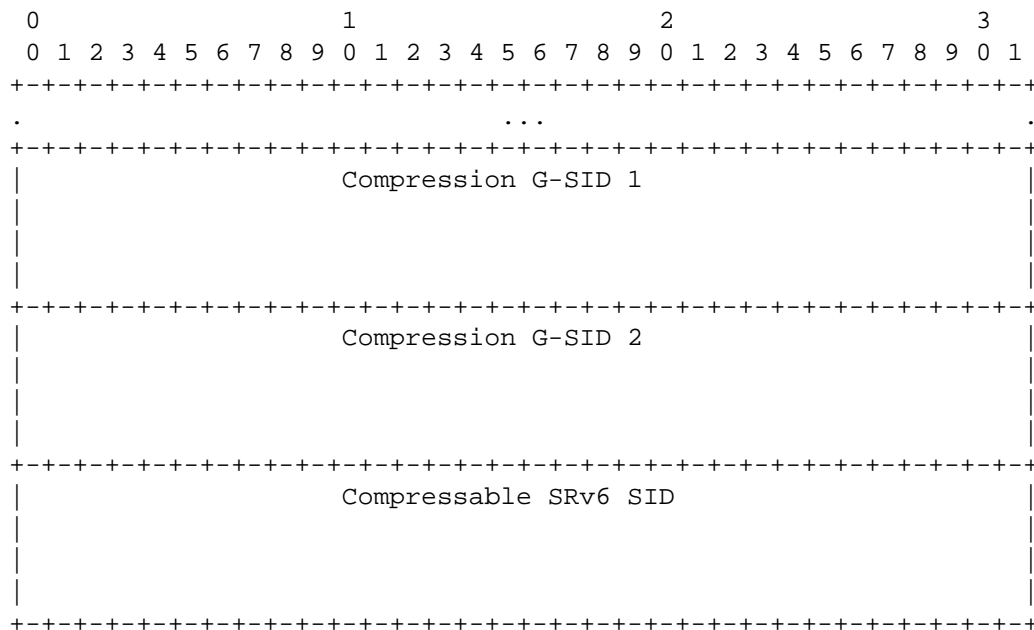
           Figure 9. G-SID list for SRv6 Compression Path

5.1.4. End of Compression Indication

   Since C-SIDs and SRv6 SIDs can be encoded in any order in an SRH, a
   mechanism for indicating the end of compression is needed. There are
   mainly two options for the indication of the end of compression as
   follows:

   o Option A: an EOC (End of Compression) flavor is introduced when
      advertise Compressable SRv6 SID. When the node determines the
      IPv6 destination address of SRv6 packet is the Compresable SRv6
      SID with EOC flavor, meaning the associated C-SID is the last
      C-SID in the G-SID, and it will skip the G-SID in which the
      corresponding C-SID located and read the following 128-bit SRv6
      SID.

   o Option B: an EOC C-SID is introduced in the G-SID to indicate the
      end of the compression. The length of EOC C-SID is a 32 bits
      value, and the it's value can be a well-known value such as 0 or a
      node allocated value. If the number of C-SIDs in a Compression
      G-SID is less than 4, the EOC can be used as the . If there are 4
      C-SIDs in the last G-SID of Compressed SRv6 sub-path, it has to
      insert a G-SID composed by 4 EOCs.

The different options for indication of end of compression are shown
in Figure 10.
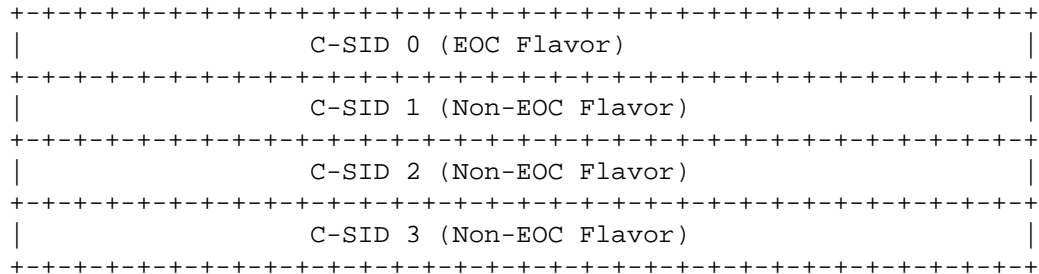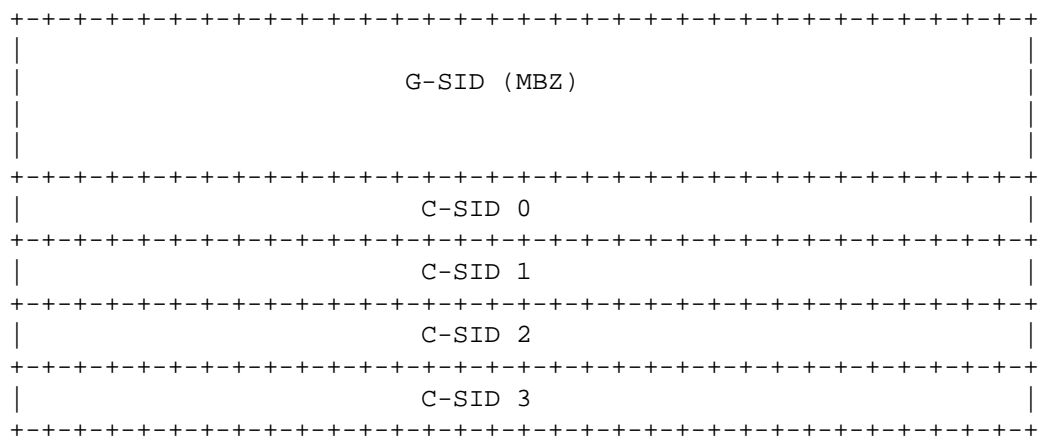
```
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    C-SID 0 (EOC Flavor)                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    C-SID 1 (Non-EOC Flavor)                   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    C-SID 2 (Non-EOC Flavor)                   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    C-SID 3 (Non-EOC Flavor)                   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                           (a) Option A

    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                              |
    |                                                              |
    |                       G-SID (MBZ)                            |
    |                                                              |
    |                                                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         C-SID 0                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         C-SID 1                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         C-SID 2                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         C-SID 3                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                           (b) Option B

             Figure 10. End of Compression Indication
```

5.1.5. Micro SID in G-SRv6 Compression

   The Micro SID instruction is proposed at
   [I-D.filsfils-spring-net-pgm-extension-srv6-usid], and it can be used
   for forwarding SRv6 packets by shifting the IPv6 DA. The Micro SID
   Carrier can be seen as a type of G-SID and can be directly used for
   G-SRv6 as shown in Figure 11 (a).

   The compressable SRv6 SID can also be used as the Micro SID and
   encapsulated in the Micro SID Carrier. As shown in Figure 11 (b),
   the first compressable SRv6 SID for the sub-path crossing SRv6
   compression domain can be changed to a Micro SID carrier with the

   locator block and multiple uSIDs which are also C-SIDs. Therefore,
   multiple C-SIDs can be updated to the IPv6 DA in a single time.

   After shifting the Micro SIDs in IPv6 DA and if the last Micro SID is
   the C-SID without EOC flavor, the following multiple C-SIDs (Micro
   segments) in the G-SID will be updated to the IPv6 DA instead of the
   Micro SID carrier and the location of the C-SIDs in the G-SID is
   recorded. If the rest C-SIDs in the current G-SID is less than the
   C-SIDs should be copied to the IPv6 DA using as the Micro SID carrier
   in a single time, only the rest C-SIDs will be copied to the IPv6 DA.
   The next copy will begin with the first C-SID in the next G-SID. The
   end of the C-SIDs shifting is indicated by a EOC flavor C-SID. When
   an EOC flavor C-SID is processed, the next 128-bits G-SID will be
   updated to the IPv6 DA.
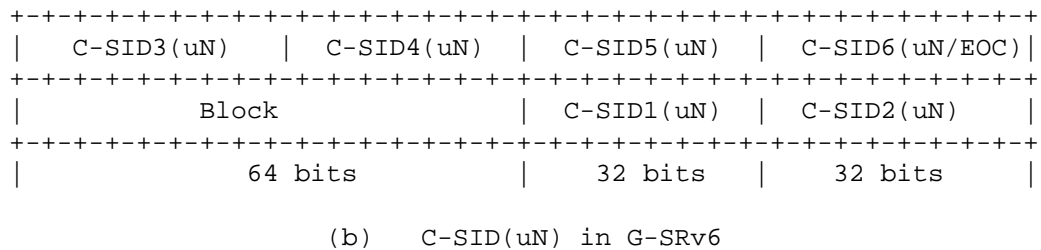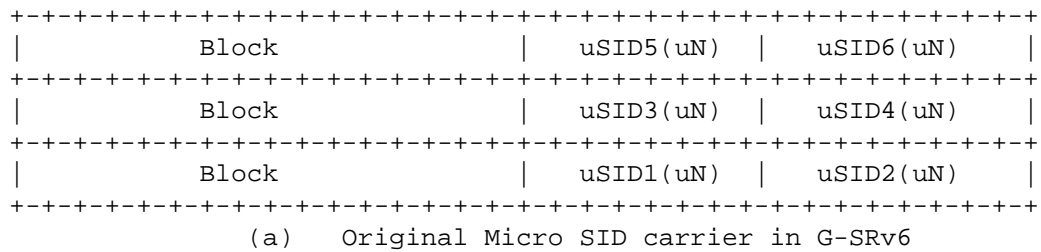
```
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Block               |   uSID5(uN)  |   uSID6(uN)    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Block               |   uSID3(uN)  |   uSID4(uN)    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Block               |   uSID1(uN)  |   uSID2(uN)    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
              (a)   Original Micro SID carrier in G-SRv6


    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |  C-SID3(uN)   |  C-SID4(uN)   |  C-SID5(uN)   |  C-SID6(uN/EOC)|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Block               |  C-SID1(uN)  |  C-SID2(uN)    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |             64 bits            |   32 bits    |   32 bits      |

              (b)   C-SID(uN) in G-SRv6

           Figure 11. Micro SID using in G-SRv6
```

   In this mechanism, more SRH overhead can be reduced but it also
   brings limitation of address planning and extra complexities. The
   details will be discussed in the future version.

5.2. Illustration

   According to the above mechanisms, the scenarios shown in the section
   3.1 can be encoded as follows:

   Scenario 1-1:

   Assuming that

   o A::1:1, A::2:1, A::3:1, A::4:1, A::5:1 are the Compressable SIDs.

   o A::1:2, A::2:2, A::3:2, A::4:2, A::5:2 are the Compressable SIDs
      with EOC flavor.

   The programmed G-SRv6 path A1->A2->A3->A4->A5->A6->A7 is shown in
   Figure 12:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            A::7:10                            |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            A6::6:1                            |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                              5:2                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                              4:1                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                              3:1                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                              2:1                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            A1::1:1                            |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

              Figure 12. G-SRv6 Path for Scenario 1-1

   Scenario 1-2:

   The programmed G-SRv6 path A1->A2->A3->A4->B1->B2->B3->B4 is shown in
   Figure 13:

```
          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
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                           Padding                             |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                            4:2                                |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                            3:1                                |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                            2:1                                |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                           B::1:1                              |
         |                                                               |
         |                                                               |
         |                                                               |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                           Padding                             |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                            4:2                                |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                            3:1                                |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                            2:1                                |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
         |                           A::1:1                              |
         |                                                               |
         |                                                               |
         |                                                               |
         +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
               Figure 13. G-SRv6 Path for Scenario 1-2
```
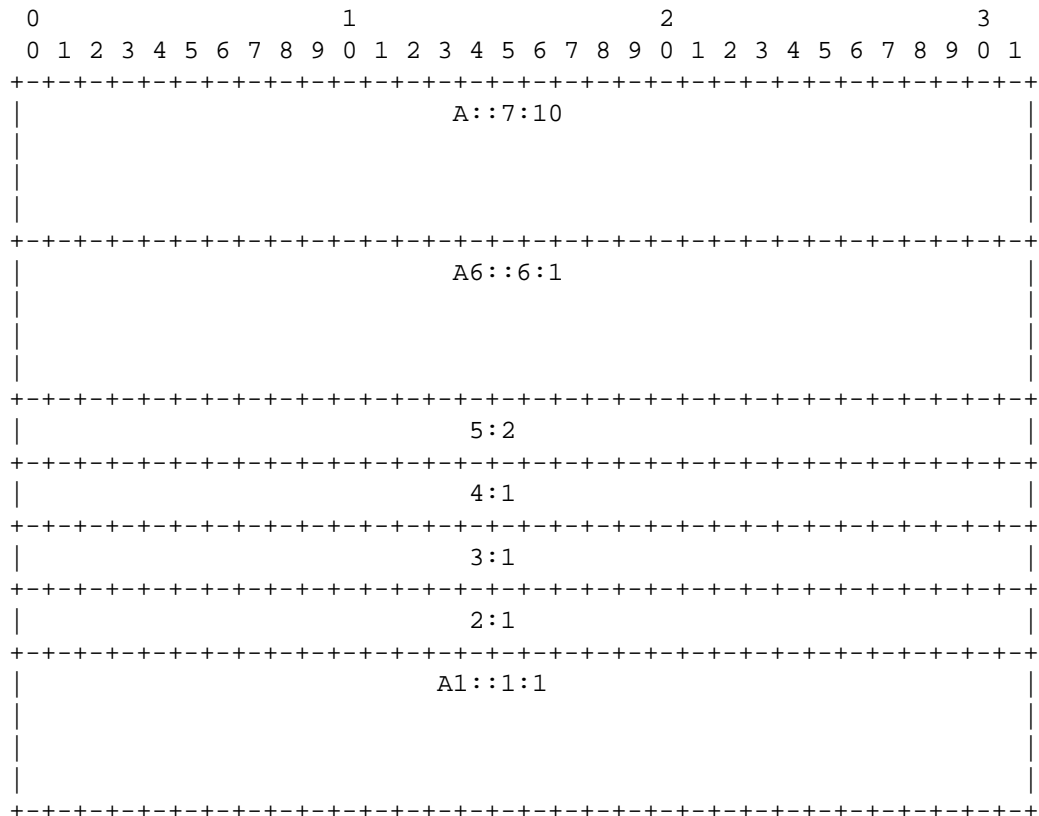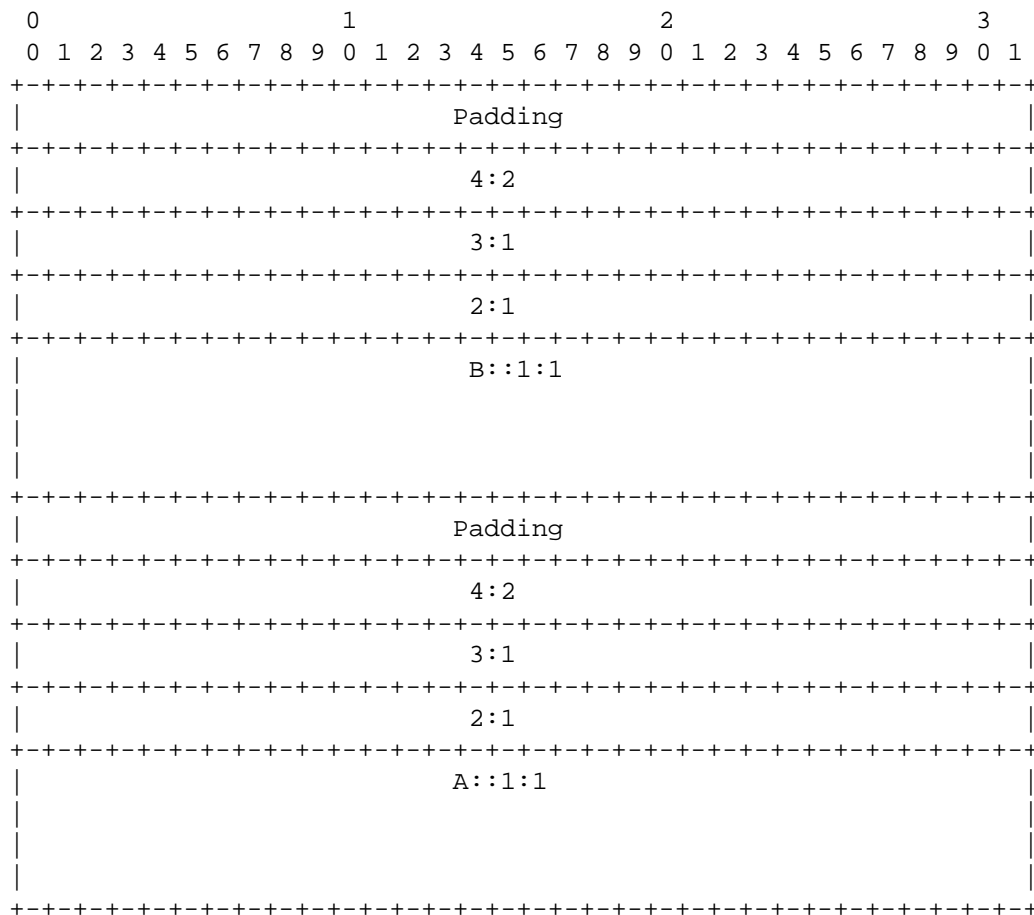
   In reduced mode, the SID A::1:1 can be removed from the G-SRH.

   The mechanism of indicating the C-SIDs within the G-SID will be
   described in the document of G-SRH.

5.3. Effect on SRv6

   G-SRv6 provides the flexibility of encoding SRv6 SID and SRv6 C-SID
   in a single SRH, which supports to program an SRv6 path that consists
   of compression capable and compression incapable nodes. In this
   case, G-SRv6 solves the problem of SRv6 overhead with a limited
   effect on SRv6.

   o Independent with SRv6: G-SRv6 does not require that the SRv6 SID
      Space has the common prefix for supporting compression. A new
      address block can be allocated for compressable SID, and the

common prefix of Compressable SIDs can be configured with
appropriate length.

o Incremental upgrade: G-SRv6 does not require to upgrade all the
   nodes along the path to support SRv6 compression, they can be
   upgraded on demand to support compression.

5.4. Protocol Extensions Requirements

This section describes the protocol extension requirements.

5.4.1. Data Plane

REQ1-01: An SRv6 compression path can be represented as a G-SID list
consists of a compressable SRv6 SID and Compression G-SIDs.

REQ1-02: A Compression G-SID consists of at most 4 (32-bits) C-SIDs,
if the number of C-SID is less than 4, then padding is required to
align with 128 bits.

REQ1-03: If the first Compressable SID is copied to the IPv6 DA, then
the C-SIDs of the following G-SIDs should be read by the nodes along
the SRv6 compression sub-path and the C-SID part in IPv6 DA should be
replaced accordingly.

REQ1-04: The last C-SID in the G-SIDs for the SRv6 compression sub-
path should be the Compressable SRv6 SID with EOC flavor.

REQ1-05: When process the Compressalbe SRv6 SID with EOC flavor in
the IPv6 DA, the corresponding G-SID in the G-SRH should be skipped
and the IPv6 DA should be updated by the following SRv6 SID if
exists.

5.4.2. Control Plane

REQ1-11: ISIS/OSPF/BGP-LS extensions for advertising the G-SRv6 for
SRv6 compression capabilities

REQ1-12: ISIS/OSPF/BGP-LS/BGP extensions for advertising the
Compression flavor for Compressable SIDs.

REQ1-13: ISIS/OSPF/BGP-LS extensions for advertising the End-of-
compression(EOC) flavor for Compressable SIDs.

REQ1-14: ISIS/OSPF/BGP-LS/BGP extensions for advertising the format
of Compressable SIDs.

   REQ1-21: BGP SRv6 Policy extensions for advertising the G-SRv6 for
   SRv6 compression capabilities.

   REQ1-22: BGP SR Policy extensions for programming a G-SRv6 path
   combining with Compressable SRv6 SIDs and SRv6 SIDs.

   REQ1-31: PCEP SRv6 Policy extensions for advertising the G-SRv6 for
   SRv6 compression capabilities.

   REQ1-32: PCEP SR Policy extension for programming a G-SRv6 path
   combining with Compressable SRv6 SIDs and SRv6 SIDs.

   REQ1-33: PCEP extensions for programming a G-SRv6 path combining with
   Compressable SRv6 SIDs and SRv6 SIDs.

6. G-SRv6 for Crossing SR-MPLS Domain

   This section describes the mechanism for encoding SRv6 SIDs and MPLS
   G-SID in a single G-SRH.

6.1. Mechanisms

   The path for crossing SR-MPLS domain is called SR-MPLS sub-path. It
   can be encoded in any location of G-SRH. There are two aspects
   should be considered in this mechanism:

   o Start of MPLS G-SIDs indication

   o End of MPLS G-SIDs indication

6.1.1. Start of MPLS G-SID Indication

   In order to indicate the start of MPLS G-SIDs, new SRv6 SIDs types
   should be defined. This document defines an SID function to indicate
   the start of MPLS G-SIDs, called End.M (End with MPLS labels).

   An SR-MPLS sub-path can be encoded in the G-SRH as follows:

```
                  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


                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                 .                               ...                            .
                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                 |                          MPLS G-SID 1                         |
                 |                                                              |
                 |                                                              |
                 |                                                              |
                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                 |                          MPLS G-SID 2                         |
                 |                                                              |
                 |                                                              |
                 |                                                              |
                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                 |                          End.M SRv6 SID                       |
                 |                                                              |
                 |                                                              |
                 |                                                              |
                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
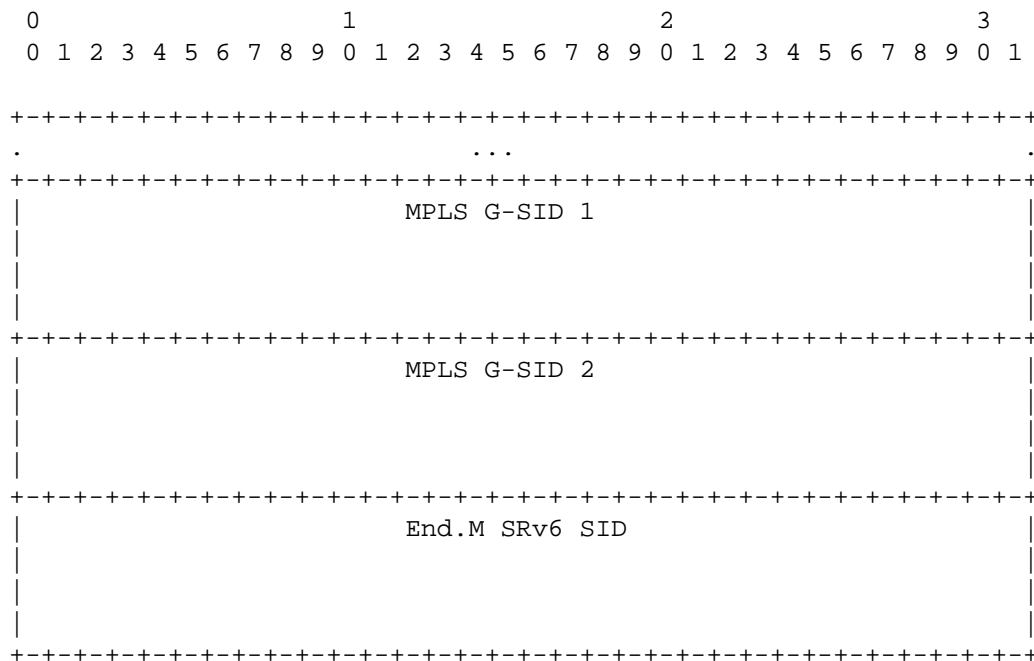
                  Figure 14. SR-MPLS Sub-path Encoding in G-SRH

   When a node processes an End.M SID, it copies the following MPLS
   label stack encapsulation information of SR-MPLS sub-path in the MPLS
   G-SIDs to the MPLS header, and set the IPv6 DA as the SRv6 SID
   following the last MPLS G-SID of the SR-MPLS sub-path, and then
   forward the packet according to the active MPLS label.

6.1.2. End of MPLS G-SID Indication

   The S-bit in the MPLS label indicates the end of the MPLS label
   within the current MPLS G-SIDs sub-list.

   When the ingress node of the SR-MPLS sub-path reads the MPLS label
   stack encapsulation information until the Label with S-bit set. If
   the S-bit is set for the label encapsulation, it will skip the G-SID
   in which the label locates and set the IPv6 DA of the SRv6 packet as
   the SRv6 SID following the G-SID if exists.

6.2. Illustration

   According to the above mechanisms, the scenarios shown in the section
   3.2 can be encoded as follows:

   Assuming that

   o A::1:100 is the End.M SID allocated by the node A1 for crossing
      SR-MPLS domain.

   o Label 1001, 1002, 1003, 1004, 1005 and 1006 are allocated as the
      node segment for A1/A2/A3/A4/A5/A6.

   The programmed G-SRv6 path B1->A1->A2->A3->A6->A5->B4 is shown in
   Figure 15:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            B::4:1                             |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            1005                     | TC |1|       TTL         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            1006                     | TC |0|       TTL         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            1003                     | TC |0|       TTL         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            1002                     | TC |0|       TTL         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       A::1:100 (End.M)                        |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            B::1:1                             |
   |                                                               |
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                   Figure 15. G-SRv6 Path for Sec 3.2

6.3. Effect on SRv6

   G-SRv6 supports to program the SRv6 SID and SR-MPLS SID/MPLS label in
   a single G-SRH, which provides to encode the end-to-end G-SRv6 path
   across SRv6 domains and SR-MPLS/MPLS domains explicitly at the
   ingress node. However, it also brings complexities of network
   programming, so this document suggests to upgrade the SR-MPLS nodes
   to support SRv6.

6.4. Protocol Extensions Requirements

   This section describes the protocol extension requirements of G-SRv6
   for MPLS G-SID.

6.4.1. Data Plane

   REQ2-01: An MPLS path can be encoded in G-SRH as a series of G-SIDs
   including a 128-bit End.M SRv6 SID and a set of MPLS G-SIDs.

   REQ2-02: An MPLS G-SID can consist of up to 4 MPLS label/SR-MPLS SID,
   if the number of MPLS label/SR-MPLS SID is less than 4, padding is
   required to align with 128 bits.

   REQ2-03: An End.M SRv6 SID indicates the start of MPLS G-SID.

   REQ2-04: The SRv6 packet can be encapsulated with an outer MPLS
   header, and the MPLS header contains the MPLS labels carried by the
   MPLS G-SIDs.

   REQ2-05: When the label encapsulation with S-bit is set is read by
   the ingress node of the SR-MPLS sub-path, the corresponding G-SID
   should be skipped and the IPv6 DA should be updated by the following
   SRv6 SID if exists.

6.4.2. Control Plane

   REQ2-11: ISIS/OSPF/BGP-LS extensions for advertising the G-SRv6 for
   MPLS capabilities

   REQ2-12: ISIS/OSPF/BGP-LS extensions for advertising the End.M SRv6
   SID.

   REQ2-21: BGP SR Policy extensions for advertising the G-SRv6 for MPLS
   capabilities

   REQ2-22: BGP SR Policy extensions for encoding G-SID list with SRv6
   SID and MPLS G-SID for G-SRv6 path.

   REQ2-31: PCEP SR Policy extensions for advertising the G-SRv6 for
   MPLS capabilities

   REQ2-31: PCEP SR Policy extensions for encoding G-SID list with SRv6
   SID and MPLS G-SID for G-SRv6 path.

   REQ2-33: PCEP extensions for encoding G-SID list with SRv6 SID and
   MPLS G-SID for G-SRv6 path.

7. G-SRv6 for Crossing IPv4 Domain

   This section describes the mechanism of G-SRv6 for crossing IPv4
   domain.

7.1. Mechanism

   The path for crossing IPv4 domain is called IPv4 tunnel sub-path. It
   should be encoded in any location of G-SRH. There are two aspects
   should be considered in this mechanism:

   o Start of IPv4 G-SID

   o IPv4 G-SID encoding

7.1.1. Start of IPv4 G-SID Indication

   In order to indicate the start of IPv4 G-SIDs, new SRv6 SIDs types
   should be defined.

   This document defines an SID function to indicate the start of IPv4
   G-SIDs, called End.4(End with IPv4 tunnel).

   When a node processes the End.4 SID, it encapsulates an outer IPv4
   tunnel header for the SRv6 packet based on the tunnel information
   carried by the following IPv4 G-SID, and set the IPv6 DA as the SRv6
   SID following the IPv4 G-SID, and then forwards the packet according
   to the IPv4 DA.

   An IPv4 tunnel sub-path can be encoded in the G-SRH as follows:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                         IPv4 G-SID                            |
   |                                                              |
   |                                                              |
   |                                                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       SRv6 End.4 SID                         |
   |                                                              |
   |                                                              |
   |                                                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
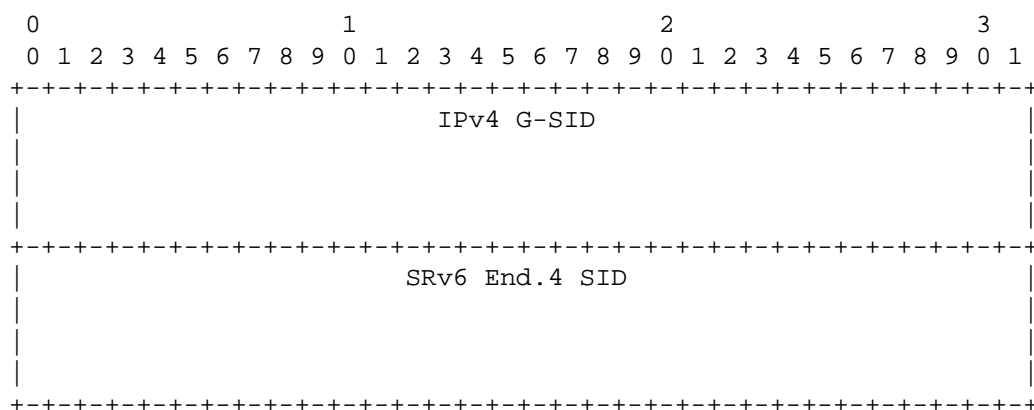
          Figure 16. IPv4 Tunnel Sub-path Encoding in G-SRH

Also, this document proposes the END.B4 (End bound to an IPv4 tunnel)
SID. A End.B4 is bound to an IPv4 tunnel. When the node receives a
packet with End.B4 SID, the packet should be steered into the binding
IPv4 tunnel.

7.1.2. IPv4 G-SID encoding

An IPv4 GID contains the IPv4 tunnel information including tunnel
type, source IPv4 address, destination IPv4 address and tunnel
parameters. Different types of IPv4 tunnels have specific
parameters:

o IPv4 UDP tunnel: the tunnel parameters includes source port and
   destination port.

o IPv4 VXLAN tunnel: the tunnel parameters includes source port,
   destination port and VN ID.

The detailed encapsulation formats for different types of IPv4 tunnel
is out of scope of the document.

7.2. Illustration

According to the above mechanisms, the scenarios shown in the section
3.3 can be encoded as follows:

Assuming that

o A::1:200 is the End.4 SID allocated by the node A1 for crossing
   IPv4 domain.

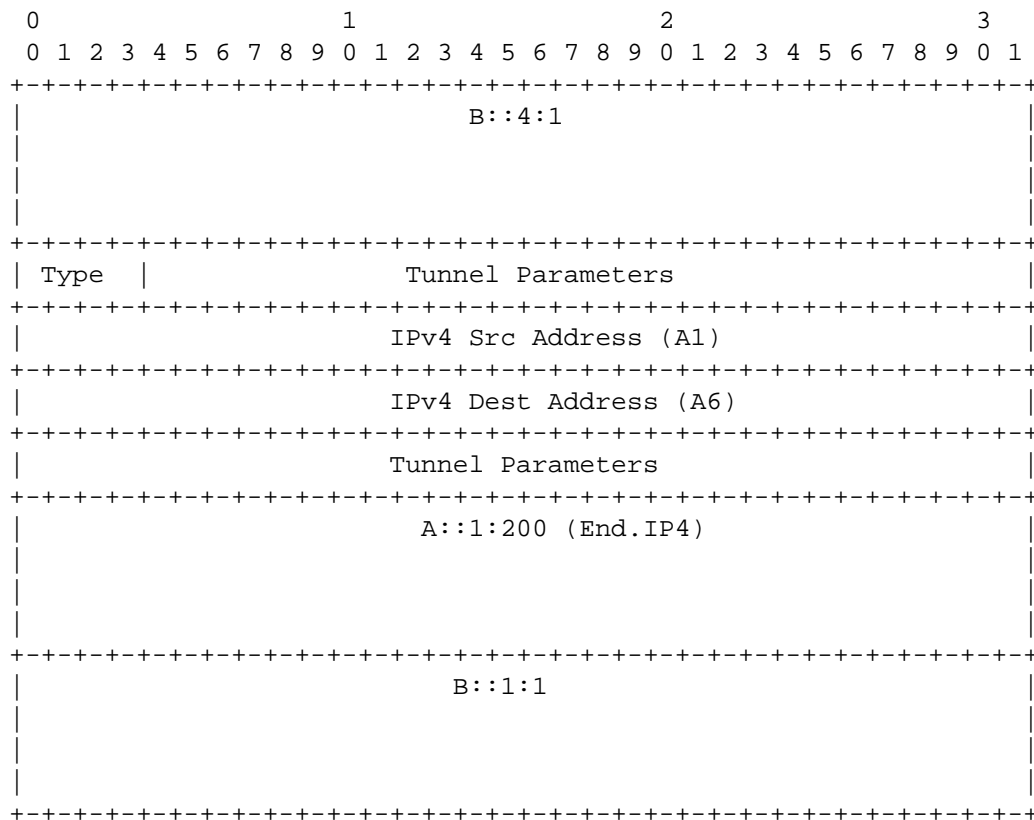The programmed G-SRv6 path B1->A1->A6->B4 is shown in Figure 17:

```
      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
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            B::4:1                            |
     |                                                             |
     |                                                             |
     |                                                             |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     | Type  |              Tunnel Parameters                      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                   IPv4 Src Address (A1)                      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                   IPv4 Dest Address (A6)                     |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                     Tunnel Parameters                        |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                     A::1:200 (End.IP4)                       |
     |                                                             |
     |                                                             |
     |                                                             |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            B::1:1                            |
     |                                                             |
     |                                                             |
     |                                                             |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                    Figure 17. G-SRv6 Path for Sec 3.3

7.3. Effect on SRv6

   G-SRv6 provides the capabilities for encoding IPv4 tunnel information
   and SRv6 SID within a single G-SRH, which brings benefits on end-to-
   end network programming on scenarios of packets traveling SRv6
   domains and IPv4 domains. However, it also brings new complexities,
   so this document suggests to upgrade the IPv4 nodes to support IPv6
   or SRv6.

7.4. Protocol Extensions Requirements

   This section describes the protocol extension requirements of G-SRv6
   for IPv4 G-SID.

7.4.1. Data Plane

   REQ3-01: An IPv4 tunnel can be encoded in G-SRH as series of G-SIDs
   including a 128 bit End.4 SRv6 SID and a set of IPv4 G-SIDs.

   REQ3-02: An IPv4 G-SID can consist of multiple IPv4 tunnel
   information, such as IPv4 source address and destination address of
   the tunnel endpoint.

   REQ3-03: An End.4 SRv6 SID indicates the start of IPv4 G-SID.

   REQ3-04: An End.B4 SRv6 SID indicates the IPv4 tunnel.

   REQ3-05: The SRv6 packet can be encapsulated with an outer IPv4
   tunnel header based on the parameters in the IPv4 G-SID.

   REQ3-06: After the tunnel information is read by the ingress node of
   the IPv4 tunnel sub-path, the corresponding G-SID should be skipped
   and the IPv6 DA should be updated by the following SRv6 SID if
   exists.

7.4.2. Control Plane

   REQ3-11: ISIS/OSPF/BGP-LS extensions for advertising the G-SRv6 for
   IPv4 capabilities

   REQ3-12: ISIS/OSPF/BGP-LS extensions for advertising the End.4 SRv6
   SID.

   REQ3-13: ISIS/OSPF/BGP-LS extensions for advertising the End.B4 SRv6
   SID.

   REQ3-21: BGP SR Policy extensions for advertising the G-SRv6 for IPv4
   capabilities

   REQ3-22: BGP SR Policy extensions for encoding G-SID list with SRv6
   SID and IPv4 G-SID for G-SRv6 path.

   REQ3-31: PCEP SR Policy extensions for advertising the G-SRv6 for
   IPv4 capabilities

   REQ3-31: PCEP SR Policy extensions for encoding G-SID list with SRv6
   SID and IPv4 G-SID for G-SRv6 path.

   REQ3-33: PCEP extensions for encoding G-SID list with SRv6 SID and
   IPv4 G-SID for G-SRv6 path.

8. IANA Considerations

   TBD

9. Security Considerations

   TBD

10. Contributors

   Zhibo Hu
   Huawei Technologies
   huzhibo@huawei.com

   Yang Xia
   Huawei Technologies
   yolanda.xia@huawei.com

11. Acknowledgements

12. References

12.1. 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,
              <https://www.rfc-editor.org/info/rfc2119>.

   [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC
              2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174,
              May 2017, <https://www.rfc-editor.org/info/rfc8174>.

   [RFC8200] Deering, S. and R. Hinden, "Internet Protocol, Version 6
              (IPv6) Specification", STD 86, RFC 8200,
              DOI 10.17487/RFC8200, July 2017,
              <https://www.rfc-editor.org/info/rfc8200>.

   [I-D.ietf-6man-segment-routing-header]
              Filsfils, C., Dukes, D., Previdi, S., Leddy, J.,
              Matsushima, S., and D. Voyer, "IPv6 Segment Routing Header
              (SRH)", draft-ietf-6man-segment-routing-header-26 (work in
              progress), October 2019.

   [RFC8402] Filsfils, C., Ed., Previdi, S., Ed., Ginsberg, L.,
              Decraene, B., Litkowski, S., and R. Shakir, "Segment
              Routing Architecture", RFC 8402, DOI 10.17487/RFC8402,
              July 2018, <https://www.rfc-editor.org/info/rfc8402>.

   [I-D.li-spring-compressed-srv6-np]
              Li, Z., Li, C., Xie, C., LEE, K., Tian, H., Zhao, F.,
              Guichard, J., Cong, L., and S. Peng, "Compressed SRv6
              Network Programming", draft-li-spring-compressed-
              srv6-np-02 (work in progress), February 2020.

12.2. Informative References

   [I-D.ietf-spring-srv6-network-programming]
              Filsfils, C., Camarillo, P., Leddy, J., Voyer, D.,
              Matsushima, S., and Z. Li, "SRv6 Network Programming",
              draft-ietf-spring-srv6-network-programming-18 (work in
              progress), August 2020.

   [I-D.filsfils-spring-srv6-net-pgm-illustration]
              Filsfils, C., Camarillo, P., Li, Z., Matsushima, S.,
              Decraene, B., Steinberg, D., Lebrun, D., Raszuk, R., and
              J. Leddy, "Illustrations for SRv6 Network Programming",
              draft-filsfils-spring-srv6-net-pgm-illustration-02 (work
              in progress), June 2020.

   [I-D.tian-spring-srv6-deployment-consideration]
              Tian, H., Zhao, F., Xie, C., Li, T., Ma, J., Mwehair, R.,
              Chingwena, E., Peng, S., Li, Z., and Y. Xiao, "SRv6
              Deployment Consideration", draft-tian-spring-srv6-
              deployment-consideration-03 (work in progress), July 2020.

   [I-D.filsfils-spring-net-pgm-extension-srv6-usid]
              Filsfils, C., Camarillo, P., Cai, D., Voyer, D., Meilik,
              I., Patel, K., Henderickx, W., Jonnalagadda, P., Melman,
              D., Liu, Y., and J. Guichard, "Network Programming
              extension: SRv6 uSID instruction", draft-filsfils-spring-
              net-pgm-extension-srv6-usid-07 (work in progress), May
              2020.

   [I-D.lc-6man-generalized-srh]
              Li, Z., Li, C., Cheng, W., Xie, C., Cong, L., Tian, H.,
              and F. Zhao, "Generalized Segment Routing Header", draft-
              lc-6man-generalized-srh-01 (work in progress), August
              2020.

Authors' Addresses

   Weiqiang Cheng
   China Mobile

   Email: chengweiqiang@chinamobile.com

   Zhenbin Li
   Huawei Technologies
   Huawei Campus, No. 156 Beiqing Rd.
   Beijing 100095
   China

   Email: lizhenbin@huawei.com

   Cheng Li
   Huawei Technologies
   Huawei Campus, No. 156 Beiqing Rd.
   Beijing 100095
   China

   Email: c.l@huawei.com

Chongfeng Xie
China Telecom
China Telecom Information Science&Technology Innovation park, Beiqijia Town,Changping District
Beijing
China

Email: xiechf@chinatelecom.cn

Cong Li
China Telecom
China Telecom Information Science&Technology Innovation park, Beiqijia Town,Changping District
Beijing
China

Email: licong@chinatelecom.cn

Hui Tian
CAICT
Beijing
China

Email: tianhui@caict.ac.cn

Feng Zhao
CAICT
Beijing
China

Email: zhaofeng@caict.ac.cn