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Performance Measurement Using Simple Two-Way Active Measurement Protocol (STAMP) for Segment Routing over the MPLS Data Plane
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Abstract

Segment Routing (SR) can be used to steer packets through a network employing source routing. SR can be applied to both MPLS (SR-MPLS) and IPv6 (SRv6) data planes. This document describes the procedures for Performance Measurement in SR-MPLS networks using the Simple Two-Way Active Measurement Protocol (STAMP), as defined in RFC 8762, along with its optional extensions defined in RFC 8972 and further augmented in RFC 9503. The described procedures are used for SR-MPLS paths (including Segment Lists of SR-MPLS Policies, SR-MPLS IGP best paths, and SR-MPLS IGP Flexible Algorithm paths), as well as Layer-3 and Layer-2 services over the SR-MPLS paths.

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 4 October 2026.

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1. Introduction

Segment Routing (SR) [RFC8402] can be used to steer packets through a network employing source routing. SR can be applied to both MPLS (SR-MPLS) and IPv6 (SRv6) data planes. SR takes advantage of Equal-Cost Multipath (ECMP) between source and transit nodes, between transit nodes, and between transit and destination nodes. SR Policies, as defined in [RFC9256], are used to steer traffic through specific user-defined paths using a list of segments.

A comprehensive SR Performance Measurement toolset is an essential requirement for measuring network performance to provide Service Level Agreements (SLAs).

The Simple Two-Way Active Measurement Protocol (STAMP), as specified in [RFC8762], provides capabilities for measuring various performance metrics in IP networks without the use of a control channel to pre-signal session parameters. [RFC8972] defines optional extensions in the form of TLVs for STAMP. [RFC9503] further augments that framework to define STAMP extensions for SR networks.

This document describes the procedures for Performance Measurement in SR-MPLS networks, using STAMP as defined in [RFC8762], along with its optional extensions defined in [RFC8972] and augmented in [RFC9503]. The described procedures are used for SR-MPLS paths [RFC8402] (including Segment Lists of SR-MPLS Policies [RFC9256], SR-MPLS IGP best paths, and Flexible Algorithm (Flex-Algo) paths [RFC9350]), as well as Layer-3 (L3) and Layer-2 (L2) services over the SR-MPLS paths.

STAMP requires protocol support on the Session-Reflector to process the received test packets. As a result, the received test packets need to be punted from the fast path in the data plane, and return test packets need to be generated. This limits the frequency of STAMP test packets and the ability to provide faster measurement intervals. This document adds new mechanisms to enhance the procedures for Performance Measurement using STAMP to improve the scalability of the number of STAMP sessions and the measurement interval for SR-MPLS paths by defining new measurement modes: one-way, loopback, and loopback with "timestamp and forward."

2. Conventions Used in This Document

2.1. 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.

2.2. Abbreviations

ECMP: Equal Cost Multi-Path.

HMAC: Hashed Message Authentication Code.

I2E: Ingress-To-Egress.

IHS: Ingress-To-Egress, Hop-By-Hop or Select Scope.

L2: Layer-2.

L3: Layer-3.

LSE: Label Stack Entry.

MBZ: Must be Zero.

MNA: MPLS Network Action.

MPLS: Multiprotocol Label Switching.

PSID: Path Segment Identifier.

SHA: Secure Hash Algorithm.

SID: Segment ID.

SR: Segment Routing.

SR-MPLS: Segment Routing with MPLS data plane.

SSID: STAMP Session Identifier.

STAMP: Simple Two-Way Active Measurement Protocol.

TC: Traffic Class.

TSF: Timestamp and Forward.

TTL: Time-To-Live.

VPN: Virtual Private Network.

3. Overview

For performance measurement in SR-MPLS networks, the STAMP Session-Sender and Session-Reflector use the STAMP test packets defined in [RFC8762], along with optional extensions defined in [RFC8972]. The STAMP test packets are encapsulated using an IP/UDP header, as specified in [RFC8762]. In this document, the STAMP test packets using the IP/UDP header are used for SR-MPLS networks, where the STAMP test packets are further encapsulated with an SR-MPLS header.

STAMP test packets are transmitted in performance measurement modes, including two-way, one-way, loopback, and loopback with "timestamp and forward" in SR-MPLS networks. Note that the two-way measurement mode is referenced in the STAMP process in [RFC8762] and is further described for SR-MPLS networks in this document. The other measurement modes, which are new and specifically described for SR-MPLS networks in this document, are not defined by the STAMP process in [RFC8762].

STAMP test packets are transmitted on the same path as the data traffic flow under measurement to measure the delay and packet loss experienced by the data traffic flow, using the same SR-MPLS

encapsulation as the data traffic flow. Similarly, STAMP test packets are transmitted on various transport data paths in the network to measure the delay and packet loss experienced by the traffic forwarded on those transport data paths. The STAMP test packets carry the same SR-MPLS headers as the data packets transmitted on the SR-MPLS path and on the L3 and L2 services for the data traffic forwarded on those services.

Typically, STAMP reply test packets are transmitted along an IP path between the Session-Reflector and Session-Sender. Matching the forward direction path and the return path for STAMP test packets, even for directly connected nodes, is not guaranteed. In SR-MPLS networks, it may be desired that the same path (i.e., the same set of links and nodes) between the Session-Sender and Session-Reflector be used for the STAMP test packets in both directions, for example, in an ECMP environment.

In two-way measurement mode, this is achieved by using the optional STAMP extensions for SR-MPLS, as specified in [RFC9503]. The STAMP Session-Reflector uses the return path parameters for the reply test packet from the STAMP extensions in the received Session-Sender test packet, as described in [RFC9503]. In loopback measurement mode, this is achieved by adding both the forward direction path and the return path in the SR-MPLS encapsulation of the Session-Sender test packets.

The performance measurement procedures defined in this document are used to measure both delay and packet loss in SR-MPLS networks based on the transmission and reception of STAMP test packets. The optional STAMP extensions, as defined in [RFC8972], are used for direct measurement in SR-MPLS networks.

3.1. STAMP Reference Model

The STAMP Reference Model, along with some typical measurement parameters, as defined in [RFC8972] for a STAMP session, is shown in Figure 1.

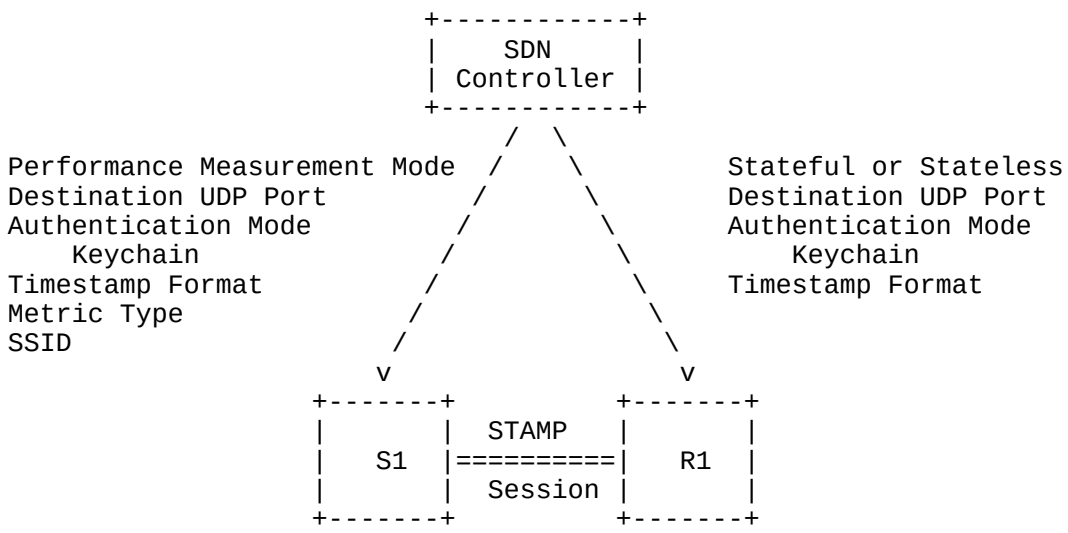


Figure 1: STAMP Reference Model

The procedure, as defined in [RFC8972], uses the two-way measurement mode.

The destination UDP port number is selected for the STAMP function as described in [RFC8762]. By default, the reflector UDP port 862 is selected as the destination UDP port for STAMP sessions [RFC8762] for SR-MPLS paths, and L3 and L2 services over the SR-MPLS paths.

The source UDP port is selected by the Session-Sender. The same or different source UDP ports may be used for different STAMP sessions.

Session-Reflector mode can be either Stateful or Stateless, as described in Section 4 of [RFC8762]. Stateless Session-Reflector mode is applicable only in two-way measurement mode.

The SSID field in the STAMP test packets [RFC8972], along with the local configuration, is used to identify the STAMP sessions.

When authentication mode is enabled for STAMP sessions, the matching Authentication Type (e.g., HMAC-SHA-256) and Keychain must be configured on both the Session-Sender and Session-Reflector [RFC8762].

Examples of the Timestamp Format include 64-bit truncated Precision Time Protocol (PTPv2) [IEEE.1588] and 64-bit Network Time Protocol (NTPv4) [RFC5905]. By default, the Session-Reflector replies using the same timestamp format as received in the Session-Sender test packet, as indicated by the "Z" flag in the Error Estimate field, as described in [RFC8762]. This behaviour can be based on the Session-Reflector's capability.

Examples of Delay Metrics are one-way delay, round-trip delay, near-end delay (forward direction), and far-end delay (backward direction), as defined in [RFC8762].

Examples of Packet Loss Metric Type are round-trip packet loss, near-end packet loss (forward direction) and far-end packet loss (backward direction), as defined in [RFC8762].

A Software-Defined Networking (SDN) controller can be used for the configuration and management of STAMP sessions, as described in [RFC8762]. The controller can also receive streaming telemetry of operational data. The YANG data model for STAMP, defined in [I-D.ietf-ippm-stamp-yang], can be used to configure Session-Senders and Session-Reflectors and to stream telemetry of operational data.

4. Two-Way Measurement Mode

As shown in Figure 2, the reference topology for two-way measurement mode, the STAMP Session-Sender S1 initiates a STAMP Session-Sender test packet, and the STAMP Session-Reflector R1 generates and transmits a reply test packet. The reply test packets are transmitted to the STAMP Session-Sender S1 on the same path (i.e., the same set of links and nodes) or on a different path in the reverse direction from the path taken towards the Session-Reflector R1.

T1 is a transmit timestamp, and T4 is a receive timestamp added by node S1. T2 is a receive timestamp, and T3 is a transmit timestamp added by node R1. All four timestamps are used by the Session-Sender to measure the round-trip delay metric as ((T4 - T1) - (T3 - T2)). Timestamps T1 and T2 are used by the Session-Sender to measure the one-way delay metric as (T2 - T1), also referred to as the near-end (forward direction) delay metric. Note that the delay value (T4 - T3), measured by the Session-Sender, is referred to as the far-end (backward direction) one-way delay metric.

The computation of the one-way delay metric requires the clocks on the Session-Sender and Session-Reflector to be synchronized using either PTPv2 or NTPv4.

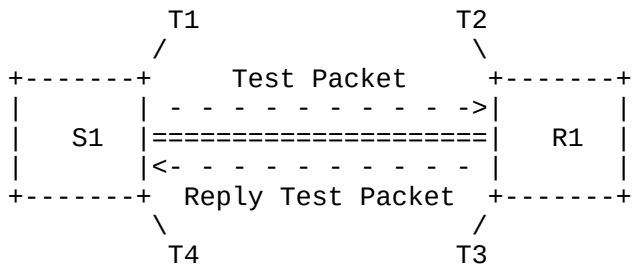


Figure 2: Reference Topology for Two-Way Measurement Mode

The nodes S1 and R1 may be connected via an SR-MPLS path [RFC8402]. The SR-MPLS path may be a Segment List (i.e., a stack of MPLS labels) of an SR-MPLS Policy [RFC9256] on node S1 (referred to as the "head-end") with a destination to node R1 (referred to as the "endpoint"), an SR-MPLS IGP best path, or an SR-MPLS IGP Flex-Algo path [RFC9350]. Additionally, a Layer-3 (L3) or Layer-2 (L2) VPN service may be carried over the SR-MPLS path between nodes S1 and R1.

4.1. Session-Sender Test Packet

The content of a Session-Sender test packet is shown in Figure 3. The payload containing the Session-Sender test packet, as defined in Section 3 of [RFC8972], is transmitted with an IP and UDP header [RFC0768].

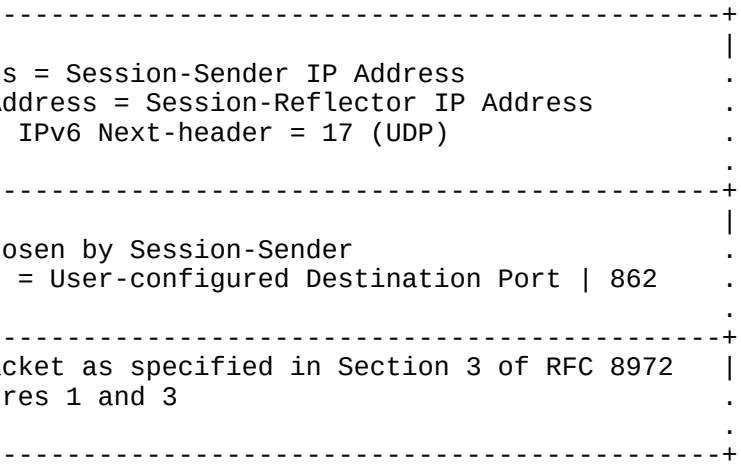


Figure 3: Content of Session-Sender Test Packet

4.2. Session-Sender Test Packet for SR-MPLS Data Plane

4.2.1. Session-Sender Test Packet for SR-MPLS Paths

An SR-MPLS Policy Candidate-Path contains one or more Segment Lists (i.e., a stack of MPLS labels) [RFC9256]. For delay measurement of an SR-MPLS Policy, the Session-Sender test packets are transmitted for every Segment List of the Candidate-Path of the SR-MPLS Policy, by creating a separate STAMP session for each Segment List.

Each SR-MPLS Segment List contains a list of 32-bit Label Stack Entries (LSE) that include a 20-bit label value, an 8-bit Time-To-Live (TTL) field, a 3-bit Traffic-Class (TC) field, and a 1-bit End-Of-Stack (S) field.

The content of a Session-Sender test packet for an SR-MPLS path, using the SR-MPLS encapsulation of the data traffic transmitted over the path, is shown in Figure 4.

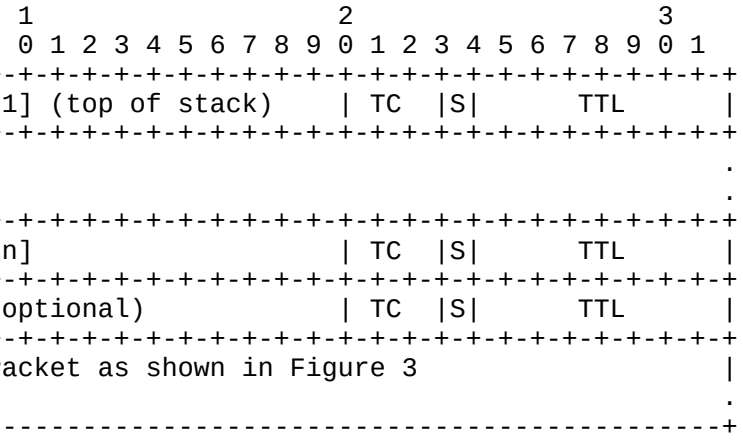


Figure 4: Content of Session-Sender Test Packet for SR-MPLS Path

The head-end node address of the SR-MPLS Policy is used as the Source Address in the IP header of the Session-Sender test packet. The endpoint address of the SR-MPLS Policy is used as the Destination Address in the IP header of the Session-Sender test packet.

In the case of Penultimate Hop Popping (PHP), the MPLS header is removed by the penultimate node. In this case, the Destination Address in the IP header ensures that the test packets reach the Session-Reflector at the SR-MPLS Policy endpoint.

In the case of an SR-MPLS Policy with Color-Only Destination Steering, where the endpoint is an unspecified address (the null endpoint is 0.0.0.0 for IPv4, as defined in Section 8.8.1 of [RFC9256], the loopback address from the range 127/8 for IPv4 is used as the Destination Address in the IPv4 header of the Session-Sender test packets, instead of using the Session-Reflector Address. In this case, the SR-MPLS encapsulation ensures that the Session-Sender test packets reach the SR-MPLS Policy endpoint, for example, by adding the Prefix SID label of the SR-MPLS Policy endpoint to the Segment List. In addition, the Session-Sender test packets carry "Destination Node IPv4 or IPv6 Address" STAMP TLV as defined in [RFC9503] to identify the intended Session-Reflector IPv4 address.

The Path Segment Identifier (PSID) [RFC9545] of an SR-MPLS Policy (for the Segment List or for the Candidate-Path) is added to the Segment List of the STAMP test packets when the egress node supports PSID processing.

Each IGP Flex-Algo path in SR-MPLS networks [RFC9350] has Prefix SID labels advertised by the nodes. For delay measurement of SR-MPLS IGP Flex-Algo paths, the Session-Sender test packets carry the Flex-Algo Prefix SID labels of the Session-Sender and Session-Reflector in the MPLS header for that IGP Flex-Algo path under measurement.

Similarly, each IGP best path in SR-MPLS networks [RFC9350] has Prefix SID labels advertised by the nodes. For delay measurement of SR-MPLS IGP best paths, the Session-Sender test packets carry the IGP Prefix SID labels of the Session-Sender and Session-Reflector in the MPLS header for that IGP best path under measurement.

4.2.2. Session-Sender Test Packet for Layer-3 Services over SR-MPLS Path

For delay measurement of the L3 service over an SR-MPLS path, the SR-MPLS label stack of the data packets transmitted over the L3 service, including the L3VPN label (advertised by the Session-Reflector), is used to encapsulate the Session-Sender test packets, as shown in Figure 5.

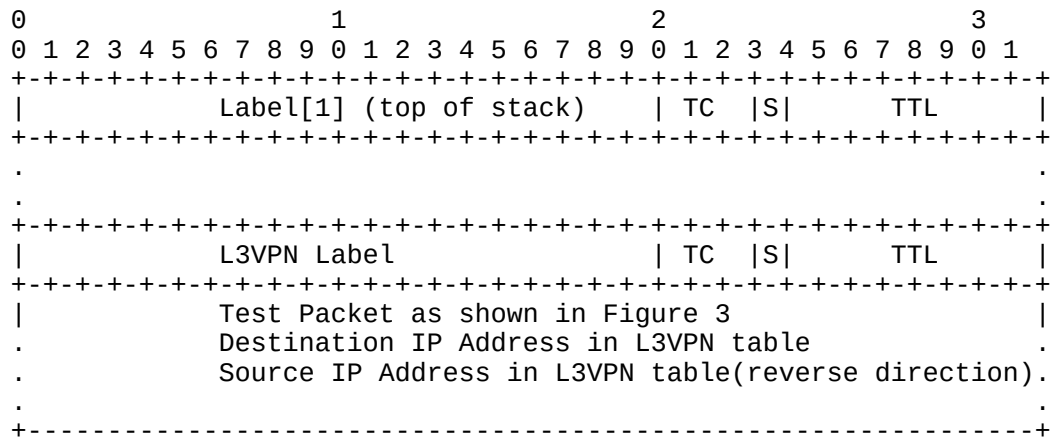


Figure 5: Content of Session-Sender Test Packet for L3 Service over SR-MPLS Path

An IP header, as shown in Figure 3, is added to the Session-Sender test packets after the SR-MPLS encapsulation. The Destination Address in the IP header is reachable via the IP table lookup associated with the L3VPN label added for the L3 service on the Session-Reflector. The Source Address in the IP header of the Session-Sender test packets is reachable via the IP table lookup associated with the L3 service in the reverse direction.

4.2.3. Session-Sender Test Packet for Layer-2 Services over SR-MPLS Path

For delay measurement of the L2 service over an SR-MPLS path, the SR-MPLS label stack of the data packets transmitted over the L2 service, including the L2VPN label (as advertised by the Session-Reflector), is used to encapsulate the Session-Sender test packets, as shown in Figure 6.

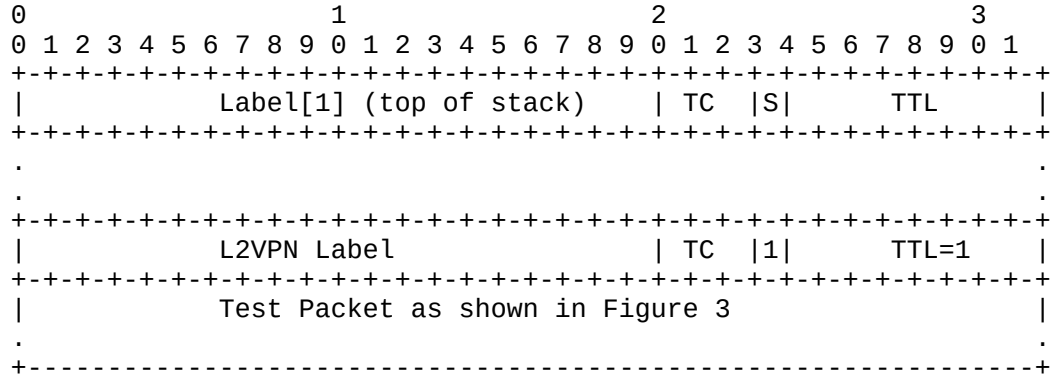


Figure 6: Content of Session-Sender Test Packet for L2 Service over SR-MPLS Path

The L2VPN label is added with a TTL value of 1 to punt the Session-Sender test packet from the data plane to the CPU or the slow path on the Session-Reflector for STAMP processing.

An IP header, as shown in Figure 3, is added to the Session-Sender test packets after the MPLS header. This header contains the Session-Sender Address as the Source Address and the Session-Reflector Address as the Destination Address.

4.3. Session-Reflector Test Packet

In two-way measurement mode, the Session-Reflector test packets are transmitted on the same SR-MPLS path (i.e., the same set of links and nodes) in the reverse direction to the Session-Sender to perform accurate two-way delay measurement.

The Session-Reflector decapsulates the SR-MPLS header, if present, from the received Session-Sender test packets. The Session-Reflector test packet is generated using the information from the received IP/UDP header of the Session-Sender test packet, as shown in Figure 7.

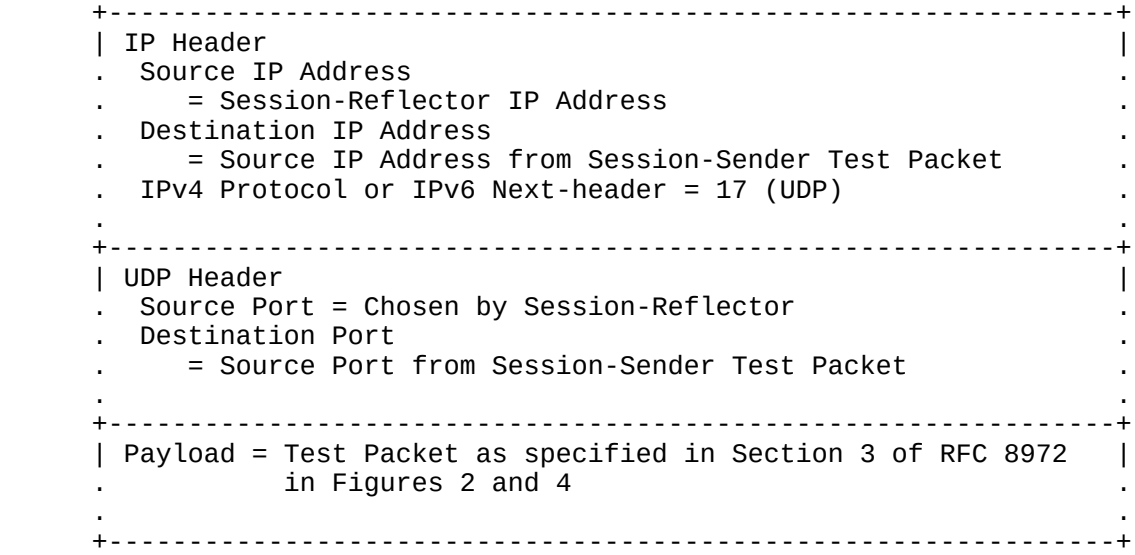


Figure 7: Content of Session-Reflector Test Packet

The payload contains the Session-Reflector test packet defined in Section 3 of [RFC8972].

For SR-MPLS paths, the Session-Sender uses the Segment List sub-TLV in the Return Path TLV defined in [RFC9503] to request that the Session-Reflector transmit the reply test packet on a specific SR-MPLS return path. Examples of specific SR-MPLS return paths include: the reverse SR-MPLS path associated with the forward direction SR-MPLS path, the Binding SID of the reverse SR-MPLS Policy, or the Prefix SID of the Session-Sender.

For SR-MPLS IGP Flex-Algo paths, the Session-Sender uses the Segment List sub-TLV in the Return Path TLV defined in [RFC9503] to request that the Session-Reflector transmit the reply test packet on the same SR-MPLS IGP Flex-Algo path in the reverse direction.

5. One-Way Measurement Mode

As shown in Figure 8, the reference topology for one-way measurement mode, the STAMP Session-Sender S1 initiates a Session-Sender test packet. The STAMP Session-Reflector does not transmit reply test packets upon receiving the Session-Sender test packets.

T1 is a transmit timestamp added by node S1, and T2 is a receive timestamp added by node R1. Timestamps T1 and T2 are used by the Session-Reflector to measure the one-way delay metric as (T2 - T1).

The computation of the one-way delay metric requires the clocks on the Session-Sender and Session-Reflector to be synchronized using either PTPv2 or NTPv4.

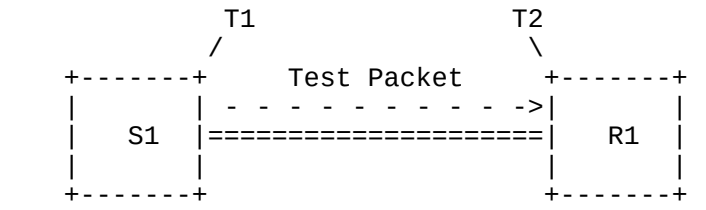


Figure 8: Reference Topology for One-Way Measurement Mode

5.1. STAMP Reference Model Considerations for One-Way Measurement Mode

In one-way measurement mode, for SR-MPLS paths, and L3 and L2 services over the SR-MPLS paths, the Session-Sender test packets, as defined in Section 4 for STAMP sessions, are transmitted.

The Stateful mode of the Session-Reflector [RFC8762] is used as the Session-Receiver in one-way measurement mode. The SSID field in the received Session-Sender test packets [RFC8972] at the Session-Reflector, along with the local configuration, is used to identify the STAMP sessions that use one-way measurement mode on the Stateful Session-Reflector.

Typically, a different destination UDP port is selected for one-way measurement mode than the one used by the STAMP Session-Reflector for two-way measurement mode. When the same STAMP Session-Reflector UDP port is selected for one-way measurement mode, the Session-Sender requests, in the test packets, that the Session-Reflector not transmit reply test packets. To achieve this, it uses the "No Reply Requested" flag in the Control Code Sub-TLV within the Return Path TLV defined in [RFC9503].

6. Loopback Measurement Mode

As shown in Figure 9, the reference topology for loopback measurement mode, the STAMP Session-Sender S1 initiates a Session-Sender test packet to measure the loopback delay of a bidirectional path. At the STAMP Session-Reflector, the received Session-Sender test packets are not punted out of the fast path in the data plane (i.e., to the CPU or the slow path) but are simply forwarded. In other words, the Session-Reflector does not perform STAMP functions or generate Session-Reflector test packets.

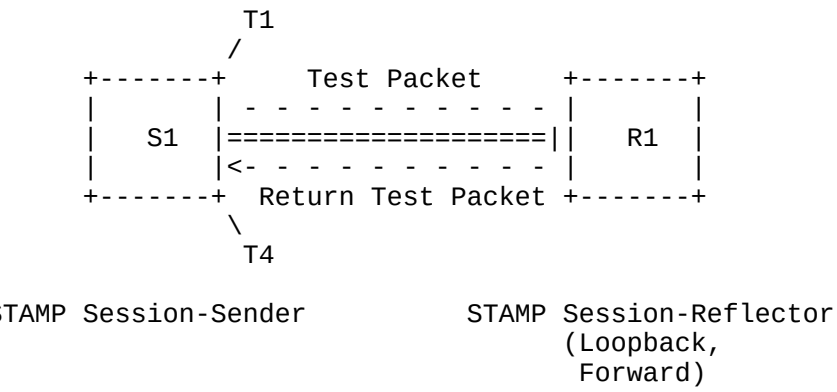


Figure 9: Reference Topology for Loopback Measurement Mode

The Session-Sender retrieves the timestamp T1 from the received Session-Sender test packet and collects the receive timestamp T4 locally. Both timestamps, T1 and T4, are used to measure the loopback delay metric as (T4 - T1). The loopback delay includes the STAMP test packet processing delay on the Session-Reflector component. The Session-Reflector processing delay component includes only the time required to loop the STAMP test packet from the incoming interface to the outgoing interface in the data plane. The Session-Reflector does not timestamp the test packets and, therefore, does not require timestamping capability.

6.1. STAMP Reference Model Considerations for Loopback Measurement Mode

The Session-Sender test packets are encapsulated with the forward direction SR-MPLS path and transmitted to the Session-Reflector, as defined in Section 4 for STAMP sessions. An IP header is added for the return path in the Session-Sender test packets, setting the Destination Address equal to the Session-Sender address, as shown in Figure 10, to return the test packets to the Session-Sender.

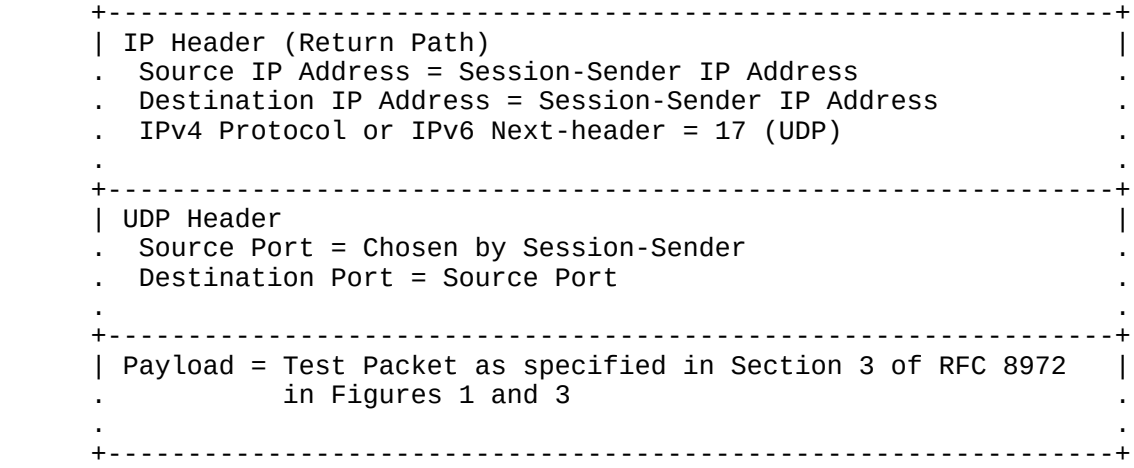


Figure 10: Content of Session-Sender Return Test Packet in Loopback Measurement Mode

The Session-Reflector does not perform the STAMP process, as the loopback function simply processes the encapsulation including the IP and SR-MPLS headers (but does not process the UDP header) to forward the received Session-Sender test packet to the Session-Sender without STAMP modifications, as defined in [RFC8762].

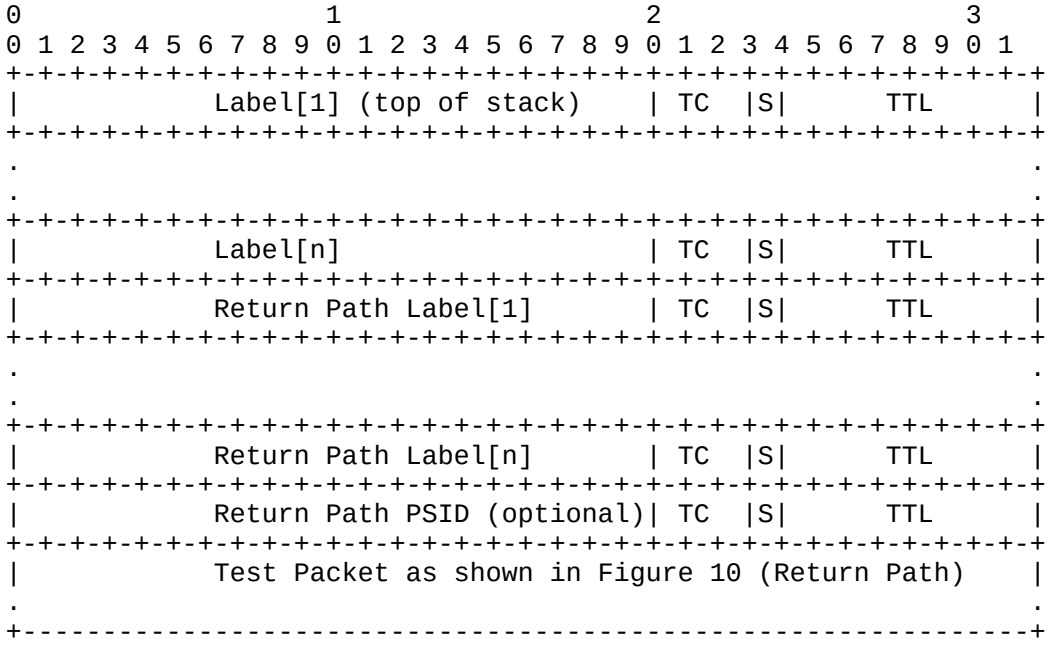
The SSID field in the received Session-Sender test packets [RFC8972] at the Session-Sender, along with the local configuration, is used to identify the STAMP sessions that use loopback measurement mode.

The Session-Sender sets the destination UDP port to the UDP port it uses to receive the return Session-Reflector test packets (other than destination UDP port 862, which is used by the Session-Reflector). The same UDP port is used as both the destination and source UDP port in the Session-Sender test packets, as shown in Figure 10.

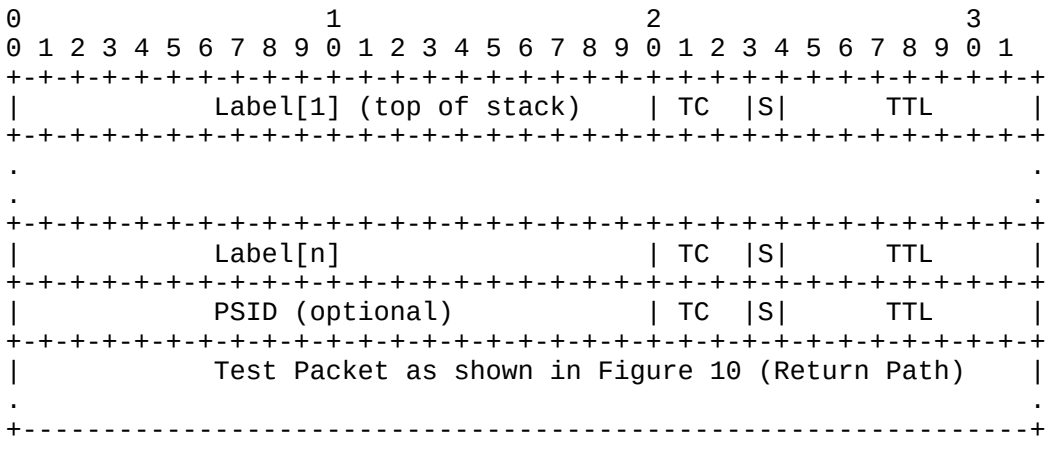
At the Session-Sender, the ’Session-Sender Sequence Number,’ ’Session-Sender Timestamp,’ ’Session-Sender Error Estimate,’ and ’Session-Sender TTL’ fields are set to zero in the transmitted Session-Sender test packets and are ignored in the received test packets.

6.2. Loopback Measurement Mode for SR-MPLS Paths

In loopback measurement mode for SR-MPLS paths, the Session-Sender test packet carries either the Segment List of the forward direction path only or both the forward direction and return paths in the MPLS header, as specified in [RFC8403], as shown in Figure 11.



Example 1: Encapsulation Using SR-MPLS Return Path



Example 2: Encapsulation Using IP Return Path

Figure 11: Content of Session-Sender Test Packet in Loopback Measurement Mode for SR-MPLS Path

In the case of an SR-MPLS Policy using Penultimate Hop Popping (PHP), the Session-Sender ensures that the STAMP test packets reach the SR-MPLS Policy endpoint, for example, by adding the Prefix SID label of the SR-MPLS Policy endpoint to the Segment List of the forward direction path.

The IP header for the return path of the Session-Sender test packets is added, setting the Destination Address to the Session-Sender's address.

6.2.1. SR-MPLS Return Path

The Session-Sender test packets, in the SR-MPLS label stack, carry the return path in addition to the forward direction path, as shown in Example 1 of Figure 11. For example, they carry the SR-MPLS label stack of the Segment List of the associated reverse Candidate-Path, the Binding SID label of the reverse SR-MPLS Policy, or the SR-MPLS Prefix SID label of the Session-Sender. The Binding SID of the reverse SR-MPLS Policy can be configured on the Session-Sender using an SDN controller, for example.

For SR-MPLS IGP Flex-Algo paths, the Session-Sender test packets carry the SR-MPLS Prefix SID label of the Session-Sender on the same SR-MPLS IGP Flex-Algo path in the reverse direction.

The PSID is added to the Segment List of the Session-Sender test packets for the SR-MPLS return path when the head-end node supports PSID allocation.

6.2.2. IP Return Path

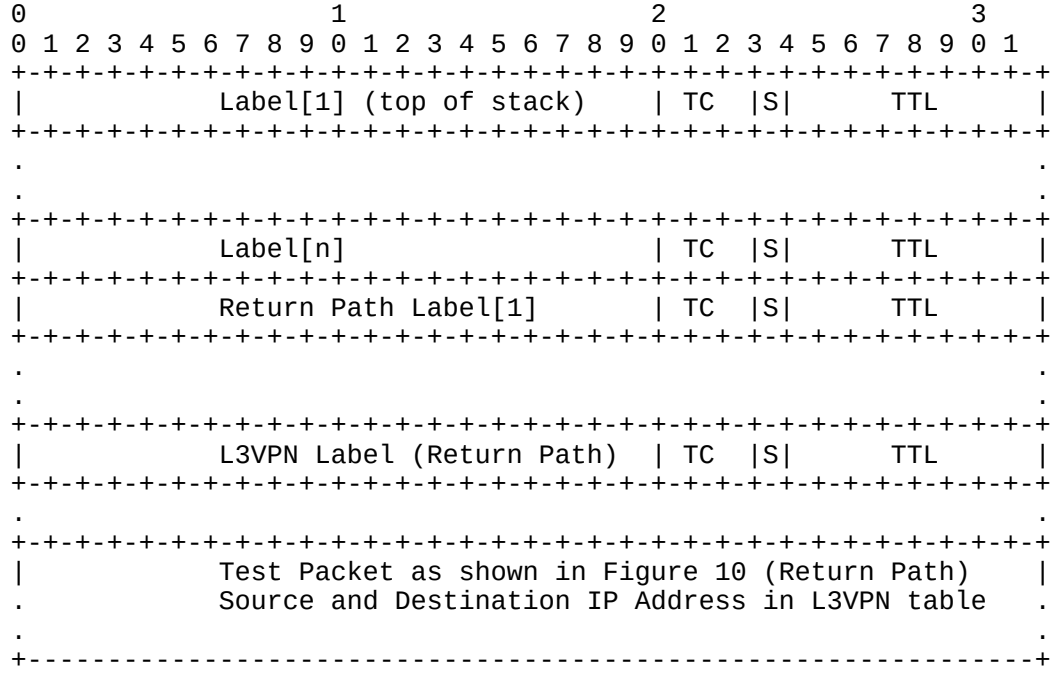
The Session-Sender test packets, in the MPLS header, carry only the SR-MPLS label stack of the forward direction path, as shown in Example 2 of Figure 11.

The Session-Reflector decapsulates the MPLS header and forwards the test packet using the IP header back to the Session-Sender.

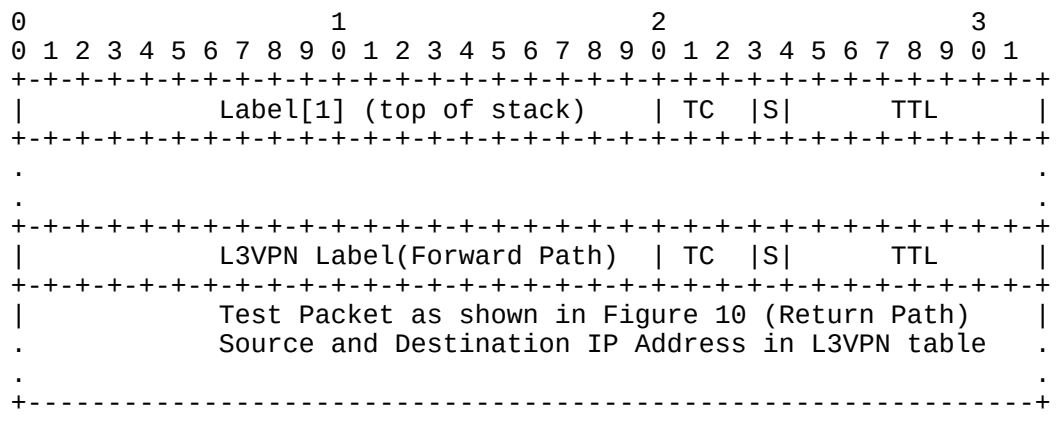
The optional PSID added to the Session-Sender test packet is for the SR-MPLS forward direction path and is allocated by the Session-Reflector.

6.3. Loopback Measurement Mode for Layer-3 Services over SR-MPLS Path

In loopback measurement mode for the L3 service over an SR-MPLS path, the SR-MPLS label stack of the data packets transmitted over the L3 service is used to encapsulate the Session-Sender test packets, as shown in Figure 12.



Example 1: Encapsulation Using SR-MPLS Return Path



Example 2: Encapsulation Using IP Return Path

Figure 12: Content of Session-Sender Test Packet in Loopback Measurement Mode for L3 Service over SR-MPLS Path

The IP header for the return path of the Session-Sender test packets is added, setting the Destination Address to the Session-Sender address. The Destination Address added in the IP header for the return path MUST be reachable via the IP table lookup associated with the L3VPN label added in the test packets.

6.3.1. SR-MPLS Return Path

The SR-MPLS label stack, except for the L3VPN label (advertised by the Session-Reflector) of the forward direction L3 service, is added in the Session-Sender test packets. In addition, the SR-MPLS label stack, including the L3VPN label for the reverse direction L3 service, is also added in the Session-Sender test packets.

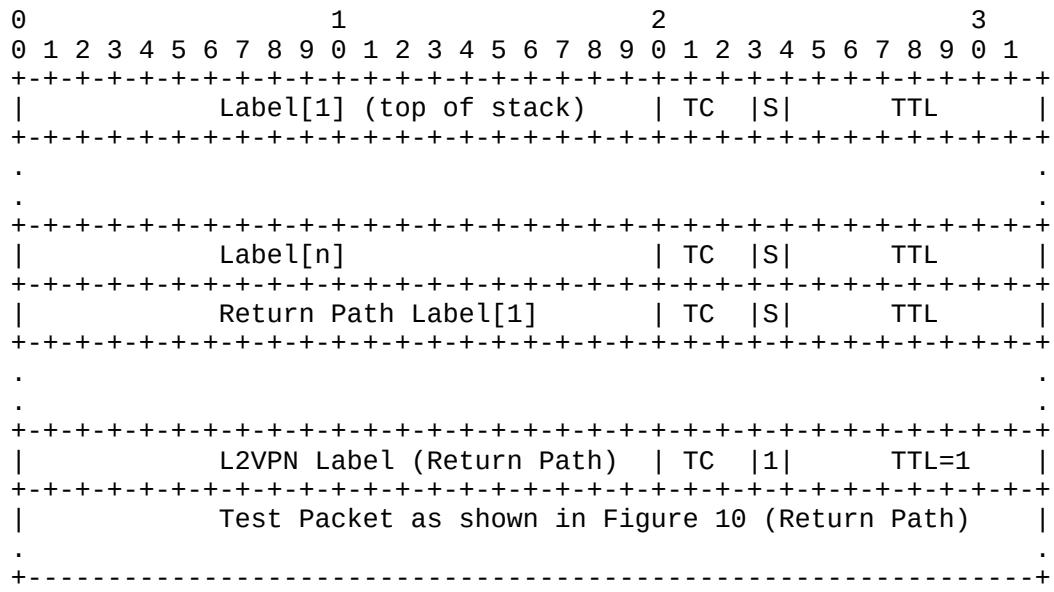
6.3.2. IP Return Path

The SR-MPLS label stack, including the L3VPN label (advertised by the Session-Reflector) for the forward direction L3 service, is added to the Session-Sender test packets.

The Session-Reflector decapsulates the MPLS header and forwards the Session-Sender test packet using the IP header back to the Session-Sender, after adding SR-MPLS encapsulation for the reverse direction L3 service.

6.4. Loopback Measurement Mode for Layer-2 Services over SR-MPLS Path

In loopback measurement mode for the L2 service over an SR-MPLS path, the SR-MPLS label stack of the data packets transmitted over the L2 service is used to encapsulate the Session-Sender test packets, as shown in Figure 13.



Encapsulation Using SR-MPLS Return Path

Figure 13: Content of Session-Sender Test Packet in Loopback Measurement Mode for L2 Service over SR-MPLS Path

The IP header for the return path is added to the Session-Sender test packets, and the Destination Address set to the Session-Sender address.

6.4.1. SR-MPLS Return Path

The SR-MPLS label stack, except for the L2VPN label (advertised by the Session-Reflector) for the forward direction L2 service, is added to the Session-Sender test packets. In addition, the SR-MPLS label stack, including the L2VPN label for the reverse direction L2 service, is added to the Session-Sender test packets with a TTL value of 1 to punt the test packets from the data plane to the CPU or the slow path on the Session-Sender for STAMP processing.

6.4.2. IP Return Path

The STAMP test packets that do not use the SR-MPLS return path are not supported.

7. Loopback Measurement Mode with Timestamp and Forward

As shown in Figure 14, the reference topology for "loopback measurement mode with timestamp and forward", the STAMP Session-Sender S1 initiates a Session-Sender test packet in loopback measurement mode. The "timestamp and forward" is used to optimize the "operations of punting the test packet and generating the return test packet" on the STAMP Session-Reflector, as timestamping is implemented in the fast path in the data plane. This helps achieve a higher number of STAMP sessions and faster measurement intervals.

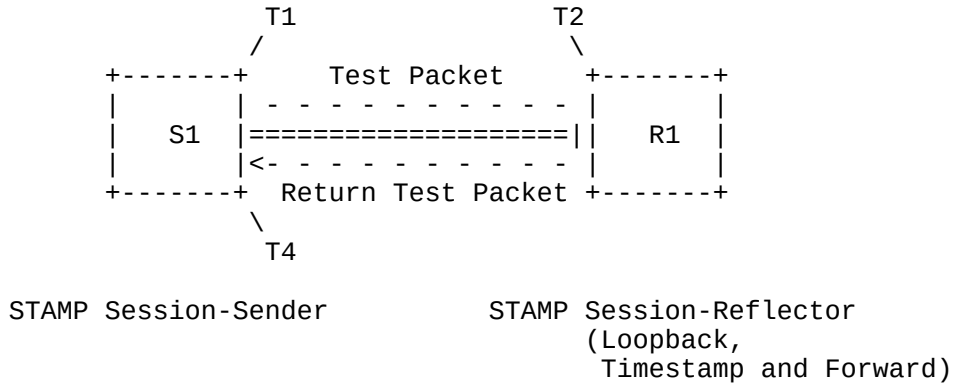


Figure 14: Reference Topology for Loopback Measurement Mode with Timestamp and Forward

The Session-Sender retrieves the timestamps T1 and T2 from the received Session-Sender test packet and collects the receive timestamp T4 locally. Timestamps T1 and T2 are used by the Session-Sender to measure the one-way delay metric as (T2 - T1). Timestamps T1 and T4 are used by the Session-Sender to measure the loopback delay metric as (T4 - T1).

The Session-Sender adds the transmit timestamp (T1) to the payload of the Session-Sender test packet. The Session-Reflector adds the receive timestamp (T2) to the payload of the received test packet in the fast path in the data plane, without punting the test packet (e.g., to the CPU or the slow path) for STAMP packet processing.

7.1. Loopback Measurement Mode with Timestamp and Forward Network Action for SR-MPLS Data Plane

The MPLS Network Action (MNA) Sub-Stack defined in [I-D.ietf-mpls-mna-hdr] is used for SR-MPLS paths for the timestamp and forward network action for STAMP test packets. A new MNA opcode (value MNA.TSF) is defined for the "Timestamp and Forward Network Action."

In the Session-Sender test packets for SR-MPLS paths, the MNA Sub-Stack with the opcode MNA.TSF is added in the MPLS header, as shown in Figure 15, to collect the timestamp in the "Receive Timestamp" field in the payload of the STAMP test packet from the Session-Reflector. The Ingress-to-Egress (I2E), Hop-By-Hop (HBH), or Select scope (IHS) field (IHS) is set to "I2E" when the return path is IP/UDP. The Network Action Sub-Stack Length (NASL) and Network Action Length (NAL) are set as defined in [I-D.ietf-mpls-mna-hdr]. The U flag is set to value 0 (to skip the network action) as defined in [I-D.ietf-mpls-mna-hdr] and forward the test packet (and not drop the packet).

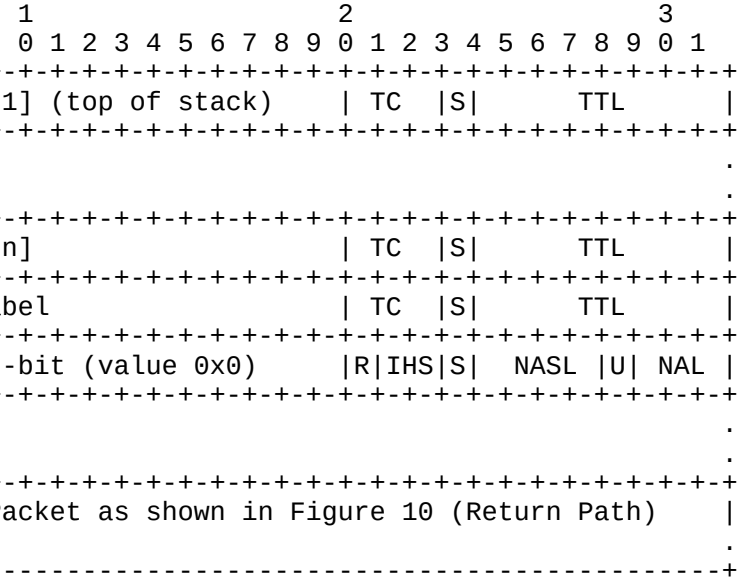


Figure 15: Content of Session-Sender Test Packet in Loopback Measurement Mode with MNA.TSF for SR-MPLS Paths

The SR-MPLS label stack of the return path can be added after the MNA Sub-Stack to receive the return test packet on a specific path, as described in the loopback measurement for SR-MPLS paths in this document. The IHS scope is set to "Select" in this case.

When a Session-Reflector receives a test packet with the MNA Sub-Stack with opcode MNA.TSF, it timestamps the test packet payload at a fixed offset, pops the MNA Sub-Stack (after completing any other network actions), and forwards the test packet as defined in the loopback measurement mode for SR-MPLS paths in this document.

7.1.1. Timestamp and Forward Network Action Assignment and Node Capability

A new MPLS Network Action opcode is defined, called "Timestamp and Forward Network Action (MNA.TSF)." The opcode MNA.TSF is locally configured on the Session-Reflector node with a value from the "Private Use Range: 111-126."

The timestamp format (e.g., 64-bit PTPv2 or NTPv4), to be added to the Session-Sender test packet payload, is also locally configured for the opcode MNA.TSF. The offset in the Session-Sender test packet payload (e.g., STAMP test packet in Figure 5 of [RFC8762] with an offset of 16 bytes for Receive Timestamp) is similarly locally configured for the opcode MNA.TSF.

The Session-Sender needs to know if the Session-Reflector is capable of processing the "Timestamp and Forward" network action to avoid dropping the test packets. The signaling extension for this capability exchange or its configuration through local settings is outside the scope of this document.

8. Packet Loss Measurement in SR-MPLS Networks

The procedure described for two-way measurement mode, allows for round-trip, near-end (forward direction), and far-end (backward direction) inferred packet loss measurement. However, this provides only an approximate view of the data packet loss.

The loopback measurement mode and loopback measurement mode with "timestamp and forward", defined in this document, allow only round-trip packet loss measurement.

Note that the packet loss measurement does not require the clocks on the Session-Sender and Session-Reflector to be synchronized using either PTPv2 or NTPv4.

9. Direct Measurement in SR-MPLS Networks

The STAMP "Direct Measurement" TLV (Type 5), defined in [RFC8972], is used in SR-MPLS networks for data packet loss measurement. The STAMP test packets with this TLV are transmitted using the procedure described for two-way measurement mode using STAMP test packets and collecting the Session-Sender transmit counters and Session-Reflector receive and transmit counters of the data packet flows for direct measurement.

The PSID carried in the data packets is used to measure received data packets (for the receive traffic counter) on the associated SR-MPLS path on the Session-Reflector.

In the case of L3 and L2 services in SR-MPLS networks, the associated SR-MPLS service labels are used to measure received data packets (for the receive traffic counters) on the Session-Reflector.

In loopback measurement mode and loopback measurement mode with "timestamp and forward", defined in this document, direct measurement is not applicable.

10. ECMP Measurement in SR-MPLS Networks

The Segment List of an SR-MPLS path can have ECMP paths between the source and transit nodes, between transit nodes, and between transit and destination nodes. The usage of a node SID [RFC8402] by the Segment List of an SR-MPLS path can result in ECMP paths. In addition, the usage of an Anycast SID [RFC8402] by the Segment List of an SR-MPLS path can result in ECMP paths via transit nodes that are part of that anycast group. The STAMP test packets are transmitted to traverse different ECMP paths to measure the delay of each ECMP path of a Segment List.

For SR-MPLS path delay measurement, different entropy label values [RFC6790] are used in the Session-Sender and Session-Reflector test packets to take advantage of the hashing function in the forwarding plane to influence the ECMP path taken by them.

In the IPv4 header of the Session-Sender and Session-Reflector test packets, different values of the Destination Address from the range 127/8 are used to traverse different IPv4 ECMP paths as described in Section 2.1 of [RFC8029]. In this case, the Session-Sender test packets carry "Destination Node IPv4 or IPv6 Address" STAMP TLV as defined in [RFC9503] to identify the intended Session-Reflector IP address.

The considerations for loss measurement for different ECMP paths of an SR-MPLS path are outside the scope of this document.

11. STAMP Session State

The threshold-based notification for the delay and packet loss metrics is not generated if the delay and packet loss metrics do not change significantly. For unambiguous monitoring, the controller needs to distinguish whether the STAMP session is active but delay and packet loss metrics do not cross the thresholds, or if the STAMP session has failed and is not transmitting or receiving test packets.

The STAMP session state monitoring allows the node to determine whether the performance measurement test is active, idle, or failed. The STAMP session state is notified as idle when the Session-Sender is not transmitting test packets. The STAMP session state is initially notified as active when the Session-Sender is transmitting test packets and as soon as one or more reply test packets are received at the Session-Sender.

The STAMP session state is notified as failed when N consecutive reply test packets are not received at the Session-Sender after the STAMP session state is notified as active, where N (the consecutive packet loss count) is a locally provisioned value. In this case, the failed state of the STAMP session on the Session-Sender also indicates the connectivity failure of the SR-MPLS path, or L3/L2 service over the SR-MPLS path, where the STAMP session was active.

12. Additional STAMP Test Packet Processing Rules

12.1. TTL

The TTL field in the IPv4 and MPLS headers of the Session-Sender and Session-Reflector test packets is set to 255, as per the Generalized TTL Security Mechanism (GTSM) [RFC5082].

12.2. IPv6 Hop Limit

The Hop Limit (HL) field in all IPv6 headers of the Session-Sender and Session-Reflector test packets is set to 255, as per the Generalized TTL Security Mechanism (GTSM) [RFC5082].

12.3. Router Alert Option

The Router Alert IP option (RAO) [RFC2113] is not required in the Session-Sender and Session-Reflector test packets to punt the STAMP test packets from the data plane to the CPU or the slow path.

12.4. IPv6 Flow Label

The Flow Label field in the IPv6 header of the Session-Sender test packets is set to the value used by the data packets for the IPv6 traffic flow being measured by the Session-Sender.

The Session-Reflector uses the Flow Label value received in the IPv6 header of the Session-Sender test packet for the reply test packet, which can be based on a local policy.

12.5. UDP Checksum

For IPv4 STAMP test packets, where the local processor, after adding the timestamp, is not capable of re-computing the UDP checksum or adding a checksum complement [RFC7820], the Session-Sender and Session-Reflector set the UDP checksum value to 0 [RFC8085].

For IPv6 STAMP test packets, where the local processor, after adding the timestamp, is not capable of re-computing the UDP checksum or adding a checksum complement [RFC7820], the Session-Sender and Session-Reflector use the procedure defined in [RFC6936] for the UDP checksum (with the value set to 0) for UDP ports used in STAMP sessions, which can be based on a local policy.

13. Implementation Status

Editorial note: Please remove this section prior to publication.

13.1. Cisco Implementation

The following Cisco routing platforms running the IOS-XR operating system have participated in interoperability testing for one-way, two-way and loopback measurement modes for SR-MPLS:

* Cisco 8000 (based on Cisco Silicon One ASIC)

* Cisco ASR9904 with Lightspeed linecard and Tomahawk linecard

* Cisco NCS5500 (based on Broadcom Jericho1 ASIC)

* Cisco NCS5700 (based on Broadcom Jericho2 ASIC)

13.2. Teaparty Implementation

An open-source implementation of the Simple Two-Way Active Measurement Protocol [RFC8762] is available in Teaparty.

https://github.com/cerfcast/teaparty

An implementation of the solution defined in [RFC9503] is available at the following location:

https://github.com/cerfcast/teaparty/commit/393abf9357a6c2439877d9bcf2dc426dd89c7158

The features implemented are:

1. Destination Node Address TLV.

2. Return Path TLV.

There is also support for these TLVs in the Wireshark dissector:

https://github.com/cerfcast/teaparty/commit/fb74e2e02396e9bb3ead017e8d9a0c187e3573e2

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14. Operational and Manageability Considerations

The operational considerations described in Section 5 of [RFC8762] and the manageability considerations described in Section 9 of [RFC8402] apply to this specification.

Various statistics for one-way (near-end, far-end), round-trip, and loopback delay metrics (such as, average delay, minimum delay, maximum delay, and delay-variance) as well as for one-way (near-end, far-end) or round-trip packet loss metrics (such as, percentage loss and consecutive packets lost) can be computed using the performance measurement procedures described in this document. Operator alerts are generated for the anomaly detection when delay or loss metrics cross user-configured thresholds.

When STAMP sessions are created for the Segment Lists of the SR-MPLS Policies, the scalability regarding the number of STAMP sessions needs to be carefully considered.

15. Security Considerations

The security considerations specified in [RFC8762], [RFC8972], and [RFC9503] also apply to the procedures described in this document.

The use of HMAC-SHA-256 in authenticated mode protects the data integrity of the STAMP test packets. The message integrity protection using HMAC, as defined in Section 4.4 of [RFC8762], can be used with the procedures described in this document.

STAMP uses a well-known UDP port number that could become a target of Denial of Service (DoS) attacks or could be used to aid in on-path attacks. Thus, the security considerations and measures to mitigate the risk of such attacks, as documented in Section 6 of [RFC8545], equally apply to the procedures described in this document.

The procedures defined in this document are intended for deployment in a single network administrative domain. As such, the Session-Sender address, Session-Reflector address, and the forward direction and return paths are provisioned by the operator for the STAMP session. It is assumed that the operator has verified the integrity of the forward direction and return paths of the STAMP test packets.

When using the procedures defined in [RFC6936], the security considerations specified in [RFC6936] also apply.

The security considerations specified in [I-D.ietf-mpls-mna-hdr] are also applicable to the procedures for the SR-MPLS data plane defined in this document.

16. IANA Considerations

This document does not require any IANA action.

17. References

17.1. Normative References

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