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Operations, Administration, and Maintenance (OAM) in Segment Routing Networks with IPv6 Data plane (SRv6)
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Abstract

This document defines building blocks that can be used for Operations, Administration, and Maintenance (OAM) in Segment Routing Networks with IPv6 Dataplane (SRv6). The document also describes some SRv6 OAM mechanisms that can be realized using these building blocks.

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1. Introduction

This document defines building blocks that can be used for Operations, Administration, and Maintenance (OAM) in Segment Routing Networks with IPv6 Dataplane (SRv6). The document also describes some SRv6 OAM mechanisms that can be implemented using these building blocks.

Additional OAM mechanisms will be added in a future revision of the document.

2. Conventions Used in This Document

2.1. Abbreviations

ECMP: Equal Cost Multi-Path.

SID: Segment ID.

SL: Segment Left.

SR: Segment Routing.

SRH: Segment Routing Header.

SRv6: Segment Routing with IPv6 Data plane.

TC: Traffic Class.

UCMP: Unequal Cost Multi-Path.

2.2. Terminology and Reference Topology

This document uses the terminology defined in [I-D.draft-filsfils-spring-srv6-network-programming]. The readers are expected to be familiar with the same.

Throughout the document, the following simple topology is used for illustration.

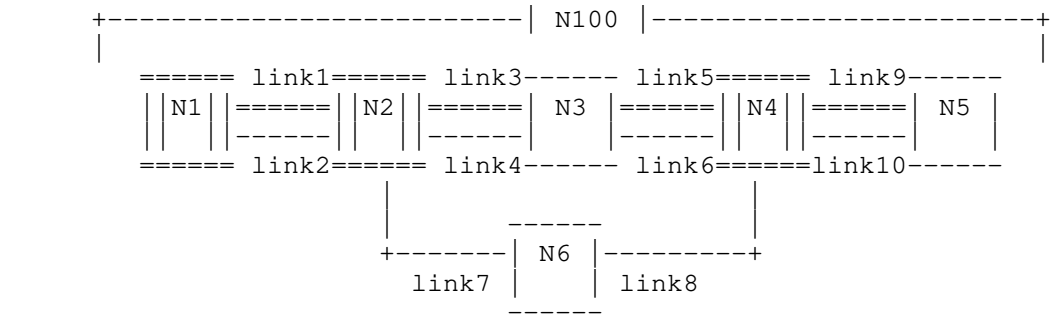

Figure 1 Reference Topology

In the reference topology:

Nodes N1, N2, and N4 are SRv6 capable nodes.

Nodes N3, N5 and N6 are classic IPv6 nodes.

Node N100 is a controller.

Node k has a classic IPv6 loopback address A:k::/128.
A SID at node k with locator block B and function F is represented by B:k:F::

The IPv6 address of the nth Link between node X and Y at the X side is represented as 2001:DB8:X:Y:Xn::, e.g., the IPv6 address of link6 (the 2nd link) between N3 and N4 at N3 in Figure 1 is 2001:DB8:3:4:32::. Similarly, the IPv6 address of link5 (the 1st link between N3 and N4) at node 3 is 2001:DB8:3:4:31::.

B:k:1:: is explicitly allocated as the END function at Node k.

B:k::Cij is explicitly allocated as the END.X function at node k towards neighbor node i via jth Link between node i and node j. e.g., B:2:C31 represents END.X at N2 towards N3 via link3 (the 1st link between N2 and N3). Similarly, B:4:C52 represents the END.X at N4 towards N5 via link10.

<S1, S2, S3> represents a SID list where S1 is the first SID and S3 is the last SID. (S3, S2, S1; SL) represents the same SID list but encoded in the SRH format where the rightmost SID (S1) in the SRH is the first SID and the leftmost SID (S3) in the SRH is the last SID.

(SA, DA) (S3, S2, S1; SL) represents an IPv6 packet, SA is the IPv6 Source Address, DA the IPv6 Destination Address, (S3, S2, S1; SL) is the SRH header that includes the SID list <S1, S2, S3>.

3. OAM Building Blocks

This section defines the various building blocks that can be used to implement OAM mechanisms in SRv6 networks. The following section describes some SRv6 OAM mechanisms that can be implemented using these building blocks.

3.1. O-flag in Segment Routing Header

[I-D. draft-ietf-6man-segment-routing-header] describes the Segment Routing Header (SRH) and how SR capable nodes use it. The draft [I-D. draft-ietf-6man-segment-routing-header] also define an OAM flag (SRH.Flags.O), which indicates that this packet is an operations and management (OAM) packet. The SRH draft also defines the processing rules for the O-flag in the SRH.Flags. The O-flag is one of the OAM building blocks considered in this document.

3.2. OAM Segments

OAM Segment IDs (SIDs) is another components of the building blocks needed to implement SRv6 OAM mechanisms. This document defines a couple of OAM SIDs. Additional SIDs will be added in the later version of the document.

3.2.1. End.OP: OAM Endpoint with Punt

Many scenarios require punting of SRv6 OAM packets at the desired nodes in the network. The "OAM Endpoint with Punt" function (End.OP for short) represents a particular OAM function to implement the punt behavior for an OAM packet. It is described using the pseudocode as follows:

When N receives a packet destined to S and S is a local End.OP SID, N does:

1. Punt the packet to CPU for SW processing (slow-path) ;; Ref1

Ref1: Hardware (microcode) only punts the packet. There is no requirement for the hardware to manipulate any TLV in the SRH (or elsewhere). Software (slow path) implements the required OAM mechanisms.

Please note that in an SRH containing END.OP SID, it is RECOMMENDED to set the SRH.Flags.O-flag = 0.

3.2.2. End.OTP: OAM Endpoint with Timestamp and Punt

Scenarios demanding performance management of an SR policy/ path requires hardware timestamping before hardware punts the packet to the software for OAM processing. The "OAM Endpoint with Timestamp and Punt" function (End.OTP for short) represents an OAM SID function to implement the timestamp and punt behavior for an OAM packet. It is described using the pseudocode as follows:

When N receives a packet destined to S and S is a local End.OTP SID, N does:

1. Timestamp the packet ;; Ref1

2. Punt the packet to CPU for SW processing (slow-path) ;; Ref2

Ref1: Timestamping is done in hardware, as soon as possible during the packet processing.

Ref2: Hardware (microcode) only punts the packet. There is no requirement for the hardware to manipulate any TLV in the SRH (or elsewhere). Software (slow path) implements the required OAM mechanisms.

Please note that in an SRH containing END.OTP SID, it is RECOMMENDED to set the SRH.Flags.O-flag = 0.

4. OAM Mechanisms

This section describes how OAM mechanisms can be implemented using the OAM building blocks described in the previous section. Additional OAM mechanisms will be added in a future revision of the document.

[RFC4443] describes Internet Control Message Protocol for IPv6 (ICMPv6) that is used by IPv6 devices for network diagnostic and error reporting purposes. As Segment Routing with IPv6 data plane (SRv6) simply adds a new type of Routing Extension Header, existing ICMPv6 ping mechanisms can be used in an SRv6 network. This section describes the applicability of ICMPv6 in the SRv6 network and how the existing ICMPv6 mechanisms can be used for providing OAM functionality.

Throughout this document, unless otherwise specified, the acronym ICMPv6 refers to multi-part ICMPv6 messages [RFC4884]. The document does not propose any changes to the standard ICMPv6 [RFC4443], [RFC4884] or standard ICMPv4 [RFC792].

4.1. Ping

There is no hardware or software change required for ping operation at the classic IPv6 nodes in an SRv6 network. That includes the classic IPv6 node with ingress, egress or transit roles. Furthermore, no protocol changes are required to the standard ICMPv6 [RFC4443], [RFC4884] or standard ICMPv4 [RFC792]. In other words, existing ICMP ping mechanisms work seamlessly in the SRv6 networks.

The following subsections outline some use cases of the ICMP ping in the SRv6 networks.

4.1.1. Classic Ping

The existing mechanism to ping a remote IP prefix, along the shortest path, continues to work without any modification. The initiator may be an SRv6 node or a classic IPv6 node. Similarly, the egress or transit may be an SRv6 capable node or a classic IPv6 node.

If an SRv6 capable ingress node wants to ping an IPv6 prefix via an arbitrary segment list <S1, S2, S3>, it needs to initiate ICMPv6 ping with an SR header containing the SID list <S1, S2, S3>. This is illustrated using the topology in Figure 1. Assume all the links have IGP metric 10 except both links between node2 and node3, which have IGP metric set to 100. User issues a ping from node N1 to a loopback of node 5, via segment list <B:2:C31, B:4:C52>.

Figure 2 contains sample output for a ping request initiated at node N1 to the loopback address of node N5 via a segment list <B:2:C31, B:4:C52>.

```
> ping A:5:: via segment-list B:2:C31, B:4:C52

Sending 5, 100-byte ICMP Echos to B5::, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 0.625
/0.749/0.931 ms
```

Figure 2 A sample ping output at an SRv6 capable node

All transit nodes process the echo request message like any other data packet carrying SR header and hence do not require any change. Similarly, the egress node (IPv6 classic or SRv6 capable) does not require any change to process the ICMPv6 echo request. For example, in the ping example of Figure 2:

- Node N1 initiates an ICMPv6 ping packet with SRH as follows (A:1::, B:2:C31)(A:5::, B:4:C52, B:2:C31, SL=2, NH = ICMPv6)(ICMPv6 Echo Request).
- Node N2, which is an SRv6 capable node, performs the standard SRH processing. Specifically, it executes the END.X function (B:2:C31) on the echo request packet.
- Node N3, which is a classic IPv6 node, performs the standard IPv6 processing. Specifically, it forwards the echo request based on DA B:4:C52 in the IPv6 header.
- Node N4, which is an SRv6 capable node, performs the standard SRH processing. Specifically, it observes the END.X function (B:4:C52) with PSP (Penultimate Segment POP) on the echo request packet and removes the SRH and forwards the packet across link10 to N5.
- The echo request packet at N5 arrives as an IPv6 packet without a SRH. Node N5, which is a classic IPv6 node, performs the standard IPv6/ ICMPv6 processing on the echo request and responds, accordingly.

4.1.2. Pinging a SID Function

The classic ping described in the previous section cannot be used to ping a remote SID function, as explained using an example in the following.

Consider the case where the user wants to ping the remote SID function B:4:C52, via B:2:C31, from node N1. Node N1 constructs the ping packet (A:1::, B:2:C31)(B:4:C52, B:2:C31, SL=1; NH=ICMPv6)(ICMPv6 Echo Request). The ping fails because the node N4 receives the ICMPv6 echo request with DA set to B:4:C52 but the next header is ICMPv6, instead of SRH. To solve this problem, the initiator needs to mark the ICMPv6 echo request as an OAM packet.

The OAM packets are identified either by setting the O-flag in SRH or by inserting the END.OP/ END.OTP SIDs at an appropriate place in the SRH. The following illustration uses END.OTP SID but the procedures are equally applicable to the END.OP SID.

In an SRv6 network, the user can exercise two flavors of the ping: end-to-end ping or segment-by-segment ping, as outlined in the following.

4.1.2.1. End-to-end ping using END.OP/ END.OTP

The end-to-end ping illustration uses the END.OTP SID but the procedures are equally applicable to the END.OP SID.

Consider the same example where the user wants to ping a remote SID function B:4:C52 , via B:2:C31, from node N1. To force a punt of the ICMPv6 echo request at the node N4, node N1 inserts the END.OTP SID just before the target SID B:4:C52 in the SRH. The ICMPv6 echo request is processed at the individual nodes along the path as follows:

- Node N1 initiates an ICMPv6 ping packet with SRH as follows (A:1::, B:2:C31)(B:4:C52, B:4:OTP, B:2:C31; SL=2; NH=ICMPv6)(ICMPv6 Echo Request).
- Node N2, which is an SRv6 capable node, performs the standard SRH processing. Specifically, it executes the END.X function (B:2:C31) on the echo request packet.
- Node N3 receives the packet as follows (A:1::, B:4:OTP)(B:4:C52, B:4:OTP, B:2:C31 ; SL=1; NH=ICMPv6)(ICMPv6 Echo Request). Node N3, which is a classic IPv6 node, performs the standard IPv6 processing. Specifically, it forwards the echo request based on DA B:4:OTP in the IPv6 header.
- When node N4 receives the packet (A:1::, B:4:OTP)(B:4:C52, B:4:OTP, B:2:C31 ; SL=1; NH=ICMPv6)(ICMPv6 Echo Request), it processes the END.OTP SID, as described in the pseudocode in Section 3. The packet gets punted to the ICMPv6 process for processing. The ICMPv6 process checks if the next SID in SRH (the target SID B:4:C52) is locally programmed.
- If the target SID is not locally programmed, N4 responses with the ICMPv6 message (Type: "SRv6 OAM (TBA)", Code: "SID not locally implemented (TBA)"); otherwise a success is returned.

4.1.2.2. Segment-by-segment ping using O-flag (Proof of Transit)

Consider the same example where the user wants to ping a remote SID function B:4:C52, via B:2:C31, from node N1. However, in this ping, the node N1 wants to get a response from each segment node in the SRH as a "proof of transit". In other words, in the segment-by-segment ping case, the node N1 expects a response from node N2 and node N4 for their respective local SID function. When a response to O-bit is desired from the last SID in a SID-list, it is the responsibility of the ingress node to use USP as the last SID. E.g., in this example, the target SID B:4:C52 is a USP SID.

To force a punt of the ICMPv6 echo request at node N2 and node N4, node N1 sets the O-flag in SRH. The ICMPv6 echo request is processed at the individual nodes along the path as follows: and

- Node N1 initiates an ICMPv6 ping packet with SRH as follows (A:1::, B:2:C31)(B:4:C52, B:2:C31; SL=1, Flags.O=1; NH=ICMPv6)(ICMPv6 Echo Request).
- When node N2 receives the packet (A:1::, B:2:C31)(B:4:C52, B:2:C31; SL=1, Flags.O=1; NH=ICMPv6)(ICMPv6 Echo Request) packet, it processes the O-flag in SRH, as described in the pseudocode in Section 3. A time-stamped copy of the packet gets punted to the ICMPv6 process for processing. Node N2 continues to apply the B:2:C31 SID function on the original packet and forwards it, accordingly. As B:4:C52 is a USP SID, N2 does not remove the SRH.
  The ICMPv6 process at node N2 checks if its local SID (B:2:C31) is locally programmed or not and responds to the ICMPv6 Echo Request.
- If the target SID is not locally programmed, N4 responses with the ICMPv6 message (Type: "SRv6 OAM (TBA)", Code: "SID not locally implemented (TBA)"); otherwise a success is returned. Please note that, as mentioned in Section 3, if node N2 does not support the O-flag, it simply ignores it and process the local SID, B:2:C31.
- Node N3, which is a classic IPv6 node, performs the standard IPv6 processing. Specifically, it forwards the echo request based on DA B:4:C52 in the IPv6 header.
- When node N4 receives the packet (A:1::, B:4:C52)(B:4:C52, B:2:C31; SL=0, Flags.O=1; NH=ICMPv6)(ICMPv6 Echo Request), it processes the O-flag in SRH, as described in the pseudocode in Section 3. A time-stamped copy of the packet gets punted to the ICMPv6 process for processing. The ICMPv6 process at node N4 checks if its local SID (B:2:C31) is locally programmed or not and responds to the ICMPv6 Echo Request. If the target SID is not locally programmed, N4 responses with the ICMPv6 message (Type: "SRv6 OAM (TBA)", Code: "SID not locally implemented (TBA)"); otherwise a success is returned.

Support for O-flag is part of node capability advertisement. That enables node N1 to know which segment nodes are capable of responding to the ICMPv6 echo request. Node N1 processes the echo responses and presents data to the user, accordingly.

Please note that segment-by-segment ping can be used to address proof of transit use-case.

4.2. Error Reporting

Any IPv6 node can use ICMPv6 control messages to report packet processing errors to the host that originated the datagram packet. To name a few such scenarios:

- If the router receives an undeliverable IP datagram, or
- If the router receives a packet with a Hop Limit of zero, or
- If the router receives a packet such that if the router decrements the packet's Hop Limit it becomes zero, or
- If the router receives a packet with problem with a field in the IPv6 header or the extension headers such that it cannot complete processing the packet, or
- If the router cannot forward a packet because the packet is larger than the MTU of the outgoing link.

In the scenarios listed above, the ICMPv6 response also contains the IP header, IP extension headers and leading payload octets of the "original datagram" to which the ICMPv6 message is a response. Specifically, the "Destination Unreachable Message", "Time Exceeded Message", "Packet Too Big Message" and "Parameter Problem Message" ICMPV6 messages can contain as much of the invoking packet as possible without the ICMPv6 packet exceeding the minimum IPv6 MTU [RFC4443], [RFC4884]. In an SRv6 network, the copy of the invoking packet contains the SR header. The packet originator can use this information for diagnostic purposes. For example, traceroute can use this information as detailed in the following.

4.3. Traceroute

There is no hardware or software change required for traceroute operation at the classic IPv6 nodes in an SRv6 network. That includes the classic IPv6 node with ingress, egress or transit roles. Furthermore, no protocol changes are required to the standard traceroute operations. In other words, existing traceroute mechanisms work seamlessly in the SRv6 networks.

The following subsections outline some use cases of the traceroute in the SRv6 networks.

4.3.1. Classic Traceroute

The existing mechanism to traceroute a remote IP prefix, along the shortest path, continues to work without any modification. The initiator may be an SRv6 node or a classic IPv6 node. Similarly, the egress or transit may be an SRv6 node or a classic IPv6 node.

If an SRv6 capable ingress node wants to traceroute to IPv6 prefix via an arbitrary segment list <S1, S2, S3>, it needs to initiate traceroute probe with an SR header containing the SID list <S1, S2, S3>. That is illustrated using the topology in Figure 1. Assume all the links have IGP metric 10 except both links between node2 and node3, which have IGP metric set to 100. User issues a traceroute from node N1 to a loopback of node 5, via segment list <B:2:C31, B:4:C52>. Figure 3 contains sample output for the traceroute request.

```
> traceroute A:5:: via segment-list B:2:C31, B:4:C52

Tracing the route to B5::

 1  2001:DB8:1:2:21:: 0.512 msec 0.425 msec 0.374 msec
    SRH: (A:5::, B:4:C52, B:2:C31, SL=2)

 2  2001:DB8:2:3:31:: 0.721 msec 0.810 msec 0.795 msec
    SRH: (A:5::, B:4:C52, B:2:C31, SL=1)

 3  2001:DB8:3:4::41:: 0.921 msec 0.816 msec 0.759 msec
    SRH: (A:5::, B:4:C52, B:2:C31, SL=1)

 4  2001:DB8:4:5::52:: 0.879 msec 0.916 msec 1.024 msec
```

Figure 3 A sample traceroute output at an SRv6 capable node

Please note that information for hop2 is returned by N3, which is a classic IPv6 node. Nonetheless, the ingress node is able to display SR header contents as the packet travels through the IPv6 classic node. This is because the "Time Exceeded Message" ICMPv6 message can contain as much of the invoking packet as possible without the ICMPv6 packet exceeding the minimum IPv6 MTU [RFC4443]. The SR header is also included in these ICMPv6 messages initiated by the classic IPv6 transit nodes that are not running SRv6 software. Specifically, a node generating ICMPv6 message containing a copy of the invoking packet does not need to understand the extension header(s) in the invoking packet.

The segment list information returned for hop1 is returned by N2, which is an SRv6 capable node. Just like for hop2, the ingress node is able to display SR header contents for hop1.

There is no difference in processing of the traceroute probe at an IPv6 classic node and an SRv6 capable node. Similarly, both IPv6 classic and SRv6 capable nodes use the address of the interface on which probe was received as the source address in the ICMPv6

response. ICMP extensions defined in [RFC5837] can be used to also display information about the IP interface through which the datagram would have been forwarded had it been forwardable, and the IP next hop to which the datagram would have been forwarded, the IP interface upon which a datagram arrived, the sub-IP component of an IP interface upon which a datagram arrived.

The information about the IP address of the incoming interface on which the traceroute probe was received by the reporting node is very useful. This information can also be used to verify if SID functions B:2:C31 and B:4:C52 are executed correctly by N2 and N4, respectively. Specifically, the information displayed for hop2 contains the incoming interface address 2001:DB8:2:3:31:: at N3. This matches with the expected interface bound to END.X function B:2:C31 (link3). Similarly, the information displayed for hop5 contains the incoming interface address 2001:DB8:4:5::52:: at N5. This matches with the expected interface bound to the END.X function B:4:C52 (link10).

4.3.2. Traceroute to a SID Function

The classic traceroute described in the previous section cannot be used to traceroute a remote SID function, as explained using an example in the following.

Consider the case where the user wants to traceroute the remote SID function B:4:C52, via B:2:C31, from node N1. The trace route fails at N4. This is because the node N4 trace route probe where next header is UDP or ICMPv6, instead of SRH (even though the hop limit is set to 1). To solve this problem, the
initiator needs to mark the ICMPv6 echo request as an OAM packet.

The OAM packets are identified either by setting the O-flag in SRH or by inserting the END.OTP SID at an appropriate place in the SRH.

In an SRv6 network, the user can exercise two flavors of the traceroute: hop-by-hop traceroute or overlay traceroute.

- In hop-by-hop traceroute, user gets responses from all nodes including classic IPv6 transit nodes, SRv6 capable transit nodes as well as SRv6 capable segment endpoints. E.g., consider the example where the user wants to traceroute to a remote SID function B:4:C52 , via B:2:C31, from node N1. The traceroute

output will also display information about node3, which is a transit (underlay) node.
- The overlay traceroute, on the other hand, does not trace the underlay nodes. In other words, the overlay traceroute only displays the nodes that acts as SRv6 segments along the route. I.e., in the example where the user wants to traceroute to a remote SID function B:4:C52 , via B:2:C31, from node N1, the overlay traceroute would only display the traceroute information from node N2 and node N2 and will not display information from node 3.

4.3.2.1. Hop-by-hop traceroute using END.OP/ END.OTP

In this section, hop-by-hop traceroute to a SID function is exemplified using UDP probes. However, the procedure is equally applicable to other implementation of traceroute mechanism. Furthermore, the illustration uses the END.OTP SID but the procedures are equally applicable to the END.OP SID

Consider the same example where the user wants to traceroute to a remote SID function B:4:C52 , via B:2:C31, from node N1. To force a punt of the traceroute probe only at the node N4, node N1 inserts the END.OTP SID just before the target SID B:4:C52 in the SRH. The traceroute probe is processed at the individual nodes along the path as follows.

- Node N1 initiates a traceroute probe packet with a monotonically increasing value of hop count and SRH as follows (A:1::, B:2:C31)(B:4:C52, B:4:OTP, B:2:C31; SL=2; NH=UDP)(Traceroute probe).
- When node N2 receives the packet with hop-count = 1, it processes the hop count expiry. Specifically, the node N2 responses with the ICMPv6 message (Type: "Time Exceeded", Code: "Time to Live exceeded in Transit").
- When Node N2 receives the packet with hop-count > 1, it performs the standard SRH processing. Specifically, it executes the END.X function (B:2:C31) on the traceroute probe.
- When node N3, which is a classic IPv6 node, receives the packet (A:1::, B:4:OTP)(B:4:C52, B:4:OTP, B:2:C31 ; HC=1, SL=1; NH=UDP)(Traceroute probe) with hop-count = 1, it processes the hop count expiry. Specifically, the node N3 responses with the ICMPv6 message (Type: "Time Exceeded", Code: "Time to Live exceeded in Transit").
- When node N3, which is a classic IPv6 node, receives the packet with hop-count > 1, it performs the standard IPv6 processing. Specifically, it forwards the traceroute probe based on DA B:4:OTP in the IPv6 header.

- When node N4 receives the packet (A:1::, B:4:OTP)(B:4:C52, B:4:OTP, B:2:C31 ; SL=1; HC=1, NH=UDP)(Traceroute probe), it processes the END.OTP SID, as described in the pseudocode in Section 3. The packet gets punted to the traceroute process for processing. The traceroute process checks if the next SID in SRH (the target SID B:4:C52) is locally programmed. If the target SID B:4:C52 is locally programmed, node N4 responses with the ICMPv6 message (Type: Destination unreachable, Code: Port Unreachable). If the target SID B:4:C52 is not a local SID, node N4 silently drops the traceroute probe.

Figure 4 displays a sample traceroute output for this example.

```
> traceroute srv6 B:4:C52 via segment-list B:2:C31

Tracing the route to SID function B:4:C52

 1  2001:DB8:1:2:21 0.512 msec 0.425 msec 0.374 msec
    SRH: (B:4:C52, B:4:OTP, B:2:C31; SL=2)

 2  2001:DB8:2:3:31 0.721 msec 0.810 msec 0.795 msec
    SRH: (B:4:C52, B:4:OTP, B:2:C31; SL=1)

 3  2001:DB8:3:4::41 0.921 msec 0.816 msec 0.759 msec
    SRH: (B:4:C52, B:4:OTP, B:2:C31; SL=1)
```

Figure 4 A sample output for hop-by-hop traceroute to a SID function

4.3.2.2. Tracing SRv6 Overlay

The overlay traceroute does not trace the underlay nodes, i.e., only displays the nodes that acts as SRv6 segments along the path. This is achieved by setting the SRH.Flags.O bit.

In this section, overlay traceroute to a SID function is exemplified using UDP probes. However, the procedure is equally applicable to other implementation of traceroute mechanism.

Consider the same example where the user wants to traceroute to a remote SID function B:4:C52 , via B:2:C31, from node N1.

- Node N1 initiates a traceroute probe with SRH as follows (A:1::, B:2:C31)(B:4:C52, B:2:C31; HC=64, SL=1, Flags.O=1; NH=UDP)(Traceroute Probe). Please note that the hop-count is

set to 64 to skip the underlay nodes from tracing. The O-flag in SRH is set to make the overlay nodes (nodes processing the SRH) respond.

- When node N2 receives the packet (A:1::, B:2:C31)(B:4:C52, B:2:C31; SL=1, HC=64, Flags.O=1; NH=UDP)(Traceroute Probe), it processes the O-flag in SRH, as described in the pseudocode in Section 3. A time-stamped copy of the packet gets punted to the traceroute process for processing. Node N2 continues to apply the B:2:C31 SID function on the original packet and forwards it, accordingly. As SRH.Flags.O=1, Node N2 also disables the PSP flavor, i.e., does not remove the SRH. The traceroute process at node N2 checks if its local SID (B:2:C31) is locally programmed. If the SID is not locally programmed, it silently drops the packet. Otherwise, it performs the egress check by looking at the SL value in SRH.
- As SL is not equal to zero (i.e., it's not egress node), node N2 responses with the ICMPv6 message (Type: "SRv6 OAM (TBA)", Code: "O-flag punt at Transit (TBA)"). Please note that, as mentioned in Section 3, if node N2 does not support the O-flag, it simply ignores it and processes the local SID, B:2:C31.
- When node N3 receives the packet (A:1::, B:4:C52)(B:4:C52, B:2:C31; SL=0, HC=63, Flags.O=1; NH=UDP)(Traceroute Probe), performs the standard IPv6 processing. Specifically, it forwards the traceroute probe based on DA B:4:C52 in the IPv6 header. Please note that there is no hop-count expiration at the transit nodes.
- When node N4 receives the packet (A:1::, B:4:C52)(B:4:C52, B:2:C31; SL=0, HC=62, Flags.O=1; NH=UDP)(Traceroute Probe), it processes the O-flag in SRH, as described in the pseudocode in Section 3. A time-stamped copy of the packet gets punted to the traceroute process for processing. The traceroute process at node N4 checks if its local SID (B:2:C31) is locally programmed. If the SID is not locally programmed, it silently drops the packet. Otherwise, it performs the egress check by looking at the SL value in SRH. As SL is equal to zero (i.e., N4 is the egress node), node N4 tries to consume the UDP probe. As UDP probe is set to access an invalid port, the node N4 responses with the ICMPv6 message (Type: Destination unreachable, Code: Port Unreachable).

Figure 5 displays a sample overlay traceroute output for this example. Please note that the underlay node N3 does not appear in the output.

```
> traceroute srv6 B:4:C52 via segment-list B:2:C31

Tracing the route to SID function B:4:C52
```

```
1  2001:DB8:1:2:21:: 0.512 msec 0.425 msec 0.374 msec
   SRH: (B:4:C52, B:4:OTP, B:2:C31; SL=2)

2  2001:DB8:3:4::41:: 0.921 msec 0.816 msec 0.759 msec
   SRH: (B:4:C52, B:4:OTP, B:2:C31; SL=1)
```

Figure 5 A sample output for overlay traceroute to a SID function

4.5. Monitoring of SRv6 Paths

In the recent past, network operators are interested in performing network OAM functions in a centralized manner. Various data models like YANG are available to collect data from the network and manage it from a centralized entity.

SR technology enables a centralized OAM entity to perform path monitoring from centralized OAM entity without control plane intervention on monitored nodes. [I.D-draft-ietf-spring-oam-usecase] describes such a centralized OAM mechanism. Specifically, the draft describes a procedure that can be used to perform path continuity check between any nodes within an SR domain from a centralized monitoring system, with minimal or no control plane intervene on the nodes. However, the draft focuses on SR networks with MPLS data plane. The same concept applies to the SRv6 networks. This document describes how the concept can be used to perform path monitoring in an SRv6 network. This document describes how the concept can be used to perform path monitoring in an SRv6 network as follows.

In the above reference topology, N100 is the centralized monitoring system implementing an END function B:100:1::. In order to verify a segment list <B:2:C31, B:4:C52>, N100 generates a probe packet with SRH set to (B:100:1::, B:4:C52, B:2:C31, SL=2). The controller routes the probe packet towards the first segment, which is B:2:C31. N2 performs the standard SRH processing and forward it over link3 with the DA of IPv6 packet set to B:4:C52. N4 also performs the normal SRH processing and forward it over link10 with the DA of IPv6 packet set to B:100:1::. This makes the probe loops back to the centralized monitoring system.

In the reference topology in Figure 1, N100 uses an IGP protocol like OSPF or ISIS to get the topology view within the IGP domain. N100 can also use BGP-LS to get the complete view of an inter-domain topology. In other words, the controller leverages the visibility of the topology to monitor the paths between the various endpoints without control plane intervention required at the monitored nodes.

5. Security Considerations

This document does not define any new protocol extensions and relies on existing procedures defined for ICMP. This document does not impose any additional security challenges to be considered beyond security considerations described in [RFC4884], [RFC4443], [RFC792] and RFCs that updates these RFCs.

6. IANA Considerations

6.1. ICMPv6 type Numbers Registry

This document defines one ICMPv6 Message, a type that has been allocated from the "ICMPv6 'type' Numbers" registry of [RFC4443].

Specifically, it requests to add the following to the "ICMPv6 Type Numbers" registry:

TBA (suggested value: 162) SRv6 OAM Message.

The document also requests the creation of a new IANA registry to the

"ICMPv6 'Code' Fields" against the "ICMPv6 Type Numbers TBA - SRv6 OAM Message" with the following codes:

Code	Name	Reference
0	No Error	This document
1	SID is not locally implemented	This document
2	O-flag punt at Transit	This document

6.3. SRv6 OAM Endpoint Types

This I-D requests to IANA to allocate, within the "SRv6 Endpoint Behaviors Registry" sub-registry belonging to the top-level "Segment-routing with IPv6 dataplane (SRv6) Parameters" registry [I-D.filsfils-spring-srv6-network-programming], the following allocations:

Value (Suggested Value)	Endpoint Behavior	Reference
TBA (30)	End.OP	[This.ID]
TBA (31)	End.OTP	[This.ID]

7. References

7.1. Normative References

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[I-D.brockners-inband-oam-transport] F.Brockners, at al., "Encapsulations for In-situ OAM Data", draft-brockners-inband-oam-transport, work in progress.

[I-D.brockners-inband-oam-requirements] F.Brockners, et al., "Requirements for In-situ OAM", draft-brockners-inband-oam-requirements, work in progress.

[I-D.spring-segment-routing-policy] Filsfils, C., et al., "Segment Routing Policy for Traffic Engineering", draft-filsfils-spring-segment-routing-policy, work in progress.

8. Acknowledgments

To be added.

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The IPv6 Probe Option
draft-bonica-6man-unrecognized-opt-03

Abstract

This document defines a new IPv6 option, called the Probe option. The Probe option elicits an ICMPv6 Parameter Problem message from all nodes that process it. When a node sends a packet that contains the Probe option and receives an ICMPv6 Parameter Problem message in response, it has verified the network's ability to convey packets that contain the Probe option.

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 February 11, 2019.

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1. Introduction

In IPv6 [RFC8200], optional internet-layer information is encoded in extension headers. Two extension headers, the Hop-by-Hop Options header and the Destination Options header, contain a variable number of options. Each option contains the following fields:

- Option Type
- Opt Data Length
- Option Data

The Option Type identifiers are encoded so that their highest-order 2 bits specify the action to be taken if the processing node does not recognize the option. Encodings follow:

- 00 - Skip over the option and continue processing the header.
- 01 - Discard the packet.
- 10 - Discard the packet and send an ICMPv6 [RFC4443] Parameter Problem, Code 2, message to the packet's Source Address, pointing to the unrecognized Option Type.
- 11 - Discard the packet and, only if the packet's Destination Address was not a multicast address, send an ICMPv6 Parameter Problem, Code 2, message to the packet's Source Address, pointing to the unrecognized Option Type.

Several upper-layer protocols [RFC6275] [I-D.leddy-6man-truncate] emit packets that contain IPv6 destination options. These protocols rely the network to convey packets that contain the IPv6 Destination Options header.

A subset of those protocols emit IPv6 destination options with high-order bits equal to "10" and "11". These IPv6 destination options elicit ICMPv6 Parameter Problem messages from destination nodes that do not recognize them. The above-mentioned protocols perform better when the network can convey ICMPv6 Parameter Problem messages from the destination node to the source node.

Operational experience [RFC7872] reveals that a significant number of networks drop all packets that contain the IPv6 Destination Options header. Similarly, a significant number of networks allow packets that contain the IPv6 Destination Options header, but only if Destination Options header does not exceed a specific size. Finally, many networks drop all ICMP Parameter Problem messages.

This document describes procedures by which a source node can discover relevant capabilities of the network that connects it to a destination node. Using these procedures, the source node can determine:

- Whether the network can convey a packet containing a Destination Options header of a specific size from the source node to a destination node.

- Whether the network can convey an ICMPv6 Parameter Problem message from the destination node to the source node.

In order to support the above-mentioned procedures, this document defines a new IPv6 option, called the Probe option. The Probe option elicits an ICMPv6 Parameter Problem message from all nodes that process it. It elicits an IPv6 Parameter Problem message, regardless of whether the processing node recognizes the option. When a source node sends a packet that contains the Probe option and receives an ICMPv6 Parameter Problem message in response, it has verified the above-mentioned network capabilities.

2. Requirements Language

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

3. The Probe Option

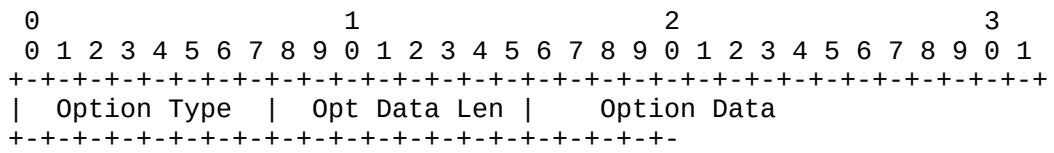

Figure 1

Figure 1 depicts the Probe Option.

Option fields are as follows:

- Option Type - Probe Option. Value TBD by IANA. See Notes below.
- Opt Data Len - Length of Option Data, measured in bytes.
- Option Data - MUST be set to zero on transmission. MUST be ignored on receipt.

The Opt Data Len and Option Data fields can be used to expand the Probe Option and the Destination Options header that contains it to a required length. See Section 4 for details.

A packet MAY contain multiple instances of the Probe option. In IPv6, the maximum size of a Destination Options header is 2048 bytes, while the maximum size of an option instance is only 256 bytes. Therefore, multiple instances of the Probe option are required to expand the Destination Options header beyond 256 bytes.

All nodes process the Probe option as follows, regardless of whether they recognize the option:

- Discard the packet.
- Send an ICMPv6 Parameter Problem, Code 2, message to the packet’s Source Address, pointing to the unrecognized Option Type.

NOTE 1: The highest-order two bits of the Option Type (i.e., the "act" bits) are 10. These bits specify the action taken by a destination node that does not recognize Probe option. The required action is to discard the packet and send an ICMPv6 Parameter Problem, Code 2, message to the packet’s Source Address, pointing to the Probe Option Type.

NOTE 2: The third highest-order bit of the Option Type (i.e., the "chg" bit) is 0. This indicates that Option Data cannot be modified along the path between the packet's source and its destination.

4. Discovering Network Capabilities

Assume that a source node needs to determine whether the network can convey a packet from itself to a destination node. The packet contains a Destination Options header whose length is N bytes. As per [RFC8200], the Destination Options header length must be a multiple of 8. Therefore, N must be a multiple of 8.

The source node executes the following procedure:

- Set a short timer (e.g., one or two seconds).
- Send a probe packet.
- Wait for either a) an ICMPv6 Parameter Problem message that matches the probe packet, or b) timer expiration

The probe packet contains an IPv6 Destination Options header and the IPv6 Destination Options header contains one or more instances of Probe option. The number of Probe option instances and the length of Option Data in each instance are chosen so that the Destination Options header length will be equal to N.

In order to influence how the packet is routed to its destination, the probe packet MAY contain upper-layer headers. However, because the packet contains the Probe option, it is always discarded and is never delivered to an upper-layer protocol.

An ICMPv6 Parameter Problem message matches a probe packet if the initial bytes of the probe packet appear in the ICMP Parameter Problem message.

If the source node receives an ICMP Parameter Problem message that matches the probe, both of the following statements are true:

- The network can convey a packet containing a Destination Options header of a specific size from the source node to a destination node.
- The network can convey an ICMPv6 Parameter Problem message from the destination node to the source node.

If the timer expires, at least one of the following statements is true:

- The network cannot convey a packet containing a Destination Options header of a specific size from the source node to a destination node.

- The network cannot convey an ICMPv6 Parameter Problem message from the destination node to the source node.

- Either the probe or the ICMPv6 Parameter Problem message was lost due to a transient issue (e.g., congestion).

As noted above, transient issues can cause false negative results. Therefore, this procedure MAY be repeated after initial failure.

5. Security Considerations

This document introduces no new security vulnerabilities. Any security vulnerabilities exposed by the Probe option are currently exposed by all undefined or unrecognized option types. This is because the Probe option elicits the same behavior as an undefined or unrecognized option

6. IANA Considerations

IANA is requested to allocate a codepoint from the Destination Options and Hop-by-hop Options registry (https://www.iana.org/assignments/ipv6-parameters/ipv6-parameters.xhtml#ipv6-parameters-2). This option is called "Probe". The "act" bits are 10 and the "chg" bit is 0.

7. Acknowledgements

Thanks to Ross Callon, Fernando Gont and Jinmei Tatuya for their careful review of this document.

8. References

8.1. Normative References

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The IPv6 Virtual Private Network (VPN) Context Information Option
draft-bonica-6man-vpn-dest-opt-01

Abstract

This document defines a new IPv6 Destination Option that can be used to encode Virtual Private Network (VPN) context information. It is applicable when VPN payload is transported over IPv6.

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/.

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This Internet-Draft will expire on June 13, 2019.

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1. Introduction

Virtual Private Network (VPN) technologies allow network providers to emulate private networks with shared infrastructure. For example, assume that a red sites and blue sites connect to a provider network. The provider network facilitates communication among red sites and facilitates communication among blue sites. However, it prevents communication between red sites and blue sites.

The IETF has standardized many VPN technologies, including:

- Layer 2 VPN (L2VPN) [RFC6624].
- Layer 3 VPN (L3VPN) [RFC4364].
- Virtual Private LAN Service (VPLS) [RFC4761][RFC4762].
- Ethernet VPN (EVPN) [RFC7432].
- Pseudowires [RFC8077].

The above-mentioned technologies include the following components:

- Customer Edge (CE) devices.
- Provider Edge (PE) devices.
- Routing Instances.
- VPN context information.

- Transport tunnels.

CE devices participate in closed communities called VPNs. CEs that participate in one VPN can communicate with one another but cannot communicate with CEs that participate in another VPN.

CE devices connect to provider networks through PE devices. Each PE maintains one Routing Instance for each VPN that it supports. A Routing Instance is a VPN specific Forwarding Information Base (FIB). In EVPN, Routing Instances are called Ethernet Virtual Instances (EVI).

Assume that one CE sends a packet through a provider network to another CE. The packet enters the provider network through an ingress PE and leaves the provider network through an egress PE. The packet may traverse one or more intermediate nodes on route from PE to PE.

When the ingress PE receives the packet, it:

- Identifies the Routing Instance that supports the originating CE's VPN.

- Searches that Routing Instance for the packet's destination.

If the search fails, the ingress PE discards the packet. If the search succeeds, it yields the following:

- VPN context information.

- The egress PE's IP address.

The ingress PE prepends VPN context information and a transport header to the packet, in that order. It then forwards the packet through a transport tunnel to the egress PE.

The egress PE removes the transport header, if it has not already been removed by an upstream device. It then examines and removes the VPN context information. Finally, it uses the VPN context information to forward the packet to its destination (i.e., a directly connected CE).

In the above-mentioned VPN technologies, the ingress PE encodes VPN context information in a Multiprotocol Label Switching (MPLS) [RFC3031] label. Depending upon the transport tunnel type, the transport header can be:

- A MPLS label or label stack.

- An IPv4 [RFC0791] header.
- An IPv6 [RFC8200] header.
- A Generic Routing Encapsulation (GRE) [RFC2784] header encapsulated in IPv4 or IPv6.

If the outermost transport header is IPv6, it may be followed by a Segment Routing Header (SRH) [I-D.ietf-6man-segment-routing-header].

Some PE devices cannot process MPLS headers. While these devices have several alternatives to MPLS-based transport tunnels, they require an alternative to MPLS-based encoding of VPN context information. This document defines a new IPv6 Destination Option that can be used to encode VPN context information. It is applicable when VPN payload is transported over IPv6.

2. Requirements Language

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

3. VPN Context Information

VPN context information specifies a forwarding procedure to be executed by the egress PE. However, VPN context information values are not globally mapped to forwarding procedures. Each egress PE maps each forwarding procedure that it supports to a VPN context information value. Therefore, VPN context information values are locally scoped to the egress PE.

PE devices can acquire VPN Context Information:

- From one another, using a distributed, control plane protocol (e.g., BGP [RFC4271] [RFC4760])
- From a controller.

The mechanisms by which PE devices acquire VPN Context Information are beyond the scope of this document.

4. The VPN Context Information Option

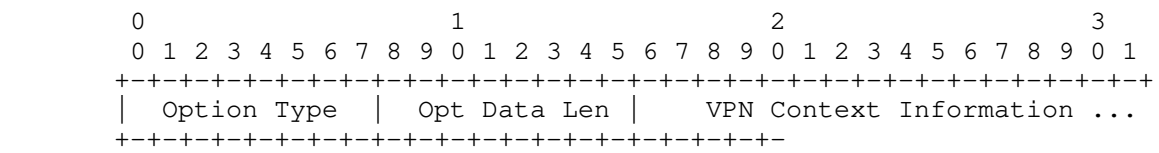

Figure 1

Figure 1 depicts the VPN Context Information Option. The IPv6 Destination Options header MAY include the VPN Context Information option. The IPv6 Hop-by-hop header MUST NOT include the VPN Context Information option.

Option fields are as follows:

- Option Type - VPN Context Information option. Value TBD by IANA. See Notes below.
- Opt Data Len - Length of Option Data, measured in bytes.
- VPN Context Information - Specifies a forwarding procedure to be executed by the egress PE.

The VPN Context Information Option MUST NOT appear multiple times in a single packet. If a node receives a packet that contains multiple instances of the VPN Context Information Option, it MUST discard the packet and send and ICMP Parameter Problem, Code 2, message to the packet's source.

NOTE 1: The highest-order two bits of the Option Type (i.e., the "act" bits) are 10. These bits specify the action taken by a destination node that does not recognize VPN Context Information option. The required action is to discard the packet and, regardless of whether or not the packet's Destination Address was a multicast address, send an ICMPv6 [RFC4443] Parameter Problem, Code 2, message to the packet's Source Address, pointing to the unrecognized Option Type.

NOTE 2: The third highest-order bit of the Option Type (i.e., the "chg" bit) is 0. This indicates that Option Data cannot be modified along the path between the packet's source and its destination.

5. Security Considerations

A VPN can be deployed:

- In a walled-garden environment.
- In an over-the-top environment.

In a walled-garden environment, all PE devices and all devices that connect PEs to one another reside in the same security domain. Therefore, there is no risk that a packet might be modified as it travels from PE to PE.

In an over-the-top environment, all PE devices reside in one security domain while devices that connect PEs to one another can reside in a different security domain. In that case, there is significant risk that a packet might be modified as it travels from PE to PE.

Therefore, the VPN Context Information option MUST be authenticated when used in over-the-top environments. In this scenario, an IPv6 Encapsulating Security Payload (ESP) [RFC4303] MUST proceed the Destination Options header that carries the VPN Context Information option. The ESP integrity service MUST be enabled.

6. IANA Considerations

IANA is requested to allocate a codepoint from the Destination Options and Hop-by-hop Options registry (https://www.iana.org/assignments/ipv6-parameters/ipv6-parameters.xhtml#ipv6-parameters-2). This option is called "VPN Context Information". The "act" bits are 10 and the "chg" bit is 0.

7. Acknowledgements

Thanks to Brian Carpenter, Adrian Farrel, Tom Herbert and John Leddy for their comments.

8. References

8.1. Normative References

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DMM Working Group
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Router Advertisement Prefix Option Extension for On-Demand Mobility
draft-feng-dmm-ra-prefixtype-03

Abstract

Router Advertisement / Router Solicitation is one of the ways for hosts to establish network IPv6 connectivity configuration. This document describes two approches to allowing a router to specify mobility service type availability to mobile hosts. Mobile hosts can then configure their IP address to the preferred type of mobile connectivity. Two possibilities are considered: (i) creating an extension to the router advertisement prefix information option to allow the router to specify mobility connectivity types, and (ii) specifying a new RA options that allows the router to specify the mobility connectivity types.

Status of This Memo

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

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

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

This Internet-Draft will expire on March 16, 2019.

Table of Contents

1. Introduction

[I-D.ietf-dmm-ondemand-mobility] defines different types of mobility related network services provided by access network to mobile hosts. In particular, it defines different types of prefix continuity types as mobile nodes move between different points of attachments.

This document proposes two such options to the router advertisement message ([RFC4861]) to allow the router to convey mobility services associated with an Ipv6 prefix. The possibilities considered are: (i) creating an extension to the router advertisement prefix information option to allow the router to specify mobility connectivity types, and (ii) specifying a new RA options that allows the router to specify the mobility connectivity types.

For (i), the prefix information option is extended to support the specification of mobility type. In (ii), a new RA option field is provided to do the same.

2. Notational Conventions

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].

3. Router Advertisement Extensions

IP prefixes are conveyed in Router Advertisement messages through the Prefix Information Option field ([RFC4861]). These prefix information option fields are used to allow hosts to configure their IPv6 addresses.

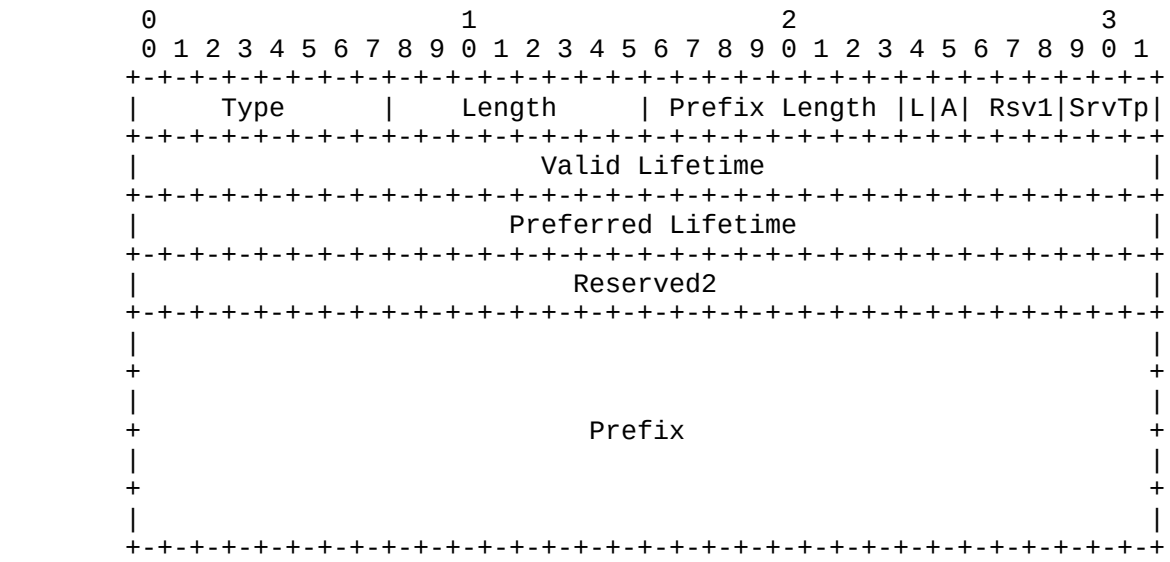
For distributed mobility management, there is a need for a network to be able to convey different prefixes for different connectivity scenarios. [I-D.ietf-dmm-ondemand-mobility] defines different service continuity requirements including: Non-Persistent, Session-Lasting, Fixed, and Graceful-replacement. Currently, however, there is no way for a router to specify the continuity type through a router advertisement message.

This document proposes two possibilities for modifying the router advertisement message to include mobility service options that it is offering to mobile hosts that are attached: (i) creating an extension to the router advertisement prefix information option (PIO) to allow the router to specify mobility connectivity types, and (ii) specifying a new RA options that allows the router to specify the mobility connectivity types.

3.1. Modifying PIO

The first option is to modify the PIO. The advantages of this approach are that it is semantically in line with the intended function. That is, specifying prefix options. This, however, requires the modification of several bits in the existing PIO to support the specification of the type.

The modified prefix information option fields are shown in the following figure:



Fields:

Type 3

Length 4

Prefix Length 8-bit unsigned integer. The number of leading bits in the Prefix that are valid. The value ranges from 0 to 128.

L 1-bit on-link flag. When set, indicates that this prefix can be used for on-link determination.

A 1-bit autonomous address-configuration flag. When set indicates that this prefix can be used for stateless address configuration.

Rsv1 3-bit unused field. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.

SrvTp 3-bit field that specifies the service type. The field can have the following values:

Non-Persistent - a non-persistent IP prefix (1)

Session-Lasting - a session-lasting IP prefix (2)

Fixed - a fixed IP prefix (3)

Graceful-replacement - a graceful-replacement IP prefix (4)

The definition of these service types is available in [I-D.ietf-dmm-ondemand-mobility].

0 is reserved and should not be used. All other values (5-7) are reserved for future use.

The value of the Service Type indicates the type of continuity service committed by the network for the associated IPv6 prefix.

Once an IPv6 prefix type is provided, any subsequent messages involving this prefix (lease renewal - for example) must include the IPv6 Continuity Service option with the same service type that was assigned by the server during the initial allocation.

Given the list of IPv6 prefixes and their associated mobility service type, the mobile host can then configure its IP address to the appropriate service required by the application

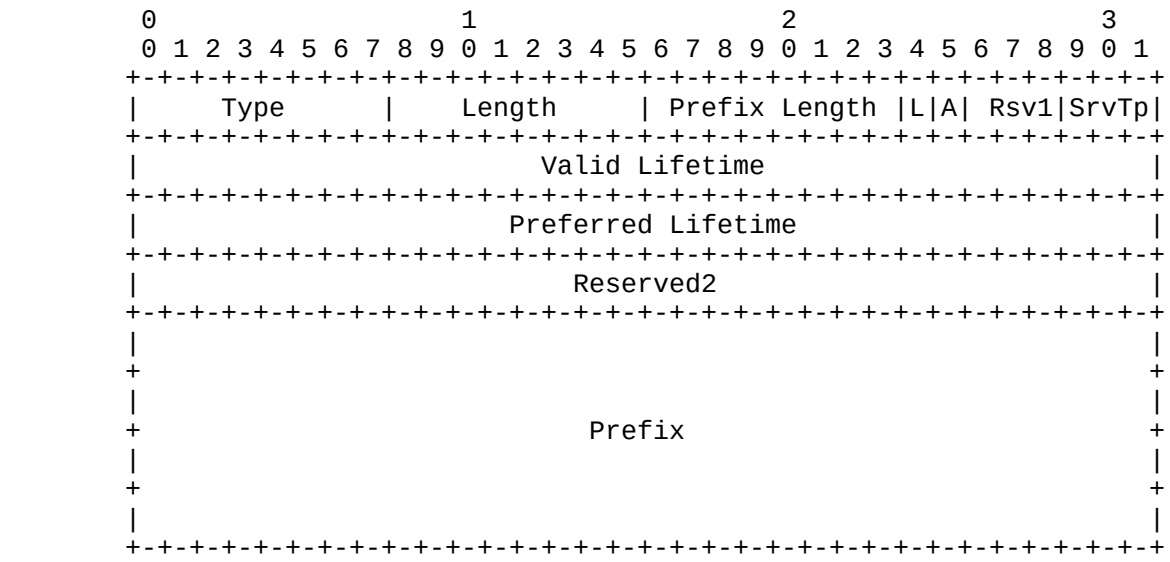
Mobile hosts that do not support this new option should ignore the prefix information option.

Routers should also send an additional prefix information option without the session-type field from time to time for hosts that do not support this new format.

3.2. Adding a new RA option

The second approach is to add a new RA option alongside the existing PIO (and other RA options). The advantage of this approach are that it leaves the existing PIO untouched. Furthermore, hosts that receive this option with the type that they do not understand can simply disregard it.

The new RA option specification is shown in the following figure:



Fields:

Type — Need to define new Type #

Length — 4

Prefix Length — 8-bit unsigned integer. The number of leading bits in the Prefix that are valid. The value ranges from 0 to 128.

L — 1-bit on-link flag. When set, indicates that this prefix can be used for on-link determination.

A — 1-bit autonomous address-configuration flag. When set indicates that this prefix can be used for stateless address configuration.

Rsv1 — 3-bit unused field. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.

SrvTp — 3-bit field that specifies the service type. The field can have the following values:

Non-Persistent - a non-persistent IP prefix (1)

Session-Lasting - a session-lasting IP prefix (2)

Fixed - a fixed IP prefix (3)

Graceful-replacement - a graceful-replacement IP prefix (4)

The definition of these service types is available in [I-D.ietf-dmm-ondemand-mobility].

0 is reserved and should not be used. All other values (5-7) are reserved for future use.

The value of the Service Type indicates the type of continuity service committed by the network for the associated IPv6 prefix.

Once an IPv6 prefix type is provided, any subsequent messages involving this prefix (lease renewal - for example) must include the IPv6 Continuity Service option with the same service type that was assigned by the server during the initial allocation.

Given the list of IPv6 prefixes and their associated mobility service type, the mobile host can then configure its IP address to the appropriate service required by the application

Mobile hosts that do not support this new option should ignore the prefix information option.

Routers should also send an additional prefix information option without the session-type field from time to time for hosts that do not support this new format.

4. Security Considerations

There are no specific security considerations for this option.

5. IANA Considerations

TBD

6. References

6.1. Normative References

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November 5, 2018

IPv6 Router Advertisement IPv6-Only Flag
draft-ietf-6man-ipv6only-flag-04

Abstract

This document specifies a Router Advertisement Flag to indicate to hosts that the administrator has configured the router to advertise that the link is IPv6-Only. This document updates RFC4861 and RFC5175.

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 http://datatracker.ietf.org/drafts/current/.

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This Internet-Draft will expire on May 9, 2019.

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1. Introduction

This document specifies a Router Advertisement Flag to indicate to hosts that the administrator has configured the router to advertise that the link is IPv6-Only. The flag only applies to IPv6 default routers.

Hosts that support IPv4 and IPv6, usually called dual stack hosts, need to also work efficiently on IPv6-Only links, i.e, links where there are no IPv4 routers and/or IPv4 services. Dual stack is the default configuration for most current host operating systems such as Windows 10, iOS, Android, Linux, and BSD, as well as devices such as some printers. Monitoring of an IPv6-Only link, for example at the IETF 100 meeting in Singapore, shows that current dual stack hosts will create local auto-configured IPv4 addresses and attempt to reach IPv4 services, even though they cannot configure a normal address using DHCP. This may be a problem for several reasons, depending on the equipment in use and its configuration, especially on large wireless networks:

- It may result in an undesirable level of wasted Layer 2 broadcast traffic.

- Switches in multi-segment wireless networks may create IPv4 state for dual stack hosts (in particular, ARP cache entries to support ARP proxying).

- Such traffic may drain battery power on wireless hosts that have no interest in link-local IPv4, ARP, and DHCPv4 relay traffic, but receive unwanted IPv4 packets. [RFC7772] indicates how this risk might be quantified.

- Similarly, hosts may waste battery power on futile attempts to access services by sending IPv4 packets.

- On an IPv6-Only link, IPv4 might be used for malicious purposes and pass unnoticed by IPv6-Only monitoring mechanisms.

In networks with managed infrastructure whose equipment allows it, these problems could be mitigated by configuring the Layer 2 infrastructure to drop IPv4 and ARP traffic by filtering Ethertypes 0x0800 and 0x0806 [IANA-Ethertype]. IPv6 uses a different Ethertype, 0x86DD, so this filtering will not interfere with IPv6 traffic. Depending on the equipment details, this would limit the traffic to the link from an IPv4 sender to the switch, and would drop all IPv4 and ARP broadcast packets at the switch. This document recommends using such mechanisms when available.

However, hosts transmitting IPv4 packets would still do so, consuming their own battery power and some radio bandwidth. The intent of this specification is to provide a mechanism that prevents such traffic, and also works on networks without the ability to filter L2 traffic, or where there are portions of a network without the ability to filter L2 traffic. It may also be valuable on unmanaged networks using routers pre-configured for IPv6-Only operations and where Layer 2 filtering is unavailable.

An assumption of this document is that because it is an IPv6-Only link there is no IPv4 DHCP server or relay active on the link. This further means that the DHCP option to disable IPv4 stateless auto-configuration [RFC2563] can not be used.

The remainder of this document therefore assumes that neither effective Layer 2 filtering nor the RFC 2563 DHCP option is applicable to the link concerned.

Because there is no IPv4 support on an IPv6-Only link, the only way to notify the dual stack hosts that this link is IPv6-Only is to use an IPv6 mechanism. An active notification will be much more precise than attempting to deduce this fact by the lack of IPv4 responses or traffic.

This document therefore defines a mechanism that a router administrator can use to inform hosts that this is an IPv6-Only link on their default routers such that they can disable IPv4 on this

link, mitigating all of the above problems. The mechanism is based on the IPv6 Router Advertisement message because this is a type of message that is certain to be received by every dual stack host, regardless of what network management protocols may or may not be in use.

IPv4-only hosts, and dual-stack hosts that do not recognize the new flag, may continue to attempt IPv4 operations, in particular IPv4 discovery protocols typically sent as link-layer broadcasts. This legacy traffic cannot be prevented by any IPv6 mechanism. The value of the new flag is limited to hosts that recognize it.

A possible subsidiary use of the IPv6-Only flag is using it to trigger IPv6-Only testing and validation on a link.

This document specifies a new flag for Router Advertisement Flag [RFC5175]. It updates [RFC5175] to add this flag. It also updates [RFC4861] to add an additional item to check and report.

2. Requirements Language

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

3. Applicability Statements

This OPTIONAL mechanism is designed to allow administrators to notify hosts that the link is IPv6-Only. It SHOULD be only used in IPv6-Only links (see below for definition). For a VLAN, the IPv6-Only flag only applies to the specific VLAN on which it was received.

Dual stack hosts that have a good reason to use IPv4, for example for a specific IPv4 link-local service, can attempt to do so. Therefore respect of the IPv6-Only flag is recommended, not mandatory, for hosts.

Administrators MUST only use this mechanism if they are certain that the link is IPv6-Only. For example, in cases where there is a need to continue to use IPv4, when there are intended to be IPv4-only hosts or IPv4 routers on the link, setting this flag to 1 is a configuration error.

This mechanism is intended to be compatible with link-layer solutions that filter out IPv4 traffic.

4. IPv6-Only Definition

IPv6-Only is defined to mean that no other versions of Internet Protocol than IPv6 are intentionally in use directly on the link. Today this effectively simply means that IPv4 is not intentionally in use on the link, and it includes:

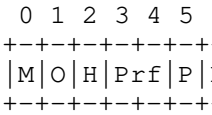
* No IPv4 traffic on the link.
* No IPv4 routers on the link.
* No DHCPv4 servers on the link.
* No IPv4 accessible services on the link.
* All IPv4 and ARP traffic may be blocked at Layer 2 by the administrator.

It is expected that on IPv6-Only networks it will be common to access to IPv4 external services by techniques such as NAT64 [RFC6146] and DNS64 [RFC6147] at the edge of the network. This is beyond the scope of this document.

Note that IPv6-Only provides no information about other network protocols than IP (and ARP) in use directly over the link layer. It is out of scope of this specification whether any such protocol is in use on the link or whether any protocol is tunneled over IPv6.

5. IPv6-Only Flag

RFC5175 currently defines the flags in the NDP Router Advertisement message and these flags are registered in the IANA IPv6 ND Router Advertisement flags Registry [IANA-RF]. This currently contains the following one-bit flags defined in published RFCs:



M	Managed Address Configuration Flag [RFC4861]
O	Other Configuration Flag [RFC4861]
H	Mobile IPv6 Home Agent Flag [RFC3775]
Prf	Router Selection Preferences [RFC4191]
P	Neighbor Discovery Proxy Flag [RFC4389]
R	Reserved

This document defines bit 6 to be the IPv6-Only Flag:

S IPv6-Only Flag

This flag has two values. These are:

0 This is not an IPv6-Only link
1 This is an IPv6-Only link

RFC 5175 requires that unused flag bits be set to zero. Therefore, a router that does not support the new flag will not appear to assert that this is an IPv6-Only link.

Hosts receiving the Router Advertisement SHOULD only process this flag if the advertising router is a Default Router. Specifically, if the Lifetime field in the Router Advertisement is not zero, otherwise it SHOULD be ignored. This is done to allow some IPv6 routers to advertise information without being a Default Router and providing IPv6 connectivity.

Note that although this mechanism uses one of only two reserved flag bits in the RA, an extension mechanism is defined in Section 4 of [RFC5175] in case additional flags are ever required for future extensions. It should be noted that since RFC5175 was published in 2008, no new RA flags have been assigned in the IANA registry.

6. Router and Operational Considerations

Default IPv6 routers that are on an IPv6-Only link SHOULD be configured by the administrator to set the IPv6-Only flag to 1 on interfaces on this link. In all other cases the flag SHOULD NOT be set to 1.

The intent is that the administrator of the router configures the router to set the IPv6-Only flag if she/he wants to tell the hosts on the link that the link is IPv6-Only. This is a configuration flag, it is not something that the router decides on its own. Routers MAY log a configuration error if the flag is set and IPv4 is still active on the router's interface to the link.

Routers implementing this document SHOULD log to system or network management inconsistent setting of the IPv6-Only flag. This extends the behaviour specified in Section 6.2.7 of [RFC4861].

Operators of large IPv6-Only wireless links are advised to also use Layer 2 techniques to drop IPv4 and ARP packets (Ethertypes 0x0800 and 0x0806) at all switches, and to ensure that IPv4 and ARP features are disabled in all switches.

7. Host Behavior Considerations

If there are multiple IPv6 default routers on a link, they might send different values of the flag. If at least one IPv6 default router sends the flag with value 0, a dual stack host MUST NOT assume that the link is IPv6-Only. If all IPv6 default routers send the flag with value 1, a dual stack host SHOULD assume that this is an IPv6-Only link.

A host that receives only RAs with the flag set to 1 SHOULD NOT attempt any IPv4 operations, unless it subsequently receives at least one RA with the flag set to zero. As soon as such an RA is received, IPv4 operations MAY be started.

A host MAY delay all IPv4 operations at start-up or reconnection until a reasonable time has elapsed for RA messages to arrive. If all RAs received have the flag set to 1, a host SHOULD NOT attempt IPv4 operations.

In all of the above, the flag's value is considered valid for the lifetime of the default router concerned, unless a subsequent RA delivers a different flag value. If a default router expires (i.e., no RA is received that refreshes its lifetime), the host must remove this router's flag value from consideration. If the result is that all surviving default routers have the flag set to 1, the host SHOULD assume that the link is IPv6-Only. In other words, at any given time, the state of the flag as seen by the host is the logical AND of the flags sent by all unexpired default IPv6 routers on the link.

This also means that if all default routers on the link have set the flag, the resulting host state for the link is IPv6-Only. If the lifetimes of all the routers on the link subsequently expire, then the host state for the link is not IPv6-Only.

8. IANA Considerations

IANA is requested to assign the new Router Advertisement flag defined in Section 5 of this document. Bit 6 is the next available bit in this registry, IANA is requested to use this bit unless there is a reason to use another bit in this registry.

IANA is also requested to register this new flag bit in the IANA IPv6 ND Router Advertisement flags Registry [IANA-RF].

9. Security Considerations

This document shares the security issues with other parts of IPv6 Neighbor Discovery. [RFC6104] discusses certain attacks and mitigations. General techniques to protect Router Advertisement traffic such as Router Guard [RFC6105] are useful in protecting against these vulnerabilities.

A bad actor could use this mechanism to attempt turn off IPv4 service on a link that is intentionally using IPv4, by sending Router Advertisements with the IPv6-Only flag set to 1. In that case, as long as there are one or more routers sending Router Advertisements with this flag set to 0, they would override this attack given the mechanism in Section 5. Specifically a host would only turn off IPv4 service if it wasn't hearing any Router Advertisement with the flag set to 0. If the advice in Section 6 is followed, this attack will fail. In a situation where the bad actor has control of all routers on the link and sends Router Advertisements with the IPv6-Only flag set to 1 from all of them, the attack will succeed, but so will many other forms of router-based attack.

Conversely, a bad actor could use this mechanism to turn on, or pretend to turn on, IPv4 service on an IPv6-Only link, by sending Router Advertisements with the flag set to 0. However, this is really no different than what such a bad actor can do anyway, if they have the ability to configure a bogus router in the first place. The advice in Section 6 will minimize such an attack by limiting it to a single link.

Note that manipulating the Router Preference [RFC4191] will not affect either of these attacks: any IPv6-Only flag of 0 will always override all flags set to 1.

The new flag is neutral from an IPv6 privacy viewpoint, since it does not affect IPv6 operations in any way. From an IPv4 privacy viewpoint, it has the potential benefit of suppressing unnecessary traffic that might reveal the existence of a host and the correlation between its hardware and IPv4 addresses. It should be noted that hosts that don't support this flag are not protected from IPv4-based attacks.

10. Acknowledgments

A closely related proposal was published earlier as [I-D.ietf-sunset4-noipv4].

Helpful comments were received from Lorenzo Colitti, David Farmer, Fernando Gont, Nick Hilliard, Lee Howard, Erik Kline, Jen Linkova,

Veronika McKillop, George Michaelson, Alexandre Petrescu, Michael Richardson, Mark Smith, Barbara Stark, Tatuya Jinmei, Ole Troan, James Woodyatt, Bjoern Zeeb, and other members of the 6MAN working group.

Bjoern Zeeb has also produced a variant of this proposal and proposed an IPv6 transition plan in [I-D.bz-v4goawayflag].

11. Change log [RFC Editor: Please remove]

draft-ietf-6man-ipv6only-flag-04, 2018-November-4:

* Added text to Section 1 explaining why the mechanism is based on Router Advertisements.
* Added text to Section 3 that for a VLAN, the IPv6-Only flag only applies to the specific VLAN on which it was received.
* Changed Section 3 that administrators MUST only use this mechanism if they are certain that the link is IPv6-Only, instead of SHOULD.
* Added ARP to Section 4 protocols that the IPv6-Only flag applies to.
* Renamed the IPv6-Only flag label from "6" to "S".
* Added pointers to Section 7.2.7 of RFC4861 in Section 6.
* Added that RFC4861 is also updated by Section 6 for routers implementing this flag.
* Changed Section 7 from SHOULD NOT to MUST NOT.
* Added Appendix A on implementations and testing.
* Many small clarifications based on IPv6 list discussion and editorial changes.

draft-ietf-6man-ipv6only-flag-03, 2018-October-16:

* Reorganized text about problem statement and applicability
* Added note about shortage of flag bits
* Clarified text about logging configuration error in Section 6
* Editorial changes.

draft-ietf-6man-ipv6only-flag-02, 2018-August-14:

* Added text to Section 9 to clarify that hosts not supporting this flag are not protected from IPv4-based attacks.
* Editorial changes.

draft-ietf-6man-ipv6only-flag-01, 2018-June-29:

* Added text to section that defines what IPv6-Only includes to clarify that only other version of the Internet Protocol are in scope.
* Added clarification if the lifetime of all routers expire.
* Editorial changes.

draft-ietf-6man-ipv6only-flag-00, 2018-May-21:

* Changed the file name to draft-ietf-6man-ipv6only-flag to match the current tile and that it is a w.g. draft.
* Added new section that defines what IPv6-Only includes.
* Expanded description of using Layer 2 filter to block IPv4 and ARP traffic.
* Editorial changes.

draft-hinden-ipv4flag-04, 2018-April-16:

* Changed the name of the document and flag to be the IPv6-Only flag.
* Rewrote text to make it affirmative that this is used by an administrator to tell the hosts that the link is IPv6-Only.
* Added an Applicability Statements section to scope the intend use.
* Changed requirement language to upper case, added Requirements Language section with references to [RFC2119] and [RFC8174].
* Editorial changes.

draft-hinden-ipv4flag-03, 2018-Feb-15:

* Changed terminology to use "link" instead of "network".
* Improved text in Section 4. "Host Behavior Considerations" and added suggestion to only perform IPv4 if an application requests it.
* Added clarification that the bit is set because an administrator configured the router to send it.
* Editorial changes.

draft-hinden-ipv4flag-02, 2018-Feb-15:

* Improved text in introduction.
* Added reference to current IANA registry in Section 2.
* Editorial changes.

draft-hinden-ipv4flag-01, 2017-Dec-12

* Inverted name of flag from "Available" to "Unavailable".
* Added problem description and clarified scope.
* Added router and operational considerations.
* Added host behavior considerations.
* Extended security considerations.
* Added Acknowledgment section, including reference to prior sunset4 draft.

draft-hinden-ipv4flag-00, 2017-Nov-17:

* Original version.

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Appendix A. Implementaton Status

At the time this document was written there is one implementation and a few comparability tests.

A.1. FreeBSD Implementation

A FreeBSD implementation was written by Bjoern Zeeb. It can be found at:

https://lists.freebsd.org/pipermail/svn-src-head/2018-October/119360.html

Summary:

This change defines the RA "6" (IPv6-Only) flag which routers may advertise, kernel logic to check if all routers on a link have the flag set and accordingly update a per-interface flag.

If all routers agree that it is an IPv6-only link, ether_output_frame(), based on the interface flag, will filter out all ETHERTYPE_IP/ARP frames, drop them, and return EAFNOSUPPORT to upper layers.

The change also updates ndp to show the "6" flag, ifconfig to display the IPV6_ONLY nd6 flag if set, and rtadvd to allow announcing the flag.

The code was tested with 2 FreeBSD IPv6 routers, a FreeBSD laptop on ethernet as well as wifi, and with Win10 and OSX clients (which did not fall over with the "6" flag set but not understood).

A.2. Test using Scapy

Independent tests have been done using [Scapy_RA] by Alexandre Petrescu and Brian Carpenter to verify that setting the IPv6-Only Flag did not break legacy hosts. Both verified that setting this flag did not cause any adverse effects on Windows 10 and Android.

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Privacy Extensions for Stateless Address Autoconfiguration in IPv6
draft-ietf-6man-rfc4941bis-00

Abstract

Nodes use IPv6 stateless address autoconfiguration to generate addresses using a combination of locally available information and information advertised by routers. Addresses are formed by combining network prefixes with an interface identifier. This document describes an extension that causes nodes to generate global scope addresses from interface identifiers that change over time. Changing the interface identifier (and the global scope addresses generated from it) over time makes it more difficult for eavesdroppers and other information collectors to identify when different addresses used in different transactions actually correspond to the same node.

Status of This Memo

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

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This Internet-Draft will expire on January 3, 2019.

Table of Contents

1. Introduction

Stateless address autoconfiguration [RFC4862] defines how an IPv6 node generates addresses without the need for a Dynamic Host Configuration Protocol for IPv6 (DHCPv6) server. The security and privacy implications of such addresses have been discussed in great detail in [RFC7721],[RFC7217], and RFC7707. This document specifies an extension for SLAAC to generate temporary addresses, such that the aforementioned issues are mitigated.

The default address selection for IPv6 has been specified in [RFC6724]. We note that the determination as to whether to use stable versus temporary addresses can in some cases only be made by an application. For example, some applications may always want to use temporary addresses, while others may want to use them only in some circumstances or not at all. An API such as that specified in [RFC5014] can enable individual applications to indicate with sufficient granularity their needs with regards to the use of temporary addresses.

Section 2 provides background information on the issue. Section 3 describes a procedure for generating temporary interface identifiers and global scope addresses. Section 4 discusses implications of changing interface identifiers.

1.1. 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].

The terms "public address", "stable address", "temporary address", "constant IID", "stable IID", and "temporary IID" are to be interpreted as specified in [RFC7721].

The term "global scope addresses" is used in this document to collectively refer to "Global unicast addresses" as defined in [RFC4291] and "Unique local addresses" as defined in [RFC4193].

1.2. Problem Statement

Addresses generated using stateless address autoconfiguration [RFC4862] contain an embedded interface identifier, which remains stable over time. Anytime a fixed identifier is used in multiple contexts, it becomes possible to correlate seemingly unrelated activity using this identifier.

The correlation can be performed by

- An attacker who is in the path between the node in question and the peer(s) to which it is communicating, and who can view the IPv6 addresses present in the datagrams.

- An attacker who can access the communication logs of the peers with which the node has communicated.

Since the identifier is embedded within the IPv6 address, which is a fundamental requirement of communication, it cannot be easily hidden. This document proposes a solution to this issue by generating interface identifiers that vary over time.

Note that an attacker, who is on path, may be able to perform significant correlation based on

- The payload contents of the packets on the wire

- The characteristics of the packets such as packet size and timing

Use of temporary addresses will not prevent such payload-based correlation.

2. Background

This section discusses the problem in more detail, provides context for evaluating the significance of the concerns in specific environments and makes comparisons with existing practices.

2.1. Extended Use of the Same Identifier

The use of a non-changing interface identifier to form addresses is a specific instance of the more general case where a constant identifier is reused over an extended period of time and in multiple independent activities. Any time the same identifier is used in multiple contexts, it becomes possible for that identifier to be used to correlate seemingly unrelated activity. For example, a network sniffer placed strategically on a link across which all traffic to/from a particular host crosses could keep track of which destinations a node communicated with and at what times. Such information can in some cases be used to infer things, such as what hours an employee was active, when someone is at home, etc. Although it might appear that changing an address regularly in such environments would be desirable to lessen privacy concerns, it should be noted that the network prefix portion of an address also serves as a constant identifier. All nodes at, say, a home, would have the same network prefix, which identifies the topological location of those nodes. This has implications for privacy, though not at the same granularity as the concern that this document addresses. Specifically, all nodes

within a home could be grouped together for the purposes of collecting information. If the network contains a very small number of nodes, say, just one, changing just the interface identifier will not enhance privacy at all, since the prefix serves as a constant identifier.

One of the requirements for correlating seemingly unrelated activities is the use (and reuse) of an identifier that is recognizable over time within different contexts. IP addresses provide one obvious example, but there are more. Many nodes also have DNS names associated with their addresses, in which case the DNS name serves as a similar identifier. Although the DNS name associated with an address is more work to obtain (it may require a DNS query), the information is often readily available. In such cases, changing the address on a machine over time would do little to address the concerns raised in this document, unless the DNS name is changed as well (see Section 4).

Web browsers and servers typically exchange "cookies" with each other [RFC6265]. Cookies allow web servers to correlate a current activity with a previous activity. One common usage is to send back targeted advertising to a user by using the cookie supplied by the browser to identify what earlier queries had been made (e.g., for what type of information). Based on the earlier queries, advertisements can be targeted to match the (assumed) interests of the end-user.

The use of a constant identifier within an address is of special concern because addresses are a fundamental requirement of communication and cannot easily be hidden from eavesdroppers and other parties. Even when higher layers encrypt their payloads, addresses in packet headers appear in the clear. Consequently, if a mobile host (e.g., laptop) accessed the network from several different locations, an eavesdropper might be able to track the movement of that mobile host from place to place, even if the upper layer payloads were encrypted.

The security and privacy implications of IPv6 addresses are discussed in detail in [RFC7721], [RFC7707], and [RFC7217].

2.2. Possible Approaches

One way to avoid having a stable non-changing address is to use DHCPv6 [RFC3315] for obtaining addresses. Section 12 of [RFC3315] discusses the use of DHCPv6 for the assignment and management of "temporary addresses", which are never renewed and provide the same property of temporary addresses described in this document with regards to the privacy concern.

Another approach, compatible with the stateless address autoconfiguration architecture, would be to change the interface identifier portion of an address over time. Changing the interface identifier can make it more difficult to look at the IP addresses in independent transactions and identify which ones actually correspond to the same node, both in the case where the routing prefix portion of an address changes and when it does not.

Many machines function as both clients and servers. In such cases, the machine would need a DNS name for its use as a server. Whether the address stays fixed or changes has little privacy implication since the DNS name remains constant and serves as a constant identifier. When acting as a client (e.g., initiating communication), however, such a machine may want to vary the addresses it uses. In such environments, one may need multiple addresses: a stable address registered in the DNS, that is used to accept incoming connection requests from other machines, and a temporary address used to shield the identity of the client when it initiates communication. These two cases are roughly analogous to telephone numbers and caller ID, where a user may list their telephone number in the public phone book, but disable the display of its number via caller ID when initiating calls.

On the other hand, a machine that functions only as a client may want to employ only temporary addresses for public communication.

To make it difficult to make educated guesses as to whether two different interface identifiers belong to the same node, the algorithm for generating alternate identifiers must include input that has an unpredictable component from the perspective of the outside entities that are collecting information.

[I-D.gont-6man-non-stable-iids] specifies requirements for temporary addresses. This document specifies a number of algorithms for generating temporary addresses that comply with the aforementioned requirements.

3. Protocol Description

The goal of this section is to define procedures that:

1. Do not result in any changes to the basic behavior of addresses generated via stateless address autoconfiguration [RFC4862].

2. Create temporary addresses based on an unpredictable interface identifier for the purpose of initiating outgoing sessions. These temporary addresses would be used for a short period of time (hours to days) and would then be deprecated. Deprecated

addresses can continue to be used for already established connections, but are not used to initiate new connections. New temporary addresses are generated periodically to replace temporary addresses that expire, with the exact time between address generation a matter of local policy.

3. Produce a sequence of temporary global scope addresses from a sequence of interface identifiers that appear to be random in the sense that it is difficult for an outside observer to predict a future address (or identifier) based on a current one and it is difficult to determine previous addresses (or identifiers) knowing only the present one.

4. By default, generate one address for each prefix advertised for stateless address autoconfiguration. The interface identifier generated for each of those prefixes should be (statistically) different. That is, a new interface identifier should be computed for each temporary address that is to be generated.

3.1. Assumptions

The following algorithm assumes that for a given temporary address, an implementation can determine the prefix from which it was generated. When a temporary address is deprecated, a new temporary address is generated. The specific valid and preferred lifetimes for the new address are dependent on the corresponding lifetime values set for the prefix from which it was generated.

Finally, this document assumes that when a node initiates outgoing communication, temporary addresses can be given preference over stable addresses (if available), when the device is configured to do so. [RFC6724] mandates implementations to provide a mechanism, which allows an application to configure its preference for temporary addresses over stable addresses. It also allows for an implementation to prefer temporary addresses by default, so that the connections initiated by the node can use temporary addresses without requiring application-specific enablement. This document also assumes that an API will exist that allows individual applications to indicate whether they prefer to use temporary or stable addresses and override the system defaults.

3.2. Generation of Randomized Interface Identifiers

The following subsections specify some possible algorithms for generating temporary interface identifiers that comply with the requirements in [I-D.gont-6man-non-stable-iids]. The algorithm specified in Section 3.2.1 benefits from a Peseudo-Random Number Generator (PRNG) available on the system. On the other hand, the

algorithm specified in Section 3.2.2 allows for code reuse by nodes that implement [RFC7217].

3.2.1. Simple Randomized Interface Identifiers

One possible approach would be to select a pseudorandom number of the appropriate length. A node employing this algorithm should generate IIDs as follows:

1. Obtain a random number (see [RFC4086] for randomness requirements for security)

2. The Interface Identifier is obtained by taking as many bits from the aforementioned random number (obtained in the previous step) as necessary.

   We note that [RFC4291] requires that the Interface IDs of all unicast addresses (except those that start with the binary value 000) be 64 bits long. However, the method discussed in this document could be employed for generating Interface IDs of any arbitrary length, albeit at the expense of reduced entropy (when employing Interface IDs smaller than 64 bits).

3. The resulting Interface Identifier SHOULD be compared against the reserved IPv6 Interface Identifiers [RFC5453] [IANA-RESERVED-IID] and against those Interface Identifiers already employed in an address of the same network interface and the same network prefix. In the event that an unacceptable identifier has been generated, a new interface identifier should be generated, by repeating the algorithm from the first step.

3.2.2. Hash-based Generation of Randomized Interface Identifiers

The algorithm in [RFC7217] can be augmented for the generation of temporary addresses. The benefit of this would be that a node could employ a single algorithm for generating stable and temporary addresses, by employing appropriate parameters.

Nodes would employ the following algorithm for generating the temporary IID:

1. Compute a random identifier with the expression:

   RID = F(Prefix, MAC_Address, Network_ID, Time, DAD_Counter, secret_key)

   Where:

RID:
Random Identifier

F():
A pseudorandom function (PRF) that MUST NOT be computable from the outside (without knowledge of the secret key). F() MUST also be difficult to reverse, such that it resists attempts to obtain the secret_key, even when given samples of the output of F() and knowledge or control of the other input parameters. F() SHOULD produce an output of at least 64 bits. F() could be implemented as a cryptographic hash of the concatenation of each of the function parameters. SHA-1 [FIPS-SHS] and SHA-256 are two possible options for F(). Note: MD5 [RFC1321] is considered unacceptable for F() [RFC6151].

Prefix:
The prefix to be used for SLAAC, as learned from an ICMPv6 Router Advertisement message.

MAC_Address:
The MAC address corresponding to the underlying network interface card. Employing the MAC address in this expression (in replacement of the Net_Iface parameter of the expression in RFC7217) means that the re-generation of a randomized MAC address will result in a different temporary address.

Network_ID:
Some network-specific data that identifies the subnet to which this interface is attached -- for example, the IEEE 802.11 Service Set Identifier (SSID) corresponding to the network to which this interface is associated. Additionally, Simple DNA [RFC6059] describes ideas that could be leveraged to generate a Network_ID parameter. This parameter is SHOULD be employed if some form of "Network_ID" is available.

Time:
An implementation-dependent representation of time. One possible example is the representation in UNIX-like systems [OPEN-GROUP], that measure time in terms of the number of seconds elapsed since the Epoch (00:00:00 Coordinated Universal Time (UTC), 1 January 1970).

DAD_Counter:
A counter that is employed to resolve Duplicate Address Detection (DAD) conflicts.

secret_key:

A secret key that is not known by the attacker. The secret key SHOULD be of at least 128 bits. It MUST be initialized to a pseudo-random number (see [RFC4086] for randomness requirements for security) when the operating system is "bootstrapped".

2. The Interface Identifier is finally obtained by taking as many bits from the RID value (computed in the previous step) as necessary, starting from the least significant bit. The resulting Interface Identifier SHOULD be compared against the reserved IPv6 Interface Identifiers [RFC5453] [IANA-RESERVED-IID] and against those Interface Identifiers already employed in an address of the same network interface and the same network prefix. In the event that an unacceptable identifier has been generated, the value DAD_Counter should be incremented by 1, and the algorithm should be restarted from the first step.

3.3. Generating Temporary Addresses

[RFC4862] describes the steps for generating a link-local address when an interface becomes enabled as well as the steps for generating addresses for other scopes. This document extends [RFC4862] as follows. When processing a Router Advertisement with a Prefix Information option carrying a global scope prefix for the purposes of address autoconfiguration (i.e., the A bit is set), the node MUST perform the following steps:

1. Process the Prefix Information Option as defined in [RFC4862], either creating a new stable address or adjusting the lifetimes of existing addresses, both stable and temporary. If a received option will extend the lifetime of a stable address, the lifetimes of temporary addresses should be extended, subject to the overall constraint that no temporary addresses should ever remain "valid" or "preferred" for a time longer than (TEMP_VALID_LIFETIME) or (TEMP_PREFERRED_LIFETIME - DESYNC_FACTOR) respectively. The configuration variables TEMP_VALID_LIFETIME and TEMP_PREFERRED_LIFETIME correspond to approximate target lifetimes for temporary addresses.

2. One way an implementation can satisfy the above constraints is to associate with each temporary address a creation time (called CREATION_TIME) that indicates the time at which the address was created. When updating the preferred lifetime of an existing temporary address, it would be set to expire at whichever time is earlier: the time indicated by the received lifetime or (CREATION_TIME + TEMP_PREFERRED_LIFETIME - DESYNC_FACTOR). A similar approach can be used with the valid lifetime.

3. When a new stable address is created as described in [RFC4862], or if the node has not configured any temporary address for the corresponding prefix, the node SHOULD create a new temporary address for such prefix.

4. When creating a temporary address, the lifetime values MUST be derived from the corresponding prefix as follows:

   * Its Valid Lifetime is the lower of the Valid Lifetime of the prefix and TEMP_VALID_LIFETIME

   * Its Preferred Lifetime is the lower of the Preferred Lifetime of prefix and TEMP_PREFERRED_LIFETIME - DESYNC_FACTOR.

5. A temporary address is created only if this calculated Preferred Lifetime is greater than REGEN_ADVANCE time units. In particular, an implementation MUST NOT create a temporary address with a zero Preferred Lifetime.

6. New temporary addresses MUST be created by appending the interface's current randomized interface identifier to the prefix that was received.

7. The node MUST perform duplicate address detection (DAD) on the generated temporary address. If DAD indicates the address is already in use, the node MUST generate a new randomized interface identifier, and repeat the previous steps as appropriate up to TEMP_IDGEN_RETRIES times. If after TEMP_IDGEN_RETRIES consecutive attempts no non-unique address was generated, the node MUST log a system error and MUST NOT attempt to generate temporary addresses for that interface. Note that DAD MUST be performed on every unicast address generated from this randomized interface identifier.

3.4. Expiration of Temporary Addresses

When a temporary address becomes deprecated, a new one MUST be generated. This is done by repeating the actions described in Section 3.3, starting at step 4). Note that, except for the transient period when a temporary address is being regenerated, in normal operation at most one temporary address per prefix should be in a non-deprecated state at any given time on a given interface. Note that if a temporary address becomes deprecated as result of processing a Prefix Information Option with a zero Preferred Lifetime, then a new temporary address MUST NOT be generated. To ensure that a preferred temporary address is always available, a new temporary address SHOULD be regenerated slightly before its predecessor is deprecated. This is to allow sufficient time to avoid

race conditions in the case where generating a new temporary address is not instantaneous, such as when duplicate address detection must be run. The node SHOULD start the address regeneration process REGEN_ADVANCE time units before a temporary address would actually be deprecated.

As an optional optimization, an implementation MAY remove a deprecated temporary address that is not in use by applications or upper layers as detailed in Section 6.

3.5. Regeneration of Randomized Interface Identifiers

The frequency at which temporary addresses change depends on how a device is being used (e.g., how frequently it initiates new communication) and the concerns of the end user. The most egregious privacy concerns appear to involve addresses used for long periods of time (weeks to months to years). The more frequently an address changes, the less feasible collecting or coordinating information keyed on interface identifiers becomes. Moreover, the cost of collecting information and attempting to correlate it based on interface identifiers will only be justified if enough addresses contain non-changing identifiers to make it worthwhile. Thus, having large numbers of clients change their address on a daily or weekly basis is likely to be sufficient to alleviate most privacy concerns.

There are also client costs associated with having a large number of addresses associated with a node (e.g., in doing address lookups, the need to join many multicast groups, etc.). Thus, changing addresses frequently (e.g., every few minutes) may have performance implications.

Nodes following this specification SHOULD generate new temporary addresses on a periodic basis. This can be achieved automatically by generating a new randomized interface identifier at least once every (TEMP_PREFERRED_LIFETIME - REGEN_ADVANCE - DESYNC_FACTOR) time units. As described above, generating a new temporary address REGEN_ADVANCE time units before a temporary address becomes deprecated produces addresses with a preferred lifetime no larger than TEMP_PREFERRED_LIFETIME. The value DESYNC_FACTOR is a random value (different for each client) that ensures that clients don’t synchronize with each other and generate new addresses at exactly the same time. When the preferred lifetime expires, a new temporary address MUST be generated using the new randomized interface identifier.

Because the precise frequency at which it is appropriate to generate new addresses varies from one environment to another, implementations SHOULD provide end users with the ability to change the frequency at

which addresses are regenerated. The default value is given in TEMP_PREFERRED_LIFETIME and is one day. In addition, the exact time at which to invalidate a temporary address depends on how applications are used by end users. Thus, the suggested default value of one week (TEMP_VALID_LIFETIME) may not be appropriate in all environments. Implementations SHOULD provide end users with the ability to override both of these default values.

Finally, when an interface connects to a new link, a new set of temporary addresses MUST be generated immediately. If a device moves from one ethernet to another, generating a new set of temporary addresses ensures that the device uses different randomized interface identifiers for the temporary addresses associated with the two links, making it more difficult to correlate addresses from the two different links as being from the same node. The node MAY follow any process available to it, to determine that the link change has occurred. One such process is described by Detecting Network Attachment [RFC4135].

3.6. Deployment Considerations

Devices implementing this specification MUST provide a way for the end user to explicitly enable or disable the use of temporary addresses. In addition, a site might wish to disable the use of temporary addresses in order to simplify network debugging and operations. Consequently, implementations SHOULD provide a way for trusted system administrators to enable or disable the use of temporary addresses.

Additionally, sites might wish to selectively enable or disable the use of temporary addresses for some prefixes. For example, a site might wish to disable temporary address generation for "Unique local" [RFC4193] prefixes while still generating temporary addresses for all other global prefixes. Another site might wish to enable temporary address generation only for the prefixes 2001::/16 and 2002::/16 while disabling it for all other prefixes. To support this behavior, implementations SHOULD provide a way to enable and disable generation of temporary addresses for specific prefix subranges. This per-prefix setting SHOULD override the global settings on the node with respect to the specified prefix subranges. Note that the per-prefix setting can be applied at any granularity, and not necessarily on a per subnet basis.

The use of temporary addresses may cause unexpected difficulties with some applications. As described below, some servers refuse to accept communications from clients for which they cannot map the IP address into a DNS name. In addition, some applications may not behave robustly if temporary addresses are used and an address expires

before the application has terminated, or if it opens multiple sessions, but expects them to all use the same addresses.

If a very small number of nodes (say, only one) use a given prefix for extended periods of time, just changing the interface identifier part of the address may not be sufficient to ensure privacy, since the prefix acts as a constant identifier. The procedures described in this document are most effective when the prefix is reasonably non static or is used by a fairly large number of nodes.

4. Implications of Changing Interface Identifiers

The desires of protecting individual privacy versus the desire to effectively maintain and debug a network can conflict with each other. Having clients use addresses that change over time will make it more difficult to track down and isolate operational problems. For example, when looking at packet traces, it could become more difficult to determine whether one is seeing behavior caused by a single errant machine, or by a number of them.

Some servers refuse to grant access to clients for which no DNS name exists. That is, they perform a DNS PTR query to determine the DNS name, and may then also perform an AAAA query on the returned name to verify that the returned DNS name maps back into the address being used. Consequently, clients not properly registered in the DNS may be unable to access some services. As noted earlier, however, a node’s DNS name (if non-changing) serves as a constant identifier. The wide deployment of the extension described in this document could challenge the practice of inverse-DNS-based "authentication," which has little validity, though it is widely implemented. In order to meet server challenges, nodes could register temporary addresses in the DNS using random names (for example, a string version of the random address itself).

Use of the extensions defined in this document may complicate debugging and other operational troubleshooting activities. Consequently, it may be site policy that temporary addresses should not be used. Consequently, implementations MUST provide a method for the end user or trusted administrator to override the use of temporary addresses.

5. Defined Constants

Constants defined in this document include:

TEMP_VALID_LIFETIME -- Default value: 1 week. Users should be able to override the default value.

TEMP_PREFERRED_LIFETIME -- Default value: 1 day. Users should be able to override the default value.

REGEN_ADVANCE -- 5 seconds

MAX_DESYNC_FACTOR -- 10 minutes. Upper bound on DESYNC_FACTOR.

DESYNC_FACTOR -- A random value within the range 0 - MAX_DESYNC_FACTOR. It is computed once at system start (rather than each time it is used) and must never be greater than (TEMP_VALID_LIFETIME - REGEN_ADVANCE).

TEMP_IDGEN_RETRIES -- Default value: 3

6. Future Work

An implementation might want to keep track of which addresses are being used by upper layers so as to be able to remove a deprecated temporary address from internal data structures once no upper layer protocols are using it (but not before). This is in contrast to current approaches where addresses are removed from an interface when they become invalid [RFC4862], independent of whether or not upper layer protocols are still using them. For TCP connections, such information is available in control blocks. For UDP-based applications, it may be the case that only the applications have knowledge about what addresses are actually in use. Consequently, an implementation generally will need to use heuristics in deciding when an address is no longer in use.

Recommendations on DNS practices to avoid the problem described in Section 4 when reverse DNS lookups fail may be needed. [RFC4472] contains a more detailed discussion of the DNS-related issues.

While this document discusses ways of obscuring a user’s IP address, the method described is believed to be ineffective against sophisticated forms of traffic analysis. To increase effectiveness, one may need to consider use of more advanced techniques, such as Onion Routing [ONION].

7. Security Considerations

Ingress filtering has been and is being deployed as a means of preventing the use of spoofed source addresses in Distributed Denial of Service (DDoS) attacks. In a network with a large number of nodes, new temporary addresses are created at a fairly high rate. This might make it difficult for ingress filtering mechanisms to distinguish between legitimately changing temporary addresses and spoofed source addresses, which are "in-prefix" (using a

topologically correct prefix and non-existent interface ID). This can be addressed by using access control mechanisms on a per-address basis on the network egress point.

8. Significant Changes from RFC4941

This section summarizes the changes in this document relative to RFC 4941 that an implementer of RFC 4941 should be aware of.

1. Discussion of IEEE-based IIDs has been removed, since the current recommendation ([RFC8064]) is to employ [RFC7217]).

2. The document employs the terminology from [RFC7721].

3. Sections 2.2 and 2.3 of [RFC4941] have been removed since the topic has been discussed in more detail in e.g. [RFC7721].

4. The algorithm to generate randomized interface identifiers was replaced by two possible alternative algorithms.

5. Generation of stable addresses is not implied or required by this document.

6. Temporary addresses are *not* disabled by default.

7. Section 3.2.1 and 3.2.2 from [RFC4941] were replaced with alternative algorithms.

8. Section 3.2.3 from [RFC4941] was removed, based on the explanation of that very section of RFC4941.

9. All the verified errata for [RFC4941] has been incorporated.

9. Acknowledgments

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IPv6 Segment Routing Header (SRH)
draft-ietf-6man-segment-routing-header-16

Abstract

Segment Routing can be applied to the IPv6 data plane using a new type of Routing Extension Header. This document describes the Segment Routing Extension Header and how it is used by Segment Routing capable nodes.

Requirements Language

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

Status of This Memo

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

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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 August 8, 2019.

Table of Contents

1. Introduction

Segment Routing can be applied to the IPv6 data plane using a new type of Routing Extension Header (SRH). This document describes the Segment Routing Extension Header and how it is used by Segment Routing capable nodes.

The Segment Routing Architecture [RFC8402] describes Segment Routing and its instantiation in two data planes MPLS and IPv6.

SR with the MPLS data plane is defined in [I-D.ietf-spring-segment-routing-mpls].

SR with the IPv6 data plane is defined in [I-D.filsfils-spring-srv6-network-programming].

The encoding of MPLS labels and label stacking are defined in [RFC3032].

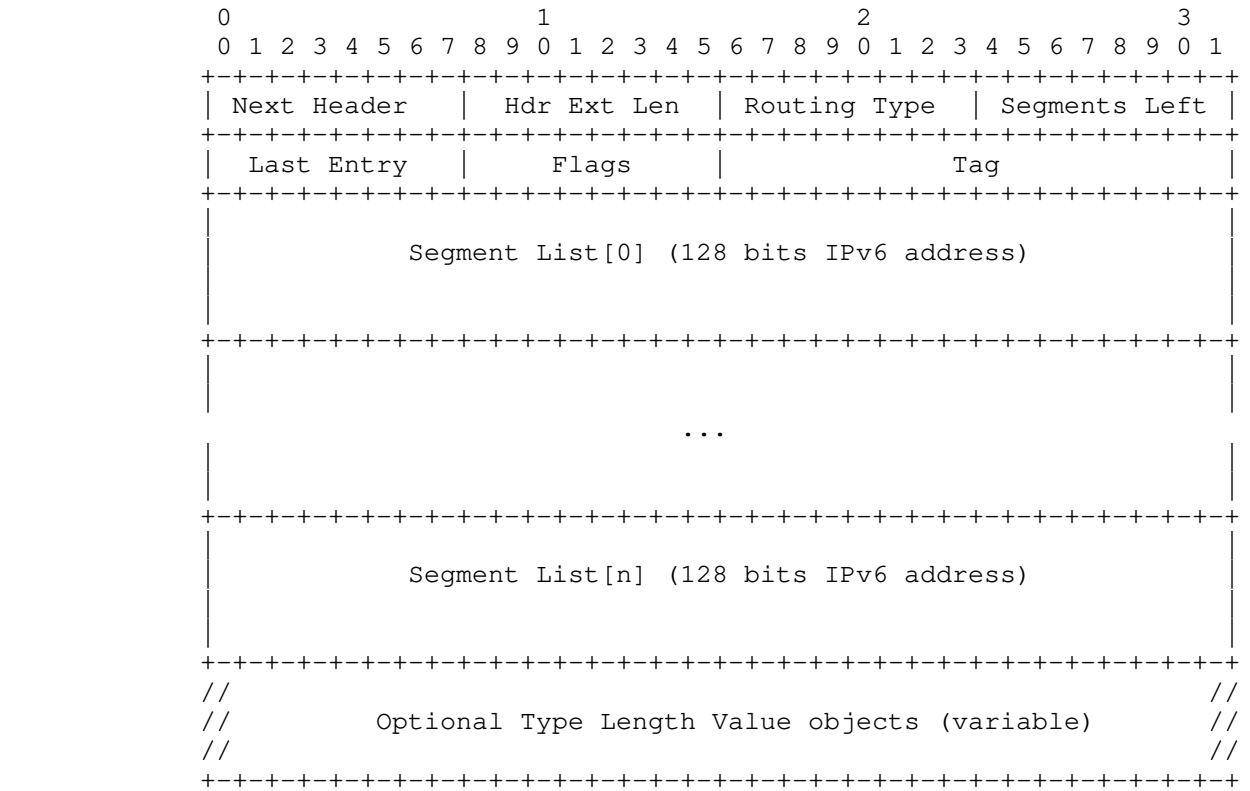
The encoding of IPv6 segments in the Segment Routing Extension Header is defined in this document.

Terminology used within this document is defined in detail in [RFC8402]. Specifically, these terms: Segment Routing, SR Domain, SRv6, Segment ID (SID), SRv6 SID, Active Segment, and SR Policy.

2. Segment Routing Extension Header

Routing Headers are defined in [RFC8200]. The Segment Routing Header has a new Routing Type (suggested value 4) to be assigned by IANA.

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



where:

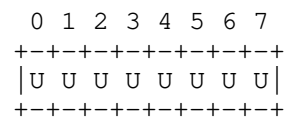
- Next Header: Defined in [RFC8200]
- Hdr Ext Len: Defined in [RFC8200]

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

- Segments Left: Defined in [RFC8200]

- Last Entry: contains the index (zero based), in the Segment List, of the last element of the Segment List.

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



  U: Unused and for future use. MUST be 0 on transmission and ignored on receipt.

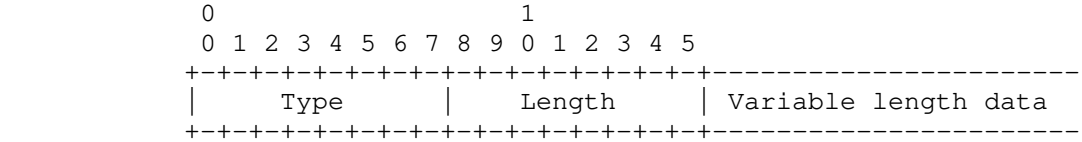
- Tag: tag a packet as part of a class or group of packets, e.g., packets sharing the same set of properties. When tag is not used at source it MUST be set to zero on transmission. When tag is not used during SRH Processing it SHOULD be ignored. The allocation and use of tag is outside the scope of this document.

- 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 SR Policy. I.e., the first element of the segment list (Segment List [0]) contains the last segment of the SR Policy, the second element contains the penultimate segment of the SR Policy and so on.

- Type Length Value (TLV) are described in Section 2.1.

2.1. SRH TLVs

This section defines TLVs of the Segment Routing Header.



Type: An 8 bit value. Unrecognized Types MUST be ignored on receipt.

Length: The length of the Variable length data. It is RECOMMENDED that the total length of new TLVs be multiple of 8 bytes to avoid the use of Padding TLVs.

Variable length data: Length bytes of data that is specific to the Type.

Type Length Value (TLV) contain OPTIONAL information that may be used by the node identified in the Destination Address (DA) of the packet.

Each TLV has its own length, format and semantic. The code-point allocated (by IANA) to each TLV Type defines both the format and the semantic of the information carried in the TLV. Multiple TLVs may be encoded in the same SRH.

TLVs may change en route at each segment. To identify when a TLV type may change en route the most significant bit of the Type has the following significance:

0: TLV data does not change en route

1: TLV data does change en route

Identifying which TLVs change en route, without having to understand the Type, is required for Authentication Header Integrity Check Value (ICV) computation. Any TLV that changes en route is considered mutable for the purpose of ICV computation, the Type Length and Variable Length Data is ignored for the purpose of ICV Computation as defined in [RFC4302].

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

The following TLVs are defined in this document:

Padding TLV

HMAC TLV

Additional TLVs may be defined in the future.

2.1.1. Padding TLVs

There are two types of padding TLVs, pad0 and padN, the following applies to both:

Padding TLVs are used to pad the TLVs to a multiple of 8 octets.

More than one Padding TLV MUST NOT appear in the SRH.

The Padding TLVs are used to align the SRH total length on the 8 octet boundary.

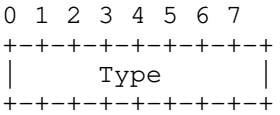
When present, a single Pad0 or PadN TLV MUST appear as the last TLV.

When present, a PadN TLV MUST have a length from 0 to 5 in order to align the SRH total length on a 8-octet boundary.

Padding TLVs are ignored by a node processing the SRH TLV, even if more than one is present.

Padding TLVs are ignored during ICV calculation.

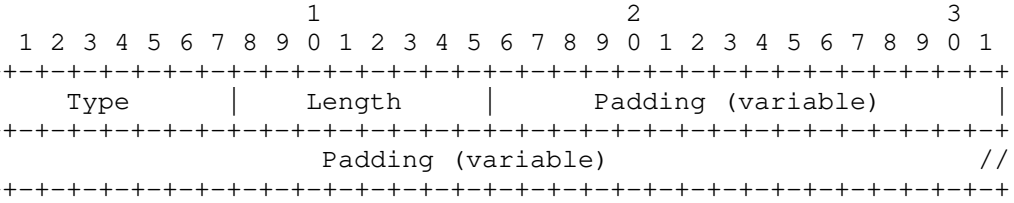
2.1.1.1. PAD0



Type: to be assigned by IANA (Suggested value 128)

A single Pad0 TLV MUST be used when a single byte of padding is required. If more than one byte of padding is required a Pad0 TLV MUST NOT be used, the PadN TLV MUST be used.

2.1.1.2. PADN



Type: to be assigned by IANA (suggested value 129).

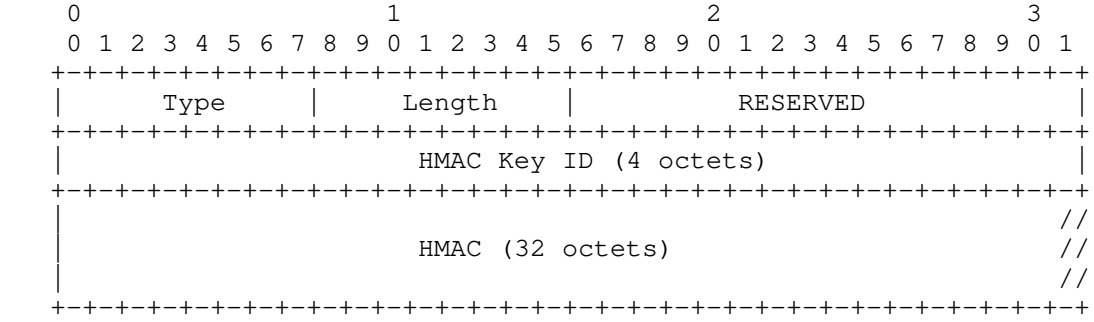
Length: 0 to 5

Padding: Length octets of padding. Padding bits have no semantics. They MUST be set to 0 on transmission and ignored on receipt.

The PadN TLV MUST be used when more than one byte of padding is required.

2.1.2. HMAC TLV

The keyed Hashed Message Authentication Code (HMAC) TLV is OPTIONAL and has the following format:



where:

- Type: to be assigned by IANA (suggested value 5).
- Length: 38.
- RESERVED: 2 octets. MUST be 0 on transmission and ignored on receipt.
- HMAC Key ID: A 4 octet opaque number which uniquely identifies the pre-shared key and algorithm used to generate the HMAC. If 0, the HMAC is not included.
- HMAC: 32 octets of keyed HMAC, not present if Key ID is 0.

The HMAC TLV is used to verify the source of a packet is permitted to use the current segment in the destination address of the packet, and ensure the segment list is not modified in transit.

2.1.2.1. HMAC Generation and Verification

Local policy determines when to check for an HMAC and potentially provides an alternate composition of Text, and a requirement on where the HMAC TLV must appear (e.g. first TLV). This local policy is outside the scope of this document. It may be based on the active segment at an SR Segment endpoint node, the result of an ACL that considers incoming interface, HMAC Key ID, or other packet fields.

The HMAC field is the output of the HMAC computation as defined in [RFC2104], using:

- key: the pre-shared key identified by HMAC Key ID
- HMAC algorithm: identified by the HMAC Key ID
- Text: a concatenation of the following fields from the IPv6 header and the SRH, as it would be received at the node verifying the HMAC:
  - IPv6 header: source address (16 octets)
  - SRH: Last Entry (1 octet)
  - SRH: Flags (1 octet)
  - SRH: HMAC Key-id (4 octets)
  - SRH: all addresses in the Segment List (variable octets)

The HMAC digest is truncated to 32 octets and placed in the HMAC field of the HMAC TLV.

For HMAC algorithms producing digests less than 32 octets, the digest is placed in the lowest order octets of the HMAC field. Remaining octets MUST be set to zero.

If HMAC verification is successful, the packet is forwarded to the next segment.

If HMAC verification fails, an ICMP error message (parameter problem, error code 0, pointing to the HMAC TLV) SHOULD be generated (but rate limited) and SHOULD be logged.

2.1.2.2. HMAC Pre-Shared Key Algorithm

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 identifier of the right combination of pre-shared key and hash algorithm, and except that a value of 0 means that there is no HMAC field.

At the HMAC TLV verification node the Key ID uniquely identifies the pre-shared key and HMAC algorithm.

At the HMAC TLV generating node the Key ID and destination address uniquely identify the pre-shared key and HMAC algorithm. Utilizing

the destination address with the Key ID allows for overlapping key IDs amongst different HMAC verification nodes. The Text for the HMAC computation is set to the IPv6 header fields and SRH fields as they would appear at the verification node, not necessarily the same as the source node sending a packet with the HMAC TLV.

Pre-shared key roll-over is supported by having two key IDs in use while the HMAC TLV generating node and verifying node converge to a new key.

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

The selection of pre-shared key and algorithm, and their distribution is outside the scope of this document, some options may include:

- in the configuration of the HMAC generating or verifying nodes, either by static configuration or any SDN oriented approach
- dynamically using a trusted key distribution protocol such as [RFC6407]

3. SR Nodes

There are different types of nodes that may be involved in segment routing networks: source SR nodes originate packets with a segment in the destination address of the IPv6 header, transit nodes that forward packets destined to a remote segment, and SR segment endpoint nodes that process a local segment in the destination address of an IPv6 header.

3.1. Source SR Node

A Source SR Node is any node that originates an IPv6 packet with a segment (i.e. SRv6 SID) in the destination address of the IPv6 header. The packet leaving the source SR Node may or may not contain an SRH. This includes either:

A host originating an IPv6 packet.

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

The mechanism through which a segment in the destination address of the IPv6 header and the Segment List in the SRH, is derived is outside the scope of this document.

3.2. Transit Node

A transit node is any node forwarding an IPv6 packet where the destination address of that packet is not locally configured as a segment nor a local interface. A transit node is not required to be capable of processing a segment nor SRH.

3.3. SR Segment Endpoint Node

A SR segment endpoint node is any node receiving an IPv6 packet where the destination address of that packet is locally configured as a segment or local interface.

4. Packet Processing

This section describes SRv6 packet processing at the SR source, Transit and SR segment endpoint nodes.

4.1. Source SR Node

A Source node steers a packet into an SR Policy. If the SR Policy results in a segment list containing a single segment, and there is no need to add information to SRH flag or TLV, the DA is set to the single segment list entry and the SRH MAY be omitted.

When needed, the SRH is created as follows:

Next Header and Hdr Ext Len fields are set as specified in [RFC8200].

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

The DA of the packet is set with the value of the first segment.

The first element of the SRH Segment List is the ultimate segment. The second element is the penultimate segment and so on.

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

The Last Entry field is set to n-1 where n is the number of elements in the SR Policy.

HMAC TLV may be set according to Section 7.

The packet is forwarded toward the packet's Destination Address (the first segment).

4.1.1. Reduced SRH

When a source does not require the entire SID list to be preserved in the SRH, a reduced SRH may be used.

A reduced SRH does not contain the first segment of the related SR Policy (the first segment is the one already in the DA of the IPv6 header), and the Last Entry field is set to n-2 where n is the number of elements in the SR Policy.

4.2. Transit Node

As specified in [RFC8200], the only node 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 toward the DA according to its IPv6 routing table.

When a SID is in the destination address of an IPv6 header of a packet, it's routed through an IPv6 network as an IPv6 address. SIDs, or the prefix(es) covering SIDs, and their reachability may be distributed by means outside the scope of this document. For example, [RFC5308] or [RFC5340] may be used to advertise a prefix covering the SIDs on a node.

4.3. SR Segment Endpoint Node

Without constraining the details of an implementation, the SR segment endpoint node creates Forwarding Information Base (FIB) entries for its local SIDs.

When an SRv6-capable node receives an IPv6 packet, it performs a longest-prefix-match lookup on the packets destination address. This lookup can return any of the following:

```
A FIB entry that represents a locally instantiated SRv6 SID
A FIB entry that represents a local interface, not locally
                              instantiated as an SRv6 SID
A FIB entry that represents a non-local route
No Match
```

4.3.1. FIB Entry Is Locally Instantiated SRv6 END SID

This document, and section, defines a single SRv6 SID called END. Future documents may define additional SRv6 SIDs. In which case, the entire content of this section will be defined in that document.

If the FIB entry represents a locally instantiated SRv6 SID, process the next header of the IPv6 header as defined in section 4 of [RFC8200]

The following sections describe the actions to take while processing next header fields.

4.3.1.1. SRH Processing

```
S01. When an SRH is processed {
S02.   If Segments Left is equal to zero {
S03.     Proceed to process the next header in the packet,
         whose type is identified by the Next Header field in
         the Routing header.
S04.   }
S05.   Else {
S06.     If local policy requires TLV processing {
S07.       Perform TLV processing (see TLV Processing)
S08.     }
S09.     max_last_entry  =  ( Hdr Ext Len /  2 ) - 1
S10.     If  ((Last Entry > max_last_entry) or
S11.          (Segments Left is greater than (Last Entry+1)) {
S12.       Send an ICMP Parameter Problem, Code 0, message to
           the Source Address, pointing to the Segments Left
           field, and discard the packet.
S13.     }
S14.     Else {
S15.       Decrement Segments Left by 1.
S16.       Copy Segment List[Segments Left] from the SRH to the
           destination address of the IPv6 header.
S17.       If the IPv6 Hop Limit is less than or equal to 1 {
S18.         Send an ICMP Time Exceeded -- Hop Limit Exceeded in
             Transit message to the Source Address and discard
             the packet.
S19.       }
S20.       Else {
S21.         Decrement the Hop Limit by 1
S22.         Resubmit the packet to the IPv6 module for transmission
             to the new destination.
S23.       }
S24.     }
S25.   }
S26. }
```

4.3.1.1.1. TLV Processing

Local policy determines how TLV's are to be processed when the Active Segment is a local END SID. The definition of local policy is outside the scope of this document.

For illustration purpose only, two example local policies that may be associated with an END SID are provided below.

```
Example 1:
For any packet received from interface I2
  Skip TLV processing

Example 2:
For any packet received from interface I1
  If first TLV is HMAC {
    Process the HMAC TLV
  }
  Else {
    Discard the packet
  }
```

4.3.1.2. Upper-layer Header or No Next Header

When processing the Upper-layer header of a packet matching a FIB entry locally instantiated as an SRv6 END SID.

```
IF (Upper-layer Header is IPv4 or IPv6) and local policy permits {
  Perform IPv6 decapsulation
  Resubmit the decapsulated packet to the IPv4 or IPv6 module
}
ELSE {
  Send an ICMP parameter problem message to the Source Address and
  discard the packet.  Error code (TBD by IANA) "SR Upper-layer
  Header Error", pointer set to the offset of the upper-layer
  header.
}
```

A unique error code allows an SR Source node to recognize an error in SID processing at an endpoint.

4.3.2. FIB Entry is a Local Interface

If the FIB entry represents a local interface, not locally instantiated as an SRv6 SID, the SRH is processed as follows:

If Segments Left is zero, the node must ignore the Routing header and proceed to process the next header in the packet, whose type is identified by the Next Header field in the Routing Header.

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.

4.3.3. FIB Entry Is A Non-Local Route

Processing is not changed by this document.

4.3.4. FIB Entry Is A No Match

Processing is not changed by this document.

5. Intra SR Domain Deployment Model

The use of the SIDs exclusively within the SR Domain and solely for packets of the SR Domain is an important deployment model.

This enables the SR Domain to act as a single routing system.

This section covers:

- securing the SR Domain from external attempt to use its SIDs
- SR Domain as a single system with delegation between components
- handling packets of the SR Domain

5.1. Securing the SR Domain

Nodes outside the SR Domain are not trusted: they cannot directly use the SID's of the domain. This is enforced by two levels of access control lists:

1. Any packet entering the SR Domain and destined to a SID within the SR Domain is dropped. This may be realized with the following logic, other methods with equivalent outcome are considered compliant:
    * allocate all the SID's from a block S/s
    * configure each external interface of each edge node of the domain with an inbound infrastructure access list (IACL) which drops any incoming packet with a destination address in S/s

* Failure to implement this method of ingress filtering exposes the SR Domain to source routing attacks as described and referenced in [RFC5095]

2. The distributed protection in #1 is complemented with per node protection, dropping packets to SIDs from source addresses outside the SR Domain. This may be realized with the following logic, other methods with equivalent outcome are considered compliant:

   * assign all interface addresses from prefix A/a

   * at node k, all SIDs local to k are assigned from prefix Sk/sk

   * configure each internal interface of each SR node k in the SR Domain with an inbound IACL which drops any incoming packet with a destination address in Sk/sk if the source address is not in A/a.

5.2. SR Domain as a single system with delegation among components

All intra SR Domain packets are of the SR Domain. The IP v6 header is originated by a node of the SR Domain, and is destined to a node of the SR Domain.

All inter domain packets are encapsulated for the part of the packet journey that is within the SR Domain. The outer IPv6 header is originated by a node of the SR Domain, and is destined to a node of the SR Domain.

As a consequence, any packet within the SR Domain is of the SR Domain.

The SR Domain is a system in which the operator may want to distribute or delegate different operations of the outer most header to different nodes within the system.

An operator of an SR domain may choose to delegate SRH addition to a host node within the SR domain, and validation of the contents of any SRH to a more trusted router or switch attached to the host. Consider a top of rack switch (T) connected to host (H) via interface (I). H receives an SRH (SRH1) with a computed HMAC via some SDN method outside the scope of this document. H classifies traffic it sources and adds SRH1 to traffic requiring a specific SLA. T is configured with an IACL on I requiring verification of the SRH for any packet destined to the SID block of the SR Domain (S/s). T checks and verifies that SRH1 is valid, contains an HMAC TLV and verifies the HMAC.

5.3. MTU Considerations

Within the SR Domain, well known mitigation techniques are RECOMMENDED, such as deploying a greater MTU value within the SR Domain than at the ingress edges.

5.4. AH ICV

Within the domain, an SR source node which includes SRH and AH extension headers can predict the content of the SRH and calculate the ICV at the SR source node, ensuring it can be confirmed at the destination.

5.5. ESP ICV

Within the domain, an SR source node may include SRH and ESP extension headers. Only the data following the ESP header is included in ICV computation. SRH precedes ESP.

5.6. ICMP Error Processing

ICMP error packets generated within the SR Domain are sent to source nodes within the SR Domain. The invoking packet in the ICMP error message may contain an SRH. Since the destination address of a packet with an SRH changes as each segment is processed, it may not be the destination used by the socket or application that generated the invoking packet.

For the source of an invoking packet to process the ICMP error message, the correct destination address must be determined. The following logic is used to determine the destination address for use by protocol error handlers.

- Walk all extension headers of the invoking IPv6 packet to the routing extension header preceding the upper layer header.
  - If routing header is type 4 (SRH)
    - Use the 0th segment in the segment list as the destination address of the invoking packet.

ICMP errors are then processed by upper layer transports as defined in [RFC4443].

For IP packets encapsulated in an outer IPv6 header, ICMP error handling is as defined in [RFC2473].

5.7. Load Balancing and ECMP

For any inter domain packet, the SR Source node MUST impose a flow label computed based on the inner packet. The computation of the flow label is as recommended in [RFC6438] for the sending Tunnel End Point.

At any transit node within an SR domain, the flow label MUST be used as defined in [RFC6438] to calculate the ECMP hash toward the destination address. If flow label is not used, the transit node may hash all packets between a pair of SR Edge nodes to the same link.

At an SR segment endpoint node, the flow label MUST be used as defined in [RFC6438] to calculate any ECMP hash used to forward the processed packet to the next segment.

5.8. Other Deployments

Other deployment models and their implications on security, MTU, HMAC, ICMP error processing and interaction with other extension headers are outside the scope of this document.

6. Illustrations

This section provides illustrations of SRv6 packet processing at SR source, transit and SR segment endpoint nodes.

6.1. Abstract Representation of an SRH

For a node k, its IPv6 address is represented as Ak, its SRv6 SID is represented as Sk.

IPv6 headers are represented as the tuple of (source, destination). For example, a packet with source address A1 and destination address A2 is represented as (A1,A2). The payload of the packet is omitted.

An SR Policy is a list of segments. A list of segments 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.

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

- Source Address is SA, Destination Addresses is DA, and next-header is SRH.
- SRH with SID list <S1, S2, S3> with SegmentsLeft = SL.

- Note the difference between the <> and () symbols. <S1, S2, S3> represents a SID list where the leftmost segment is the first segment. Whereas, (S3, S2, S1; SL) represents the same SID list but encoded in the SRH Segment List format where the leftmost segment is the last segment. 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 detailed behavior, the (S3, S2, S1; SL) notation is more convenient.

At its SR Policy headend, the Segment List <S1,S2,S3> results in SRH (S3,S2,S1; SL=2) represented fully as:

```
Segments Left=2
Last Entry=2
Flags=0
Tag=0
Segment List[0]=S3
Segment List[1]=S2
Segment List[2]=S1
```

6.2. Example Topology

The following topology is used in examples below:

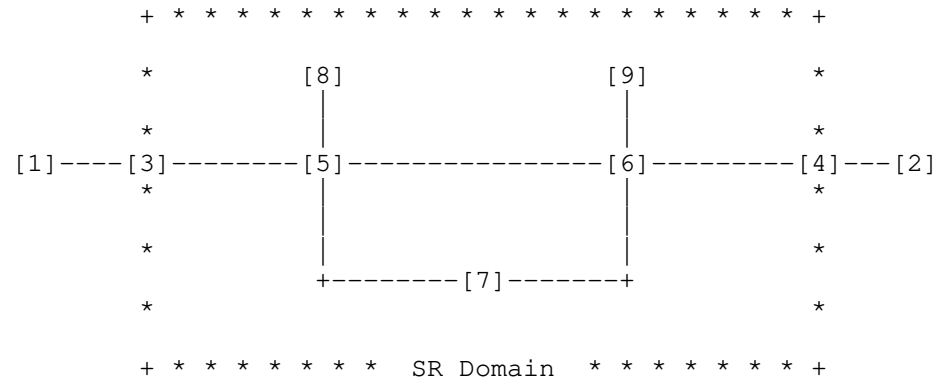


Figure 3

- 3 and 4 are SR Domain edge routers
- 5, 6, and 7 are all SR Domain routers
- 8 and 9 are hosts within the SR Domain
- 1 and 2 are hosts outside the SR Domain

- The SR domain is secured as per Section 5.1 and no external packet can enter the domain with a destination address equal to a segment of the domain.

6.3. Source SR Node

6.3.1. Intra SR Domain Packet

When host 8 sends a packet to host 9 via an SR Policy <S7,A9> the packet is

P1: (A8,S7)(A9,S7; SL=1)

6.3.1.1. Reduced Variant

When host 8 sends a packet to host 9 via an SR Policy <S7,A9> and it wants to use a reduced SRH, the packet is

P2: (A8,S7)(A9; SL=1)

6.3.2. Inter SR Domain Packet - Transit

When host 1 sends a packet to host 2, the packet is

P3: (A1,A2)

The SR Domain ingress router 3 receives P3 and steers it to SR Domain egress router 4 via an SR Policy <S7, S4>. Router 3 encapsulates the received packet P3 in an outer header with an SRH. The packet is

P4: (A3, S7)(S4, S7; SL=1)(A1, A2)

If the SR Policy contains only one segment (the egress router 4), the ingress Router 3 encapsulates P3 into an outer header (A3, S4). The packet is

P5: (A3, S4)(A1, A2)

6.3.2.1. Reduced Variant

The SR Domain ingress router 3 receives P3 and steers it to SR Domain egress router 4 via an SR Policy <S7, S4>. If router 3 wants to use a reduced SRH, Router 3 encapsulates the received packet P3 in an outer header with a reduced SRH. The packet is

P6: (A3, S7)(S4; SL=1)(A1, A2)

6.3.3. Inter SR Domain Packet - Internal to External

When host 8 sends a packet to host 1, the packet is encapsulated for the portion of its journey within the SR Domain. From 8 to 3 the packet is

P7: (A8,S3)(A8,A1)

In the opposite direction, the packet generated from 1 to 8 is

P8: (A1,A8)

At node 3 P8 is encapsulated for the portion of its journey within the SR domain. Resulting in

P9: (A3,S8)(A1,A8)

At node 9 the outer IPv6 header is removed by S6 processing then processed again when received by A8.

6.4. Transit Node

Nodes 5 acts as transit nodes for packet P1, and sends packet

P1: (A8,S7)(A9,S7;SL=1)

on the interface toward node 7.

6.5. SR Segment Endpoint Node

Node 7 receives packet P1 and, using the logic in Section 4.3.1, sends packet

P7: (A8,A9)(A9,S7; SL=0)

on the interface toward router 6.

6.6. Delegation of Function with HMAC Verification

This section describes how a function may be delegated within the SR Domain to non SR source nodes. In the following sections consider a host 8 connected to a top of rack 5.

6.6.1. SID List Verification

An operator may prefer to add the SRH at source 8, while 5 verifies the SID list is valid.

For illustration purpose, an SDN controller provides 8 an SRH terminating at node 9, with segment list <S5,S7,S6,A9>, and HMAC TLV computed for the SRH. The HMAC key is shared with 5, node 8 does not know the key. Node 5 is configured with an IACL applied to the interface connected to 8, requiring HMAC verification for any packet destined to S/s.

Node 8 originates packets with the received SRH with HMAC TLV.

P15:(A8,S5)(A9,S6,S7,S5;SL=3;HMAC)

Node 5 receives and verifies the HMAC for the SRH, then forwards the packet to the next segment

P16:(A8,S7)(A9,S6,S7,S5;SL=2;HMAC)

Node 6 receives

P17:(A8,S6)(A9,S6,S7,S5;SL=1;HMAC)

Node 9 receives

P18:(A8,A9)(A9,S6,S7,S5;SL=0;HMAC)

This use of an HMAC is particularly valuable within an enterprise based SR Domain [SRN].

7. Security Considerations

This section reviews security considerations related to the SRH, given the SRH processing and deployment models discussed in this document.

As describe in Section 5, it is necessary to filter packets ingress to the SR Domain destined to segments within the SR Domain. This ingress filtering is via an IACL at SR Domain ingress border nodes. Additional protection is applied via an IACL at each SR Segment Endpoint node, filtering packets not from within the SR Domain, destined to SIDs in the SR Domain. ACLs are easily supported for small numbers of prefixes, making summarization important, and when the prefixes requiring filtering is kept to a seldom changing set.

Additionally, ingress filtering of IPv6 source addresses as recommended in BCP38 SHOULD be used.

7.1. Source Routing Attacks

[RFC5095] deprecates the Type 0 Routing header due to a number of significant attacks that are referenced in that document. Such attacks include bypassing filtering devices, reaching otherwise unreachable Internet systems, network topology discovery, bandwidth exhaustion, and defeating anycast.

Because this document specifies that the SRH is for use within an SR domain protected by ingress filtering via IACLs; such attacks cannot be mounted from outside an SR Domain. As specified in this document, SR Domain ingress edge nodes drop packets entering the SR Domain destined to segments within the SR Domain.

Additionally, this document specifies the use of IACL on SR Segment Endpoint nodes within the SR Domain to limit the source addresses permitted to send packets to a SID in the SR Domain.

Such attacks may, however, be mounted from within the SR Domain, from nodes permitted to source traffic to SIDs in the domain. As such, these attacks and other known attacks on an IP network (e.g. DOS/ DDOS, topology discovery, man-in-the-middle, traffic interception/ siphoning), can occur from compromised nodes within an SR Domain.

7.2. Service Theft

Service theft is defined as the use of a service offered by the SR Domain by a node not authorized to use the service.

Service theft is not a concern within the SR Domain as all SR Source nodes and SR segment endpoint nodes within the domain are able to utilize the services of the Domain. If a node outside the SR Domain learns of segments or a topological service within the SR domain, IACL filtering denies access to those segments.

7.3. Topology Disclosure

The SRH may contains SIDs of some intermediate SR-nodes in the path towards the destination, this reveals those addresses to attackers if they are able to intercept packets containing SRH.

This is applicable within an SR Domain but the disclosure is less relevant as an attacker has other means of learning topology.

7.4. ICMP Generation

The generation of ICMPv6 error messages may be used to attempt denial-of-service attacks by sending an error-causing destination address or SRH in back-to-back packets. An implementation that correctly follows Section 2.4 of [RFC4443] would be protected by the ICMPv6 rate-limiting mechanism.

8. 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

This document request IANA to create and maintain a new Registry: "Segment Routing Header TLVs"

8.1. Segment Routing Header Flags Register

This document requests the creation of a new IANA managed registry to identify SRH Flags Bits. The registration procedure is "Expert Review" as defined in [RFC8126]. Suggested registry name is "Segment Routing Header Flags". Flags is 8 bits, the following bits are defined in this document:

Suggested Bit	Description	Reference
4	HMAC	This document

8.2. Segment Routing Header TLVs Register

This document requests the creation of a new IANA managed registry to identify SRH TLVs. The registration procedure is "Expert Review" as defined in [RFC8126]. Suggested registry name is "Segment Routing Header TLVs". A TLV is identified through an unsigned 8 bit codepoint value. The following codepoints are defined in this document:

Suggested Value	Description	Reference
5	HMAC TLV	This document
128	Pad0 TLV	This document
129	PadN TLV	This document

9. Implementation Status

This section is to be removed prior to publishing as an RFC.

9.1. Linux

Name: Linux Kernel v4.14

Status: Production

Implementation: adds SRH, performs END processing, supports HMAC TLV

Details: https://irtf.org/anrw/2017/anrw17-final3.pdf and [I-D.filsfils-spring-srv6-interop]

9.2. Cisco Systems

Name: IOS XR and IOS XE

Status: Pre-production

Implementation: adds SRH, performs END processing, no TLV processing

Details: [I-D.filsfils-spring-srv6-interop]

9.3. FD.io

Name: VPP/Segment Routing for IPv6

Status: Production

Implementation: adds SRH, performs END processing, no TLV processing

Details: https://wiki.fd.io/view/VPP/Segment_Routing_for_IPv6 and [I-D.filsfils-spring-srv6-interop]

9.4. Barefoot

Name: Barefoot Networks Tofino NPU

Status: Prototype

Implementation: performs END processing, no TLV processing

Details: [I-D.filsfils-spring-srv6-interop]

9.5. Juniper

Name: Juniper Networks Trio and vTrio NPU's

Status: Prototype & Experimental

Implementation: SRH insertion mode, Process SID where SID is an interface address, no TLV processing

9.6. Huawei

Name: Huawei Systems VRP Platform

Status: Production

Implementation: adds SRH, performs END processing, no TLV processing

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IPv6 Packet Truncation
draft-leddy-6man-truncate-05

Abstract

This document defines IPv6 packet truncation procedures. These procedures make Path MTU Discovery (PMTUD) more reliable. Upper-layer protocols can leverage these procedures in order to take advantage of large MTUs.

Status of This Memo

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

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This Internet-Draft will expire on April 15, 2019.

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1. Introduction

An Internet path connects a source node to a destination node. A path can contain links and routers.

Each link is constrained by the number of bytes that it can convey in a single IP packet. This constraint is called the link Maximum Transmission Unit (MTU). IPv6 [RFC8200] requires every link to have an MTU of 1280 bytes or greater. This value is called IPv6 minimum link MTU.

Likewise, each Internet path is constrained by the number of bytes that it can convey in a single IP packet. This constraint is called the Path MTU (PMTU). For any given path, the PMTU is equal to the smallest of its link MTUs.

IPv6 allows fragmentation at the source node only. If an IPv6 source node sends a packet whose length exceeds the PMTU, an intermediate node will discard the packet. In order to prevent this, IPv6 nodes can either:

- Refrain from sending packets whose length exceeds the IPv6 minimum link MTU.

- Maintain a running estimate of the PMTU and refrain from sending packets whose length exceeds that estimate.

In order to maintain a running estimate of the PMTU, IPv6 nodes can execute Path MTU Discovery (PMTUD) [RFC8201] procedures. In these procedures, the source node produces an initial PMTU estimate. This initial estimate equals the MTU of the first link along the path to the destination. It can be greater than the actual PMTU.

Having produced an initial PMTU estimate, the source node sends packets to the destination node. If one of these packets is larger than the actual PMTU, an intermediate node will not be able to forward the packet through the next link along the path. Therefore, the intermediate node discards the packet and sends an Internet Control Message Protocol (ICMP) [RFC4443] Packet Too Big (PTB) message to the source node. The ICMP PTB message indicates the MTU of the link through which the packet could not be forwarded. The source node uses this information to refine its PMTU estimate.

PMTUD relies on the network to deliver ICMP PTB messages from the intermediate node to the source node. If the network cannot deliver these messages, a persistent black hole can develop. In this scenario, the source node sends a packet whose length exceeds the PMTU. An intermediate node discards the packet and sends an ICMP PTB message to the source. However, the network cannot deliver the ICMP PTB message to the source. Therefore, the source node does not update its PMTU estimate and it continues to send packets whose length exceeds the PMTU. The intermediate node discards these packets and sends more ICMP PTB messages to the source. These ICMP PTB messages are lost, exactly as previous ICMP PTB messages were lost.

In some operational scenarios (Section 3), networks cannot deliver ICMP PTB messages from an intermediate node to the source node. Therefore, enhanced procedures are required.

This document defines IPv6 packet truncation procedures. When an IPv6 source node originates a packet, it executes the following procedure:

- Mark the packet as being eligible for truncation.

- Forward the packet towards its destination.

If an intermediate node cannot forward the packet because of an MTU issue, it executes the following procedure:

- Detect that the packet is eligible for truncation.
- Send an ICMP PTB message to the source node, with the MTU field indicating the MTU of the link through which the packet could not be forwarded.
- Truncate the packet.
- Mark the packet as being truncated.
- Update the packet's upper-layer checksum (if possible).
- Forward the packet towards its destination.

When the destination node receives the packet, it executes the following procedure:

- Detect that the packet has been truncated.
- Send an ICMP PTB message to the source node, with the MTU field indicating the length of the truncated packet.
- Discard the packet.

Both ICMP PTB messages, mentioned above, contain MTU information that the source node can use to refine its PMTU estimate.

The procedures described herein prevent incomplete (i.e., truncated) data from being delivered to upper-layer protocols. While IPv6 packet truncation may facilitate new upper-layer procedures, upper-layer procedures are beyond the scope of this document.

The procedures described herein make PMTUD more reliable by increasing the probability that the source node will receive ICMP PTB feedback from a downstream device. Even when the network cannot deliver ICMP PTB messages from an intermediate router to a source node, it may be able to deliver an ICMP PTB messages from the destination node to the source node.

However, the procedures described herein do not make PMTUD one hundred per cent reliable. In some operational scenarios, the network cannot deliver any ICMP messages to the source node, regardless of their origin.

2. Requirements Language

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

3. Operational Considerations

The packet truncation procedures described herein make PMTUD more resilient when:

- The network can deliver ICMP messages from the destination node to the source node.
- The network cannot deliver ICMP messages from an intermediate node to the source node.

The following are common operational scenarios in which packet truncation procedures can make PMTUD more resilient:

- The destination node has a viable route to the source node, but the intermediate node does not.
- The source node is protected by a firewall that administratively blocks all packets except for those from specified subnetworks. The destination node resides in one of the specified subnetworks, but the intermediate node does not.
- The source address of the original packet (i.e., the packet that elicited the ICMP message) was an anycast address. Therefore, the destination address of the ICMP message is the same anycast address. In this case, an ICMP message from the destination node is likely to be delivered to the correct anycast instance. By contrast, an ICMP message from an intermediate node is less likely to be delivered to the correct anycast instance.

Packet truncation procedures do not make PMTUD more resilient when the network cannot reliably deliver any ICMP messages to the source node. The following are operational scenarios where the network cannot reliably deliver any ICMP PTB messages to the source node:

- The source node is protected by a firewall that administratively blocks all ICMP messages.

- The source node is an anycast instance served by a load-balancer as defined in [RFC7690]. The load-balancer does not implement the mitigations defined in [RFC7690].

4. IPv6 Destination Options

This document defines the following IPv6 Destination options:

4.1. The Truncation Eligible Option

The Truncation Eligible option indicates that the packet is eligible for truncation. It also indicates that the packet has not been truncated.

The Truncation Eligible option contains the following fields:

- Option Type - Truncation Eligible option. Value TBD by IANA. See Notes below.

- Opt Data Len - Length of Option Data, measured in bytes. MUST be equal to 0.

IPv6 packets that include the Fragment header MUST NOT include the Truncation Eligible option.

IPv6 packets whose length is less than the IPv6 minimum link MTU SHOULD NOT include the Truncation Eligible option.

The IPv6 Hop-by-hop Options header SHOULD NOT include the Truncation Eligible option.

The IPv6 Destination Options header:

- MAY include a single instance of the Truncation Eligible option.

- SHOULD NOT include multiple instances of the Truncation Eligible option.

- MUST NOT include both the Truncation Eligible option and the Truncated Packet option (Section 4.2).

NOTE 1: According to [RFC8200], the highest-order two bits of the Option Type (i.e., the "act" bits) specify the action taken by a processing node that does not recognize Option Type. The required action is skip over this option and continue processing the header. Therefore, IANA is requested to assign this Option Type with "act" bits "00".

NOTE 2: According to [RFC8200], the third-highest-order bit (i.e., the "chg" bit) of the Option Type specifies whether Option Data can change on route to the packet's destination. Because this option contains no Option Data, IANA can assign this Option Type without regard to the "chg" bit.

4.2. The Truncated Packet Option

The Truncated Packet option indicates that the packet has been truncated and is eligible for further truncation.

The Truncated Packet option contains the following fields:

- Option Type - Truncated Packet option. Value TBD by IANA. See Notes below.
- Opt Data Len - Length of Option Data, measured in bytes. MUST be equal to 0.

IPv6 packets that include the Fragment header MUST NOT include the Truncated Packet option.

IPv6 packets whose length is less than the IPv6 minimum link MTU MUST NOT include the Truncated Packet option.

The IPv6 Hop-by-hop Options header SHOULD NOT include the Truncated Packet option.

The IPv6 Destination Options:

- MAY include a single instance of the Truncated Packet option.
- SHOULD NOT include multiple instances of the Truncated Packet option.
- MUST NOT include both the Truncated Packet option and the Truncation Eligible option.

NOTE 1: According to [RFC8200], the highest-order two bits of the Option Type (i.e., the "act" bits) specify the action taken by a processing node that does not recognize Option Type. The required action is to discard the packet and send an ICMP Parameter Problem, Code 2, message to the packet's Source Address, pointing to the unrecognized Option Type. Therefore, IANA is requested to assign this Option Type with "act" bits "10".

NOTE 2: According to [RFC8200], the third-highest-order bit (i.e., the "chg" bit) of the Option Type specifies whether Option Data of

that option can change on route to the packet's destination. Because this option contains no Option Data, IANA can assign this Option Type without regard to the "chg" bit.

5. Reference Topology

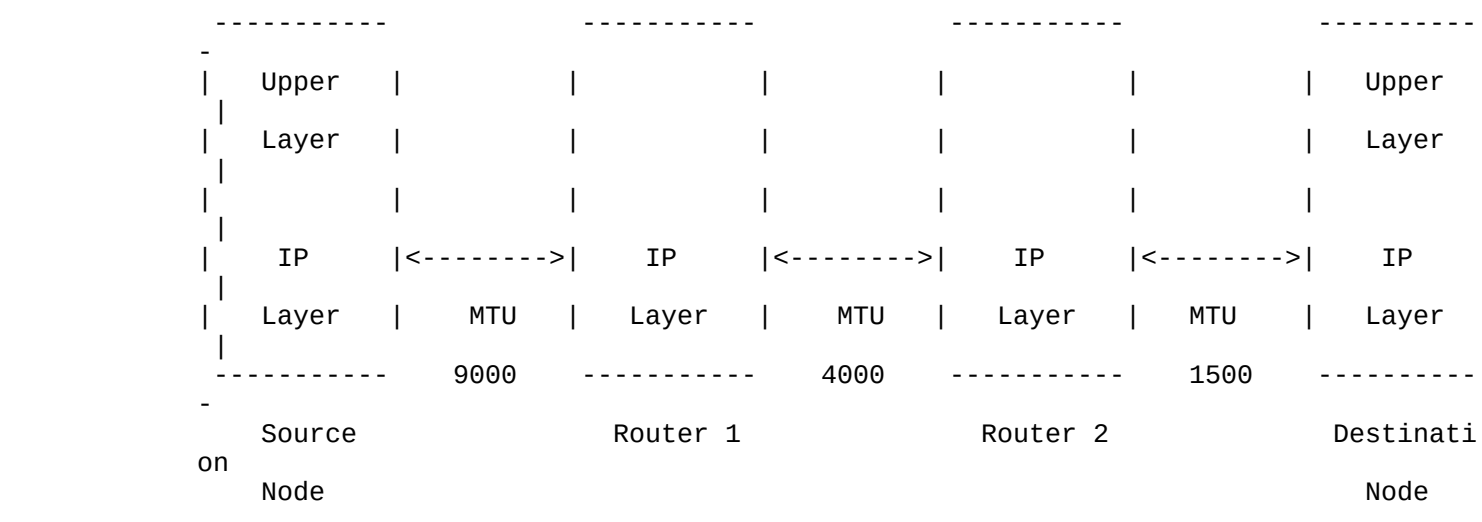

Figure 1: Reference Topology

Figure 1 depicts a network that contains a Source Node, intermediate nodes (i.e., Router 1, Router 2), and a Destination Node. The link that connects the Source Node to Router 1 has an MTU of 9000 bytes. The link that connects Router 1 to Router 2 has an MTU of 4000 bytes, and the link that connects Router 2 to the Destination Node has an MTU of 1500 bytes. The PMTU between the Source Node and the Destination Node is 1500 bytes.

This topology is used in examples throughout the document.

6. Truncation Procedures

In the Reference Topology (Figure 1), the Source Node produces an initial estimate of the PMTU between itself and the Destination Node. This initial estimate equals the MTU of the first link on the path to the Destination Node (e.g., 9000 bytes).

The Source Node refrains from sending packets whose length exceeds the above-mentioned estimate. However, the above-mentioned estimate is significantly larger than the actual PMTU (1500 bytes). Therefore, the Source Node may send packets whose length exceeds the actual PMTU.

At some time in the future, an upper-layer protocol on the Source Node causes the IP layer to emit a packet. The packet contains a Destination Options header and the Destination Options header contains a Truncation Eligible option. The total packet length, including all headers and the payload, is 1350 bytes. Because the total packet length is less than the actual PMTU, this packet can be

delivered to the Destination Node without encountering any MTU issues.

The IP layer on the Source Node forwards the packet to the Router 1, Router 1 forwards the packet to Router 2, and the Router 2 forwards the packet to the Destination Node. The IP layer on the Destination Node examines the Destination Options header and finds the Truncation Eligible option. The Truncation Eligible option requires no action by the Destination Node. Therefore, the Destination Node processes the next header and delivers the packet to an upper-layer protocol.

Subsequently, the same upper-layer protocol on the Source Node causes the IP layer to emit another packet. This packet is identical to the first, except that the total packet length is 2000 bytes. Because the packet length is greater than the actual PMTU, this packet cannot be delivered without encountering an MTU issue.

The IP layer on the source node forwards the packet to Router 1. Router 1 forwards the packet to Router 2, but the Router 2 cannot forward the packet because its length exceeds the MTU of the next link in the path (i.e., 1500 bytes). Because an MTU issue has been encountered, Router 2 examines the Destination Options header, searching for either a Truncation Eligible option or a Truncated Packet option. (Normally, the Router 2 would ignore the Destination Options header).

Because Router 2 finds one of the above-mentioned options, it:

- Sends an ICMP PTB message to the Source Node. The ICMP PTB message contains an MTU field indicating the MTU of the next link in the path (i.e. 1500 bytes).

- Truncates the packet, so that its total length equals the MTU of the next link in the path.

- Updates the IPv6 Payload Length.

- Overwrites all instances of the Truncation Eligible option with a Truncated Packet option.

- Updates the upper-layer checksum (if possible)

- Forwards the packet to the Destination Node.

The IP layer on the Destination Node receives the packet and examines the Destination Options header. Because it finds the Truncated Packet option, it discards the packet and sends an ICMP PTB message

to the Source Node. The MTU field in the ICMP PTB message represents the length of the received packet.

When the Source Node receives the ICMP PTB message, it updates its PMTU estimate, as per [RFC8201].

7. Additional Truncation Considerations

A packet can be truncated multiple times. In the Reference Topology (Figure 1), assume that the Source Node sends a 5000 byte packet to the Destination Node. Using the procedures described in Section 6, Router 1 truncates this packet to 4000 bytes and Router 2 truncates it again, to 1500 bytes.

A truncated packet MUST contain the basic IPv6 header, all extension headers and the first upper-layer header. When an intermediate node cannot forward a packet due to MTU issues, and the total length of the basic IPv6 header, all extension headers, and first upper-layer header exceeds the MTU of the next link in the path, the intermediate node MUST discard the packet and send and ICMP PTB message to the source node. It MUST NOT truncate the packet.

A truncated packet MUST NOT include the Fragment header. When an intermediate node cannot forward a packet due to MTU issues, and the packet contains a Fragment header, the intermediate node MUST discard the packet and send and ICMP PTB message to the source node. It MUST NOT truncate the packet.

A truncated packet must have a total length that is greater than or equal to the IPv6 minimum link MTU.

8. Backwards Compatibility

Section 6 of this document assumes that all nodes recognize the Truncation Eligible and Truncated Packet options. This section explores backwards compatibility issues, where one or more nodes do not recognize the above-mentioned options.

An intermediate node that does not recognize the above-mentioned options behaves exactly as described in [RFC8200]. When it receives a packet that does not cause an MTU issue, it processes the packet. When it receives a packet that causes an MTU issue, it discards the packet and sends an ICMP PTB message to the source node. In neither case does the intermediate node examine the Destination Options header or truncate the packet.

A destination node that does not recognize the Truncation Eligible option also behaves exactly as described in [RFC8200]. When it

receives a packet that contains the Truncation Eligible option, its behavior is determined by the highest-order two bits of the Option Type (i.e., the "act" bits). Because the "act" bits are equal to "00", the destination node skips over the option and continues to process the packet. This is exactly what the destination node would have done if it had recognized the Truncation Eligible option.

A destination node that does not recognize the Truncated Packet option also behaves exactly as described in [RFC8200]. When it receives a packet that contains the Truncated Packet option, its behavior is determined by the highest-order two bits of the Option Type (i.e., the "act" bits). Because the "act" bits are equal to "10", the destination node discards the packet and sends an ICMP Parameter Problem, Code 2, message to the packet's Source Address, pointing to the Truncated Packet option. The destination node does not emit an ICMP PTB message.

The source node takes appropriate action when it receives the ICMP Parameter Problem message.

9. Checksum Considerations

When an intermediate node truncates a packet, it SHOULD update the upper-layer checksum, if possible. This is desirable because it increases the probability that the truncated packet will be delivered to the destination node.

Middleboxes residing downstream of the intermediate node may attempt to validate the upper-layer checksum. If validation fails, they may discard the packet without sending an ICMP message.

10. Invalid Packet Types

The following packet types are invalid:

- Packets that contain the Fragment header and the Truncation Eligible option.
- Packets that contain the Fragment header and the Packet Truncated option.
- Packets that contain the Truncation Eligible option and the Packet Truncated option.
- Packets that specify an Option Data Length greater than 0 in the Truncation Eligible option.

- Packets that specify an Option Data Length greater than 0 in the Truncated Packet option.

- Packets that have a total length less than the IPv6 minimum link MTU and contain the Packet Truncated option.

If an intermediate node cannot forward one of the above-mentioned packets because of an MTU issue, its behavior is as described in [RFC8200]. The intermediate node discards the packet and sends an ICMP PTB message to the source node. It does not truncate or forward the packet.

When the destination node receives one of the above-mentioned packets, it MUST:

- Discard the packet

- Send an ICMP Parameter Problem, Code 2, message to the packet's Source Address, pointing to the first invalid option.

The destination node MUST NOT send an ICMP PTB message.

11. Network Considerations

The procedures described herein rely upon the networks ability:

- To convey packets that contain destination options from the source node to the destination node.

- To convey ICMP Parameter Problem messages in the reverse direction.

Operational experience [RFC7872] reveals that a significant number of networks drop packets that contain IPv6 destination options. Likewise, many networks drop ICMP Parameter Problem messages.

[I-D.bonica-6man-unrecognized-opt] describes procedures that upper-layer protocols can execute to verify that the above-mentioned requirements are satisfied. Upper-layer protocols can execute these procedures before emitting packets that contain the Truncation Eligible option.

12. Encapsulating Security Payload Considerations

An IPv6 packet can contain both:

- An Encapsulating Security Payload (ESP) [RFC4303] header.

- Truncation options (i.e., the Truncation Eligible or Truncated Packet options).

In this case, the packet MUST contain a Destination Options header that precedes the ESP. That Destination Options header contains the truncation options and is not protected by the ESP. The packet MAY also contain another Destination Options header the follows the ESP. That Destination Options header is protected by the ESP and MUST NOT contain the truncation options.

As per RFC 4303, a packet can contain two Destination Options headers one preceding the ESP and one following the ESP.

13. Extension Header Considerations

According to [RFC8200], the following IPv6 extension headers can contain options:

- The Hop-by-hop Options header.

- The Destination Options header.

The Hop-by-hop option can be examined by each node along the path to a packet's destination. Destination options are examined by the destination node only. However, [RFC2473] provides a precedent for intermediate nodes examining the Destination options on an exception basis. (See the Tunnel Encapsulation Limit.)

The truncation options described herein are examined by:

- Intermediate nodes, on an exception basis (i.e, when the packet cannot be forwarded due to MTU issues).

- The Destination node.

Therefore, the above-mentioned options can be processed most efficiently when they are contained by the Destination Option header. When contained by the Destination Options header, the above-mentioned options are examined by intermediate nodes on an exception basis, only when they are relevant. If contained by the Hop-by-hop Options header, they are always examined by intermediate nodes, even when they are irrelevant.

14. Security Considerations

PMTUD is vulnerable to ICMP PTB forgery attacks. The procedures described herein do nothing to mitigate that vulnerability.

The procedures described herein are susceptible to a new variation on that attack, in which an attacker forges a truncated packet. In this case, the attackers cause the Destination Node to produce an ICMP PTB message on their behalf. To some degree, this vulnerability is mitigated, because the Destination Node will not emit an ICMP PTB message in response to a truncated packet whose length is less than the IPv6 minimum link MTU.

In order to mitigate denial of service attacks, intermediate nodes MUST rate limit the number of packets that they truncate per second.

15. IANA Considerations

IANA is requested to allocate the following codepoints from the Destination Options and Hop-by-hop Options registry (https://www.iana.org/assignments/ipv6-parameters/ipv6-parameters.xhtml#ipv6-parameters-2).

- Truncation Eligible ("act-bits" are "00. "chg-bit" can be either 0 or 1.)
- Truncated Packet ("act-bits" are "10". "chg-but can be either 0 or 1.)

16. Acknowledgements

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A Unified Stateful/Stateless Configuration Service for IPv6
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Abstract

IPv6 Neighbor Discovery (IPv6ND) specifies a control message set for nodes to discover neighbors, routers, prefixes and other services on the link. It also supports a manner of StateLess Address AutoConfiguration (SLAAC), while the Dynamic Host Configuration Protocol for IPv6 (DHCPv6) specifies a separate stateful service. This document presents IPv6ND extensions for providing a unified stateful/stateless configuration service.

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This Internet-Draft will expire on June 20, 2019.

Table of Contents

1. Introduction

IPv6 Neighbor Discovery (IPv6ND) [RFC4861] specifies a control message set for nodes to discover neighbors, routers, prefixes and other services on the link. It also supports a manner of StateLess Address AutoConfiguration (SLAAC). The Dynamic Host Configuration Protocol for IPv6 (DHCPv6) specifies a separate service for delegation of prefixes, addresses and any other stateful information [RFC3315][RFC3633]. This document presents IPv6ND extensions for providing a unified stateful/stateless configuration service.

If the network can provide such a unified service, multi-message procedures can be condensed into a single and concise message exchange. This would ease network management as well as simplify host and router operations. It would further accommodate both stateless and stateful services in a way that combines the best aspects of both. The operating model is based on harnessing the IPv6 ND Router Solicitation (RS) / Router Advertisement (RA) functions to provide all configuration information in a single message exchange.

When a node first comes onto a link, it sends an RS to elicit an RA from one or more routers for the link. If the node also needs to acquire stateful information it then sends a DHCPv6 Solicit message to elicit a Reply message from a DHCPv6 server. This two round-trip message exchange can add delay as well as waste critical link bandwidth on low-end links (e.g., 6LoWPAN, satellite communications, aeronautical wireless, etc.). While it is possible to start both round trip exchanges at the same time, this would still result in twice as many channel access transactions as necessary. Moreover, the multicast nature of these messages could disturb other nodes on the link, e.g., resulting in an unnecessary wakeup from sleep mode.

This document proposes methods for combining all stateless and stateful configuration operations into a single, unified exchange based on IPv6ND messaging extensions. It notes that stateful exchanges should include:

- an explicit request for stateful information
- the identity of the requesting node
- a transaction identification that the requesting node can use to match replies with their corresponding requests
- any security parameters necessary for the requesting node to establish its authorization to receive stateful information

The first method is through definition of a new IPv6ND option called the "DHCPv6 Option" that combines the IPv6ND router discovery and DHCPv6 stateful processes into a single message exchange. Nodes include the DHCPv6 option in RS messages to solicit an RA message with a DHCPv6 option in return. This allows the IPv6ND and DHCPv6 functions to work together to supply the client with all needed configuration information in a minimum number of messages.

The second method proposes the inclusion of Prefix Information Options (PIOs) in RS messages for the purpose of soliciting stateful information. [I-D.naveen-slaac-prefix-management] discusses the

maintenance and management functions required for supporting the operation.

The third method entails the encoding of a prefix in the IPv6 link-local source address of the RS message. If the node is pre-configured with the prefix that it will solicit from the network, and if the network has a way of accepting the node's prefix assertion without the threat of spoofing, the network can then delegate the prefix and establish the necessary routing information.

The fourth method uses out-of-band messaging for the node to request stateful information outside of the scope of IPv6ND messaging. The out-of-band messaging could entail some sort of network login process (e.g., through Layer-2 (L2) messaging, etc.).

The following sections present considerations for nodes that employ these approaches.

2. DHCPv6 Options in IPv6 ND Messages

The first method entails the inclusion of DHCPv6 messages within IPv6ND RS and RA messages, as discussed in the following sections.

2.1. The DHCPv6 Option

The DHCPv6 option is a new IPv6ND option that simply embeds a standard DHCPv6 message per section 6 of [RFC3315], beginning with the 'msg-type' followed by the 'transaction-id' and all DHCPv6 'options'. The format of the option is as follows:

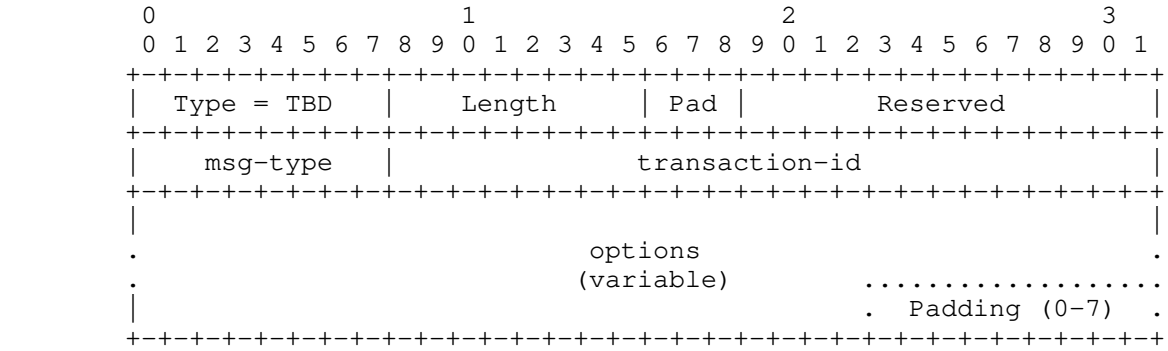

Figure 1: IPv6 ND DHCPv6 Option Format

In this format, 'Type' and 'Length' are exactly as defined in Section 4.6 of [RFC4861], 'Pad' is a 3-bit integer that encodes the padding length, 'Reserved' is included for alignment and future use,

and the rest of the option is formatted as specified in Section 6 of [RFC3315] except with trailing null padding added as necessary for 8 octet alignment. The length of the full DHCPv6 message is determined by (((’Length’ * 8) - 4) - ’Pad’), for a maximum message length of 2036 octets.

The ’Reserved’ field MUST be set to 0 on transmission and ignored on reception. Future specifications MAY define new uses for these bits.

2.2. DHCPv6 Option Usage

When a node first comes onto the link, it creates an RS message containing a DHCPv6 option that embeds a DHCPv6 Solicit message. The Solicit may include a Rapid Commit option if a two-message exchange (i.e., instead of four) is required. The RS message may also include a Nonce option to provide an extended transaction identifier [RFC3971]. The node then sends the RS message either to the unicast address of a specific router on the link, or to the all-routers multicast address.

When a router receives an RS message with a DHCPv6 option, if it does not recognize the option and/or does not employ a DHCPv6 relay agent or server, it returns an RA message as normal with any stateless configuration information and without including a DHCPv6 option. By receiving the RA message with no DHCPv6 option, the node can determine that the router does not recognize the option and/or does not support a DHCPv6 relay/server function. In this way, no harm will have come from the node including the DHCPv6 option in the RS, and the function is fully backwards compatible.

When a router receives an RS message with a DHCPv6 option, if it recognizes the option and employs a DHCPv6 relay agent or server, it extracts the encapsulated DHCPv6 message and forwards it to the relay agent or server. When the DHCPv6 message reaches a DHCPv6 server, the server processes the DHCPv6 Solicit message and prepares either an Advertise (four message) or Reply (two message) DHCPv6 message containing any delegated addresses, prefixes and/or any other information the server is configured to send. The server then returns the Advertise/Reply message to the router.

When the router receives the DHCPv6 Advertise/Reply message, it creates a Router Advertisement (RA) message that includes any autoconfiguration information necessary for the link and also embeds the DHCPv6 message in a DHCPv6 option within the body of the RA. (The RA also echos the Nonce value if a Nonce was included in the RS message.) The router then returns the RA as a unicast message response to the node that sent the RS.

In a two message exchange, the stateless/stateful exchange is completed when the node receives the RA. In a four message exchange, the requesting node can Decline any stateful information it does not wish to accept and/or send unicast Request options in subsequent RSes to get RA messages with Reply options back from the router or routers of its choosing.

At any time after the initial RS/RA exchange, the node may need to issue DHCPv6 Renew, Release or Rebind messages to manage address/ prefix lifetimes. In that case, the node prepares a DHCPv6 message option and inserts it in an RS message which it then sends via unicast to the router. The router in turn processes the message the same as for DHCPv6 Solicit/Reply.

At any time after the initial RS/RA exchange, the DHCPv6 server may need to issue a DHCPv6 Reconfigure message. In that case, when the router receives the DHCPv6 Reconfigure message it prepares a unicast RA message with a DHCPv6 option that encodes the Reconfigure and sends the RA as an unsolicited unicast message to the node. The node then follows the DHCPv6 client procedures for processing and responding to Reconfigure messages.

At any time after the initial RS/RA exchange, the router can initiate an unsolicited RA/Reply, e.g., to cause the node to update its configuration information quickly. In this method, the router sends a synthesized DHCPv6 Renew or Information-request message that induces the server to return a DHCPv6 Reply. The message includes the same DHCPv6 transaction-id and IPv6 ND Nonce values that the router had echoed in its initial Reply. The server then wraps the Reply message in the body of an RA message, and sends the unsolicited RA/Reply. When the node receives the unsolicited RA/Reply message, it matches the transaction-id and Nonce values with the initial RA/ Reply it had received from the router. If the identification information matches, the node processes the message and initiates a new RS/RA exchange if necessary; otherwise it drops the message.

2.3. Stateful Provisioning Requirements

Using the DHCPv6 Option, the message itself includes sub-options to request stateful information. The DHCPv6 Device Unique IDentifier (DUID) provides the identity of the requesting node, and the DHCPv6 transaction-id and IPv6 ND Nonce provide a unique identifier for matching RS and RA messages. Finally, the message can be protected using SEcure Neighbor Discovery (SEND) [RFC3971].

2.4. Implementation Considerations

The IPv6ND and DHCPv6 functions are typically implemented in separate router modules. In that case, the IPv6ND function extracts the DHCPv6 message from the option included in the RS message and wraps it in IP/UDP headers with the same addresses and port numbers the soliciting node would have used had it send an ordinary IP/UDP/DHCPv6 message. The IPv6ND function then acts as a Lightweight DHCPv6 Relay Agent (LDRA) [RFC6221] to forward the message to the DHCPv6 relay or server function on-board the router.

The forwarded DHCPv6 message then traverses any additional relays on the reverse path until it reaches the DHCPv6 server. When the DHCPv6 server processes the message, it delegates any necessary resources and returns a Reply via the same relay agent path as had occurred on the reverse path so that the Reply will eventually arrive back at the IPv6ND function. The IPv6ND function then prepares an RA message with any autoconfiguration information associated with the link, embeds the DHCPv6 message body in an IPv6ND DHCPv6 option, and returns the message via unicast to the node that sent the RS.

In an ideal implementation, the IPv6ND and DHCPv6 functions could be co-located in the same module on the router. In that way the two functions would be coupled as though they were in fact a single unified function without the need for any LDRA processing.

3. PIO Options in RS Messages

The second method entails the inclusion of Prefix Information Options (PIOs) in IPv6ND RS messages, as discussed in the following sections.

3.1. The PIO Option in RS Messages

This document proposes the inclusion of PIOs in RS messages to solicit and maintain prefixes that are delegated in subsequent RA messages. Prefix management is performed as discussed in [I-D.naveen-slaac-prefix-management] (an alternate prefix management proposal based on unsolicited advertisements with special flag settings is found in [I-D.pioxfolks-6man-pio-exclusive-bit]).

3.2. PIO Option Usage

When a node that wishes to request a prefix delegation first comes onto the link, it creates an RS message containing a PIO. It sets the Prefix Length to either the length of the prefix it wishes to receive or '0' (unspecified) if it will defer to the router's preference. The node then sets the Valid and Preferred Lifetimes to either its preferred values or '0' (unspecified) if it will defer to

the router's preference. The node then sets the Prefix to either the prefix it wishes to receive, or '0' (unspecified) if it will defer to the router's preference. The node then sends the RS message either to the unicast address of a specific router on the link, or to the all-routers multicast address.

When a router receives an RS message with a PIO, if it is not configured to accept PIOs in RS messages it returns an RA message as normal and without including a PIO. By receiving the RA message with no PIO, the node can determine that the router does not recognize the option and/or does not support an IPv6ND-based prefix delegation service. In this way, no harm will have come from the node including the PIO in the RS, and the function is fully backwards compatible.

When a router receives an RS message with a PIO, if it is configured to accept the option and can provide prefix delegation services it examines the fields in the message and selects a prefix to delegate to the node. If the PIO included a specific Prefix, the router delegates the node's preferred prefix if possible. Otherwise, the router selects a prefix to delegate to the node with length based on the node's Prefix Length. The router sets lifetimes matching the lifetimes requested by the node if possible, or shorter lifetimes if the node's requested lifetimes are too long. The router finally prepares a PIO containing this information and inserts it into an RA message to send back to the source of the RS.

3.3. Stateful Provisioning Requirements

Using the PIO in RS messages, the option itself requests stateful information. The RS message link-layer address can be used as the identity of the requesting node. The RS message includes a Nonce option [RFC3971] to provide a transaction identifier for matching RS and RA messages. Finally, the message can be protected using SEND the same as for the DHCPv6 option.

3.4. Implementation Considerations

Each router can implement a stateful database management service of their own choosing, but a functional alternative would be to use the standard DHCPv6 service as the back-end management service. In this way, all communications between the router's link to the requesting node are via RS/RA messaging. But, when the router receives an RS message with a PIO it can create a synthesized DHCPv6 Solicit message to send to the DHCPv6 server. This can be done in the same way as for the approach discussed in Section 2.4. In this way, the node on the link over which the PIO is advertised only ever sees RS/RA messages on the front end, and the router gets to use the DHCPv6 service for stateful configuration management on the back end.

4. Embedded Prefix Assertion

The third method entails a simple RS/RA exchange with no additional options where the node asserts a prefix by embedding the prefix in the source address of the RS message. The following sections provide further details.

4.1. Embedded Prefix Assertion

In this method, the node is pre-provisioned with the prefix it will use on its downstream networks (e.g., through network management, manual configuration, etc.). To invoke this method, the node includes its pre-provisioned prefix in the link-local source address of its RS message according to the AERO address format [I-D.templin-6man-aeroaddr]. For example, if the node is pre-provisioned with the prefix 2001:db8:1000:2000, it creates its IPv6 link-local source address as fe80::2001:db8:1000:2000.

4.2. Embedded Prefix Usage

When a node that wishes to assert a prefix first comes onto the link, it statelessly configures an AERO address based on its pre-provisioned prefix. The node then includes the AERO address as the source address of a standard RS message. If a router that receives the RS message has a way of verifying that the node is authorized to receive the solicited prefix, the router injects the prefix into the routing system and returns a standard RA message. When the node receives the RA message, it then has assurance that the proper routing state has been established.

The node examines the default router lifetime in the RA message as guidance for when subsequent RS/RA exchanges are necessary, i.e., the same as for normal IPv6ND. The node sends additional RS messages before the default router lifetime expires in order to keep the prefix assertion alive in the network. The RS messages may be sent either to the all-routers multicast address or to the unicast address(es) of the router(s) it received previous RAs from.

4.3. Stateful Provisioning Requirements

Using embedded prefix assertion, the network must have some way of determining the node's authority to assert its claimed prefix. This could be, e.g., through examination of the link-layer source address of the RS message. The network must also have some way of knowing the node's claimed prefix length, as the length cannot be conveyed in the RS message. If necessary, the exchange can also include some form of transaction identifier, e.g., by including a Nonce option in

the RS. Finally, the exchange can be protected using SEND the same as for the previous two methods.

4.4. Implementation Considerations

This method can be conducted using standard RS/RA messages with no extra options added to either message. It entails an administrative assignment of the node's AERO address to the upstream interface over which it will send the RS. When the router receives the standard RS message, it statelessly derives the node's prefix from the AERO address and injects the prefix into the routing system. The router then returns a standard RA message.

When the router returns the RA message, if it is configured to do so it can include a PIO option as discussed in Section 3.1. The PIO option includes prefix lifetimes and the prefix length. This "hybrid" combination of methods two and three could be useful in some deployment scenarios.

As for the PIO-based service discussed in Section 3.4, DHCPv6 can be used as the back-end service for stateful configuration management.

5. Out-of-Band Network Login Messaging

The fourth method entails an out-of-band messaging exchange through a "network login" procedure. During the network login, the requesting node could have an out-of-band messaging exchange with the network to set the stage for the router eventually sending an RA message as discussed in the following sections

5.1. Out-of-Band Network Login

In the out-of-band network login, the node signs into the network using, e.g., a login/password, a security certificate, etc. The node authenticates itself to the network, and can optionally have an iterative exchange to request certain aspects of the node's desired stateful configuration information. The first-hop router is then signaled to prepare an RA message to return to the node, i.e., either through some out-of-band signaling or through the node sending an RS message.

5.2. Out-of-Band Network Login Usage

When a node first comes onto the link, it engages in a network login session using some form of out-of-band messaging such as Layer-2 (L2) messaging. The session entails a security exchange where the node authenticates itself to the network and proves its authorization to receive the stateful configuration information. The network then

signals the router to send an RA message to the node, either unsolicited or in response to the node's RS message.

5.3. Stateful Provisioning Requirements

Using out-of-band messaging, the node engages in an iterative exchange where a request for stateful configuration information is conveyed. The exchange includes an identity for the requesting node and provides a unique per-message identifier so that the node can correlate its message requests with the responses it gets back from the network. Finally, the message exchange itself contains security parameters for authenticating the requesting node.

5.4. Implementation Considerations

The network login system and routers must be tightly coupled so that the network login can securely convey the requesting node's identity to the router.

As for the PIO-based service discussed in Section 3.4, DHCPv6 can be used as the back-end service for managing the stateful configuration database.

6. Implementation Status

The approach discussed in Section 2 has been implemented as extensions to the OpenVPN open source software distribution. The implementation is available at: http://linkupnetworks.net/aero/AERO-OpenVPN-2.0.tgz.

7. IANA Considerations

The IANA is instructed to assign an IPv6ND option Type value TBD for the DHCPv6 option.

The IANA is instructed to create a registry for the DHCPv6 option "Reserved" field (with no initial assignments) so that future uses of the field can be coordinated.

8. Security Considerations

Security considerations for IPv6 Neighbor Discovery [RFC4861] and DHCPv6 [RFC3315][RFC3633] apply to this document.

SEcure Neighbor Discovery (SEND) [RFC3971] can provide authentication for IPv6 ND messages with no need for additional securing mechanisms.

9. Acknowledgements

This work was motivated by discussions on the 6man and v6ops list. Those individuals who provided encouragement and critical review are acknowledged.

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This work is aligned with the Boeing Information Technology (BIT) MobileNet program and the Boeing Research & Technology (BR&T) enterprise autonomy program.

10. References

10.1. Normative References

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Appendix A. Change Log

<< RFC Editor - remove prior to publication >>

Changes from -06 to -07:

- Added "unsolicited DHCPv6 Reply" considerations
- Added refeence to new IPv6ND-based PD proposal.
- No longer associate the term "autoconfiguration" with the term "stateful".
- Added URL for implementation.

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June 30, 2018

Zero valid lifetimes on point-to-point links
draft-zerorafolks-6man-ra-zero-lifetime-00

Abstract

This document allows implementations to accept low or zero valid lifetimes in Router Advertisement Prefix Information Options in cases where it is known that there can only be one router on the link.

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/.

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This Internet-Draft will expire on January 1, 2019.

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1. Introduction

Currently, Prefix Information Options in Router Advertisements cannot reduce the Valid Lifetime of an IPv6 address below 2 hours. This is due to an explicit restriction in Section 5.5.3 of [RFC4862]. The reason is to avoid a denial-of-service attack whereby a malicious attacker can cause a node's addresses to expire prematurely by sending a Router Advertisement with a low Valid Lifetime.

1.1. 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].

2. Cases when it is useful to reduce Valid Lifetime to zero

In some cases, it is useful for the network to inform the host that a given prefix is no longer valid or will shortly no longer be valid. One example is if the host has moved beyond the mobility scope of the prefix and the network will no longer deliver packets for that prefix to the host. The host can thus terminate any upper-layer connections using that prefix and notify applications that continued communication will require using a new source address.

In order to ensure uninterrupted communications and no dispution to applications, this should be done only if the host already has other IPv6 addresses of equivalent scope and sufficient Valid Lifetime.

3. Changes to RFC 4862

The following clause is added between points 1 and 2 of clause e, Section 5.5.3 of [RFC4862]:

2. If the link-layer guarantees that there is only one node on the link from which the host can receive Router Advertiesements (e.g., if the link is a point-to-point link, such as a PPP link or a 3GPP link as defined in [RFC6459]), and the link has another prefix of the same scope with sufficient Valid Lifetime, set the valid lifetime of the corresponding address to the advertised Valid Lifetime.

4. IANA Considerations

This memo includes no request to IANA.

5. Security Considerations

The denial-of-service attack that motivated this restriction cannot be mounted on a link where no other devices can send Router Advertisements to the host.

6. References

6.1. Normative References

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6.2. Informative References

[RFC6459] Korhonen, J., Ed., Soininen, J., Patil, B., Savolainen, T., Bajko, G., and K. Iisakkila, "IPv6 in 3rd Generation Partnership Project (3GPP) Evolved Packet System (EPS)", RFC 6459, DOI 10.17487/RFC6459, January 2012, <https://www.rfc-editor.org/info/rfc6459>.

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