SRv6 Implementation and Deployment Status
draft-matsushima-spring-srv6-deployment-status-04

Abstract

   This draft provides an overview of IPv6 Segment Routing (SRv6)
   deployment status. It lists various SRv6 features that have been
   deployed in the production networks. It also provides an overview of
   SRv6 implementation and interoperability testing status.

Requirements Language

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

Status of This Memo

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

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

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

   This Internet-Draft will expire on June 13, 2020.

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[1](1). Introduction

   This draft provides an overview of IPv6 Segment Routing (SRv6)
   deployment status. It lists various SRv6 features that have been

deployed in the production networks. It also provides an overview of
SRv6 implementation and interoperability testing status.

2. Deployment Status

2.1. Softbank

As part of the 5G rollout, Softbank have deployed a nationwide SRv6
network.

The following SRv6 features have been deployed:

o A Segment Routing Header [I-D.ietf-6man-segment-routing-header]
   based data plane.

o END (PSP), END.X (PSP), END.DT4, T.Encaps.Red and T.Insert.Red
   functions as per [I-D.ietf-spring-srv6-network-programming], [I-
   D.filsfils-spring-srv6-net-pgm-insertion].

o ISIS SRv6 extensions [I-D.ietf-isis-srv6-extensions].

o BGP VPN SRv6 extensions [I-D.ietf-bess-srv6-services].

o SRH based Topology Independent (TI-LFA) Fast Reroute mechanisms
   using T.Insert.Red for the O(50msec) protection against node and
   link, as described in [I-D.ietf-rtgwg-segment-routing-ti-lfa], [I-
   D.voyer-6man-extension-header-insertion].

o BGP Prefix Independent Convergence (PIC) core and edge [I-D.ietf-
   rtgwg-bgp-pic].

o Support for Ping and Traceroute as defined in [I-D.ietf-6man-
   spring-srv6-oam].

2.2. China Telecom

China Telecom (Sichuan) have deployed a multi-city SRv6 network.

The following SRv6 features have been deployed:

o A Segment Routing Header [I-D.ietf-6man-segment-routing-header].
   based data plane.

o END.DT4 function as per [I-D.ietf-spring-srv6-network-
   programming].

o BGP VPN SRv6 extensions [I-D.ietf-bess-srv6-services].

o BGP Prefix Independent Convergence (PIC) core and edge [I-D.ietf-rtgwg-bgp-pic].

o Support for Ping and Traceroute as defined in [I-D.ietf-6man-spring-srv6-oam].

2.3. Iliad

As part of the 5G rollout, Iliad has deployed a nationwide SRv6 network to provide a new mobile offering in Italy. This is a complete mobile IP network.

The SRv6 backbone is based on Cisco ASR 9000 and Cisco NCS 5500. All the cell site routers are Iliad's Nodebox, which are SRv6 capable and has been build in-house by the provider. In this deployment SRv6 is running on ASR 9000, NCS 5500 and Iliad's Nodebox. I.e., the deployment includes interoperating multiple implementations of SRv6.

As of the end of 2019, the SRv6 network consists of:

o 1000 Cisco NCS 5500 routers.

o 1800 Iliad's Nodeboxes.

o The network services 4.5 million mobile subscribers (as of Q3 2019).

o The network is carrying 300 Gbps of commercial traffic at peak hours.

o It is expected to grow to more than 4000 Nodeboxes in 2020.

The following SRv6 features have been deployed:

o A Segment Routing Header [I-D.ietf-6man-segment-routing-header]. based data plane.

o End (PSP), End.X (PSP), End.DT4, T.Encaps.Red, T.Insert.Red functions as per [I-D.ietf-spring-srv6-network-programming] , [I-D.filsfils-spring-srv6-net-pgm-insertion].

o BGP VPN SRv6 extensions [I-D.ietf-bess-srv6-services].

o ISIS SRv6 extensions [I-D.ietf-isis-srv6-extensions].

o SRH based Topology Independent (TI-LFA) Fast Reroute mechanisms using T.Insert.Red for the O(50msec) protection against node and

link, as described in [I-D.ietf-rtgwg-segment-routing-ti-lfa], [I-D.voyer-6man-extension-header-insertion].

o Support for Ping and Traceroute as defined in [I-D.ietf-6man-spring-srv6-oam].

2.4. LINE Corporation

LINE Corporation have deployed multi-tenants SRv6 network in the Data Center. The network provides per-service policy on a shared SRv6 underlay.

The following SRv6 features have been deployed:

o A Segment Routing Header [I-D.ietf-6man-segment-routing-header]. based data plane.

o SRv6 implementation in the Linux kernel for the End.DX4, T.Encap functions as per [I-D.ietf-spring-srv6-network-programming].

o Hardware support (RSS: Receive-Side Scaling) for the SRv6 packets on the NIC to get required throughput at the receiving cores.

o SRv6 data plane aware OpenStack Neutron ML2 driver and API extension to provision tenant networks.

2.5. China Unicom

China Unicom has deployed SRv6 L3VPN over 169 backbone network from Guangzhou to Beijing to provide inter-domain CloudVPN service. The SRv6 network is based on Huawei NE40E hardware platform.

The following SRv6 features have been deployed:

o A Segment Routing Header [I-D.ietf-6man-segment-routing-header]. based data plane.

o END.DT4 function as per [I-D.filsfils-spring-srv6-network-programming].

o BGP VPN SRv6 extensions [I-D.ietf-bess-srv6-services].

o BGP Prefix Independent Convergence (PIC) core and edge [I-D.ietf-rtgwg-bgp-pic].

o Support for Ping and Traceroute as defined in [I-D.ietf-6man-spring-srv6-oam].

2.6. **CERNET2**

   CERNET2 (CERNET: China Education and Research Network) has deployed
   SRv6 L3VPN from Beijing to Nanjing to provide inter-domain L3VPN
   service for universities. CERNET2 is the largest pure IPv6 education
   backbone networking in the world. The SRv6 network is based on
   Huawei NE40E hardware platform.

   The following SRv6 features have been deployed:

   o A Segment Routing Header [I-D.ietf-6man-segment-routing-header].
      based data plane.

   o END.DT4 function as per [I-D.filsfils-spring-srv6-network-
      programming].

   o BGP VPN SRv6 extensions [I-D.ietf-bess-srv6-services].

   o BGP Prefix Independent Convergence (PIC) core and edge [I-D.ietf-
      rtgwg-bgp-pic].

   o Support for Ping and Traceroute as defined in [I-D.ietf-6man-
      spring-srv6-oam].

2.7. **MTN Uganda Ltd.**

   As part of the complete mobile IP network, Uganda MTN has deployed a
   SRv6 network that carries all services in its backbone.

   The following SRv6 features have been deployed:

   o A Segment Routing Header [I-D.ietf-6man-segment-routing-header].
      based data plane.

   o End (PSP), End.X (PSP), End.DT4, End.DX2, End.DT2U, End.DT2M,
      T.Encaps, T.Insert as per [I-D.ietf-spring-srv6-network-
      programming], [I-D.filsfils-spring-srv6-net-pgm-insertion].

   o SRH based Topology Independent (TI-LFA) Fast Reroute mechanisms
      using T.Insert for the O(50msec) protection against node and link,
      as described in [I-D.ietf-rtgwg-segment-routing-ti-lfa], [I-
      D.voyer-6man-extension-header-insertion].

   o BGP VPN SRv6 extensions [I-D.ietf-bess-srv6-services].

   o BGP Prefix Independent Convergence (PIC) core and edge [I-D.ietf-
      rtgwg-bgp-pic].

o Support for Ping and Traceroute as defined in [I-D.ietf-6man-
   spring-srv6-oam].

2.8. NOIA Network

NOIA Network have deployed a nationwide SRv6 network backbone. The
SRv6 backbone is based on white box and cloud routers with FD.io VPP
or Linux srext module installed. Details can be found at [noia-
whitepaper1], [noia-whitepaper2].

The following SRv6 features have been deployed:

o A Segment Routing Header [I-D.ietf-6man-segment-routing-header].
   based data plane.

o END (PSP), END.X (PSP), END.DT4, End.DT6 as per [I-D.ietf-spring-
   srv6-network-programming].

o iOAM Proof of Transit and Trace options as per [I-D.ietf-ippm-
   ioam-data]

o BFD for Multihop Paths as per [I-D.ietf-bfd-multihop].

o SRH based Topology Independent (TI-LFA) Fast Reroute mechanisms
   using T.Insert for the O(50msec) protection against node and link,
   as described in [I-D.ietf-rtgwg-segment-routing-ti-lfa], [I-
   D.voyer-6man-extension-header-insertion].

2.9. Additional Deployments

Several other deployments are in preparation.

Details to be added after the public announcements.

3. Significant industry collaboration for SRv6 standardization

The work on SRv6 started in IETF in 2013 and was later published in
6man working group as [I-D.previdi-6man-segment-routing-header-00] in
March 2014. The first implementation was done in 2014 [WC-2015].

A significant industry group of operators, academics and vendors
supported and refined the idea according to the IETF process:

o Twenty-four revisions of the document were published.

o Over 1000 emails were exchanged.

o Over 16 IETF presentations were delivered.

o Over 50 additional drafts were submitted to the IETF to specify
   SRv6 protocol extensions and use-cases [SRH-REF-BY]. These
   documents are either working group drafts or are well on their way
   to be adopted by their respective working group. The work spans
   13 working group, including 6man, Spring, idr, bess, pce, lsr,
   detnet, dmm, mpls, etc. Appendix A lists IETF contribution on
   SRv6.

The outcome of this significant support from the operators and
vendors led to the adoption of the draft by the 6man working group in
December 2015.

The first last call for the SRH document was issued in March 2018.

A significant industry group of operators, academics and vendors
supported and refined the idea according to the IETF process:

o 63 tickets were open.

o 50 have been closed.

o Hundreds of emails have been exchanged to support the closure.

o Five revisions of the document have been published to reflect the
   work of the group and the closure of the tickets.

There is clear confidence that the remaining 13 tickets can be
formally closed during IETF 104.

3.1. Academic Contributions

Academia has made significant contribution to SRv6 work. This
includes both Scholastic publications as well as writing open source
software.

Appendix 2 provides a list of academic contributions.

4. Implementation Status of SRv6

The hardware and software platforms listed below are either shipping
or have demonstrated support for SRv6 including processing of the SRH
as described in [I-D.ietf-6man-segment-routing-header]. This section
also indicates the supported SRv6 functions and transit behaviors on
open-source software

4.1. Open-source platforms

The following open source platforms supports SRv6 including
processing of an SRH as described in [I-D.ietf-6man-segment-routing-
header]:

o Linux kernel[ref-1],[ref-2]: End, End.X, End.T, End.DX2, End.DX6,
   End.DX4, End.DT6, End.B6, End.B6.Encaps, T.Insert, T.Encaps,
   T.Encaps.L2

o Linux srext module: End, End.X, End.DX2, End.DX6, End.DX4, End.AD,
   End.AM

o FD.io VPP: End, End.X, End.DX2, End.DX6, End.DX4, End.DT6,
   End.DT4, End.B6, End.B6.Encaps, End.AS, End.AD, End.AM, T.Insert,
   T.Encaps, T.Encaps.L2

4.2. Additional Routing platforms

To date, 18 publicly known routing platforms from 8 different vendors
support SRv6 in hardware. Specifically, the following routing
platforms supports SRv6 features, including processing of the SRH as
described in [I-D.ietf-6man-segment-routing-header]:

Cisco:

Cisco hardware platforms supports SRH processing since April 2017,
with current status as follows:

o Cisco ASR 9000 platform with IOS XR shipping code.

o Cisco NCS 5500 platform with IOS XR shipping code.

o Cisco NCS 560 platform with IOS XR shipping code.

o Cisco NCS 540 platform with IOS XR shipping code.

o Cisco ASR 1000 platform with IOS XE engineering code.

Huawei:

o Huawei ATN with VRPV8 shipping code.

o Huawei CX600 with VRPV8 shipping code.

o Huawei NE40E with VRPV8 shipping code.

o Huawei ME60 with VRPV8 shipping code.

o Huawei NE5000E with VRPV8 shipping code.

o Huawei NE9000 with VRPV8 shipping code.

o Huawei NG-OLT MA5800 with VRPV8 shipping code.

Barefoot Networks:

o Hardware implementation in the Tofino NPU is present since May
   2017.

Marvell:

o Hardware implementation in the Prestera family of Ethernet
   switches.

Intel:

o Hardware support on Intel's FPGA Programmable Acceleration Card
   N3000.

UTStarcom:

o Hardware implementation in UTStarcom SkyFlux UAR500.

Spirent:

o Support in Spirent TestCenter.

Ixia:

o Support in Ixia IxNetwork.

4.3. Applications

In addition to the aforementioned routing platforms, the following
open-source applications have been extended to support the processing
of IPv6 packets containing an SRH. For Wireshark, tcpdump, iptables
and nftables, these extensions have been included in the mainstream
version.

o Wireshark [ref-3]

o tcpdump [ref-4]

o iptables [ref-5], [ref-6]

o nftables [ref-7]

   o Snort [ref-8]

5. Interoperability Status of SRv6

   This section provides a brief inventory of publicly disclosed SRv6
   interoperability testing, including processing of the SRH as
   described in [I-D.ietf-6man-segment-routing-header], among many
   implementations.

   Please refer to [I-D.filsfils-spring-srv6-interop] for details.

5.1. EANTC 2019

   In March 2019, the European Advanced Networking Test Center (EANTC)
   successfully validated multiple implementations of [I-D.ietf-6man-
   segment-routing-header], [I.D-draft-ietf-spring-srv6-network-
   programming], [I-D.ietf-bess-srv6-services], [draft-bashandy-isis-
   srv6-extensions], [draft-ietf-rtgwg-segment-routing-ti-lfa-01] and
   [draft-ietf-6man-spring-srv6-oam]. The Results from this event were
   showcased at the MPLS + SDN + NFV World Congress conference in April
   2019 [EANTC-19].

   Five different implementations of the SRv6 drafts, including SRH as
   described in [I-D.ietf-6man-segment-routing-header] were used in this
   testing:

   o Hardware implementation in Cisco NCS 5500 router.

   o Hardware implementation in Huawei NE9000-8 router.

   o Hardware implementation in Huawei NE40E-F1A router.

   o Spirent TestCenter.

   o Keysight Ixia IxNetwork.

   SRv6 interoperability, including SRH processing as described in [I-
   D.ietf-6man-segment-routing-header], was validated for the following
   scenarios:

   o L3VPN for IPv4 traffic using the SRv6 T.Encaps and End.DT4
      behaviors.

   o L3VPN for IPv6 traffic using the SRv6 T.Encaps and End.DT6
      behaviors.

o The testing validated the interoperability of T.Encaps and
   End.DT4/ End.DT6 behaviors combined with the End and End.X
   functions.

o SRH based Topology Independent (TI-LFA) Fast Reroute mechanisms
   using T.Insert.Red for link protection.

o OAM procedures (Ping and traceroute) [draft-ietf-6man-spring-
   srv6-oam]

Bidirectional traffic was sent between the ingress PE and Egress PE,
i.e., the PEs were performing both the encapsulation (T.Encaps) and
the decapsulation (END.DT4/ END.DT6) functionality, simultaneously.
Multiple implementations of Classic (non-SRv6 capable) P nodes were
tested to validate that a transit node only needs to be IPv6 capable.

5.2. SIGCOM 2017

The following interoperability testing scenarios were publicly
showcased on August 21-24, 2017 at the SIGCOMM conference.

Five different implementations of SRv6 behaviors were used for this
testing:

o Software implementation in Linux using the srext kernel module
   created by University of Rome, Tor Vergata, Italy.

o Software implementation in the FD.io Vector Packet Processor (VPP)
   virtual router.

o Hardware implementation in Barefoot Networks Tofino NPU using the
   P4 programming language.

o Hardware implementation in Cisco NCS 5500 router using
   commercially available NPU.

o Hardware implementation in Cisco ASR 1000 router using custom
   ASIC.

SRH interoperability including processing of the SRH as described in
[I-D.ietf-6man-segment-routing-header] was validated in the following
scenarios:

o L3VPN using the SRv6 behaviors T.Encaps and End.DX6.

o L3VPN with traffic engineering in the underlay. The testing
   validated the interoperability of T.Encaps and End.DX6 behaviors
   combined with the End and End.X functions.

o L3 VPN with traffic engineering and service chaining. This
   scenario validated the L3 VPN service with underlay optimization
   and service programming using SRH.

The results confirm consistency among SRH [I-D.ietf-6man-segment-
routing-header], network programming [I.D-draft-ietf-spring-srv6-
network-programming] and the dependent SRv6 drafts.

5.3. EANTC 2018

In March 2018, the European Advanced Networking Test Center (EANTC)
successfully validated multiple implementations of [I-D.ietf-6man-
segment-routing-header]. The Results from this event were showcased
at the MPLS + SDN + NFV World Congress conference in April 2018
[EANTC-18].

Four different implementations of the SRv6 drafts, including SRH as
described in [I-D.ietf-6man-segment-routing-header] were used in this
testing:

o Hardware implementation in Cisco NCS 5500 router.

o Hardware implementation in UTStarcom UAR500.

o Spirent TestCenter.

o Ixia IxNetwork.

SRv6 interoperability, including SRH processing as described in [I-
D.ietf-6man-segment-routing-header], was validated for the following
scenarios:

o L3-VPN for IPv4 traffic using the SRv6 T.Encaps and End.DT4
   behaviors.

o L3VPN with traffic engineering in the underlay. The testing
   validated the interoperability of T.Encaps and End.DT4 behaviors
   combined with the End and End.X functions.

o SRH based Topology Independent (TI-LFA) Fast Reroute mechanisms
   using T.Insert.Red.

The results confirm consistency among SRH [I-D.ietf-6man-segment-
routing-header], network programming [I.D-draft-ietf-spring-srv6-
network-programming] and the dependent SRv6 drafts.

6. **Appendix 1**

   The following IETF working group documents or individual submissions
   references SRH Draft [I-D.ietf-6man-segment-routing-header] (see
   [SRH-REF-BY] for the source of the information):

   o draft-ietf-6man-spring-srv6-oam

   o draft-ali-spring-ioam-srv6

   o draft-bashandy-isis-srv6-extensions

   o draft-ietf-bess-srv6-services

   o draft-dawra-idr-bgpls-srv6-ext

   o draft-ietf-spring-srv6-network-programming

   o draft-geng-detnet-dp-sol-srv6

   o draft-hu-mpls-sr-inter-domain-use-cases

   o draft-ietf-dmm-srv6-mobile-uplane

   o draft-li-6man-service-aware-ipv6-network

   o draft-li-spring-light-weight-srv6-ioam

   o draft-li-spring-srv6-path-segment

   o draft-mirsky-6man-unified-id-sr

   o draft-peng-spring-srv6-compatibility

   o draft-xuclad-spring-sr-service-programming

   o draft-bonica-6man-comp-rtg-hdr

   o draft-bonica-6man-vpn-dest-opt

   o draft-boutros-nvo3-geneve-applicability-for-sfc

   o draft-carpenter-limited-domains

   o draft-chunduri-lsr-isis-preferred-path-routing

   o draft-chunduri-lsr-ospf-preferred-path-routing

o   [draft-dawra-idr-bgp-ls-sr-service-segments](#)

o   [draft-dhody-pce-pcep-extension-pce-controller-srv6](#)

o   [draft-dong-spring-sr-for-enhanced-vpn](#)

o   [draft-dukes-spring-mtu-overhead-analysis](#)

o   [draft-dukes-spring-sr-for-sdwan](#)

o   [draft-dunbar-sr-sdwan-over-hybrid-networks](#)

o   [draft-filsfils-spring-srv6-interop](#)

o   [draft-filsfils-spring-srv6-net-pgm-illustration](#)

o   [draft-gandhi-spring-rfc6374-srpm-udp](#)

o   [draft-gandhi-spring-twamp-srpm](#)

o   [draft-guichard-spring-nsh-sr](#)

o   [draft-heitz-idr-msdc-fabric-autoconf](#)

o   [draft-herbert-ipv4-udpencap-eh](#)

o   [draft-herbert-simple-sr](#)

o   [draft-homma-dmm-5gs-id-loc-coexistence](#)

o   [draft-homma-nmrg-slice-gateway](#)

o   [draft-ietf-idr-bgp-prefix-sid](#)

o   [draft-ietf-idr-segment-routing-te-policy](#)

o   [draft-ietf-intarea-gue-extensions](#)

o   [draft-ietf-mpls-sr-over-ip](#)

o   [draft-ietf-pce-segment-routing](#)

o   [draft-ietf-pce-segment-routing-ipv6](#)

o   [draft-ietf-spring-mpls-path-segment](#)

o   [draft-ietf-spring-segment-routing-msdc](#)

   o draft-ietf-teas-pcecc-use-cases

   o draft-li-6man-ipv6-sfc-ifit

   o draft-li-idr-flowspec-srv6

   o draft-li-ospf-ospfv3-srv6-extensions

   o draft-li-pce-pcep-flowspec-srv6

   o draft-li-tsvwg-loops-problem-opportunities

   o draft-raza-spring-srv6-yang

   o draft-su-bgp-trigger-segment-routing-odn

   o draft-voyer-6man-extension-header-insertion

   o [RFC 7855](RFC 7855)

   o [RFC 8218](RFC 8218)

   o [RFC 8402](RFC 8402)

[7](7). Appendix 2

   The following is an partial list of SRv6 Contributions from Academia,
   including open source implementation of SRH Draft [I-D.ietf-6man-
   segment-routing-header], network programming [I.D-draft-ietf-spring-
   srv6-network-programming] draft and the related IETF drafts:

o An Efficient Linux Kernel Implementation of Service Function
   Chaining for legacy VNFs based on IPv6 Segment Routing.
   Netsoft2019, https://arxiv.org/abs/1901.00936.

o Flexible failure detection and fast reroute using eBPF and SRv6
   (https://ieeexplore.ieee.org/document/8584995).

o Zero-Loss Virtual Machine Migration with IPv6 Segment Routing
   (https://ieeexplore.ieee.org/document/8584942).

o SDN Architecture and Southbound APIs for IPv6 Segment Routing
   Enabled Wide Area Networks, IEEE Journals & Magazine
   (https://doi.org/10.1109/TNSM.2018.2876251).

o Leveraging eBPF for programmable network functions with IPv6
   Segment Routing
   (https://doi.org/10.1145/3281411.3281426).

o Snort demo, http://netgroup.uniroma2.it/Stefano_Salsano/
   papers/18-sr-snort-demo.pdf.

o Performance of IPv6 Segment Routing in Linux Kernel,
   IEEE Conference Publication,
   (https://ieeexplore.ieee.org/document/8584976).

o Interface Counters in Segment Routing v6: a powerful
   instrument for Traffic Matrix Assessment
   (https://doi.org/10.1109/NOF.2018.8597768).

o Exploring various use cases for IPv6 Segment Routing
   (https://doi.org/10.1145/3234200.3234213).

o SRv6Pipes: enabling in-network bytestream functions
   (http://hdl.handle.net/2078.1/197480).

o SERA: SEgment Routing Aware Firewall for Service Function
   Chaining scenarios
   (http://netgroup.uniroma2.it/Stefano_Salsano/papers/
   18-ifip-sera-firewall-sfc.pdf).

o Software Resolved Networks
   (https://doi.org/10.1145/3185467.3185471).

o 6LB: Scalable and Application-Aware Load Balancing
   with Segment Routing
   (https://doi.org/10.1109/TNET.2018.2799242).

o Implementation of virtual network function chaining through
   segment routing in a linux-based NFV infrastructure,
   IEEE Conference Publication,
   (https://doi.org/10.1109/NETSOFT.2017.8004208).

o A Linux kernel implementation of Segment Routing with IPv6,
   IEEE Conference Publication(https://doi.org/10.1109/
   INFCOMW.2016.7562234).

o Leveraging IPv6 Segment Routing for Service Function Chaining
   (http://hdl.handle.net/2078.1/168097)

8. IANA Considerations

   None

9. Security Considerations

   None

10. Acknowledgements

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11. Contributors

   The following people have contributed to this document:

   Hirofumi Ichihara
   LINE Corporation
   Email: hirofumi.ichihara@linecorp.com

   Toshiki Tsuchiya
   LINE Corporation
   Email: toshiki.tsuchiya@linecorp.com

   Francois Clad
   Cisco Systems
   Email: fclad@cisco.com

   Robbins Mwehair
   MTN Uganda Ltd.
   Email: Robbins.Mwehair@mtn.com

   Sebastien Parisot
   Iliad
   Email: sparisot@free-mobile.fr

   Tadas Planciunas
   NOIA Network
   Email: tadas@noia.network

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Authors' Addresses

   Satoru Matsushima
   Softbank

   Email: satoru.matsushima@g.softbank.co.jp

   Clarence Filsfils
   Cisco Systems

   Email: cfilsfil@cisco.com

   Zafar Ali
   Cisco Systems

   Email: zali@cisco.com

Zhenbin Li
Huawei Technologies

Email: lizhenbin@huawei.com