Network Working Group
Internet-Draft
Intended status: Standards Track
Expires: August 5, 2017

S. Previdi, Ed.
C. Filsfils
Cisco Systems, Inc.
B. Field
Comcast
I. Leung
Rogers Communications
J. Linkova
Google
E. Aries
Facebook
T. Kosugi
NTT
E. Vyncke
Cisco Systems, Inc.
D. Lebrun
Universite Catholique de Louvain
February 1, 2017

IPv6 Segment Routing Header (SRH)
draft-ietf-6man-segment-routing-header-05

Abstract

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

Segment Routing can be applied to the IPv6 data plane with the addition of a new type of Routing Extension Header. This draft describes the Segment Routing Extension Header Type and how it is used by SR capable nodes.

Requirements Language

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

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1. Segment Routing Documents

Segment Routing terminology is defined in [I-D.ietf-spring-segment-routing].

Segment Routing use cases are described in [RFC7855] and [I-D.ietf-spring-ipv6-use-cases].

Segment Routing protocol extensions are defined in [I-D.ietf-isis-segment-routing-extensions], and [I-D.ietf-ospf-ospfv3-segment-routing-extensions].

2. Introduction

Segment Routing (SR), defined in [I-D.ietf-spring-segment-routing], allows a node to steer a packet through a controlled set of instructions, called segments, by prepending an SR header to the packet. A segment can represent any instruction, topological or service-based. SR allows to enforce a flow through any path (topological or service/application based) while maintaining per-flow state only at the ingress node to the SR domain. Segments can be derived from different components: IGP, BGP, Services, Contexts, Locators, etc. The list of segment forming the path is called the Segment List and is encoded in the packet header.

SR allows the use of strict and loose source based routing paradigms without requiring any additional signaling protocols in the infrastructure hence delivering an excellent scalability property.

The source based routing model described in [I-D.ietf-spring-segment-routing] is inherited from the ones proposed by [RFC1940] and [RFC2460]. The source based routing model offers the support for explicit routing capability.

2.1. Data Planes supporting Segment Routing

Segment Routing (SR), can be instantiated over MPLS ([I-D.ietf-spring-segment-routing-mpls]) and IPv6. This document defines its instantiation over the IPv6 data-plane based on the use-cases defined in [I-D.ietf-spring-ipv6-use-cases].

This document defines a new type of Routing Header (originally defined in [RFC2460]) called the Segment Routing Header (SRH) in order to convey the Segment List in the packet header as defined in [I-D.ietf-spring-segment-routing]. Mechanisms through which segment are known and advertised are outside the scope of this document.

A segment is materialized by an IPv6 address. A segment identifies a topological instruction or a service instruction. A segment can be either:

- o global: a global segment represents an instruction supported by all nodes in the SR domain and it is instantiated through an IPv6 address globally known in the SR domain.

o local: a local segment represents an instruction supported only by the node who originates it and it is instantiated through an IPv6 address that is known only by the local node.

2.2. Segment Routing (SR) Domain

We define the concept of the Segment Routing Domain (SR Domain) as the set of nodes participating into the source based routing model. These nodes may be connected to the same physical infrastructure (e.g.: a Service Provider's network) as well as nodes remotely connected to each other (e.g.: an enterprise VPN or an overlay).

A non-exhaustive list of examples of SR Domains is:

o The network of an operator, service provider, content provider, enterprise including nodes, links and Autonomous Systems.

o A set of nodes connected as an overlay over one or more transit providers. The overlay nodes exchange SR-enabled traffic with segments belonging solely to the overlay routers (the SR domain). None of the segments in the SR-enabled packets exchanged by the overlay belong to the transit networks

The source based routing model through its instantiation of the Segment Routing Header (SRH) defined in this document equally applies to all the above examples.

It is assumed in this document that the SRH is added to the packet by its source, consistently with the source routing model defined in [RFC2460]. For example:

o At the node originating the packet (host, server).

o At the ingress node of an SR domain where the ingress node receives an IPv6 packet and encapsulates it into an outer IPv6 header followed by a Segment Routing header.

2.2.1. SR Domain in a Service Provider Network

The following figure illustrates an SR domain consisting of an operator's network infrastructure.

```
     (-------------------------- Operator 1 -----------------------)
     (                                                             )
     (  (-----AS 1-----)  (-------AS 2-------)  (----AS 3-------)  )
     (  (              )  (                  )  (               )  )
 A1--(--(--11---13--14-)--(-21---22---23--24-)--(-31---32---34--)--)--Z1
     (  ( /|\  /|\  /| )  ( |\  /|\  /|\  /| )  ( |\  /|\  /| \ )  )
 A2--(--(/ | \/ | \/ | )  ( | \/ | \/ | \/ | )  ( | \/ | \/ |  \)--)--Z2
     (  (  | /\ | /\ | )  ( | /\ | /\ | /\ | )  ( | /\ | /\ |   )  )
     (  (  |/  \|/  \| )  ( |/  \|/  \|/  \| )  ( |/  \|/  \|   )  )
 A3--(--(--15---17--18-)--(-25---26---27--28-)--(-35---36---38--)--)--Z3
     (  (              )  (                  )  (               )  )
     (  (--------------)  (------------------)  (---------------)  )
     (                                                             )
     (-------------------------------------------------------------)
```

Figure 1: Service Provider SR Domain

Figure 1 describes an operator network including several ASes and delivering connectivity between endpoints. In this scenario, Segment Routing is used within the operator networks and across the ASes boundaries (all being under the control of the same operator). In this case segment routing can be used in order to address use cases such as end-to-end traffic engineering, fast re-route, egress peer

engineering, data-center traffic engineering as described in [RFC7855], [I-D.ietf-spring-ipv6-use-cases] and [I-D.ietf-spring-resiliency-use-cases].

Typically, an IPv6 packet received at ingress (i.e.: from outside the SR domain), is classified according to network operator policies and such classification results into an outer header with an SRH applied to the incoming packet. The SRH contains the list of segment representing the path the packet must take inside the SR domain. Thus, the SA of the packet is the ingress node, the DA (due to SRH procedures described in Section 4) is set as the first segment of the path and the last segment of the path is the egress node of the SR domain.

The path may include intra-AS as well as inter-AS segments. It has

to be noted that all nodes within the SR domain are under control of the same administration. When the packet reaches the egress point of the SR domain, the outer header and its SRH are removed so that the destination of the packet is unaware of the SR domain the packet has traversed.

The outer header with the SRH is no different from any other tunneling encapsulation mechanism and allows a network operator to implement traffic engineering mechanisms so to efficiently steer traffic across his infrastructure.

2.2.2. SR Domain in a Overlay Network

The following figure illustrates an SR domain consisting of an overlay network over multiple operator's networks.

```
    (--Operator 1---)  (-----Operator 2-----)  (--Operator 3---)
    (               )  (                    )  (               )
A1--(--11---13--14--)--(--21---22---23--24--)--(-31---32---34--)--C1
    ( /|\  /|\  /|  )  (  |\  /|\  /|\  /|  )  ( |\  /|\  /| \ )
A2--(/ | \/ | \/ |  )  (  | \/ | \/ | \/ |  )  ( | \/ | \/ |  \)--C2
    (  | /\ | /\ |  )  (  | /\ | /\ | /\ |  )  ( | /\ | /\ |   )
    (  |/  \|/  \|  )  (  |/  \|/  \|/  \|  )  ( |/  \|/  \|   )
A3--(--15---17--18--)--(--25---26---27--28--)--(-35---36---38--)--C3
    (               )  (  |    |         |  )  (               )
    (---------------)  (--|----|---------|--)  (---------------)
                          |    |         |
                          B1   B2        B3
```

Figure 2: Overlay SR Domain

Figure 2 describes an overlay consisting of nodes connected to three different network operators and forming a single overlay network where Segment routing packets are exchanged.

The overlay consists of nodes A1, A2, A3, B1, B2, B3, C1, C2 and C3. These nodes are connected to their respective network operator and form an overlay network.

Each node may originate packets with an SRH which contains, in the segment list of the SRH or in the DA, segments identifying other overlay nodes. This implies that packets with an SRH may traverse operator's networks but, obviously, these SRHs cannot contain an address/segment of the transit operators 1, 2 and 3. The SRH originated by the overlay can only contain address/segment under the administration of the overlay (e.g. address/segments supported by A1, A2, A3, B1, B2, B3, C1,C2 or C3).

In this model, the operator network nodes are transit nodes and, according to [RFC2460], MUST NOT inspect the routing extension header since they are not the DA of the packet.

It is a common practice in operators networks to filter out, at ingress, any packet whose DA is the address of an internal node and it is also possible that an operator would filter out any packet destined to an internal address and having an extension header in it.

This common practice does not impact the SR-enabled traffic between the overlay nodes as the intermediate transit networks never see a destination address belonging to their infrastructure. These SR-enabled overlay packets will thus never be filtered by the transit operators.

In all cases, transit packets (i.e.: packets whose DA is outside the domain of the operator's network) will be forwarded accordingly without introducing any security concern in the operator's network. This is similar to tunneled packets.

3. Segment Routing Extension Header (SRH)

A new type of the Routing Header (originally defined in [RFC2460]) is defined: the Segment Routing Header (SRH) which has a new Routing Type, (suggested value 4) to be assigned by IANA.

The Segment Routing Header (SRH) is defined as follows:


```
     0                   1                   2                   3
```

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Next Header   |  Hdr Ext Len  | Routing Type  | Segments Left |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| First Segment |     Flags     |           RESERVED            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|            Segment List[0] (128 bits IPv6 address)            |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
                              ...
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|            Segment List[n] (128 bits IPv6 address)            |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                                                             //
//         Optional Type Length Value objects (variable)       //
//                                                             //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

- o Next Header: 8-bit selector. Identifies the type of header immediately following the SRH.

- o Hdr Ext Len: 8-bit unsigned integer, is the length of the SRH header in 8-octet units, not including the first 8 octets.

- o Routing Type: TBD, to be assigned by IANA (suggested value: 4).

- o Segments Left. Defined in [RFC2460], it contains the index, in the Segment List, of the next segment to inspect. Segments Left is decremented at each segment.

- o First Segment: contains the index, in the Segment List, of the first segment of the path which is in fact the last element of the Segment List.

- o Flags: 8 bits of flags. Following flags are defined:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|U|P|O|A|H|  U  |
+-+-+-+-+-+-+-+-+
```

U: Unused and for future use. SHOULD be unset on transmission and MUST be ignored on receipt.

P-flag: Protected flag. Set when the packet has been rerouted through FRR mechanism by an SR endpoint node.

O-flag: OAM flag. When set, it indicates that this packet is an operations and management (OAM) packet.

A-flag: Alert flag. If present, it means important Type Length Value (TLV) objects are present. See Section 3.1 for details on TLVs objects.

H-flag: HMAC flag. If set, the HMAC TLV is present and is encoded as the last TLV of the SRH. In other words, the last 36 octets of the SRH represent the HMAC information. See Section 3.1.5 for details on the HMAC TLV.

- RESERVED: SHOULD be unset on transmission and MUST be ignored on receipt.

- Segment List[n]: 128 bit IPv6 addresses representing the nth segment in the Segment List. The Segment List is encoded starting from the last segment of the path. I.e., the first element of the segment list (Segment List [0]) contains the last segment of the path while the last segment of the Segment List (Segment List[n]) contains the first segment of the path. The index contained in "Segments Left" identifies the current active segment.

- Type Length Value (TLV) are described in Section 3.1.

3.1. SRH TLVs

This section defines TLVs of the Segment Routing Header.

Type Length Value (TLV) contain optional information that may be used by the node identified in the DA of the packet. It has to be noted that the information carried in the TLVs is not intended to be used by the routing layer. Typically, TLVs carry information that is consumed by other components (e.g.: OAM) than the routing function.

Each TLV has its own length, format and semantic. The code-point allocated (by IANA) to each TLV defines both the format and the

semantic of the information carried in the TLV. Multiple TLVs may be encoded in the same SRH.

The "Length" field of the TLV is primarily used to skip the TLV while inspecting the SRH in case the node doesn't support or recognize the TLV codepoint. The "Length" defines the TLV length in octets and not including the "Type" and "Length" fields.

The primary scope of TLVs is to give the receiver of the packet information related to the source routed path (e.g.: where the packet entered in the SR domain and where it is expected to exit).

Additional TLVs may be defined in the future.

3.1.1. Ingress Node TLV

The Ingress Node TLV is optional and identifies the node this packet traversed when entered the SR domain. The Ingress Node TLV has following format:

```
 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     |    Length     |   RESERVED    |     Flags     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                   Ingress Node (16 octets)                    |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

- o Type: to be assigned by IANA (suggested value 1).
- o Length: 18.
- o RESERVED: 8 bits. SHOULD be unset on transmission and MUST be ignored on receipt.

o Flags: 8 bits. No flags are defined in this document.

o Ingress Node: 128 bits. Defines the node where the packet is expected to enter the SR domain. In the encapsulation case described in Section 2.2.1, this information corresponds to the SA of the encapsulating header.

3.1.2. Egress Node TLV

The Egress Node TLV is optional and identifies the node this packet is expected to traverse when exiting the SR domain. The Egress Node TLV has following format:

```
 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     |    Length     |   RESERVED    |     Flags     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                  Egress Node (16 octets)                      |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

o Type: to be assigned by IANA (suggested value 2).

o Length: 18.

o RESERVED: 8 bits. SHOULD be unset on transmission and MUST be ignored on receipt.

o Flags: 8 bits. No flags are defined in this document.

o Egress Node: 128 bits. Defines the node where the packet is expected to exit the SR domain. In the encapsulation case described in Section 2.2.1, this information corresponds to the last segment of the SRH in the encapsulating header.

3.1.3. Opaque Container TLV

The Opaque Container TLV is optional and has the following format:


```
 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     |    Length     |   RESERVED    |     Flags     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|             Opaque Container (16 octets)                      |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

- Type: to be assigned by IANA (suggested value 3).

- Length: 18.

- RESERVED: 8 bits. SHOULD be unset on transmission and MUST be ignored on receipt.

- Flags: 8 bits. No flags are defined in this document.

- Opaque Container: 128 bits of opaque data not relevant for the routing layer. Typically, this information is consumed by a non-routing component of the node receiving the packet (i.e.: the node

in the DA).

3.1.4. Padding TLV

The Padding TLV is optional and with the purpose of aligning the SRH on a 8 octet boundary. The Padding TLV has the following format:

```
 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      |    Length     |      Padding (variable)       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                     Padding (variable)                       //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

o Type: to be assigned by IANA (suggested value 4).

o Length: 1 to 7

o Padding: from 1 to 7 octets of padding. Padding bits have no semantic. They SHOULD be set to 0 on transmission and MUST be ignored on receipt.

The following applies to the Padding TLV:

o Padding TLV is optional and MAY only appear once in the SRH. If present, it MUST have a length between 1 and 7 octets.

o The Padding TLV is used in order to align the SRH total length on the 8 octet boundary.

o When present, the Padding TLV MUST appear as the last TLV before the HMAC TLV (if HMAC TLV is present).

o When present, the Padding TLV MUST have a length from 1 to 7 in order to align the SRH total lenght on a 8-octet boundary.

o When a router inspecting the SRH encounters the Padding TLV, it MUST assume that no other TLV (other than the HMAC) follow the Padding TLV.

3.1.5. HMAC TLV

HMAC TLV is optional and contains the HMAC information. The HMAC TLV has the following format:

```
 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     |    Length     |            RESERVED           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      HMAC Key ID (4 octets)                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                              //
|                      HMAC (32 octets)                        //
|                                                              //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

o Type: to be assigned by IANA (suggested value 5).

o Length: 38.

o RESERVED: 2 octets. SHOULD be unset on transmission and MUST be ignored on receipt.

o HMAC Key ID: 4 octets.

o HMAC: 32 octets.

o HMAC and HMAC Key ID usage is described in Section 5

The Following applies to the HMAC TLV:

o When present, the HMAC TLV MUST be encoded as the last TLV of the SRH.

o If the HMAC TLV is present, the SRH H-Flag (Figure 4) MUST be set.

o When the H-flag is set in the SRH, the router inspecting the SRH MUST find the HMAC TLV in the last 38 octets of the SRH.

3.2. SRH and RFC2460 behavior

The SRH being a new type of the Routing Header, it also has the same properties:

SHOULD only appear once in the packet.

Only the router whose address is in the DA field of the packet header MUST inspect the SRH.

Therefore, Segment Routing in IPv6 networks implies that the segment identifier (i.e.: the IPv6 address of the segment) is moved into the DA of the packet.

The DA of the packet changes at each segment termination/completion and therefore the final DA of the packet MUST be encoded as the last segment of the path.

4. SRH Procedures

In this section we describe the different procedures on the SRH.

4.1. Source SR Node

A Source SR Node can be any node originating an IPv6 packet with its IPv6 and Segment Routing Headers. This include either:

A host originating an IPv6 packet.

An SR domain ingress router encapsulating a received IPv6 packet into an outer IPv6 header followed by an SRH.

The mechanism through which a Segment List is derived is outside of the scope of this document. As an example, the Segment List may be obtained through:

Local path computation.

Local configuration.

Interaction with a centralized controller delivering the path.

Any other mechanism.

The following are the steps of the creation of the SRH:

Next Header and Hdr Ext Len fields are set according to [RFC2460].

Routing Type field is set as TBD (to be allocated by IANA, suggested value 4).

The Segment List is built with the FIRST segment of the path encoded in the LAST element of the Segment List. Subsequent segments are encoded on top of the first segment. Finally, the LAST segment of the path is encoded in the FIRST element of the Segment List. In other words, the Segment List is encoded in the reverse order of the path.

The final DA of the packet is encoded as the last segment of the path (encoded in the first element of the Segment List).

The DA of the packet is set with the value of the first segment (found in the last element of the segment list).

The Segments Left field is set to n-1 where n is the number of elements in the Segment List.

The First Segment field is set to n-1 where n is the number of elements in the Segment List.

The packet is sent out towards the first segment (i.e.: represented in the packet DA).

HMAC TLV may be set according to Section 5.

4.2. Transit Node

According to [RFC2460], the only node who is allowed to inspect the Routing Extension Header (and therefore the SRH), is the node corresponding to the DA of the packet. Any other transit node MUST

NOT inspect the underneath routing header and MUST forward the packet towards the DA and according to the IPv6 routing table.

In the example case described in Section 2.2.2, when SR capable nodes are connected through an overlay spanning multiple third-party infrastructure, it is safe to send SRH packets (i.e.: packet having a Segment Routing Header) between each other overlay/SR-capable nodes as long as the segment list does not include any of the transit provider nodes. In addition, as a generic security measure, any service provider will block any packet destined to one of its internal routers, especially if these packets have an extended header in it.

4.3. SR Segment Endpoint Node

The SR segment endpoint node is the node whose address is in the DA. The segment endpoint node inspects the SRH and does:

```
1.   IF DA = myself (segment endpoint)
2.      IF Segments Left > 0 THEN
           decrement Segments Left
           update DA with Segment List[Segments Left]
3.      ELSE continue IPv6 processing of the packet
             End of processing.
4.   Forward the packet out
```

5. Security Considerations

This section analyzes the security threat model, the security issues and proposed solutions related to the new Segment Routing Header.

The Segment Routing Header (SRH) is simply another type of the routing header as described in RFC 2460 [RFC2460] and is:

- o Added by an SR edge router when entering the segment routing domain or by the originating host itself. The source host can even be outside the SR domain;

- o inspected and acted upon when reaching the destination address of the IP header per RFC 2460 [RFC2460].

Per RFC2460 [RFC2460], routers on the path that simply forward an IPv6 packet (i.e. the IPv6 destination address is none of theirs) will never inspect and process the content of the SRH. Routers whose one interface IPv6 address equals the destination address field of the IPv6 packet MUST parse the SRH and, if supported and if the local configuration allows it, MUST act accordingly to the SRH content.

According to RFC2460 [RFC2460], the default behavior of a non SR-capable router upon receipt of an IPv6 packet with SRH destined to an address of its, is to:

- o ignore the SRH completely if the Segment Left field is 0 and proceed to process the next header in the IPv6 packet;

- o discard the IPv6 packet if Segment Left field is greater than 0, it MAY send a Parameter Problem ICMP message back to the Source Address.

5.1. Threat model

5.1.1. Source routing threats

Using an SRH is similar to source routing, therefore it has some well-known security issues as described in RFC4942 [RFC4942] section 2.1.1 and RFC5095 [RFC5095]:

- o amplification attacks: where a packet could be forged in such a way to cause looping among a set of SR-enabled routers causing unnecessary traffic, hence a Denial of Service (DoS) against bandwidth;

- o reflection attack: where a hacker could force an intermediate node to appear as the immediate attacker, hence hiding the real attacker from naive forensic;

- o bypass attack: where an intermediate node could be used as a stepping stone (for example in a De-Militarized Zone) to attack another host (for example in the datacenter or any back-end server).

5.1.2. Applicability of RFC 5095 to SRH

First of all, the reader must remember this specific part of section 1 of RFC5095 [RFC5095], "A side effect is that this also eliminates benign RH0 use-cases; however, such applications may be facilitated by future Routing Header specifications.". In short, it is not forbidden to create new secure type of Routing Header; for example,

RFC 6554 (RPL) [RFC6554] also creates a new Routing Header type for a specific application confined in a single network.

In the segment routing architecture described in [I-D.ietf-spring-segment-routing] there are basically two kinds of nodes (routers and hosts):

- o nodes within the SR domain, which is within one single administrative domain, i.e., where all nodes are trusted anyway else the damage caused by those nodes could be worse than amplification attacks: traffic interception, man-in-the-middle attacks, more server DoS by dropping packets, and so on.

- o nodes outside of the SR domain, which is outside of the administrative segment routing domain hence they cannot be trusted because there is no physical security for those nodes, i.e., they can be replaced by hostile nodes or can be coerced in wrong behaviors.

The main use case for SR consists of the single administrative domain where only trusted nodes with SR enabled and configured participate in SR: this is the same model as in RFC6554 [RFC6554]. All non-trusted nodes do not participate as either SR processing is not enabled by default or because they only process SRH from nodes within their domain.

Moreover, all SR nodes ignore SRH created by outsiders based on topology information (received on a peering or internal interface) or on presence and validity of the HMAC field. Therefore, if intermediate nodes ONLY act on valid and authorized SRH (such as within a single administrative domain), then there is no security threat similar to RH-0. Hence, the RFC 5095 [RFC5095] attacks are not applicable.

5.1.3. Service stealing threat

Segment routing is used for added value services, there is also a need to prevent non-participating nodes to use those services; this is called 'service stealing prevention'.

5.1.4. Topology disclosure

The SRH may also contains IPv6 addresses of some intermediate SR-nodes in the path towards the destination, this obviously reveals those addresses to the potentially hostile attackers if those attackers are able to intercept packets containing SRH. On the other hand, if the attacker can do a traceroute whose probes will be forwarded along the SR path, then there is little learned by intercepting the SRH itself.

5.1.5. ICMP Generation

Per section 4.4 of RFC2460 [RFC2460], when destination nodes (i.e. where the destination address is one of theirs) receive a Routing Header with unsupported Routing Type, the required behavior is:

- o If Segments Left is zero, the node must ignore the Routing header and proceed to process the next header in the packet.

- o If Segments Left is non-zero, the node must discard the packet and send an ICMP Parameter Problem, Code 0, message to the packet's Source Address, pointing to the unrecognized Routing Type.

This required behavior could be used by an attacker to force the generation of ICMP message by any node. The attacker could send packets with SRH (with Segment Left set to 0) destined to a node not supporting SRH. Per RFC2460 [RFC2460], the destination node could generate an ICMP message, causing a local CPU utilization and if the source of the offending packet with SRH was spoofed could lead to a reflection attack without any amplification.

It must be noted that this is a required behavior for any unsupported Routing Type and not limited to SRH packets. So, it is not specific to SRH and the usual rate limiting for ICMP generation is required anyway for any IPv6 implementation and has been implemented and deployed for many years.

5.2. Security fields in SRH

This section summarizes the use of specific fields in the SRH. They are based on a key-hashed message authentication code (HMAC).

The security-related fields in the SRH are instantiated by the HMAC TLV, containing:

o HMAC Key-id, 32 bits wide;

o HMAC, 256 bits wide (optional, exists only if HMAC Key-id is not 0).

The HMAC field is the output of the HMAC computation (per RFC 2104 [RFC2104]) using a pre-shared key identified by HMAC Key-id and of the text which consists of the concatenation of:

o the source IPv6 address;

o First Segment field;

o an octet of bit flags;

o HMAC Key-id;

o all addresses in the Segment List.

The purpose of the HMAC TLV is to verify the validity, the integrity and the authorization of the SRH itself. If an outsider of the SR domain does not have access to a current pre-shared secret, then it cannot compute the right HMAC field and the first SR router on the path processing the SRH and configured to check the validity of the HMAC will simply reject the packet.

The HMAC TLV is located at the end of the SRH simply because only the router on the ingress of the SR domain needs to process it, then all other SR nodes can ignore it (based on local policy) because they trust the upstream router. This is to speed up forwarding operations because SR routers which do not validate the SRH do not need to parse the SRH until the end.

The HMAC Key-id field allows for the simultaneous existence of several hash algorithms (SHA-256, SHA3-256 ... or future ones) as well as pre-shared keys. The HMAC Key-id field is opaque, i.e., it has neither syntax nor semantic except as an index to the right combination of pre-shared key and hash algorithm and except that a

value of 0 means that there is no HMAC field. Having an HMAC Key-id field allows for pre-shared key roll-over when two pre-shared keys are supported for a while when all SR nodes converged to a fresher pre-shared key. It could also allow for interoperation among different SR domains if allowed by local policy and assuming a collision-free HMAC Key Id allocation.

When a specific SRH is linked to a time-related service (such as turbo-QoS for a 1-hour period) where the DA, Segment ID (SID) are identical, then it is important to refresh the shared-secret frequently as the HMAC validity period expires only when the HMAC Key-id and its associated shared-secret expires.

5.2.1. Selecting a hash algorithm

The HMAC field in the HMAC TLV is 256 bit wide. Therefore, the HMAC MUST be based on a hash function whose output is at least 256 bits. If the output of the hash function is 256, then this output is simply inserted in the HMAC field. If the output of the hash function is larger than 256 bits, then the output value is truncated to 256 by taking the least-significant 256 bits and inserting them in the HMAC field.

SRH implementations can support multiple hash functions but MUST implement SHA-2 [FIPS180-4] in its SHA-256 variant.

NOTE: SHA-1 is currently used by some early implementations used for quick interoperations testing, the 160-bit hash value must then be

right-hand padded with 96 bits set to 0. The authors understand that this is not secure but is ok for limited tests.

5.2.2. Performance impact of HMAC

While adding an HMAC to each and every SR packet increases the security, it has a performance impact. Nevertheless, it must be noted that:

- the HMAC field is used only when SRH is added by a device (such as a home set-up box) which is outside of the segment routing domain. If the SRH is added by a router in the trusted segment routing

domain, then, there is no need for an HMAC field, hence no performance impact.

- o when present, the HMAC field MUST only be checked and validated by the first router of the segment routing domain, this router is named 'validating SR router'. Downstream routers may not inspect the HMAC field.

- o this validating router can also have a cache of <IPv6 header + SRH, HMAC field value> to improve the performance. It is not the same use case as in IPsec where HMAC value was unique per packet, in SRH, the HMAC value is unique per flow.

- o Last point, hash functions such as SHA-2 have been optimized for security and performance and there are multiple implementations with good performance.

With the above points in mind, the performance impact of using HMAC is minimized.

5.2.3. Pre-shared key management

The field HMAC Key-id allows for:

- o key roll-over: when there is a need to change the key (the hash pre-shared secret), then multiple pre-shared keys can be used simultaneously. The validating routing can have a table of <HMAC Key-id, pre-shared secret> for the currently active and future keys.

- o different algorithms: by extending the previous table to <HMAC Key-id, hash function, pre-shared secret>, the validating router can also support simultaneously several hash algorithms (see section Section 5.2.1)

The pre-shared secret distribution can be done:

- o in the configuration of the validating routers, either by static configuration or any SDN oriented approach;

- o dynamically using a trusted key distribution such as [RFC6407]

The intent of this document is NOT to define yet-another-key-distribution-protocol.

5.3. Deployment Models

5.3.1. Nodes within the SR domain

An SR domain is defined as a set of interconnected routers where all routers at the perimeter are configured to add and act on SRH. Some routers inside the SR domain can also act on SRH or simply forward IPv6 packets.

The routers inside an SR domain can be trusted to generate SRH and to process SRH received on interfaces that are part of the SR domain. These nodes MUST drop all SRH packets received on an interface that is not part of the SR domain and containing an SRH whose HMAC field cannot be validated by local policies. This includes obviously packet with an SRH generated by a non-cooperative SR domain.

If the validation fails, then these packets MUST be dropped, ICMP error messages (parameter problem) SHOULD be generated (but rate limited) and SHOULD be logged.

5.3.2. Nodes outside of the SR domain

Nodes outside of the SR domain cannot be trusted for physical security; hence, they need to request by some trusted means (outside of the scope of this document) a complete SRH for each new connection (i.e. new destination address). The received SRH MUST include an HMAC TLV which is computed correctly (see Section 5.2).

When an outside node sends a packet with an SRH and towards an SR domain ingress node, the packet MUST contain the HMAC TLV (with a Key-id and HMAC fields) and the the destination address MUST be an address of an SR domain ingress node .

The ingress SR router, i.e., the router with an interface address equals to the destination address, MUST verify the HMAC TLV.

If the validation is successful, then the packet is simply forwarded as usual for an SR packet. As long as the packet travels within the SR domain, no further HMAC check needs to be done. Subsequent

routers in the SR domain MAY verify the HMAC TLV when they process the SRH (i.e. when they are the destination).

If the validation fails, then this packet MUST be dropped, an ICMP error message (parameter problem) SHOULD be generated (but rate limited) and SHOULD be logged.

5.3.3. SR path exposure

As the intermediate SR nodes addresses appears in the SRH, if this SRH is visible to an outsider then he/she could reuse this knowledge to launch an attack on the intermediate SR nodes or get some insider knowledge on the topology. This is especially applicable when the path between the source node and the first SR domain ingress router is on the public Internet.

The first remark is to state that 'security by obscurity' is never enough; in other words, the security policy of the SR domain MUST assume that the internal topology and addressing is known by the attacker. A simple traceroute will also give the same information (with even more information as all intermediate nodes between SID will also be exposed). IPsec Encapsulating Security Payload [RFC4303] cannot be use to protect the SRH as per RFC4303 the ESP header must appear after any routing header (including SRH).

To prevent a user to leverage the gained knowledge by intercepting SRH, it it recommended to apply an infrastructure Access Control List (iACL) at the edge of the SR domain. This iACL will drop all packets from outside the SR-domain whose destination is any address of any router inside the domain. This security policy should be tuned for local operations.

5.3.4. Impact of BCP-38

BCP-38 [RFC2827], also known as "Network Ingress Filtering", checks whether the source address of packets received on an interface is valid for this interface. The use of loose source routing such as SRH forces packets to follow a path which differs from the expected routing. Therefore, if BCP-38 was implemented in all routers inside the SR domain, then SR packets could be received by an interface which is not expected one and the packets could be dropped.

As an SR domain is usually a subset of one administrative domain, and as BCP-38 is only deployed at the ingress routers of this administrative domain and as packets arriving at those ingress routers have been normally forwarded using the normal routing information, then there is no reason why this ingress router should

drop the SRH packet based on BCP-38. Routers inside the domain commonly do not apply BCP-38; so, this is not a problem.

6. IANA Considerations

This document makes the following registrations in the Internet Protocol Version 6 (IPv6) Parameters "Routing Type" registry maintained by IANA:

Suggested Value	Description	Reference
4	Segment Routing Header (SRH)	This document

In addition, this document request IANA to create and maintain a new Registry: "Segment Routing Header Type-Value Objects". The following code-points are requested from the registry:

Registry: Segment Routing Header Type-Value Objects

Suggested Value	Description	Reference
1	Ingress Node TLV	This document
2	Egress Node TLV	This document
3	Opaque Container TLV	This document
4	Padding TLV	This document
5	HMAC TLV	This document

7. Manageability Considerations

TBD

8. Contributors

Dave Barach, John Leddy, John Brzozowski, Pierre Francois, Nagendra Kumar, Mark Townsley, Christian Martin, Roberta Maglione, James Connolly, Aloys Augustin contributed to the content of this document.

9. Acknowledgements

The authors would like to thank Ole Troan, Bob Hinden, Fred Baker,

Brian Carpenter, Alexandru Petrescu and Punit Kumar Jaiswal for their comments to this document.

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Authors' Addresses

Stefano Previdi (editor)
Cisco Systems, Inc.
Via Del Serafico, 200
Rome 00142
Italy

Email: sprevidi@cisco.com

Clarence Filsfils
Cisco Systems, Inc.
Brussels
BE

Email: cfilsfil@cisco.com

Brian Field
Comcast
4100 East Dry Creek Road
Centennial, CO 80122
US

Email: Brian_Field@cable.comcast.com

Ida Leung
Rogers Communications
8200 Dixie Road
Brampton, ON L6T 0C1
CA

Email: Ida.Leung@rci.rogers.com

Jen Linkova
Google
1600 Amphitheatre Parkway
Mountain View, CA 94043
US

Email: furry@google.com

Ebben Aries
Facebook
US

Email: exa@fb.com

Tomoya Kosugi
NTT
3-9-11, Midori-Cho Musashino-Shi,
Tokyo 180-8585
JP

Email: kosugi.tomoya@lab.ntt.co.jp

Eric Vyncke
Cisco Systems, Inc.
De Kleetlaann 6A
Diegem 1831
Belgium

Email: evyncke@cisco.com

David Lebrun
Universite Catholique de Louvain
Place Ste Barbe, 2
Louvain-la-Neuve, 1348
Belgium

Email: david.lebrun@uclouvain.be