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S. Matsushima
Softbank
C. Filsfils
Z. Ali
Cisco Systems
Z. Li
Huawei Technologies
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SRv6 Implementation and Deployment Status
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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].

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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.bashandy-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.

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,End.X,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].

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

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

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

2.8. 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:

- Twenty-four revisions of the document were published.

- Over 1000 emails were exchanged.

- Over 16 IETF presentations were delivered.

- 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:

- Cisco ASR 9000 platform with IOS XR shipping code.
- Cisco NCS 5500 platform with IOS XR shipping code.
- Cisco NCS 560 platform with IOS XR shipping code.
- Cisco NCS 540 platform with IOS XR shipping code.
- Cisco ASR 1000 platform with IOS XE engineering code.

Huawei:

- Huawei ATN with VRPV8 shipping code.
- Huawei CX600 with VRPV8 shipping code.
- Huawei NE40E with VRPV8 shipping code.
- Huawei ME60 with VRPV8 shipping code.
- Huawei NE5000E with VRPV8 shipping code.
- Huawei NE9000 with VRPV8 shipping code.
- Huawei NG-OLT MA5800 with VRPV8 shipping code.

Barefoot Networks:

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

Marvell:

- 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

- draft-bashandy-isis-srv6-extensions
- draft-ietf-bess-srv6-services
- draft-dawra-idr-bgpls-srv6-ext
- draft-ietf-spring-srv6-network-programming
- draft-geng-detnet-dp-sol-srv6
- draft-hu-mpls-sr-inter-domain-use-cases
- draft-ietf-dmm-srv6-mobile-uplane
- draft-li-6man-service-aware-ipv6-network
- draft-li-spring-light-weight-srv6-ioam
- draft-li-spring-srv6-path-segment
- draft-mirsky-6man-unified-id-sr
- draft-peng-spring-srv6-compatibility
- draft-xuclad-spring-sr-service-programming
- draft-bonica-6man-comp-rtg-hdr
- draft-bonica-6man-vpn-dest-opt
- draft-boutros-nvo3-geneve-applicability-for-sfc
- draft-carpenter-limited-domains
- draft-chunduri-lsr-isis-preferred-path-routing
- draft-chunduri-lsr-ospf-preferred-path-routing
- draft-dawra-idr-bgp-ls-sr-service-segments
- draft-dhody-pce-pcep-extension-pce-controller-srv6
- draft-dong-spring-sr-for-enhanced-vpn
- draft-dukes-spring-mtu-overhead-analysis
- draft-dukes-spring-sr-for-sdwan

- draft-dunbar-sr-sdwan-over-hybrid-networks
- draft-filsfils-spring-srv6-interop
- draft-filsfils-spring-srv6-net-pgm-illustration
- draft-gandhi-spring-rfc6374-srpm-udp
- draft-gandhi-spring-twamp-srpm
- draft-guichard-spring-nsh-sr
- draft-heitz-idr-msdc-fabric-autoconf
- draft-herbert-ipv4-udpencap-eh
- draft-herbert-simple-sr
- draft-homma-dmm-5gs-id-loc-coexistence
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- draft-ietf-idr-bgp-prefix-sid
- draft-ietf-idr-segment-routing-te-policy
- draft-ietf-intarea-gue-extensions
- draft-ietf-mpls-sr-over-ip
- draft-ietf-pce-segment-routing
- draft-ietf-pce-segment-routing-ipv6
- draft-ietf-spring-mpls-path-segment
- draft-ietf-spring-segment-routing-msdc
- draft-ietf-teas-pcecc-use-cases
- draft-li-6man-ipv6-sfc-ifit
- draft-li-idr-flowspec-srv6
- draft-li-ospf-ospfv3-srv6-extensions
- 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
- o RFC 8218
- o RFC 8402

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).
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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).
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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

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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