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Performance Measurement Using Simple TWAMP (STAMP) for Segment Routing Networks

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Abstract

Segment Routing (SR) leverages the source routing paradigm. SR is applicable to both Multiprotocol Label Switching (SR-MPLS) and IPv6 (SRv6) data planes. This document specifies procedure for sending and processing probe query and response messages for Performance Measurement (PM) in Segment Routing networks. The procedure uses the mechanisms defined in RFC 8762 (Simple Two-Way Active Measurement Protocol (STAMP)) and its TLV extensions for Performance Measurement. The procedure specified is applicable to SR-MPLS and SRv6 data planes and is used for both Links and end-to-end SR Paths including SR Policies.

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1. Introduction

Segment Routing (SR) leverages the source routing paradigm and greatly simplifies network operations for Software Defined Networks (SDNs). SR is applicable to both Multiprotocol Label Switching (SR-MPLS) and IPv6 (SRv6) data planes. SR takes advantage of the Equal-Cost Multipaths (ECMPs) between source and transit nodes, between transit nodes and between transit and destination nodes. SR Policies as defined in [I-D.ietf-spring-segment-routing-policy] are used to steer traffic through a specific, user-defined paths using a stack of Segments. Built-in SR Performance Measurement (PM) is one of the essential requirements to provide Service Level Agreements (SLAs).

The Simple Two-way Active Measurement Protocol (STAMP) provides capabilities for the measurement of various performance metrics in IP networks using probe messages [RFC8762]. It eliminates the need for control-channel signaling by using configuration data model to provision a test-channel (e.g. UDP paths). [I-D.ietf-ippm-stamp-option-tlv] defines TLV extensions for STAMP messages.

This document specifies procedures for sending and processing probe query and response messages for Performance Measurement in SR networks. The procedure uses the mechanisms defined in [RFC8762] (STAMP) and its TLV extensions [I-D.ietf-ippm-stamp-option-tlv] for Performance Measurement. The procedure specified is applicable to SR-MPLS and SRv6 data planes and is used for both Links and end-to-end SR Paths including SR Policies and Flex-Algo IGP Paths. Unless otherwise specified, the mechanisms defined in [RFC8762] and [I-D.ietf-ippm-stamp-option-tlv] are not modified by this document.

2. Conventions Used in This Document

2.1. 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 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2.2. Abbreviations

BSID: Binding Segment ID.

DM: Delay Measurement.

ECMP: Equal Cost Multi-Path.

HMAC: Hashed Message Authentication Code.

LM: Loss Measurement.

MPLS: Multiprotocol Label Switching.

NTP: Network Time Protocol.

OWAMP: One-Way Active Measurement Protocol.

PM: Performance Measurement.

PSID: Path Segment Identifier.

PTP: Precision Time Protocol.

SID: Segment ID.

SL: Segment List.

SR: Segment Routing.

SRH: Segment Routing Header.

SR-MPLS: Segment Routing with MPLS data plane.

SRv6: Segment Routing with IPv6 data plane.

SSID: STAMP Session Identifier.

STAMP: Simple Two-way Active Measurement Protocol.

TC: Traffic Class.

2.3. Reference Topology

In the reference topology shown below, the sender node R1 initiates a performance measurement probe query message and the reflector node R5 sends a probe response message for the query message received. The probe response message is typically sent to the sender node R1.

SR is enabled on nodes R1 and R5. The nodes R1 and R5 may be directly connected via a Link or there exists a Point-to-Point (P2P) SR Path e.g. SR Policy [I-D.ietf-spring-segment-routing-policy] on node R1 (called head-end) with destination to node R5 (called tail-end).

```
                     t1                 t2
                    /                     \
               +-------+       Query       +-------+
               |       | - - - - - - - - - ->|       |
               |   R1  |=====================|   R5  |
               |       |<- - - - - - - - - - |       |
               +-------+       Response      +-------+
                    \                     /
                     t4                 t3
                Sender                       Reflector

                        Reference Topology
```

3. Overview

For one-way and two-way delay measurements in Segment Routing networks, the probe messages defined in [RFC8762] are used. For direct-mode and inferred-mode loss measurements, the probe messages defined in [I-D.gandhi-ippm-stamp-srpm] are used. For both Links and end-to-end SR Paths including SR Policies and Flex-Algo IGP Paths, no PM state for delay or loss measurement need to be created on the reflector node R5.

Separate UDP destination port numbers are user-configured for delay and loss measurements from the range specified in [RFC8762]. As specified in [RFC8762], the reflector supports the destination UDP port 862 for delay measurement probe messages by default. This UDP port however, is not used for loss measurement probe messages. The sender uses the UDP port number following the guidelines specified in Section 6 in [RFC6335]. The same destination UDP port is used for Links and SR Paths and the reflector is unaware if the query is for the Links or SR Paths. The number of UDP ports with PM functionality needs to be minimized due to limited hardware resources.

For Performance Measurement, probe query and response messages are sent as following:

- o For delay measurement, the probe messages are sent on the congruent path of the data traffic by the sender node, and are used to measure the delay experienced by the actual data traffic flowing on the Links and SR Paths.

- o For loss measurement, the probe messages are sent on the congruent path of the data traffic by the sender node, and are used to collect the receive traffic counters for the incoming link or incoming SID where the probe query messages are received at the reflector node (incoming link or incoming SID needed since the reflector node does not have PM state present).

The In-Situ Operations, Administration, and Maintenance (IOAM) mechanisms for SR-MPLS defined in [I-D.gandhi-mpls-ioam-sr] and for SRv6 defined in [I-D.ali-spring-ioam-srv6] are used to carry PM information such as timestamp in-band as part of the data packets, and are outside the scope of this document.

3.1. Example Provisioning Model

An example of a provisioning model and typical measurement parameters for each user-configured destination UDP port for performance delay and loss measurements is shown in the following Figure 1:

```
                           +------------+
                           | Controller |
                           +------------+
Destination UDP Port           /  \         Destination UDP port
Measurement Protocol          /    \        Measurement Protocol
Measurement Type             /      \       Measurement Type
  Delay/Loss                /        \        Delay/Loss
Authentication Mode & Key  /          \     Authentication Mode & Key
Timestamp Format          /            \    Loss Measurement Mode
Delay Measurement Mode   /              \   SSID (Wildcard)
Loss Measurement Mode   /                \
                       v                  v
                +-------+            +-------+
                |       |            |       |
                |   R1  |============|   R5  |
                |       |  SR Path   |       |
                +-------+  Or Link   +-------+
                 Sender              Reflector
```

Figure 1: Example Provisioning Model

Example of Measurement Protocol is STAMP, example of the Timestamp Format is PTPv2 [IEEE1588] or NTP and example of the Loss Measurement mode is inferred-mode or direct-mode.

The mechanisms to provision the sender and reflector nodes are outside the scope of this document. The provisioning model is not used for signaling the PM parameters between the reflector and sender nodes in SR networks.

The reflector node R5 uses the parameters for the timestamp format and delay measurement mode (i.e. one-way or two-way mode) from the received probe query message.

4. Probe Messages

4.1. Probe Query Message

The probe messages defined in [RFC8762] are used for delay measurement for Links and end-to-end SR Paths including SR Policies. For loss measurement, the probe messages defined in [I-D.gandhi-ippm-stamp-srpm] are used.

4.1.1. Delay Measurement Query Message

The message content for delay measurement probe query message using UDP header [RFC0768] is shown in Figure 2. The DM probe query message is sent with user-configured Destination UDP port number for DM. The Destination UDP port cannot be used as Source port, since the message does not have any indication to distinguish between the query and response message. The payload of the DM probe query message contains the delay measurement message defined in [RFC8762].

```
+---------------------------------------------------------------+
| IP Header                                                     |
.  Source IP Address = Sender IPv4 or IPv6 Address              .
.  Destination IP Address = Reflector IPv4 or IPv6 Address      .
.  Protocol = UDP                                               .
.                                                               .
+---------------------------------------------------------------+
| UDP Header                                                    |
.  Source Port = As chosen by Sender                            .
.  Destination Port = User-configured Port for Delay Measurement.
.                                                               .
+---------------------------------------------------------------+
| Payload = DM Message as specified in Section 4.2 of RFC 8762  |
.                                                               .
+---------------------------------------------------------------+
```

Figure 2: DM Probe Query Message

Timestamp field is eight bytes and use the format defined in Section 4.2.1 of [RFC8762]. It is recommended to use the IEEE 1588v2 Precision Time Protocol (PTP) truncated 64-bit timestamp format [IEEE1588] as specified in [RFC8186], with hardware support in Segment Routing networks.

4.1.1.1. Delay Measurement Authentication Mode

When using the authenticated mode for delay measurement, the matching authentication type (e.g. HMAC-SHA-256) and key are user-configured on both the sender and reflector nodes. A separate user-configured

destination UDP port is used for the delay measurement in authentication mode due to the different probe message format.

4.1.2. Loss Measurement Query Message

The message content for loss measurement probe query message using UDP header [RFC0768] is shown in Figure 3. The LM probe query message is sent with user-configured Destination UDP port number for LM, which is a different Destination UDP port number than DM. Separate Destination UDP ports are used for direct-mode and inferred-mode loss measurements. The Destination UDP port cannot be used as Source port, since the message does not have any indication to distinguish between the query and response message. The LM probe query message contains the payload for loss measurement as defined in [I-D.gandhi-ippm-stamp-srpm].

```
+---------------------------------------------------------------+
| IP Header                                                     |
.  Source IP Address = Sender IPv4 or IPv6 Address              .
.  Destination IP Address = Reflector IPv4 or IPv6 Address      .
.  Protocol = UDP                                               .
.                                                               .
+---------------------------------------------------------------+
| UDP Header                                                    |
.  Source Port = As chosen by Sender                            .
.  Destination Port = User-configured Port for Loss Measurement .
.                                                               .
+---------------------------------------------------------------+
| Payload = LM Message specified in [I-D.gandhi-ippm-stamp-srpm]|
.                                                               .
+---------------------------------------------------------------+
```

Figure 3: LM Probe Query Message

4.1.2.1. Loss Measurement Authentication Mode

When using the authenticated mode for loss measurement, the matching authentication type (e.g. HMAC-SHA-256) and key are user-configured on both the sender and reflector nodes. A separate user-configured destination UDP port is used for the loss measurement in authentication mode due to the different message format.

4.1.3. Probe Query for Links

The probe query message as defined in Figure 2 for delay measurement and Figure 3 for loss measurement are used for Links which may be physical, virtual or LAG (bundle), LAG (bundle) member, numbered/ unnumbered Links. The probe messages are pre-routed over the Link

for both delay and loss measurement. The local and remote IP addresses of the link are used as Source and Destination Addresses. They can also be IPv6 link local address as probe messages are pre-routed.

4.1.4. Probe Query for SR Policy

The performance delay and loss measurement for segment routing is applicable to both end-to-end SR-MPLS and SRv6 Policies.

The sender IPv4 or IPv6 address is used as the source address. The endpoint IPv4 or IPv6 address is used as the destination address. In the case of SR Policy with IPv4 endpoint of 0.0.0.0 or IPv6 endpoint of ::0 [I-D.ietf-spring-segment-routing-policy], the loopback address from range 127/8 for IPv4, or the loopback address ::1/128 for IPv6 is used as the destination address, respectively. In this case, Node Address TLV [I-D.gandhi-ippm-stamp-srpm] can be sent in the probe query message to identify the intended destination node. The reflector node MUST NOT send response message if it is not the intended destination node in the Node Address TLV [I-D.gandhi-ippm-stamp-srpm].

4.1.4.1. Probe Query Message for SR-MPLS Policy

The probe query messages for performance measurement of an end-to-end SR-MPLS Policy is sent using its SR-MPLS header containing the MPLS segment list as shown in Figure 4.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Segment(1)             | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
.                                                               .
.                                                               .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Segment(n)             | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                PSID                   | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Message as shown in Figure 2 for DM or Figure 3 for LM      |
.                                                               .
+---------------------------------------------------------------+
```

Figure 4: Example Probe Query Message for SR-MPLS Policy

The Segment List (SL) can be empty to indicate Implicit NULL label case for a single-hop SR Policy.

The Path Segment Identifier (PSID) [I-D.ietf-spring-mpls-path-segment] of the SR-MPLS Policy is used for accounting received traffic on the egress node for loss measurement.

4.1.4.2. Probe Query Message for SRv6 Policy

An SRv6 Policy setup using the SRv6 Segment Routing Header (SRH) and a Segment List as defined in [RFC8754]. The SRv6 network programming is defined in [I-D.ietf-spring-srv6-network-programming]. The probe query messages for performance measurement of an end-to-end SRv6 Policy is sent using its SRH with Segment List as shown in Figure 5. The procedure defined for upper-layer header processing for SRv6 SIDs in [I-D.ietf-spring-srv6-network-programming] is used to process the UDP header in the received probe query messages.

```
+---------------------------------------------------------------+
| IP Header                                                     |
.  Source IP Address = Sender IPv6 Address                      .
.  Destination IP Address = Destination IPv6 Address            .
.                                                               .
+---------------------------------------------------------------+
| SRH as specified in RFC 8754                                  |
.  &lt;Segment List&gt;                                               .
.                                                               .
+---------------------------------------------------------------+
| IP Header (as needed)                                         |
.  Source IP Address = Sender IPv6 Address                      .
.  Destination IP Address = Reflector IPv6 Address              .
.                                                               .
+---------------------------------------------------------------+
| UDP Header                                                    |
.  Source Port = As chosen by Sender                            .
.  Destination Port = User-configured Port                      .
.                                                               .
+---------------------------------------------------------------+
| Payload = DM Message as specified in Section 4.2 of RFC 8762  |
. Payload = LM Message specified in [I-D.gandhi-ippm-stamp-srpm].
.                                                               .
+---------------------------------------------------------------+
```

Figure 5: Example Probe Query Message for SRv6 Policy

4.2. Probe Response Message

The probe response message is sent using the IP/UDP information from the received probe query message. The content of the probe response message is shown in Figure 6.

```
+---------------------------------------------------------------+
| IP Header                                                     |
.  Source IP Address = Reflector IPv4 or IPv6 Address           .
.  Destination IP Address = Source IP Address from Query        .
.  Protocol = UDP                                               .
.                                                               .
+---------------------------------------------------------------+
| UDP Header                                                    |
.  Source Port = As chosen by Reflector                         .
.  Destination Port = Source Port from Query                    .
.                                                               .
+---------------------------------------------------------------+
| Payload = DM Message as specified in Section 4.3 of RFC 8762  |
. Payload = LM Message specified in [I-D.gandhi-ippm-stamp-srpm].
.                                                               .
+---------------------------------------------------------------+
```

Figure 6: Probe Response Message

4.2.1. One-way Measurement Mode

In one-way measurement mode, the probe response message as defined in Figure 6 is sent back out-of-band to the sender node, for both Links and SR Policies. The Sender Control Code is set to "Out-of-band Response Requested". In this delay measurement mode, as per Reference Topology, all timestamps t1, t2, t3, and t4 are collected by the probes. However, only timestamps t1 and t2 are used to measure one-way delay as (t2 - t1).

For one-way performance measurement, the sender node address may not be reachable via IP route from the reflector node. The sender node in this case needs to send its reachability path information to the reflector node using Return Path TLV defined in [I-D.gandhi-ippm-stamp-srpm].

4.2.2. Two-way Measurement Mode

In two-way measurement mode, when using a bidirectional path, the probe response message as defined in Figure 6 is sent back to the sender node on the congruent path of the data traffic on the same reverse direction Link or associated reverse SR Policy [I-D.ietf-pce-sr-bidir-path]. The Sender Control Code is set to "In-

band Response Requested". In this delay measurement mode, as per Reference Topology, all timestamps t1, t2, t3, and t4 are collected by the probes. All four timestamps are used to measure two-way delay as ((t4 - t1) - (t3 - t2)).

For two-way measurement mode for Links, the probe response message is sent back on the incoming physical interface where the probe query message is received.

For two-way measurement mode for SR Policy, the reflector node needs to send the probe response message on a specific reverse path. The sender node can request in the probe query message to the reflector node to send a response message back on a given reverse path (e.g. co-routed bidirectional path) using Return Path TLV defined in [I-D.gandhi-ippm-stamp-srpm]. This way the reflector node does not require any additional SR state for PM (recall that in SR networks, the state is in the probe packet and signaling of the parameters is undesired).

4.2.2.1. Probe Response Message for SR-MPLS Policy

The message content for sending probe response message for two-way performance measurement of an end-to-end SR-MPLS Policy is shown in Figure 7.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                Segment(1)             | TC  |S|      TTL      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 .                                                               .
 .                                                               .
 .                                                               .
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                Segment(n)             | TC  |S|      TTL      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                Message as shown in Figure 6                   |
 .                                                               .
 +---------------------------------------------------------------+
```

Figure 7: Example Probe Response Message for SR-MPLS Policy

The Path Segment Identifier (PSID) [I-D.ietf-spring-mpls-path-segment] of the forward SR Policy in the probe query can be used to find the associated reverse SR Policy [I-D.ietf-pce-sr-bidir-path] to send the probe response message for two-way measurement of SR Policy unless when using STAMP message with Return Path TLV.

4.2.2.2. Probe Response Message for SRv6 Policy

The message content for sending probe response message on the congruent path of the data traffic for two-way performance measurement of an end-to-end SRv6 Policy with SRH is shown in Figure 8. The procedure defined for upper-layer header processing for SRv6 SIDs in [I-D.ietf-spring-srv6-network-programming] is used to process the UDP header in the received probe response messages.

```
+---------------------------------------------------------------+
| IP Header                                                     |
.  Source IP Address = Reflector IPv6 Address                   .
.  Destination IP Address = Destination IPv6 Address            .
.                                                               .
+---------------------------------------------------------------+
| SRH as specified in RFC 8754                                  |
.  &lt;Segment List&gt;                                               .
.                                                               .
+---------------------------------------------------------------+
| IP Header (as needed)                                         |
.  Source IP Address = Reflector IPv6 Address                   .
.  Destination IP Address = Source IPv6 Address from Query      .
.                                                               .
+---------------------------------------------------------------+
| UDP Header                                                    |
.  Source Port = As chosen by Sender                            .
.  Destination Port = User-configured Port                      .
.                                                               .
+---------------------------------------------------------------+
| Payload = DM Message as specified in Section 4.3 of RFC 8762  |
. Payload = LM Message specified in [I-D.gandhi-ippm-stamp-srpm].
.                                                               .
+---------------------------------------------------------------+
```

Figure 8: Example Probe Response Message for SRv6 Policy

4.2.3. Loopback Measurement Mode

The Loopback measurement mode can be used to measure round-trip delay for a bidirectional SR Path. The IP header of the probe query message contains the destination address equals to the sender address and the source address equals to the reflector address. Optionally, the probe query message can carry the reverse path information (e.g. reverse path label stack for SR-MPLS) as part of the SR header. The probe messages are not punted at the reflector node and it does not process them and generate response messages. The Sender Control Code is set to the default value of 0. In this mode, as the probe packet is not punted on the reflector node for processing, the querier

copies the 'Sequence Number' in 'Session-Sender Sequence Number' directly. In this delay measurement mode, as per Reference Topology, the timestamps t1 and t4 are collected by the probes. Both these timestamps are used to measure round-trip delay as (t4 - t1).

4.3. Additional Probe Message Processing Rules

The processing rules defined in this section are applicable to the STAMP messages for delay and loss measurement for Links and end-to-end SR Paths including SR Policies.

4.3.1. TTL and Hop Limit

The TTL field in the IPv4 and MPLS headers of the probe query messages is set to 255 [RFC8762]. Similarly, the Hop Limit field in the IPv6 and SRH headers of the probe query messages is set to 255 [RFC8762].

When using the Destination IPv4 Address from range 127/8, the TTL field in the IPv4 header is set to 1 [RFC8029]. Similarly, when using the Destination IPv6 Address from the ::FFFF:127/104 range, the Hop Limit field in the IPv6 header is set to 1.

For Link performance delay and loss measurements, the TTL or Hop Limit field in the probe message is set to 1 in both one-way and two-way measurement modes.

4.3.2. Router Alert Option

The Router Alert IP option (RAO) [RFC2113] is not set in the probe messages.

4.3.3. UDP Checksum

The UDP Checksum Complement for delay and loss measurement messages follows the procedure defined in [RFC7820] and can be optionally used with the procedures defined in this document.

For IPv4 and IPv6 probe messages, where the hardware is not capable of re-computing the UDP checksum or adding checksum complement [RFC7820], the sender node sets the UDP checksum to 0 [RFC6936] [RFC8085]. The receiving node bypasses the checksum validation and accepts the packets with UDP checksum value 0 for the UDP port being used for delay and loss measurements.

5. Performance Measurement for P2MP SR Policies

The Point-to-Multipoint (P2MP) SR Path that originates from a root node terminates on multiple destinations called leaf nodes (e.g. P2MP SR Policy [I-D.ietf-pim-sr-p2mp-policy] or P2MP Transport [I-D.shen-spring-p2mp-transport-chain]).

The procedures for delay and loss measurement described in this document for P2P SR Policies are also equally applicable to the P2MP SR Policies. The procedure for one-way measurement is defined as following:

- o The sender root node sends probe query messages using the Tree-SID defined in [I-D.ietf-pim-sr-p2mp-policy] for the P2MP SR-MPLS Policy as shown in Figure 9.

- o The probe query messages can contain the replication SID as defined in [I-D.ietf-spring-sr-replication-segment].

- o The Destination Address is set to the loopback address from range 127/8 for IPv4, or the loopback address ::1/128 for IPv6 address.

- o Each reflector leaf node sends its IP address in the Source Address of the probe response messages as shown in Figure 9. This allows the sender root node to identify the reflector leaf nodes of the P2MP SR Policy.

- o The P2MP root node measures the delay and loss performance for each P2MP leaf node of the end-to-end P2MP SR Policy.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Tree-SID                 | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
.                                                               .
.                                                               .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Message as shown in Figure 2 for DM or Figure 3 for LM      |
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 9: Example Probe Query with Tree-SID for SR-MPLS Policy

The probe query messages can also be sent using the scheme defined for P2MP Transport using Chain Replication that may contain Bud SID as defined in [I-D.shen-spring-p2mp-transport-chain].

The considerations for two-way mode for performance measurement for P2MP SR Policy (e.g. for bidirectional SR Path) are outside the scope of this document.

6. ECMP Support for SR Policies

An SR Policy can have ECMPs between the source and transit nodes, between transit nodes and between transit and destination nodes. Usage of Anycast SID [RFC8402] by an SR Policy can result in ECMP paths via transit nodes part of that Anycast group. The probe messages need to be sent to traverse different ECMP paths to measure performance delay of an SR Policy.

Forwarding plane has various hashing functions available to forward packets on specific ECMP paths. The mechanisms described in [RFC8029] and [RFC5884] for handling ECMPs are also applicable to the performance measurement. In IPv4 header of the probe messages, sweeping of Destination Address from range 127/8 can be used to exercise particular ECMP paths. As specified in [RFC6437], Flow Label field in the outer IPv6 header can also be used for sweeping.

The considerations for performance loss measurement for different ECMP paths of an SR Policy are outside the scope of this document.

7. Performance Delay and Liveness Monitoring

Liveness monitoring is required for connectivity verification and continuity check in an SR network. The procedure defined in this document for delay measurement using the STAMP probe messages can also be applied to liveness monitoring of Links and SR Paths. The one-way or two-way measurement mode can be used for liveness monitoring. Liveness failure is notified when consecutive N number of probe response messages are not received back at the sender node, where N is locally provisioned value. Note that for one-way and two-way modes, the failure detection interval and scale for number of probe messages need to account for the processing of the probe query messages which need to be punted from the forwarding fast path (to slow path or control plane) and response messages need to be injected on the reflector node. This is improved by using the probes in loopback mode.

8. Security Considerations

The performance measurement is intended for deployment in well-managed private and service provider networks. As such, it assumes that a node involved in a measurement operation has previously verified the integrity of the path and the identity of the far-end reflector node.

If desired, attacks can be mitigated by performing basic validation and sanity checks, at the sender, of the counter or timestamp fields in received measurement response messages. The minimal state associated with these protocols also limits the extent of measurement disruption that can be caused by a corrupt or invalid message to a single query/response cycle.

Use of HMAC-SHA-256 in the authenticated mode protects the data integrity of the probe messages. SRv6 has HMAC protection authentication defined for SRH [RFC8754]. Hence, probe messages for SRv6 may not need authentication mode. Cryptographic measures may be enhanced by the correct configuration of access-control lists and firewalls.

9. IANA Considerations

This document does not require any IANA action.

10. References

10.1. Normative References

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