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Segment Routing IPv6 for Mobile User Plane
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Abstract

This document shows the applicability of SRv6 (Segment Routing IPv6) to the user-plane of mobile networks. The network programming nature of SRv6 accomplish mobile user-plane functions in a simple manner. The statelessness of SRv6 and its ability to control both service layer path and underlying transport can be beneficial to the mobile user-plane, providing flexibility, end-to-end network slicing and SLA control for various applications. This document describes the SRv6 mobile user plane.

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[1.](#) Introduction

In mobile networks, mobility management systems provide connectivity over a wireless link to stationary and non-stationary nodes. The user-plane establishes a tunnel between the mobile node and its anchor node over IP-based backhaul and core networks.

This document shows the applicability of SRv6 (Segment Routing IPv6) to mobile networks.

Segment Routing [[RFC8402](#)] is a source routing architecture: a node steers a packet through an ordered list of instructions called "segments". A segment can represent any instruction, topological or service based.

SRv6 applied to mobile networks enables a source-routing based mobile architecture, where operators can explicitly indicate a route for the packets to and from the mobile node. The SRv6 Endpoint nodes serve as mobile user-plane anchors.

[2.](#) Conventions and Terminology

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

[2.1.](#) Terminology

- o CNF: Cloud-native Network Function
- o NFV: Network Function Virtualization
- o PDU: Packet Data Unit
- o PDU Session: Context of an UE connects to a mobile network.
- o UE: User Equipment
- o UPF: User Plane Function
- o VNF: Virtual Network Function (including CNFs)

The following terms used within this document are defined in [[RFC8402](#)]: Segment Routing, SR Domain, Segment ID (SID), SRv6, SRv6

SID, Active Segment, SR Policy, Prefix SID, Adjacency SID and Binding SID.

The following terms used within this document are defined in [\[RFC8754\]](#): SRH, SR Source Node, Transit Node, SR Segment Endpoint Node and Reduced SRH.

The following terms used within this document are defined in [\[NET-PGM\]](#): NH, SL, FIB, SA, DA, SRv6 SID behavior, SRv6 Segment Endpoint Behavior.

2.2. Conventions

An SR Policy is resolved to a SID list. A SID list is represented as <S1, S2, S3> where S1 is the first SID to visit, S2 is the second SID to visit and S3 is the last SID to visit along the SR path.

(SA,DA) (S3, S2, S1; SL) represents an IPv6 packet with:

- Source Address is SA, Destination Address is DA, and next-header is SRH
- SRH with SID list <S1, S2, S3> with Segments Left = SL
- Note the difference between the <> and () symbols: <S1, S2, S3> represents a SID list where S1 is the first SID and S3 is the last SID to traverse. (S3, S2, S1; SL) represents the same SID list but encoded in the SRH format where the rightmost SID in the SRH is the first SID and the leftmost SID in the SRH is the last SID. When referring to an SR policy in a high-level use-case, it is simpler to use the <S1, S2, S3> notation. When referring to an illustration of the detailed packet behavior, the (S3, S2, S1; SL) notation is more convenient.
- The payload of the packet is omitted.

SRH[n]: A shorter representation of Segment List[n], as defined in [\[RFC8754\]](#). SRH[SL] can be different from the DA of the IPv6 header.

- o gNB::1 is an IPv6 address (SID) assigned to the gNB.
- o U1::1 is an IPv6 address (SID) assigned to UPF1.
- o U2::1 is an IPv6 address (SID) assigned to UPF2.
- o U2:: is some other IPv6 address (SID) assigned to UPF2.

2.3. Predefined SRv6 Endpoint Behaviors

The following SRv6 Endpoint Behaviors are defined in [\[I-D.ietf-spring-srv6-network-programming\]](#).

- o End.DT4: decapsulate and forward using a specific IPv4 table lookup.

- o End.DT6: decapsulate and forward using a specific IPv6 table lookup.
- o End.DX4: decapsulate the packet and forward through a particular outgoing interface -or set of OIFs- configured with the SID.
- o End.DX6: decapsulate and forward through a particular outgoing interface -or set of OIFs- configured with the SID.
- o End.DX2: decapsulate the L2 frame and forward through a particular outgoing interface -or set of OIFs- configured with the SID.
- o End.T: forward through the shortest path using a specific IPv6 table.
- o End.X: forward through an L3 adjacency with the SID.

New SRv6 behaviors are defined in [Section 6](#) of this document to mechanisms described in this document.

3. Motivation

Mobile networks are becoming more challenging to operate. On one hand, traffic is constantly growing, and latency requirements are tighter; on the other-hand, there are new use-cases like distributed NFVi that are also challenging network operations.

The current architecture of mobile networks does not take into account the underlying transport. The user-plane is rigidly fragmented into radio access, core and service networks, connected by tunneling according to user-plane roles such as access and anchor nodes. These factors have made it difficult for the operator to optimize and operate the data-path.

In the meantime, applications have shifted to use IPv6, and network operators have started adopting IPv6 as their IP transport. SRv6, the IPv6 dataplane instantiation of Segment Routing [[RFC8402](#)], integrates both the application data-path and the underlying transport layer into a single protocol, allowing operators to optimize the network in a simplified manner and removing forwarding state from the network. It is also suitable for virtualized environments, like VNF/CNF to VNF/CNF networking.

SRv6 defines the network-programming concept [[I-D.ietf-spring-srv6-network-programming](#)]. Applied to mobility, SRv6 can provide the user-plane behaviors needed for mobility management. SRv6 takes advantage of the underlying transport awareness and flexibility together with the ability to also include services to optimize the end-to-end mobile dataplane.

The use-cases for SRv6 mobility are discussed in [[I-D.camarilloelmaliky-springdmm-srv6-mob-usecases](#)].

4. A 3GPP Reference Architecture

This section presents a reference architecture and possible deployment scenarios.

Figure 1 shows a reference diagram from the 5G packet core architecture [TS.23501].

The user plane described in this document does not depend on any specific architecture. The 5G packet core architecture as shown is based on the latest 3GPP standards at the time of writing this draft.

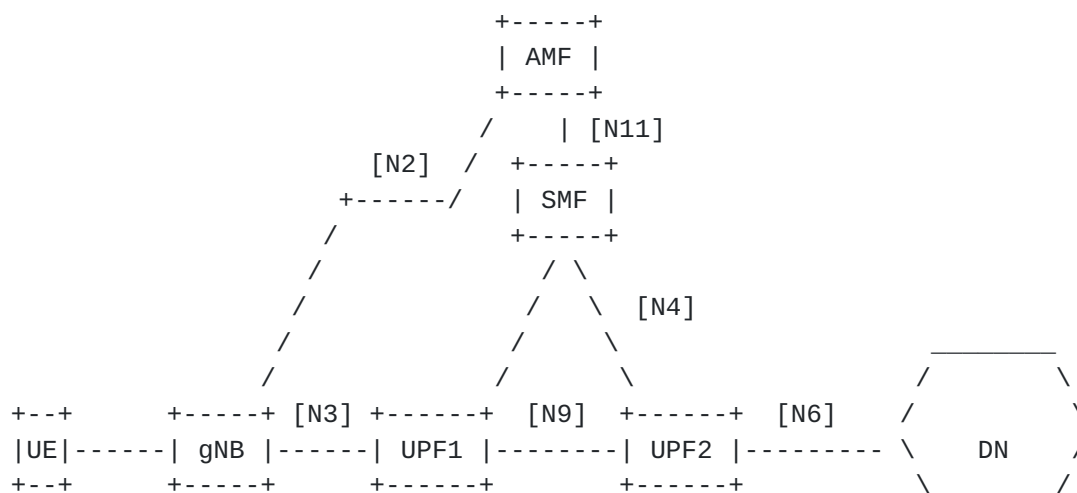


Figure 1: 3GPP 5G Reference Architecture

- o gNB: gNodeB with N3 interface towards packet core (and N2 for control plane)
- o UPF1: UPF with Interfaces N3 and N9 (and N4 for control plane)
- o UPF2: UPF with Interfaces N9 and N6 (and N4 for control plane)
- o SMF: Session Management Function
- o AMF: Access and Mobility Management Function
- o DN: Data Network e.g. operator services, Internet access

This reference diagram does not depict a UPF that is only connected to N9 interfaces, although the description in this document also work for such UPFs.

Each session from a UE gets assigned to a UPF. Sometimes multiple UPFs may be used, providing richer service functions. A UE gets its IP address from the DHCP block of its UPF. The UPF advertises that IP address block toward the Internet, ensuring that return traffic is routed to the right UPF.

5. User-plane behaviors

This section introduces an SRv6 based mobile user-plane.

In order to simplify the adoption of SRv6, we present two different "modes" that vary with respect to the use of SRv6. The first one is the "Traditional mode", which inherits the current 3GPP mobile user-plane. In this mode GTP-U [[TS.29281](#)] is replaced by SRv6, however the N3, N9 and N6 interfaces are still point-to-point interfaces with no intermediate waypoints as in the current mobile network architecture.

The second mode is the "Enhanced mode". This is an evolution from the "Traditional mode". In this mode the N3, N9 or N6 interfaces have intermediate waypoints -SIDs- that are used for Traffic Engineering or VNF purposes. This results in optimal end-to-end policies across the mobile network with transport and services awareness.

In both, the Traditional and the Enhanced modes, we assume that the gNB as well as the UPFs are SR-aware (N3, N9 and -potentially- N6 interfaces are SRv6).

In addition to those two modes, we introduce two mechanisms for interworking with legacy access networks (those where the N3 interface is unmodified). In this document we introduce them as a variant to the Enhanced mode, however they are equally applicable to the Traditional mode.

One of these mechanisms is designed to interwork with legacy gNBs using GTP/IPv4. The second mechanism is designed to interwork with legacy gNBs using GTP/IPv6.

This document uses SRv6 Segment Endpoint Behaviors defined in [[I-D.ietf-spring-srv6-network-programming](#)] as well as new SRv6 Segment Endpoint Behaviors designed for the mobile user plane that are defined in this document [Section 6](#).

5.1. Traditional mode

In the traditional mode, the existing mobile UPFs remain unchanged except for the use of SRv6 as the data plane instead of GTP-U. There is no impact to the rest of the mobile system.

In existing 3GPP mobile networks, a PDU Session is mapped 1-for-1 with a specific GTP tunnel (TEID). This 1-for-1 mapping is mirrored here to replace GTP encapsulation with the SRv6 encapsulation, while

not changing anything else. There will be a unique SRv6 SID associated with each PDU Session.

The traditional mode minimizes the changes required to the mobile system; hence it is a good starting point for forming a common ground.

Our example topology is shown in Figure 2. In traditional mode the gNB and the UPFs are SR-aware. In the descriptions of the uplink and downlink packet flow, A is an IPv6 address of the UE, and Z is an IPv6 address reachable within the Data Network DN. A new SRv6 function End.MAP, defined in [Section 6.2](#), is used.

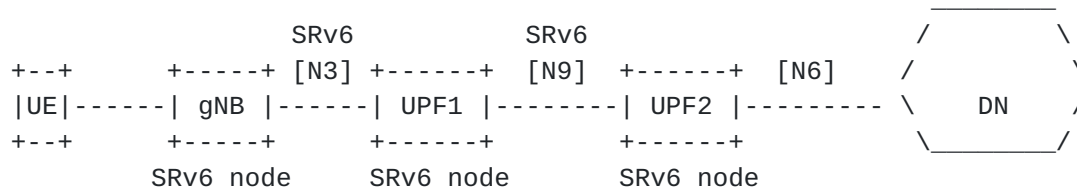


Figure 2: Traditional mode - example topology

5.1.1. Packet flow - Uplink

The uplink packet flow is as follows:

```

UE_out   : (A,Z)
gNB_out  : (gNB, U1::1) (A,Z)    -> H.Encaps.Red <U1::1>
UPF1_out : (gNB, U2::1) (A,Z)    -> End.MAP
UPF2_out : (A,Z)                 -> End.DT4 or End.DT6

```

When the UE packet arrives at the gNB, the gNB performs a H.Encaps.Red operation. Since there is only one SID, there is no need to push an SRH. gNB only adds an outer IPv6 header with IPv6 DA U1::1. U1::1 represents an anchoring SID specific for that session at UPF1. gNB obtains the SID U1::1 from the existing control plane (N2 interface).

When the packet arrives at UPF1, the SID U1::1 identifies a local End.MAP function. End.MAP replaces U1::1 by U2::1, that belongs to the next UPF (U2).

When the packet arrives at UPF2, the SID U2::1 corresponds to an End.DT function. UPF2 decapsulates the packet, performs a lookup in a specific table associated with that mobile network and forwards the packet toward the data network (DN).

5.1.2. Packet flow - Downlink

The downlink packet flow is as follows:

```
UPF2_in : (Z,A)
UPF2_out: (U2::, U1::2) (Z,A)    -> H.Encaps.Red <U1::2>
UPF1_out: (U2::, gNB::1) (Z,A)  -> End.MAP
gNB_out  : (Z,A)                 -> End.DX4, End.DX6, End.DX2
```

When the packet arrives at the UPF2, the UPF2 maps that flow into a PDU Session. This PDU Session is associated with the segment endpoint <U1::2>. UPF2 performs a H.Encaps.Red operation, encapsulating the packet into a new IPv6 header with no SRH since there is only one SID.

Upon packet arrival on UPF1, the SID U1::2 is a local End.MAP function. This function maps the SID to the next anchoring point and replaces U1::2 by gNB::1, that belongs to the next hop.

Upon packet arrival on gNB, the SID gNB::1 corresponds to an End.DX4, End.DX6 or End.DX2 behavior (depending on PDU Session Type). The gNB decapsulates the packet, removing the IPv6 header and all its extensions headers, and forwards the traffic toward the UE.

5.2. Enhanced Mode

Enhanced mode improves scalability, provides traffic engineering capabilities and allows service programming [[I-D.ietf-spring-sr-service-programming](#)], thanks to the use of multiple SIDs in the SID list (instead of a direct connectivity in between UPFs with no intermediate waypoints as in Traditional Mode).

Thus, the main difference is that the SR policy MAY include SIDs for traffic engineering and service programming in addition to the anchoring SIDs at UPFs.

Additionally in this mode the operator may choose to aggregate several devices under the same SID list (e.g. stationary residential meters connected to the same cell) to improve scalability.

The gNB control-plane (N2 interface) is unchanged, specifically a single IPv6 address is provided to the gNB.

The gNB MAY resolve the IP address received via the control plane into a SID list using a mechanism like PCEP, DNS-lookup, LISP control-plane or others.

Note that the SIDs MAY use the arguments Args.Mob.Session if required by the UPFs.

Figure 3 shows an Enhanced mode topology. In the Enhanced mode, the gNB and the UPF are SR-aware. The Figure shows two service segments, S1 and C1. S1 represents a VNF in the network, and C1 represents an intermediate router used for Traffic Engineering purposes to enforce a low-latency path in the network. Note that both S1 and C1 are not required to have an N4 interface.

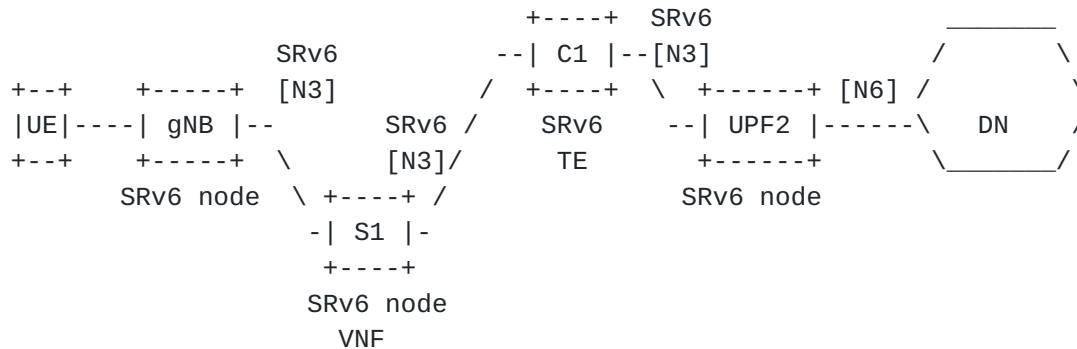


Figure 3: Enhanced mode - Example topology

5.2.1. Packet flow - Uplink

The uplink packet flow is as follows:

```

UE_out   : (A,Z)
gNB_out  : (gNB, S1)(U2::1, C1; SL=2)(A,Z)-> H.Encaps.Red<S1,C1,U2::1>
S1_out   : (gNB, C1)(U2::1, C1; SL=1)(A,Z)
C1_out   : (gNB, U2::1)(A,Z) -> PSP
UPF2_out : (A,Z) -> End.DT4, End.DT6, End.DT2U
  
```

UE sends its packet (A,Z) on a specific bearer to its gNB. gNB's control plane associates that session from the UE(A) with the IPv6 address B. gNB's control plane does a lookup on B to find the related SID list <S1, C1, U2::1>.

When gNB transmits the packet, it contains all the segments of the SR policy. The SR policy includes segments for traffic engineering (C1) and for service programming (S1).

Nodes S1 and C1 perform their related Endpoint functionality and forward the packet.

When the packet arrives at UPF2, the active segment (U2::1) is an End.DT4/End.DT6/End.DT2U which performs the decapsulation (removing

the IPv6 header with all its extension headers) and forwards toward the data network.

5.2.2. Packet flow - Downlink

The downlink packet flow is as follows:

UPF2_in : (Z,A)	-> UPF2 maps the flow w/ SID list <C1,S1, gNB>
UPF2_out: (U2::1, C1)(gNB, S1; SL=2)(Z,A)	-> H.Encaps.Red
C1_out : (U2::1, S1)(gNB, S1; SL=1)(Z,A)	
S1_out : (U2::1, gNB)(Z,A)	-> PSP
gNB_out : (Z,A)	-> End.DX4/End.DX6/End.DX2

When the packet arrives at the UPF2, the UPF2 maps that particular flow into a UE PDU Session. This UE PDU Session is associated with the policy <C1, S1, gNB>. The UPF2 performs a H.Encaps.Red operation, encapsulating the packet into a new IPv6 header with its corresponding SRH.

The nodes C1 and S1 perform their related Endpoint processing.

Once the packet arrives at the gNB, the IPv6 DA corresponds to an End.DX4, End.DX6 or End.DX2 behavior at the gNB (depending on the underlying traffic). The gNB decapsulates the packet, removing the IPv6 header and forwards the traffic toward the UE.

5.3. Enhanced mode with unchanged gNB GTP behavior

This section describes three mechanisms for interworking with legacy gNBs that still use GTP: one for IPv4, the other for IPv6.

In the interworking scenarios as illustrated in Figure 4, gNB does not support SRv6. gNB supports GTP encapsulation over IPv4 or IPv6. To achieve interworking, a SR Gateway (SRGW-UPF1) entity is added. The SRGW maps the GTP traffic into SRv6.

The SRGW is not an anchor point and maintains very little state. For this reason, both IPv4 and IPv6 methods scale to millions of UEs.

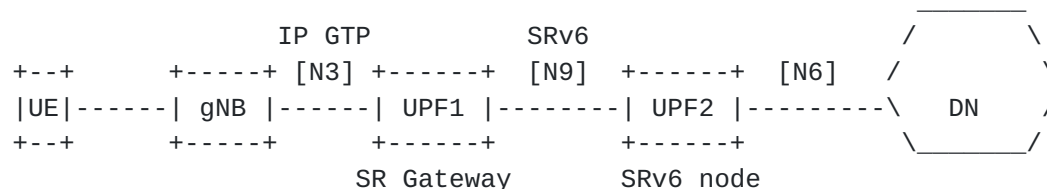


Figure 4: Example topology for interworking

Both of the mechanisms described in this section are applicable to either the Traditional Mode or the Enhanced Mode.

5.3.1. Interworking with IPv6 GTP

In this interworking mode the gNB at the N3 interface uses GTP over IPv6.

Key points:

- o The gNB is unchanged (control-plane or user-plane) and encapsulates into GTP (N3 interface is not modified).
- o The 5G Control-Plane (N2 interface) is unmodified; one IPv6 address is needed (i.e. a BSID at the SRGW).
- o The SRGW removes GTP, finds the SID list related to the IPv6 DA, and adds SRH with the SID list.
- o There is no state for the downlink at the SRGW.
- o There is simple state in the uplink at the SRGW; using Enhanced mode results in fewer SR policies on this node. An SR policy is shared across UEs.
- o When a packet from the UE leaves the gNB, it is SR-routed. This simplifies network slicing [[I-D.ietf-lsr-flex-algo](#)].
- o In the uplink, the IPv6 DA BSID steers traffic into an SR policy when it arrives at the SRGW-UPF1.

An example topology is shown in Figure 5.

S1 and C1 are two service segments. S1 represents a VNF in the network, and C1 represents a router configured for Traffic Engineering.

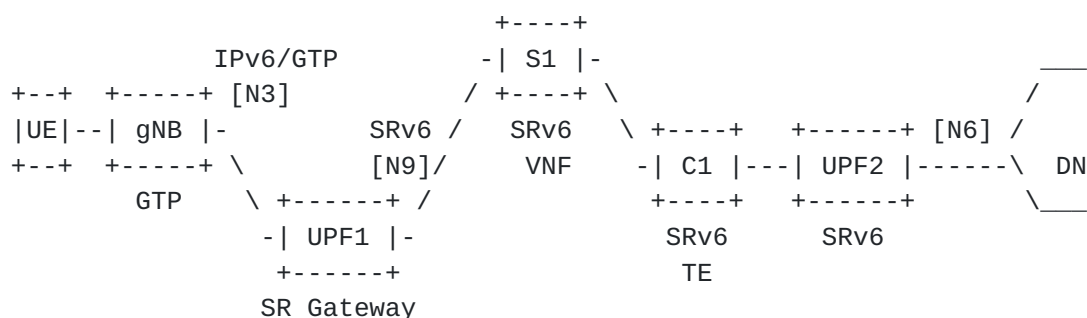


Figure 5: Enhanced mode with unchanged gNB IPv6/GTP behavior

5.3.1.1. Packet flow - Uplink

The uplink packet flow is as follows:


```

UE_out   : (A,Z)
gNB_out  : (gNB, B)(GTP: TEID T)(A,Z)      -> Interface N3 unmodified
                                              (IPv6/GTP)
SRGW_out : (SRGW, S1)(U2::1, C1; SL=2)(A,Z) -> B is an End.M.GTP6.D
                                              SID at the SRGW
S1_out   : (SRGW, C1)(U2::1, C1; SL=1)(A,Z)
C1_out   : (SRGW, U2::1)(A,Z)               -> PSP
UPF2_out : (A,Z)                           -> End.DT4 or End.DT6

```

The UE sends a packet destined to Z toward the gNB on a specific bearer for that session. The gNB, which is unmodified, encapsulates the packet into IPv6, UDP and GTP headers. The IPv6 DA B, and the GTP TEID T are the ones received in the N2 interface.

The IPv6 address that was signaled over the N2 interface for that UE PDU Session, B, is now the IPv6 DA. B is an SRv6 Binding SID at the SRGW. Hence the packet is routed to the SRGW.

When the packet arrives at the SRGW, the SRGW identifies B as an End.M.GTP6.D Binding SID (see [Section 6.3](#)). Hence, the SRGW removes the IPv6, UDP and GTP headers, and pushes an IPv6 header with its own SRH containing the SIDs bound to the SR policy associated with this BindingSID. There is one instance of the End.M.GTP6.D SID per PDU type.

S1 and C1 perform their related Endpoint functionality and forward the packet.

When the packet arrives at UPF2, the active segment is (U2::1) which is bound to End.DT4/6. UPF2 then decapsulates (removing the outer IPv6 header with all its extension headers) and forwards the packet toward the data network.

[5.3.1.2](#). Packet flow - Downlink

The downlink packet flow is as follows:

```

UPF2_in  : (Z,A)                           -> UPF2 maps the flow with
                                              <C1, S1, SRGW::TEID,gNB>
UPF2_out : (U2::1, C1)(gNB, SRGW::TEID, S1; SL=3)(Z,A) -> H.Encaps.Red
C1_out   : (U2::1, S1)(gNB, SRGW::TEID, S1; SL=2)(Z,A)
S1_out   : (U2::1, SRGW::TEID)(gNB, SRGW::TEID, S1, SL=1)(Z,A)
SRGW_out : (SRGW, gNB)(GTP: TEID=T)(Z,A)    -> SRGW/96 is End.M.GTP6.E
gNB_out  : (Z,A)

```

When a packet destined to A arrives at the UPF2, the UPF2 performs a lookup in the table associated to A and finds the SID list <C1, S1, SRGW::TEID, gNB>. The UPF2 performs an H.Encaps.Red operation,

encapsulating the packet into a new IPv6 header with its corresponding SRH.

C1 and S1 perform their related Endpoint processing.

Once the packet arrives at the SRGW, the SRGW identifies the active SID as an End.M.GTP6.E function. The SRGW removes the IPv6 header and all its extensions headers. The SRGW generates new IPv6, UDP and GTP headers. The new IPv6 DA is the gNB which is the last SID in the received SRH. The TEID in the generated GTP header is an argument of the received End.M.GTP6.E SID. The SRGW pushes the headers to the packet and forwards the packet toward the gNB. There is one instance of the End.M.GTP6.E SID per PDU type.

Once the packet arrives at the gNB, the packet is a regular IPv6/GTP packet. The gNB looks for the specific radio bearer for that TEID and forward it on the bearer. This gNB behavior is not modified from current and previous generations.

5.3.1.3. Scalability

For the downlink traffic, the SRGW is stateless. All the state is in the SRH inserted by the UPF2. The UPF2 must have the UE states since it is the UE's session anchor point.

For the uplink traffic, the state at the SRGW does not necessarily need to be unique per PDU Session; the SR policy can be shared among UEs. This enables more scalable SRGW deployments compared to a solution holding millions of states, one or more per UE.

5.3.2. Interworking with IPv4 GTP

In this interworking mode the gNB uses GTP over IPv4 in the N3 interface

Key points:

- o The gNB is unchanged and encapsulates packets into GTP (the N3 interface is not modified).
- o In the uplink, traffic is classified by SRGW's Uplink Classifier and steered into an SR policy. The SRGW is a UPF1 functionality and can coexist with UPF1's Uplink Classifier functionality.
- o SRGW removes GTP, finds the SID list related to DA, and adds a SRH with the SID list.

An example topology is shown in Figure 6. In this mode the gNB is an unmodified gNB using IPv4/GTP. The UPFs are SR-aware. As before, the SRGW maps the IPv4/GTP traffic to SRv6.

S1 and C1 are two service segment endpoints. S1 represents a VNF in the network, and C1 represents a router configured for Traffic Engineering.

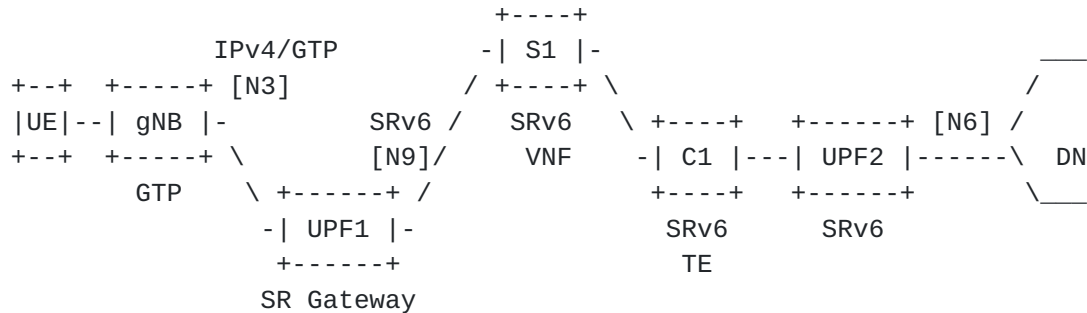


Figure 6: Enhanced mode with unchanged gNB IPv4/GTP behavior

5.3.2.1. Packet flow - Uplink

The uplink packet flow is as follows:

```

gNB_out : (gNB, B)(GTP: TEID T)(A,Z)          -> Interface N3
                                                unchanged IPv4/GTP
SRGW_out: (SRGW, S1)(U2::1, C1; SL=2)(A,Z)    -> H.M.GTP4.D function
S1_out  : (SRGW, C1)(U2::1, C1; SL=1)(A,Z)
C1_out  : (SRGW, U2::1) (A,Z)                  -> PSP
UPF2_out: (A,Z)                                -> End.DT4 or End.DT6
  
```

The UE sends a packet destined to Z toward the gNB on a specific bearer for that session. The gNB, which is unmodified, encapsulates the packet into a new IPv4, UDP and GTP headers. The IPv4 DA, B, and the GTP TEID are the ones received at the N2 interface.

When the packet arrives at the SRGW for UPF1, the SRGW has an Uplink Classifier rule for incoming traffic from the gNB, that steers the traffic into an SR policy by using the function H.M.GTP4.D. The SRGW removes the IPv4, UDP and GTP headers and pushes an IPv6 header with its own SRH containing the SIDs related to the SR policy associated with this traffic. The SRGW forwards according to the new IPv6 DA.

S1 and C1 perform their related Endpoint functionality and forward the packet.

When the packet arrives at UPF2, the active segment is (U2::1) which is bound to End.DT4/6 which performs the decapsulation (removing the outer IPv6 header with all its extension headers) and forwards toward the data network.

5.3.2.2. Packet flow - Downlink

The downlink packet flow is as follows:

```
UPF2_in : (Z,A)                                -> UPF2 maps flow with SID
                                                <C1, S1,SRGW::SA:DA:TEID>
UPF2_out: (U2::1, C1)(SRGW::SA:DA:TEID, S1; SL=2)(Z,A) ->H.Encaps.Red
C1_out   : (U2::1, S1)(SRGW::SA:DA:TEID, S1; SL=1)(Z,A)
S1_out   : (U2::1, SRGW::SA:DA:TEID)(Z,A)
SRGW_out: (SA, DA)(GTP: TEID=T)(Z,A)           -> End.M.GTP4.E
gNB_out  : (Z,A)
```

When a packet destined to A arrives at the UPF2, the UPF2 performs a lookup in the table associated to A and finds the SID list <C1, S1, SRGW::SA:DA:TEID>. The UPF2 performs a H.Encaps.Red operation, encapsulating the packet into a new IPv6 header with its corresponding SRH.

The nodes C1 and S1 perform their related Endpoint processing.

Once the packet arrives at the SRGW, the SRGW identifies the active SID as an End.M.GTP4.E function. The SRGW removes the IPv6 header and all its extensions headers. The SRGW generates an IPv4, UDP and GTP headers. The IPv4 SA and DA are received as SID arguments. The TEID in the generated GTP header is also the arguments of the received End.M.GTP4.E SID. The SRGW pushes the headers to the packet and forwards the packet toward the gNB.

When the packet arrives at the gNB, the packet is a regular IPv4/GTP packet. The gNB looks for the specific radio bearer for that TEID and forward it on the bearer. This gNB behavior is not modified from current and previous generations.

5.3.2.3. Scalability

For the downlink traffic, the SRGW is stateless. All the state is in the SRH inserted by the UPF. The UPF must have this UE-base state anyway (since it is its anchor point).

For the uplink traffic, the state at the SRGW is dedicated on a per UE/session basis according to an Uplink Classifier. There is state for steering the different sessions in the form of a SR Policy. However, SR policies are shared among several UE/sessions.

5.3.3. Extensions to the interworking mechanisms

In this section we presented three mechanisms for interworking with gNBs and UPFs that do not support SRv6. These mechanisms are used to support GTP over IPv4 and IPv6.

Even though we have presented these methods as an extension to the "Enhanced mode", it is straightforward in its applicability to the "Traditional mode".

Furthermore, although these mechanisms are designed for interworking with legacy RAN at the N3 interface, these methods could also be applied for interworking with a non-SRv6 capable UPF at the N9 interface (e.g. L3-anchor is SRv6 capable but L2-anchor is not).

5.4. SRv6 Drop-in Interworking

In this section we introduce another mode useful for legacy gNB and UPFs that still operate with GTP-U. This mode provides an SRv6-enabled user plane in between two GTP-U tunnel endpoints.

In this mode we employ two SRGWs that map GTP-U traffic to SRv6 and vice-versa.

Unlike other interworking modes, in this mode both of the mobility overlay endpoints use GTP-U. Two SRGWs are deployed in either N3 or N9 interface to realize an intermediate SR policy.

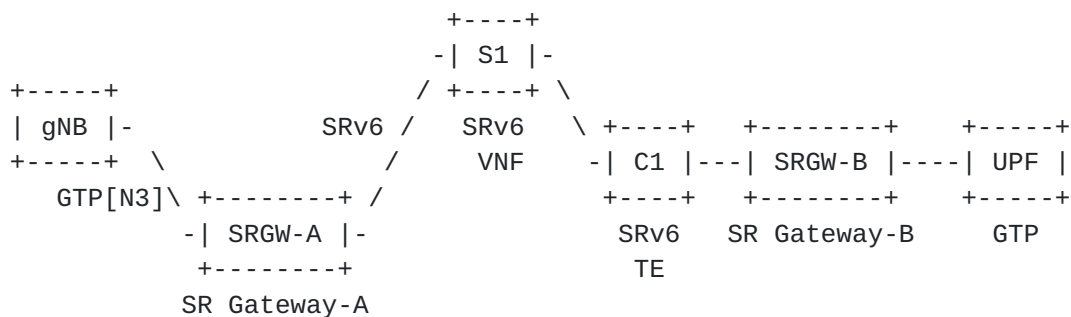


Figure 7: Example topology for SRv6 Drop-in mode

The packet flow of Figure 7 is as follows:


```

gNB_out : (gNB, U::1)(GTP: TEID T)(A,Z)
GW-A_out: (SRGW-A, S1)(U::1, SGB::TEID, C1; SL=3)(A,Z) ->U::1 is an
                                                    End.M.GTP6.D.Di
                                                    SID at SRGW-A

S1_out   : (SRGW-A, C1)(U::1, SGB::TEID, C1; SL=2)(A,Z)
C1_out   : (SRGW-A, SGB::TEID)(U::1, SGB::TEID, C1; SL=1)(A,Z)
GW-B_out: (SRGW-B, U::1)(GTP: TEID T)(A,Z)           ->U1b::TEID is an
                                                    End.M.GTP6.E
                                                    SID at SRGW-B

UPF_out  : (A,Z)

```

When a packet destined to Z to the gNB, which is unmodified, it performs encapsulation into a new IP, UDP and GTP headers. The IPv6 DA, U::1, and the GTP TEID are the ones received at the N2 interface.

The IPv6 address that was signaled over the N2 interface for that PDU Session, U::1, is now the IPv6 DA. U2b:: is an SRv6 Binding SID at SRGW-A. Hence the packet is routed to the SRGW.

When the packet arrives at SRGW-A, the SRGW identifies U2b:: as an End.M.GTP6.D.Di Binding SID (see [Section 6.4](#)). Hence, the SRGW removes the IPv6, UDP and GTP headers, and pushes an IPv6 header with its own SRH containing the SIDs bound to the SR policy associated with this Binding SID. There is one instance of the End.M.GTP6.D.Di SID per PDU type.

S1 and C1 perform their related Endpoint functionality and forward the packet.

Once the packet arrives at SRGW-B, the SRGW identifies the active SID as an End.M.GTP6.E function. The SRGW removes the IPv6 header and all its extensions headers. The SRGW generates new IPv6, UDP and GTP headers. The new IPv6 DA is U::1 which is the last SID in the received SRH. The TEID in the generated GTP header is an argument of the received End.M.GTP6.E SID. The SRGW pushes the headers to the packet and forwards the packet toward UPF2b. There is one instance of the End.M.GTP6.E SID per PDU type.

Once the packet arrives at UPF2b, the packet is a regular IPv6/GTP packet. The UPF looks for the specific rule for that TEID to forward the packet. This UPF behavior is not modified from current and previous generations.

6. SRv6 Segment Endpoint Mobility Behaviors

6.1. Args.Mob.Session

Args.Mob.Session provide per-session information for charging, buffering and lawful intercept (among others) required by some mobile nodes. The Args.Mob.Session argument format is used in combination with End.Map, End.DT and End.DX behaviors. Note that proposed format is applicable for 5G networks, while similar formats could be proposed for legacy networks.

```

      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
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|   QFI       |R|U|                PDU Session ID                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|PDU Sess(cont')|
+--+--+--+--+--+--+--+

```

Args.Mob.Session format

- o QFI: QoS Flow Identifier [[TS.38415](#)]
- o R: Reflective QoS Indication [[TS.23501](#)]. This parameter indicates the activation of reflective QoS towards the UE for the transferred packet. Reflective QoS enables the UE to map UL User Plane traffic to QoS Flows without SMF provided QoS rules.
- o U: Unused and for future use. MUST be 0 on transmission and ignored on receipt.
- o PDU Session ID: Identifier of PDU Session. The GTP-U equivalent is TEID.

Arg.Mob.Session is required in case that one SID aggregates multiple PDU Sessions. Since the SRv6 SID is likely NOT to be instantiated per PDU session, Args.Mob.Session helps the UPF to perform the behaviors which require per QFI and/or per PDU Session granularity.

6.2. End.MAP

The "Endpoint behavior with SID mapping" behavior (End.MAP for short) is used in several scenarios. Particularly in mobility, End.MAP is used in the UPFs for the PDU Session anchor functionality.

When a SR node N receives a packet destined to S and S is a local End.MAP SID, N does the following:

1. Lookup the IPv6 DA in the mapping table
2. update the IPv6 DA with the new mapped SID ; ; Ref1
3. IF segment_list > 1
4. insert a new SRH
5. forward according to the new mapped SID

Ref1: The SIDs in the SRH are NOT modified.

6.3. End.M.GTP6.D

The "Endpoint behavior with IPv6/GTP decapsulation into SR policy" behavior (End.M.GTP6.D for short) is used in interworking scenario for the uplink toward from the legacy gNB using IPv6/GTP. Suppose, for example, this SID is associated with an SR policy <S1, S2, S3> and an IPv6 Source Address A.

When the SR Gateway node N receives a packet destined to S and S is a local End.M.GTP6.D SID, N does:

1. IF NH=UDP & UDP_DST_PORT = GTP THEN
2. copy TEID to form SID S3
3. pop the IPv6, UDP and GTP headers
4. push a new IPv6 header with a SR policy in SRH <S1, S2, S3>
5. set the outer IPv6 SA to A
6. set the outer IPv6 DA to S1
7. set the outer IPv6 NH ;; Ref1
8. forward according to the S1 segment of the SRv6 Policy
9. ELSE
10. Drop the packet

Ref1: The NH is set based on the SID parameter. There is one instantiation of the End.M.GTP6.D SID per PDU Session Type, hence the NH is already known in advance. For the IPv4v6 PDU Session Type, in addition we inspect the first nibble of the PDU to know the NH value.

The prefix of last segment (S3 in above example) SHOULD be followed by an Arg.Mob.Session argument space which is used to provide the session identifiers.

The prefix of A SHOULD be an End.M.GTP6.E SID instantiated at an SR gateway.

6.4. End.M.GTP6.D.Di

The "Endpoint behavior with IPv6/GTP decapsulation into SR policy for Drop-in Mode" behavior (End.M.GTP6.D.Di for short) is used in SRv6 drop-in interworking scenario described in [Section 5.4](#). The difference between End.M.GTP6.D as another variant of IPv6/GTP decapsulation function is that the original IPv6 DA of GTP packet is preserved as the last SID in SRH. Suppose, for example, this SID is associated with an SR policy <S1, S2, S3> and an IPv6 Source Address A.

When the SR Gateway node N receives a packet destined to S and S is a local End.M.GTP6.D.Di SID, N does:

- ```

1. IF NH=UDP & UDP_DST_PORT = GTP THEN
2. preserve S and copy TEID to form SID S3
3. pop the IPv6, UDP and GTP headers
4. push a new IPv6 header with a SR policy in SRH <S1, S2, S3, S>
5. set the outer IPv6 SA to A
6. set the outer IPv6 DA to S1
7. set the outer IPv6 NH ;; Ref1
8. forward according to the S1 segment of the SRv6 Policy
9. ELSE
10. Drop the packet

```

Ref1: The NH is set based on the SID parameter. There is one instantiation of the End.M.GTP6.D.Di SID per PDU Session Type, hence the NH is already known in advance. For the IPv4v6 PDU Session Type, in addition we inspect the first nibble of the PDU to know the NH value.

The prefix of last segment(S3 in above example) SHOULD be followed by an Arg.Mob.Session argument space which is used to provide the session identifiers.

The prefix of A SHOULD be an End.M.GTP6.E SID instantiated at an SR gateway.

### 6.5. End.M.GTP6.E

The "Endpoint behavior with encapsulation for IPv6/GTP tunnel" behavior (End.M.GTP6.E for short) is used in interworking scenario for the downlink toward the legacy gNB using IPv6/GTP.

The prefix of End.M.GTP6.E SID MUST be followed by the Arg.Mob.Session argument space which is used to provide the session identifiers.

When the SR Gateway node N receives a packet destined to S, and S is a local End.M.GTP6.E SID, N does the following:



```

1. IF NH=SRH & SL = 1 THEN ;; Ref1
2. store SRH[0] in variable new_DA
3. store TEID in variable new_TEID from IPv6 DA ;; Ref2
4. pop IP header and all its extension headers
5. push new IPv6 header and GTP-U header
6. set IPv6 DA to new_DA
7. set IPv6 SA to A
8. set GTP_TEID to new_TEID
9. lookup the new_DA and forward the packet accordingly
10. ELSE
11. Drop the packet

```

Ref1: An End.M.GTP6.E SID MUST always be the penultimate SID.

Ref2: TEID is extracted from the argument space of the current SID.

The source address A SHOULD be an End.M.GTP6.D SID instantiated at an SR gateway.

#### 6.6. End.M.GTP4.E

The "Endpoint behavior with encapsulation for IPv4/GTP tunnel" behavior (End.M.GTP4.E for short) is used in the downlink when doing interworking with legacy gNB using IPv4/GTP.

When the SR Gateway node N receives a packet destined to S and S is a local End.M.GTP4.E SID, N does:

```

1. IF (NH=SRH and SL = 0) or ENH=4 THEN
2. store IPv6 DA in buffer S
3. store IPv6 SA in buffer S'
4. pop the IPv6 header and its extension headers
5. push UDP/GTP headers with GTP TEID from S
6. push outer IPv4 header with SA, DA from S' and S
7. ELSE
8. Drop the packet

```

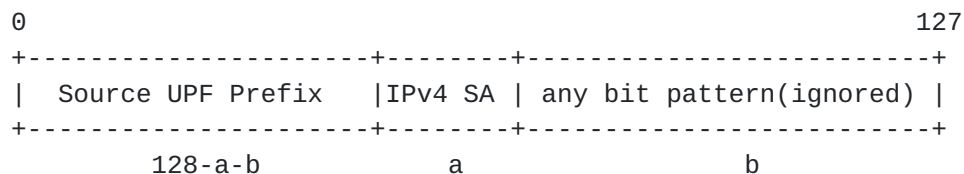
The End.M.GTP4.E SID in S has the following format:

|                           |                                                 |
|---------------------------|-------------------------------------------------|
| 0                         | 127                                             |
| +-----+-----+-----+-----+ |                                                 |
| SRGW-IPv6-LOC-FUNC        | IPv4DA  Args.Mob.Session 0 Padded               |
| +-----+-----+-----+-----+ |                                                 |
| 128-a-b-c                 | a                      b                      c |

End.M.GTP4.E SID Encoding



S' has the following format:



IPv6 SA Encoding for End.M.GTP4.E

### 6.7. H.M.GTP4.D

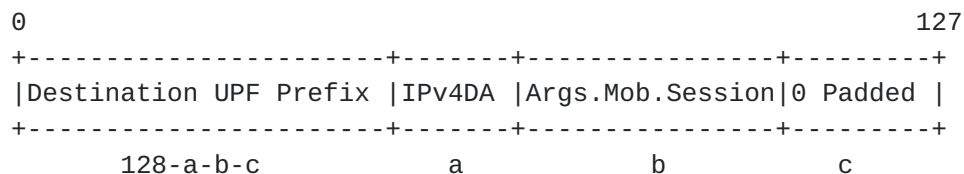
The "SR Policy Headend with tunnel decapsulation and map to an SRv6 policy" behavior (H.M.GTP4.D for short) is used in the direction from legacy IPv4 user-plane to SRv6 user-plane network.

When the SR Gateway node N receives a packet destined to a IW-IPv4-Prefix, N does:

1. IF Payload == UDP/GTP THEN
2.   pop the outer IPv4 header and UDP/GTP headers
3.   copy IPv4 DA, TEID to form SID B
4.   copy IPv4 SA to form IPv6 SA B'
5.   encapsulate the packet into a new IPv6 header   ;;Ref1
6.   set the IPv6 DA = B
7.   forward along the shortest path to B
8. ELSE
9.   Drop the packet

Ref1: The NH value is identified by inspecting the first nibble of the inner payload.

The SID B has the following format:



H.M.GTP4.D SID Encoding

The SID B MAY be an SRv6 Binding SID instantiated at the first UPF (U1) to bind a SR policy [[I-D.ietf-spring-segment-routing-policy](#)].



The prefix of B' SHOULD be an End.M.GTP4.E SID with its format instantiated at an SR gateway with the IPv4 SA of the receiving packet.

### 6.8. End.Limit: Rate Limiting behavior

The mobile user-plane requires a rate-limit feature. For this purpose, we define a new behavior "End.Limit". The "End.Limit" behavior encodes in its arguments the rate limiting parameter that should be applied to this packet. Multiple flows of packets should have the same group identifier in the SID when those flows are in an same AMBR (Aggregate Maximum Bit Rate) group. The encoding format of the rate limit segment SID is as follows:

```

+-----+-----+-----+
| LOC+FUNC rate-limit | group-id | limit-rate|
+-----+-----+-----+
 128-i-j i j

```

End.Limit: Rate limiting behavior argument format

If the limit-rate bits are set to zero, the node should not do rate limiting unless static configuration or control-plane sets the limit rate associated to the SID.

## 7. SRv6 supported 3GPP PDU session types

The 3GPP [[TS.23501](#)] defines the following PDU session types:

- o IPv4
- o IPv6
- o IPv4v6
- o Ethernet
- o Unstructured

SRv6 supports the 3GPP PDU session types without any protocol overhead by using the corresponding SRv6 behaviors (End.DX4, End.DT4 for IPv4 PDU sessions; End.DX6, End.DT6, End.T for IPv6 PDU sessions; End.DT46 for IPv4v6 PDU sessions; End.DX2 for L2 and Unstructured PDU sessions).

## 8. Network Slicing Considerations

A mobile network may be required to implement "network slices", which logically separate network resources. User-plane behaviors represented as SRv6 segments would be part of a slice.



[I-D.ietf-spring-segment-routing-policy] describes a solution to build basic network slices with SR. Depending on the requirements, these slices can be further refined by adopting the mechanisms from:

- o IGP Flex-Algo [[I-D.ietf-lsr-flex-algo](#)]
- o Inter-Domain policies [[I-D.ietf-spring-segment-routing-central-epe](#)]

Furthermore, these can be combined with ODN/AS [[I-D.ietf-spring-segment-routing-policy](#)] for automated slice provisioning and traffic steering.

Further details on how these tools can be used to create end to end network slices are documented in [[I-D.ali-spring-network-slicing-building-blocks](#)].

## **9. Control Plane Considerations**

This document focuses on user-plane behavior and its independence from the control plane.

The control plane could be the current 3GPP-defined control plane with slight modifications to the N4 interface [[TS.29244](#)].

Alternatively, SRv6 could be used in conjunction with a new mobility control plane as described in LISP [[I-D.rodriqueznatal-lisp-srv6](#)], hICN [[I-D.auge-dmm-hicn-mobility-deployment-options](#)] or in conjunction with FPC [[I-D.ietf-dmm-fpc-cpdp](#)]. The analysis of new mobility control-planes and its applicability to an SRv6 user-plane is out of the scope of this document.

[Section 11](#) allocates SRv6 Segment Endpoint Behavior codepoints for the new behaviors defined in this document.

## **10. Security Considerations**

The security considerations for Segment Routing are discussed in [[RFC8402](#)]. More specifically for SRv6 the security considerations and the mechanisms for securing an SR domain are discussed in [[RFC8754](#)]. Together, they describe the required security mechanisms that allow establishment of an SR domain of trust to operate SRv6-based services for internal traffic while preventing any external traffic from accessing or exploiting the SRv6-based services.

The technology described in this document is applied to a mobile network that is within the SR Domain.



This document introduces new SRv6 Endpoint Behaviors. Those behaviors do not need any especial security consideration given that it is deployed within that SR Domain.

## 11. IANA Considerations

IANA is requested to allocate, within the "SRv6 Endpoint Behaviors" sub-registry belonging to the top-level "Segment Routing Parameters" registry [[I-D.ietf-spring-srv6-network-programming](#)], the following values:

| Value | Hex | Endpoint behavior | Reference |
|-------|-----|-------------------|-----------|
| TBA   | TBA | End.MAP           | [This.ID] |
| TBA   | TBA | End.M.GTP6.D      | [This.ID] |
| TBA   | TBA | End.M.GTP6.Di     | [This.ID] |
| TBA   | TBA | End.M.GTP6.E      | [This.ID] |
| TBA   | TBA | End.M.GTP4.E      | [This.ID] |
| TBA   | TBA | End.Limit         | [This.ID] |

Table 1: SRv6 Mobile User-plane Endpoint Behavior Types

## 12. Acknowledgements

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## **Appendix A. Implementations**

This document introduces new SRv6 Endpoint Behaviors. These behaviors have an open-source P4 implementation available in [<https://github.com/ebiken/p4srv6>](https://github.com/ebiken/p4srv6).

Additionally, a full implementation of this document is available in Linux Foundation FD.io VPP project since release 20.05. More information available here: [<https://docs.fd.io/vpp/20.05/d7/d3c/srv6\\_mobile\\_plugin\\_doc.html>](https://docs.fd.io/vpp/20.05/d7/d3c/srv6_mobile_plugin_doc.html).

There are also experimental implementations in M-CORD NGIC and Open Air Interface (OAI).

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