SPRING Working Group
Internet-Draft
Intended Status: Standards Track
Expires: April 6, 2020

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October 4, 2019

Performance Measurement for Segment Routing Networks with MPLS Data Plane
draft-gandhi-spring-rfc6374-srpm-mpls-02

Abstract

Segment Routing (SR) leverages the source routing paradigm. RFC 6374 specifies protocol mechanisms to enable the efficient and accurate measurement of packet loss, one-way and two-way delay, as well as related metrics such as delay variation in MPLS networks using probe messages. This document utilizes these mechanisms for Performance Delay and Loss Measurements in Segment Routing (SR) networks with MPLS data plane (SR-MPLS), for both SR links and end-to-end SR Policies. In addition, this document defines Return Path TLV for two-way performance measurement and Block Number TLV for loss measurement.

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1. Introduction

Service provider's ability to satisfy Service Level Agreements (SLAs) depend on the ability to measure and monitor performance metrics for packet loss and one-way and two-way delay, as well as related metrics such as delay variation. The ability to monitor these performance metrics also provides operators with greater visibility into the performance characteristics of their networks, thereby facilitating planning, troubleshooting, and network performance evaluation.

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.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).

[RFC6374] specifies protocol mechanisms to enable the efficient and accurate measurement of performance metrics in MPLS networks using probe messages. The One-Way Active Measurement Protocol (OWAMP) defined in [RFC4656] and Two-Way Active Measurement Protocol (TWAMP) defined in [RFC5357] provide capabilities for the measurement of various performance metrics in IP networks. However, mechanisms defined in [RFC6374] are more suitable for Segment Routing (SR) when using MPLS data plane (SR-MPLS). [RFC6374] also supports IEEE 1588 timestamps [IEEE1588] and "direct mode" Loss Measurement (LM), which are required in SR networks.

[RFC7876] specifies the procedures to be used when sending and processing out-of-band performance measurement probe replies over an UDP return path when receiving RFC 6374 based probe queries. These procedures can be used to send out-of-band PM replies for both SR-MPLS links and Policies [I-D.spring-segment-routing-policy] for one-way measurement.

This document utilizes the probe-based mechanisms defined in [RFC6374] for Performance Delay and Loss Measurements in SR networks with MPLS data plane, for both SR links and end-to-end SR Policies. In addition, this document defines Return Path TLV for two-way performance measurement and Block Number TLV for loss measurement. The Performance Measurements (PM) for SR links are used to compute extended Traffic Engineering (TE) metrics for delay and loss and can be advertised in the network using the routing protocol extensions.

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

ACH: Associated Channel Header.

DM: Delay Measurement.

ECMP: Equal Cost Multi-Path.

G-ACh: Generic Associated Channel (G-ACh).

GAL: Generic Associated Channel (G-ACh) Label.

LM: Loss Measurement.

MPLS: Multiprotocol Label Switching.

NTP: Network Time Protocol.

PM: Performance Measurement.

PSID: Path Segment Identifier.

PTP: Precision Time Protocol.

SID: Segment ID.

SL: Segment List.

SR: Segment Routing.

SR-MPLS: Segment Routing with MPLS data plane.

TC: Traffic Class.

TE: Traffic Engineering.

URO: UDP Return Object.

2.3. Reference Topology

In the reference topology shown in Figure 1, the sender node R1 initiates a performance measurement probe query and the responder node R5 sends a probe response for the query message received. The probe response is typically sent back to the sender node R1. The nodes R1 and R5 may be directly connected via a link enabled with Segment Routing or there exists a Point-to-Point (P2P) SR Policy [I-D.spring-segment-routing-policy] on node R1 with destination to node R5. In case of Point-to-Multipoint (P2MP), SR Policy originating from source node R1 may terminate on multiple destination leaf nodes [I-D.spring-sr-p2mp-policy].

```
+-------+        Query        +-------+
|       | - - - - - - - - - ->|       |
|   R1  |---------------------|   R5  |
|       |<- - - - - - - - - - |       |
+-------+       Response      +-------+
 Sender                        Responder
```

Figure 1: Reference Topology

3. Overview

One-way delay and two-way delay measurement procedure defined in Section 2.4 of [RFC6374] are used. Transmit and Receive packet loss measurement procedures defined in Section 2.2 and Section 2.6 of [RFC6374] are used. One-way loss measurement provides receive packet loss whereas two-way loss measurement provides both transmit and receive packet loss. For both links and end-to-end SR Policies, no PM session for delay or loss measurement is created on the responder node R5 [RFC6374].

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

- 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 Policies.

- 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 responder node (incoming link or incoming SID needed since the

responder node does not have PM session state present).

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

4. Probe Query and Response Packets

4.1. Probe Packet Header for SR-MPLS Policies

As described in Section 2.9.1 of [RFC6374], MPLS PM probe query and response messages flow over the MPLS Generic Associated Channel (G-ACh). A probe packet for an end-to-end measurement for SR Policy contains SR-MPLS label stack [I-D.spring-segment-routing-policy], with the G-ACh Label (GAL) at the bottom of the stack (with S=1). The GAL is followed by an Associated Channel Header (ACH), which identifies the message type, and the message payload following the ACH as shown in Figure 2.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Label(1)             | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
.                                                               .
.                                                               .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Label(n)             | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  GAL (value 13)       | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 1|Version|  Reserved     | GAL Channel Type              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: Probe Packet Header for an End-to-end SR-MPLS Policy

The SR-MPLS label stack can be empty (as shown in Figure 3) to indicate Implicit NULL label case.

4.2. Probe Packet Header for SR-MPLS Links

As described in Section 2.9.1 of [RFC6374], MPLS PM probe query and response messages flow over the MPLS Generic Associated Channel (G-ACh). A probe packet for SR-MPLS links contains G-ACh Label (GAL)

(with S=1). The GAL is followed by an Associated Channel Header (ACH), which identifies the message type, and the message payload following the ACH as shown in Figure 3.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              GAL (value 13)           | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 1|Version|  Reserved     | GAL Channel Type              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Probe Packet Header for an SR-MPLS Link

4.3. Probe Response Message for SR-MPLS Links and Policies

4.3.1. One-way Measurement Mode

In one-way performance measurement mode [RFC7679], the PM sender node can receive "out-of-band" probe replies by properly setting the UDP Return Object (URO) TLV in the probe query message. The URO TLV (Type=131) is defined in [RFC7876] and includes the UDP-Destination-Port and IP Address. In particular, if the sender sets its own IP address in the URO TLV, the probe response is sent back by the responder node to the sender node. In addition, the "control code" in the probe query message is set to "out-of-band response requested". The "Source Address" TLV (Type 130), and "Return Address" TLV (Type 1), if present in the probe query message, are not used to send probe response message.

4.3.2. Two-way Measurement Mode

In two-way performance measurement mode [RFC6374], when using a bidirectional path, the probe response message is sent back to the sender node on the congruent path of the data traffic on the reverse direction SR Link or SR Policy using a message with format similar to their probe query message. In this case, the "control code" in the probe query message is set to "in-band response requested".

A Path Segment Identifier (PSID) [I-D.spring-mpls-path-segment] of the forward SR-MPLS Policy can be used to find the reverse SR-MPLS Policy and to send back the probe response message for two-way measurement.

4.3.2.1. Return Path TLV

For two-way performance measurement, the responder node needs to send

the probe response message on a specific reverse path. This way the destination node does not require any additional SR Policy state. The sender node can request the responder node to send a response message back on a given reverse path (e.g. co-routed path for two-way measurement).

[RFC6374] defines DM and LM probe query messages that can include one or more optional TLVs. New TLV Type (TBA1) is defined in this document for Return Path to carry reverse path for probe response messages (in the payload of the message). The format of the Return Path TLV is shown in Figure 7A and 7B:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Type = TBA1  |     Length    |       Reserved                |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                     Return Path Sub-TLVs                      |
 .                                                               .
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7A: Return Path TLV

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     Type      |     Length    |       Reserved                |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                     Segment List(1)                           |
 .                                                               .
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 .                                                               .
 .                                                               .
 .                                                               .
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                     Segment List(n)                           |
 .                                                               .
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7B: Segment List Sub-TLV in Return Path TLV

The Segment List Sub-TLV in the Return Path TLV can be one of the following Types:

o Type (value 1): Respond back on Incoming Interface (Layer-3 and

Layer-2) (Segment List is Empty)

o Type (value 2): SR-MPLS Segment List (Label Stack) of the Reverse SR Path

o Type (value 3): SR-MPLS Binding SID [I-D.pce-binding-label-sid] of the Reverse SR Policy

The Return Path TLV is optional. The PM sender node MUST only insert one Return Path TLV in the probe query message and the responder node MUST only process the first Return Path TLV in the probe query message and ignore other Return Path TLVs if present. The responder node MUST send probe response message back on the reverse path specified in the Return Path TLV and MUST NOT add Return Path TLV in the probe response message.

4.3.3. Loopback Measurement Mode

The Loopback measurement mode defined in Section 2.8 of [RFC6374] can be used to measure round-trip delay for a bidirectional SR Path. The probe query messages in this case carries the reverse SR Path label stack as part of the MPLS header. The GAL is still carried at the bottom of the label stack (with S=1). The responder node does not process the PM probe messages and generate response messages.

5. Performance Delay Measurement

5.1. Delay Measurement Message Format

As defined in [RFC6374], MPLS DM probe query and response messages use Associated Channel Header (ACH) (value 0x000C for delay measurement) [RFC6374], which identifies the message type, and the message payload following the ACH. For both SR links and end-to-end measurement for SR-MPLS Policies, the same MPLS DM ACH value is used.

The DM message payload as defined in Section 3.2 of [RFC6374] is used for SR-MPLS delay measurement, for both SR links and end-to-end SR Policies.

5.2. Timestamps

The Section 3.4 of [RFC6374] defines timestamp format that can be used for delay measurement. The IEEE 1588 Precision Time Protocol (PTP) timestamp format [IEEE1588] is used by default as described in Appendix A of [RFC6374], preferred with hardware support. As an alternative, Network Time Protocol (NTP) timestamp format can also be

used [RFC6374].

Note that for one-way delay measurement mode, clock synchronization between the sender and responder nodes using the methods detailed in [RFC6374] is required. The two-way delay measurement mode and loopback measurement mode do not require clock synchronization between the sender and responder nodes.

6. Performance Loss Measurement

The LM protocol can perform two distinct kinds of loss measurement as described in Section 2.9.8 of [RFC6374].

o In inferred mode, LM will measure the loss of specially generated test messages in order to infer the approximate data plane loss level. Inferred mode LM provides only approximate loss accounting.

o In direct mode, LM will directly measure data plane packet loss. Direct mode LM provides perfect loss accounting, but may require hardware support.

For both of these modes of LM, Path Segment Identifier (PSID) [I-D.spring-mpls-path-segment] is used for accounting received traffic on the egress node of the SR-MPLS Policy as shown in Figure 4. Different values of PSID can be used to measure packet loss per SR-MPLS Policy, per Candidate Path or per Segment List of the 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  PSID                 | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  GAL (value 13)       | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 1|Version|  Reserved     | GAL Channel Type              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: With Path Segment Identifier for SR-MPLS Policy

6.1. Loss Measurement Message Format

As defined in [RFC6374], MPLS LM probe query and response messages use Associated Channel Header (ACH) (value 0x000A for direct loss

measurement or value 0x000B for inferred loss measurement), which identifies the message type, and the message payload following the ACH. For both SR links and end-to-end measurement for SR-MPLS Policies, the same MPLS LM ACH value is used.

The LM message payload as defined in Section 3.1 of [RFC6374] is used for SR-MPLS loss measurement, for both SR links and end-to-end SR Policies.

6.1.1. Block Number TLV

The Loss Measurement using Alternate-Marking method defined in [RFC8321] requires to identify the Block Number (or color) of the traffic counters carried by the probe query and response messages. Probe query and response messages specified in [RFC6374] for Loss Measurement do not define any means to carry the Block Number.

[RFC6374] defines probe query and response messages that can include one or more optional TLVs. New TLV Type (value TBA2) is defined in this document to carry Block Number (16-bit) for the traffic counters in the probe query and response messages for loss measurement. The format of the Block Number TLV is shown in Figure 5:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Type TBA2   |    Length     |      Reserved                 |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Reserved                    |      Block Number             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Block Number TLV

The Block Number TLV is optional. The PM sender node SHOULD only insert one Block Number TLV in the probe query message and the responder node in the probe response message SHOULD return the first Block Number TLV from the probe query messages and ignore other Block Number TLVs if present. In both probe query and response messages, the counters MUST belong to the same Block Number.

7. Performance Measurement for P2MP SR Policies

The procedures for delay and loss measurement reviewed in this document for Point-to-Point (P2P) SR-MPLS Policies [I-D.spring-segment-routing-policy] are also equally applicable to the Point-to-Multipoint (P2MP) SR-MPLS Policies [I-D.spring-sr-p2mp-policy] as following:

o The sender root node sends probe query messages using the either Spray P2MP segment or TreeSID P2MP segment defined in [I-D.spring-sr-p2mp-policy] over the P2MP SR Policy as shown in Figure 6.

o Each responder leaf node adds the "Source Address" TLV (Type 130) [RFC6374] with its IP address in the probe response messages. This TLV allows the sender root node to identify the responder leaf nodes of the P2MP SR Policy.

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

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              TreeSID OR Spray SID     | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              GAL (value 13)           | TC  |S|      TTL      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 1|Version|  Reserved     | GAL Channel Type              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: With P2MP Segment Identifier for SR-MPLS Policy

8. ECMP for SR-MPLS 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 PM 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. For SR-MPLS Policy, entropy label [RFC6790] can be used in PM probe messages to take advantage of the hashing function in forwarding plane to influence the ECMP path taken by them.

9. SR Link Extended TE Metrics Advertisements

The extended TE metrics for SR link delay and loss computed using the performance measurement procedures reviewed in this document can be advertised in the routing domain as follows:

o For OSPF, ISIS, and BGP-LS, protocol extensions defined in [RFC7471], [RFC8570], and [RFC8571] are used, respectively for advertising the extended TE link metrics in the network.

o The extended TE link delay metrics advertised are minimum-delay, maximum-delay, average-delay, and delay-variance for one-way.

o The delay-variance metric is computed as specified in Section 4.2 of [RFC5481].

o The one-way delay metrics can be computed using two-way delay measurement or round-trip delay measurement from loopback mode by dividing the measured delay values by 2.

o The extended TE link loss metric advertised is one-way percentage packet loss.

o Similarly, the extended TE link delay and loss metrics are advertised for Layer 2 bundle members in ISIS [I-D.lsr-ospf-l2bundles] and OSPF [I-D.isis-l2bundles] using the same mechanisms defined in [RFC8570] and [RFC7471], respectively.

10. Security Considerations

This document reviews the procedures for performance delay and loss measurement for SR-MPLS networks, for both links and end-to-end SR Policies using the mechanisms defined in [RFC6374] and [RFC7876]. This document does not introduce any additional security considerations other than those covered in [RFC6374], [RFC7471], [RFC8570], [RFC8571], and [RFC7876].

11. IANA Considerations

IANA is requested to allocate a value for the following Return Path TLV Type for RFC 6374 to be carried in PM probe query messages:

o Type TBA1: Return Path TLV

IANA is requested to allocate the values for the following Sub-TLV Types for the Return Path TLV for RFC 6374.

o Type (value 1): Respond back on Incoming Interface (Layer-3 and Layer-2) (Segment List is Empty)

o Type (value 2): SR-MPLS Segment List (Label Stack) of the Reverse

SR Path

o Type (value 3): SR-MPLS Binding SID [I-D.pce-binding-label-sid] of the Reverse SR Policy

IANA is also requested to allocate a value for the following Block Number TLV Type for RFC 6374 to be carried in the PM probe query and response messages for loss measurement:

o Type TBA2: Block Number TLV

12. References

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Acknowledgments

The authors would like to thank Thierry Couture for the discussions on the use-cases for the performance measurement in segment routing networks. The authors would like to thank Greg Mirsky for providing many useful comments and suggestions. The authors would also like to thank Stewart Bryant, Sam Aldrin, and Rajiv Asati for their review comments.

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