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MPLS Forwarding Benchmarking Methodology for IP Flows

Abstract

This document describes a methodology specific to the benchmarking of Multiprotocol Label Switching (MPLS) forwarding devices, limited to the most common MPLS packet forwarding scenarios and delay measurements for each, considering IP flows. It builds upon the tenets set forth in RFC 2544, RFC 1242, and other IETF Benchmarking Methodology Working Group (BMWG) efforts. This document seeks to extend these efforts to the MPLS paradigm.

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1. Introduction

Over the past several years, there has been an increase in the use of MPLS as a forwarding architecture in new and existing network designs. MPLS, defined in [RFC3031], is a foundation technology and the basis for many advanced technologies such as Layer 3 MPLS VPNs, Layer 2 MPLS VPNs, and MPLS Traffic Engineering.

However, there is no standard method defined to compare and contrast the foundational MPLS packet forwarding capabilities of network devices. This document proposes a methodology using common criteria (such as throughput, latency, frame-loss rate, system recovery, reset, etc.) to evaluate MPLS forwarding of any implementation.

2. Document Scope

The benchmarking methodology principles outlined in RFC 2544 [RFC2544] are independent of forwarding techniques; however, they don't fully address MPLS benchmarking. The workload on network forwarding device resources that MPLS forwarding places is different from that of IP forwarding; therefore, MPLS forwarding benchmarking specifics are desired.

The purpose of this document is to describe a methodology specific to the benchmarking of MPLS forwarding devices. The methods described are limited in scope to the most common MPLS packet forwarding scenarios and corresponding performance measurements in a laboratory setting. It builds upon the tenets set forth in RFC 2544 [RFC2544], RFC 1242 [RFC1242], and other IETF Benchmarking Methodology Working Group (BMWG) efforts. In other words, this document is not a replacement for, but a complement to, RFC 2544.

This document focuses on the MPLS label stack [RFC3032] that has only one entry, as it is the fundamental of MPLS forwarding. It is expected that future documents may cover the benchmarking of MPLS applications such as Layer 3 VPN (L3VPN) [RFC4364], Layer 2 VPN (L2VPN) [RFC4664], Fast ReRoute [RFC4090], etc., which require more than one entry in the MPLS label stack.

Moreover, to address the majority of current deployments' needs, this document focuses on having IP packets as the MPLS payload. In other words, label distribution for IP Forwarding Equivalence Class (FEC) [RFC3031] is prescribed (see Section 4.1.3) by this document. It is expected that future documents may focus on having non-IP packets as the MPLS payload.

Note that the presence of an MPLS label stack does not require the length of MPLS payload (which is an IP packet, per this document) to be changed; hence, the effective maximum size of a frame can increase by Z octets (where $Z = 4 \times \text{number of label stack entries}$), as observed in current deployments. This document focuses on benchmarking such a scenario.

3. Key Words To Reflect Requirements

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 BCP 14, RFC 2119 [RFC2119]. RFC 2119 defines the use of these key words to help make the intent of Standards Track documents as clear as possible. While this document uses these keywords, this document is not a Standards Track document.

4. Test Methodology

The set of methodologies described in this document will use the topology described in this section. An effort has been made to exclude superfluous equipment needs such that each test can be carried out with a minimal number of devices. Figure 1 illustrates the sample topology in which the Device Under Test (DUT) is connected to the test ports on the test tool in accord with Figure 1 of RFC 2544.

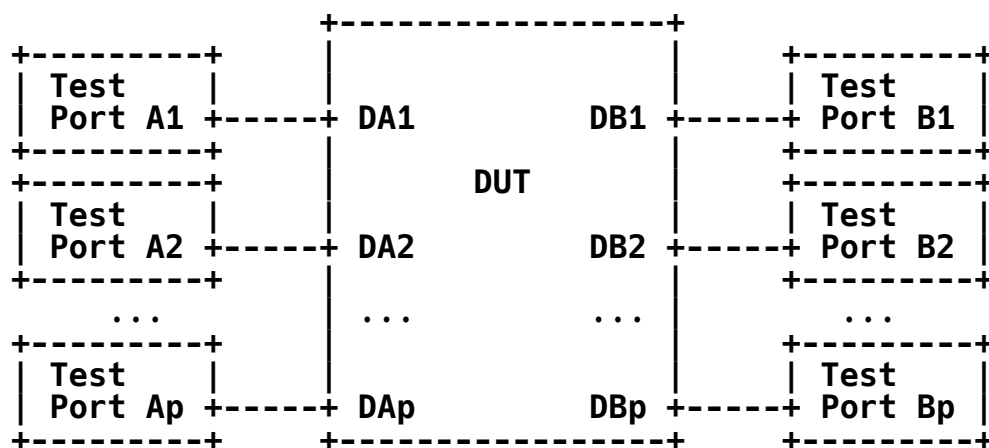


Figure 1: Topology for MPLS Forwarding Benchmarking

A represents a Tx-side Module of the test tool, whereas B represents an Rx-side Module of the same test tool. Of course, the suffixed numbers (1, 2, ..., p) represent ports on a Module.

Similarly, DA represents an Rx-side Module of the DUT, whereas DB represents a Tx-side Module. The suffixed numbers (1, 2, ..., p) represent ports on a Module.

p = the number of {DA, DB} pair ports on the DUT. It is determined by the maximum unidirectional forwarding throughput of the DUT and the load capacity of the port media (e.g., interface) connecting the DUT to the test tool.

For example, if the DUT's maximum forwarding throughput is 100 frames per second (fps) and the load capacity of the port media (e.g., interface) is 50 fps, then $p \geq 2$ is needed to sufficiently test the maximum frame forwarding.

The exact throughput is a measured quantity obtained through testing. Throughput may vary depending on the number of ports used and other factors. The number of ports (p) used SHOULD be reported. Please see "Test Setup" in Section 6. Following Figure 1 from Section 6 of RFC 2544 is recommended.

4.1. Test Considerations

This methodology assumes a full-duplex, uniform medium topology. The medium used MUST be reported in each test result. Issues regarding mixed transmission media, speed mismatches, media header differences, etc., are not under consideration. Traffic affecting features such as Flow control, Quality of Service (QoS), Graceful Restart, etc. MUST be disabled, unless explicitly requested in the test case. Additionally, any non-essential traffic MUST also be avoided.

4.1.1. Abbreviations Used

The terms used in this document remain consistent with those defined in "Benchmarking Terminology for Network Interconnect Devices" RFC 1242 [RFC1242]. This terminology SHOULD be consulted before using or applying the recommendations of this document.

Please refer to Figure 1 for a topology view of the network. The following abbreviations are used in this document:

M := Module on a device (i.e., Line-Card or Slot; could be A or B)

p := Port number (i.e., port on the Module; could be 1, 2, etc.)

RN := Remote Network (i.e., network that is reachable via a port of a module; could be B1RN1 or B2RN5 to mean the first network reachable via port 1 of module B, e.g., B1, or the fifth network reachable via port 2 of module B, etc.). RN is considered to be the IP Prefix FEC from the MPLS perspective.

4.1.2. IGP Support

It is RECOMMENDED that all of the ports (A1, DA1, DB1, and A2) on the DUT and test tool support a dynamic Interior Gateway Protocol (IGP) for routing such as IS-IS, OSPF, RIP, etc. Furthermore, there are testing considerations in this document that the device be able to provide a stable control plane during heavy forwarding workloads. In particular, the procedures defined in Section 11.3 of RFC 2544 must be followed. This is to ensure that control plane instability during load conditions is not the contributing factor towards frame forwarding performance.

The route distribution method (OSPF, IS-IS, Enhanced Interior Gateway Routing Protocol (EIGRP), RIP, Static, etc.), if used, MUST be reported. Furthermore, if any specific configuration is used to maintain control plane stability during the test (i.e., Control Plane Protection, Control Plane Rate Limiting, etc.), then it MUST also be reported.

4.1.3. Label Distribution Support

The DUT and test tool must support at least one protocol for exchanging MPLS label/FEC bindings for Prefix Forwarding Equivalence Class (FEC) [RFC3031]. The DUT and test tool MUST be capable of learning and advertising MPLS label/FEC bindings via the chosen protocol(s) and use them during packet forwarding all the time (including when the label/FEC bindings change). The most commonly used protocols are Label Distribution Protocol (LDP) [RFC5036], Resource Reservation Protocol-Traffic Engineering (RSVP-TE) [RFC3209], and Border Gateway Protocol (BGP) [RFC3107].

All of the ports (A1, DA1, DB1, B1, etc.) either on the DUT or the test tool used in the testing SHOULD support LDP, RSVP-TE, and BGP for IPv4 or IPv6 Prefix Forwarding Equivalence Classes (FECs).

Static labels SHOULD NOT be used to establish the MPLS label switched paths (LSPs), unless specified explicitly by the test case.

This is because the use of a static label is quite uncommon in the production networks.

The IPv4 and IPv6 Explicit NULL labels (label values 0 and 2) are sometimes used to identify the payload of an MPLS packet on an LSP [RFC3032]. Explicit NULL labels are not used in the tests described in this document because the tests are limited to the use of no more than one non-reserved MPLS label in the label stack of all packets to, from, or through the DUT.

4.1.4. Frame Formats

This section explains the frame formats for IP and MPLS packets (Section 4.1.4.1), the usage of IP as the mandatory Layer 3 protocol and as the MPLS packet payload (Section 4.1.4.2), change in frame format during forwarding (Section 4.1.4.3), and recommended frame formats for the MPLS benchmarking (Section 4.1.4.4).

4.1.4.1. Frame Format for IP versus MPLS

A test frame carrying an IP packet is illustrated in Figure 2 below. Note that RFC 2544 [RFC2544] prescribes using such a frame as the test frame over the chosen Layer 2 media.

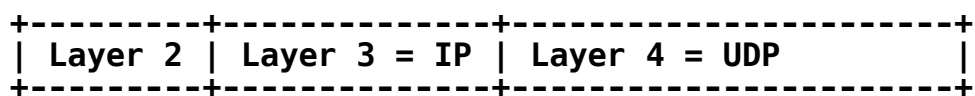


Figure 2: Frame Format for IP Packets

Unlike a test frame carrying an IP packet, a test frame carrying an MPLS packet contains an "MPLS label stack" [RFC3032] immediately after the Layer 2 header (and before the IP header, if any) as illustrated in Figure 3 below.

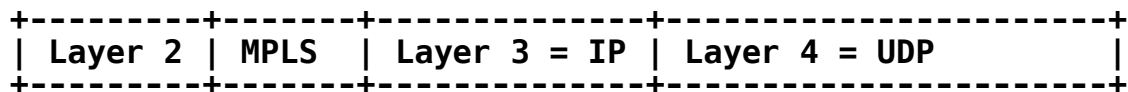


Figure 3: Frame Format for MPLS Packets

The MPLS label stack is represented as a sequence of "label stack entries", where each label stack entry is 4 octets, as illustrated in Figure 1 of [RFC3032]. This document requires exactly one entry in the MPLS label stack in an MPLS packet.

MPLS label values used in any test case MUST be outside the reserved label value (0-15) unless stated otherwise.

4.1.4.2. MPLS Packet Payload

This document prescribes using an IP packet as the MPLS payload (as illustrated in Figure 3 above). Generically speaking, this document mandates the test frame to include IP (either IPv4 or IPv6) as the Layer 3 protocol, in accord with Section 8 of [RFC2544] and independent of the MPLS label stack presence, for three reasons:

1. This enables using IP Prefix Forwarding Equivalence Class (FEC) [RFC3031], which is a must for every MPLS network.
2. This provides the foundation or baseline for the benchmarking of various other MPLS applications such as L3VPN, L2VPN, TE-FRR, etc.
3. This enables leveraging RFC 2544 [RFC2544], which prescribes using IP packets with UDP data as the test frames. (Note that [RFC5180] also uses this prescription for IPv6 benchmarking).

While the usage of non-IP payloads is possible, it requires an MPLS application, e.g., L2VPN, whose benchmarking may be covered in separate BMWG documents (MPLS L2VPN Benchmarking, for example) in the future. This is also explained in Section 2.

4.1.4.3. Change in Frame Format Due to MPLS Push and Pop

A frame carrying an IP or MPLS packet may go through any of the three MPLS forwarding operations: label push (or LSP Ingress), label swap, and label pop (or LSP Egress), as defined in [RFC3031]. It is important to understand the change of the frame format from IP to MPLS or vice versa depending on the forwarding operation.

In a label push (or LSP Ingress) operation, the DUT receives a frame containing an IP packet and forwards a frame containing an MPLS packet if the corresponding forwarding lookup for the IP destination points to a label push operation.

In a label swap operation, the DUT receives a frame containing an MPLS packet and forwards a frame containing an MPLS packet if the corresponding forwarding lookup for the label value points to a label swap operation.

In a label pop (or LSP Egress) operation, the DUT receives a frame containing an MPLS packet and forwards a frame containing an IP packet if the corresponding forwarding lookup for the label value points to a label pop operation.

4.1.4.4. Frame Formats to Be Used for Benchmarking

This document prescribes using two test frame formats to appropriately test the forwarding operations: (1) Frame format for IP and (2) Frame format for MPLS. Both formats are explained in Section 4.1.4.1. Additionally, the format of the test frame may change depending on the forwarding operation.

1. For test cases involving the label push operation, the test tool must use the frame format for IP packets (Figure 2) to send the test frames to the DUT, and must use the frame format for MPLS packets (Figure 3) to receive the test frames from the DUT.
2. For test cases involving the label swap operation, the test tool must use the frame format for MPLS packets (Figure 3) to send the test frames to the DUT, and must use the frame format for MPLS packets (Figure 3) to receive the test frames from the DUT.
3. For test cases involving the label pop operation, the test tool must use the frame format for MPLS packets (Figure 3) to send the test frames to the DUT, and must use the frame format for IP packets (Figure 2) to receive the test frames from the DUT.

4.1.5. Frame Sizes

Two types of port media are commonly deployed: Ethernet and POS (Packet Over Synchronous Optical Network). This section identifies the frame sizes that **SHOULD** be used for each media type, if supported by the DUT; Section 4.1.5.1 covers Ethernet and Section 4.1.5.2 covers POS.

First, it is important to note the possible increase in frame size due to the presence of an MPLS label stack in the frame (as explained in Section 4.1.4.3).

As observed in the current deployments, presence of an MPLS label stack in a Layer 2 frame is assumed to be transparent to Layer3=IP, which continues to follow the conventional maximum frame payload size [RFC3032] (1500 octets for Ethernet, say). This means that the effective maximum frame payload size [RFC3032] of the resulting Layer 2 frame is Z octets more than the conventional maximum frame payload size, where $Z = 4 \times \text{number of entries in the label stack}$.

Hence, to ensure successful delivery of Layer 2 frames carrying MPLS packets and realistic benchmarking, it is **RECOMMENDED** to set the media MTU value to the effective maximum frame payload size [RFC3032], which equals Z octets + conventional maximum frame payload size. It is expected that such a change in the media MTU value only impacts the effective Maximum Frame Payload Size for MPLS packets, but not for IP packets.

Note that this document requires exactly a single entry in the MPLS label stack in an MPLS packet. In other words, the depth of the label stack is set to one, e.g., $Z = 4 \times 1 = 4$ octets. Furthermore, in accord with Sections 9 and 9.1 of RFC 2544, this document prescribes that each test case is run with different (Layer 2) frame

sizes in different trials. Additionally, results MAY also be collected with multiple simultaneous frame sizes (sometimes referred to as an Interactive Multimodal Information Extraction (IMIX) to simulate real network traffic according to the frame size ordering and usage). There is no standard for mixtures of frame sizes, and the results are subject to wide interpretation (see Section 18 of RFC 2544). When running trials using multiple simultaneous frame sizes, the DUT configuration MUST remain the same.

4.1.5.1. Frame Sizes To Be Used on Ethernet Media

Ethernet media, in all its types, has become the most commonly deployed port media in MPLS networks. If any test case execution (such as the Label Push case) requires the test tool to send (or receive) a Layer 2 frame containing an IP packet, then the following frame sizes SHOULD be used for benchmarking over Ethernet media: 64, 128, 256, 512, 1024, 1280, and 1518 octets. This is in-line with Sections 9 and 9.1 of RFC 2544. Figure 4 illustrates the header sizes for an untagged Ethernet frame containing an IP payload (per RFC 2544).

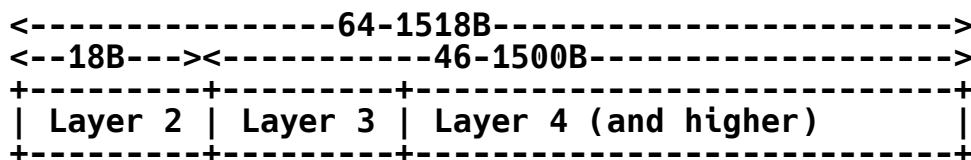


Figure 4: Frame Size for Label Push Cases

Note 1: The 64- and 1518-octet frame size represents the minimum and maximum length of an untagged Ethernet frame, as per IEEE 802.3 [IEE8023]. A frame size commonly used in operational environments may range from 68 to 1522 octets, which are the minimum and maximum lengths of a single VLAN-tagged frame, as per IEEE 802.1D [IEE8021].

Note 2: While jumbo frames are outside the scope of the 802.3 IEEE standard, tests SHOULD be executed with the frame sizes that are supported by the DUT. Examples of commonly used jumbo (Ethernet) frame sizes are: 4096, 8192, and 9216 octets.

If any test case execution (such as Label Swap and Label Pop cases) requires the test tool to transmit (or receive) a Layer 2 frame containing an MPLS packet, then the untagged Layer 2 frame must

include an additional 4 octets for the MPLS header, resulting in the following frame sizes to be used for benchmarking over Ethernet media: 68, 132, 260, 516, 1028, 1284, and 1522 octets. Figure 5 illustrates the header sizes for an untagged Ethernet frame containing an MPLS packet.

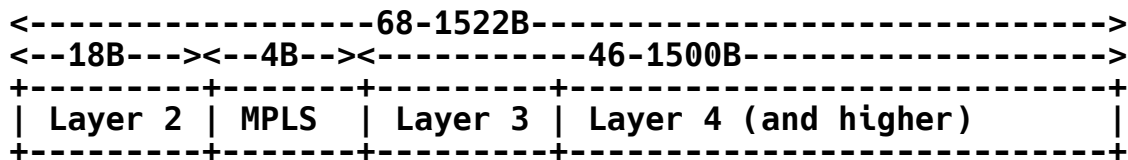


Figure 5: Frame Size for Label Swap and Pop Cases

Note: The Media MTU on the link between the test tool and the DUT must be changed, if needed, to accommodate the effective maximum frame payload size [RFC3032] resulting from adding an MPLS label stack to the IP packet. As clarified in Section 3.1 of RFC 3032, most Layer 2 media drivers are capable of sending and receiving Layer 2 frames with effective maximum frame payload size. Many vendors also allow the Media MTU to be changed for MPLS, without changing it for IP. The recommended link MTU value for MPLS is Z octets more than the conventional maximum frame payload size [RFC3032] (for example, the conventional maximum frame payload size for Ethernet is 1500 octets). This document prescribes Z=4 octets. If a vendor DUT doesn't allow such an MTU change, then the benchmarking cannot be performed for the true maximum frame payload size [RFC3032] and this must be reported.

4.1.5.2. Frame Sizes to Be Used on POS Media

Packet over SONET (POS) media are commonly used for edge uplinks and high-bandwidth core links. POS may use one of various encapsulations techniques (such as PPP, High-Level Data Link Control (HDLC), Frame Relay, etc.), resulting in the Layer 2 header (~4 octets) being less than that of the Ethernet media. The rest of the frame format (illustrated in Figures 2 and 3) remains pretty much unchanged.

If the MPLS forwarding characterization of POS interfaces on the DUT is desired, then the following frame sizes SHOULD be used:

Label Push test cases:	47, 64, 128, 256, 512, 1024, 1280, 1518, 2048, and 4096 octets.
Label Swap and Pop test cases:	51, 68, 132, 260, 516, 1028, 1284, 1522, 2052, and 4100 octets.

4.1.6. Time-to-Live (TTL) or Hop Limit

The TTL value in the frame header **MUST** be large enough to allow a TTL decrement to happen and still be forwarded through the DUT. The aforementioned TTL field may be referring to either the MPLS TTL, IPv4 TTL, or IPv6 Hop Limit depending on the exact forwarding scenario under evaluation.

If TTL/Hop Limit decrement, as specified in [RFC3443], is a configurable option on the DUT, the setting **SHOULD** be reported.

4.1.7. Trial Duration

Unless otherwise specified, the test portion of each trial **SHOULD** be no less than 30 seconds when static routing is in place, and no less than 200 seconds when a dynamic routing protocol and LDP (default LDP holddown timer is 180 seconds) are being used. If the holddown timer default value is changed, then it should be reported and the trial duration should still be 20 seconds more than the holddown timer value.

The longer trial time used for dynamic routing protocols is to verify that the DUT is able to maintain a stable control plane when the data-forwarding plane is under stress.

4.1.8. Traffic Verification

In all cases, sent traffic **MUST** be accounted for, whether it was received on the wrong port, the correct port, or not received at all. Specifically, traffic loss (also referred to as frame loss) is defined as the traffic (i.e., one or more frames) not received where expected (i.e., received on the incorrect port, or received with incorrect Layer 2 or above header information, etc.). In addition, the presence or absence of the MPLS label stack, every field value inside the label stack, if present, ethertype (0x8847 or 0x8848 versus 0x0800 or 0x86DD), frame sequencing, and frame check sequence (FCS) **MUST** be verified in the received frame.

Many test tools may, by default, only verify that they have received the embedded signature on the receive side. However, for MPLS header presence verification, some tests will require the MPLS header to be pushed while others will require a swap or pop. Hence, this document requires the test tool to verify the MPLS stack depth. An even greater level of verification would be to check if the correct label was pushed. However, some test tools are not capable of checking the received label value for correctness. Test tools **SHOULD** verify that the packets received carry the expected MPLS label.

4.1.9. Address Resolution and Dynamic Protocol State

If a test setup utilizes any dynamic protocols for control plane signaling (e.g., ARP, PPP (including MPLSCP), OSPF, LDP, etc.), then all state for the protocols **MUST** be pre-established before the test case is executed (i.e., packet streams are started).

5. Reporting Format

For each test case, it is **RECOMMENDED** that the following variables be reported in addition to the specific parameters requested by the test case:

Parameter	Units or Examples
Prefix Forwarding Equivalence Class (FEC)	IPv4, IPv6, Both
Label Distribution Protocol	LDP, RSVP-TE, BGP (or combinations)
MPLS Forwarding Operation	Push, Swap, Pop
IGP	ISIS, OSPF, EIGRP, RIP, static.
Throughput	Frames per second and bits per second
Port Media	GigE (Gigabit Ethernet), POS, ATM, etc.
Port Speed	1 gbps, 100 Mbps, etc.
Interface Encapsulation	Ethernet, Ethernet VLAN, PPP, HDLC, etc.
Frame Size (Section 4.1.5)	Octets
p (Number of {DA, DB} pair ports per Figure 1)	1,2, etc.

The individual test cases may have additional reporting requirements that may refer to other RFCs.

6. MPLS Forwarding Benchmarking Tests

MPLS is a different forwarding paradigm from IP. Unlike IP packets and IP forwarding, an MPLS packet may contain more than one MPLS header and may go through one of three forwarding operations: push (or LSP Ingress), swap, or pop (or LSP Egress), as defined in [RFC3031]. Such characteristics desire further granularity in MPLS forwarding benchmarking than those described in RFC 2544. Thus, the benchmarking may include, but is not limited to:

1. Throughput
2. Latency
3. Frame-Loss Rate
4. System Recovery
5. Reset
6. MPLS TC (previously known as EXP [RFC5462]) field Operations (including explicit-null cases)
7. Negative Scenarios (TTL expiry, etc.)
8. Multicast

However, this document focuses only on the first five categories, inline with the spirit of RFC 2544. All the benchmarking test cases described in this document are expected to, at a minimum, follow the "Test Setup" and "Test Procedure" below:

Test Setup

Referring to Figure 1, a single port ($p = 1$) on both A and B Modules SHOULD be used. However, if the forwarding throughput of the DUT is more than that of the media rate of a single port, then additional ports on A and B Modules MUST be enabled as follows: if the DUT can be configured with the A and B ports so as to exceed the DUT's forwarding throughput without overloading any B ports, then those MUST be enabled; if, on the other hand, the DUT's forwarding throughput capacity is greater than what can be achieved enabling all ports, then all A_n and B_n ports MUST be enabled. In the case where more than one A and B port is enabled, the procedures described in Section 16 of RFC 2544 must be

followed to accommodate the multi-port scenario. The frame formats transmitted and received must be in accord with Sections 4.1.4.3 and 4.1.4.4, and frame sizes must be in accord with Section 4.1.5.

Note: The test tool must be configured not to advertise a prefix or FEC to the DUT on more than one port. In other words, the DUT must associate a FEC with one and only one DB port. The Equal Cost Multi-Path (ECMP) behavior in MPLS networks uses heuristics [RFC4928]; hence, the usage of ECMP is NOT permitted by this document to ensure the deterministic forwarding behavior during benchmarking.

Test Procedure

In accord with Section 26 of RFC 2544 [RFC2544], the traffic is sent from test tool port(s) Ap to the DUT at a constant load for a fixed-time interval, and is received from the DUT on test tool port(s) Bp. As described in Section 4.1.4.3, the frame may contain either an IP packet or an MPLS packet depending on the test case need. Furthermore, the IP packet must be either an IPv4 or IPv6 packet, depending on whether the MPLS benchmarking is done for IPv4 or IPv6.

If any frame loss is detected, then a new iteration is needed where the offered load is decreased and the sender will transmit again. An iterative search algorithm MUST be used to determine the maximum offered frame rate with a zero frame loss.

This maximum offered frame rate that results in zero frame loss through the DUT is defined as the Throughput in Section 3.17 of [RFC1242] for that test case. Informally, this rate is referred to as the No-Drop Rate (NDR).

Each iteration should involve varying the offered load of the traffic, while keeping the other parameters (test duration, number of ports, number of addresses, frame size, etc.) constant, until the maximum rate at which none of the offered frames are dropped is determined.

6.1. Throughput

This section contains the description of the tests that are related to the characterization of a DUT's MPLS traffic forwarding.

6.1.1. Throughput for MPLS Label Push

Objective

To obtain the DUT's Throughput (as per RFC 2544) during label push or LSP Ingress forwarding operation (i.e., IP to MPLS).

Test Setup

In addition to the "Test Setup" described in Section 6, the test tool must advertise the IP prefix(es), i.e., RNx (using a routing protocol as per Section 4.1.2) and associated MPLS label-FEC binding(s) (using a label distribution protocol as per Section 4.1.3) on its receive ports Bp to the DUT. The test tool may learn the IP prefix(es) on its transmit ports Ap from the DUT.

MPLS and/or the label distribution protocol must be enabled only on the test tool receive ports Bp and DUT transmit ports DBp.

Discussion

The DUT's MPLS forwarding table (also referred to as Incoming Label Map (ILM) to Next Hop Label Forwarding Entry (NHLFE) mapping table per Section 3.11 of [RFC3031]) must contain a non-reserved MPLS label value as the outgoing label for each learned IP prefix corresponding to the label-FEC binding, resulting in the DUT performing the IP-to-MPLS forwarding operation. The test tool must receive MPLS packets on receive ports Bp (from the DUT) with the same label values that were advertised.

Procedure

Please see "Test Procedure" in Section 6. Additionally, the test tool MUST send the frames containing IP packets (with the IP destination belonging to the advertised IP prefix(es)) on transmit ports Ap, and expect to receive frames containing MPLS packets on receive ports Bp, as described in Section 4.1.4.4.

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

Results for each test SHOULD be in the form of a table with a row for each of the tested frame sizes. Additional columns SHOULD include offered load and measured throughput.

6.1.2. Throughput for MPLS Label Swap

Objective

To obtain the DUT's Throughput (as per RFC 2544) during label swapping operation (i.e., MPLS-to-MPLS).

Test Setup

In addition to the setup described in Section 6, the test tool must advertise IP prefix(es) (using a routing protocol as per Section 4.1.2) and associated MPLS label-FEC bindings (using a label distribution protocol as per Section 4.1.3) on the receive ports Bp, and then learn the IP prefix(es) as well as the label-FEC binding(s) on the transmit ports Ap. The test tool must use the learned MPLS label values and learned IP prefix values in the frames transmitted on ports Ap to the DUT.

MPLS and/or label distribution protocol must be enabled on the test tool ports Bp and Ap, and the DUT ports DBp and DAp.

Discussion

The DUT's MPLS forwarding table (also referred to as ILM to NHLFE mapping table per Section 3.11 of [RFC3031]) must contain non-reserved MPLS label values as the outgoing and incoming labels for the learned IP prefixes, resulting in an MPLS-to-MPLS forwarding operation, e.g., label swap. The test tool must receive MPLS packets on receive ports Bp (from the DUT) with the same label values that were advertised using the label distribution protocol. The received frames must contain the same number of MPLS headers as those of transmitted frames.

Procedure

Please see "Test Procedure" in Section 6. Additionally, the test tool must send frames containing MPLS packets (with the IP destination belonging to the advertised IP prefix(es)) on its transmit ports Ap, and expect to receive frames containing MPLS packets on its receive ports Bp, as described in Section 4.1.4.4.

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

Results for each test SHOULD be in the form of a table with a row for each of the tested frame sizes.

6.1.3. Throughput for MPLS Label Pop (Unlabeled)

Objective

To obtain the DUT's Throughput (as per RFC 2544) during label pop or LSP Egress forwarding operation (i.e., MPLS-to-IP) using "Unlabeled" outgoing label.

Test Setup

In addition to the setup described in Section 6, the test tool must advertise the IP prefix(es) (using a routing protocol as per Section 4.1.2) without any MPLS label-FEC bindings on the receive ports Bp, and then learn the IP prefix(es) as well as the FEC-label binding(s) on the transmit ports Ap. The test tool must use the learned MPLS label values and learned IP prefix values in the frames transmitted on ports Ap.

MPLS and/or label distribution protocol must be enabled only on the test tool port(s) Ap and DUT port(s) DAp.

Discussion

The DUT's MPLS forwarding table (also referred to as ILM to NHLFE mapping table per Section 3.11 of [RFC3031]) must contain an Unlabeled outgoing label (also known as untagged) for the learned IP prefix, resulting in an MPLS-to-IP forwarding operation.

Procedure

Please see "Test Procedure" in Section 6. Additionally, the test tool must send frames containing MPLS packets on its transmit ports Ap (with the IP destination belonging to the IP prefix(es) advertised on port Bp), and expect to receive frames containing IP packets on its receive ports Bp, as described in Section 4.1.4.4.

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

Results for each test SHOULD be in the form of a table with a row for each of the tested frame sizes.

6.1.4. Throughput for MPLS Label Pop (Aggregate)

Objective

To obtain the DUT's Throughput (as per RFC 2544) during label pop or LSP Egress forwarding operation (i.e., MPLS-to-IP) using the "Aggregate" outgoing label [RFC3031].

Test Setup

In addition to the setup described in Section 6, the DUT must be provisioned such that it allocates an aggregate outgoing label (please see Section 3.20 in [RFC3031]) to an IP prefix, which aggregates a set of prefixes learned on ports DBp from the test tool. The prefix aggregation can be performed using BGP aggregation (Section 9.2.2.2 of [RFC4271]), IGP aggregation (Section 16.5 of [RFC2328]), etc.

The DUT must advertise the aggregating IP prefix along with the associated MPLS label-FEC binding on ports DAp to the test tool.

The test tool then must use the learned MPLS label values and learned IP prefix values in frames transmitted on ports Ap to the DUT. The test tool must receive frames containing IP packets on ports Bp from the DUT.

MPLS and/or label distribution protocol must be enabled only on the test tool port(s) Ap and DUT port(s) DAp.

Discussion

The DUT's MPLS forwarding table (also referred to as ILM to NHLFE mapping table per Section 3.11 of [RFC3031]) must contain an aggregate outgoing label and IP forwarding table must contain a valid entry for the learned prefix(es), resulting in MPLS-to-IP forwarding operation (i.e., MPLS header removal followed by IP lookup).

Procedure

Please see "Test Procedure" in Section 6. Additionally, the test tool must send frames containing MPLS packets on its transmit ports Ap (with IP destination belonging to the IP prefix(es) advertised on port Bp), and expect to receive frames containing IP packets on its receive ports Bp, as described in Section 4.1.4.4.

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

Results for each test SHOULD be in the form of a table with a row for each of the tested frame sizes.

6.1.5. Throughput for MPLS Label Pop (PHP)

Objective

To obtain the DUT's Throughput (as per RFC 2544) during label pop (i.e., MPLS-to-IP) or penultimate hop popping (PHP) using the "imp-null" outgoing label.

Test Setup

In addition to the setup described in Section 6, the test tool must be set up to advertise the IP prefix(es) (using a routing protocol as per Section 4.1.2) and associated MPLS label-FEC binding with a reserved MPLS label value = 3 (using a label distribution protocol as per Section 4.1.3) on its receive ports Bp. The test tool must learn the IP prefix(es) as well as the MPLS label-FEC bindings on its transmit ports Ap. The test tool then must use the learned MPLS label values and learned IP prefix values in the frames transmitted on ports Ap to the DUT. The test tool must receive frames containing IP packets on receive ports Bp (from the DUT).

MPLS and/or label distribution protocol must be enabled on the test tool ports Bp and Ap, and DUT ports DBp and DAp.

Discussion

This test case characterizes Penultimate Hop Popping (PHP), which is described in RFC 3031.

The DUT's MPLS forwarding table (also referred to as ILM to NHLFE mapping table per Section 3.11 of [RFC3031]) must contain a reserved MPLS label value = 3 (e.g., pop or imp-null) as the outgoing label for the learned prefix(es), resulting in MPLS-to-IP forwarding operation.

This test case characterizes DUT's penultimate hop popping (PHP) functionality.

Procedure

Please see "Test Procedure" in Section 6. Additionally, the test tool must send frames containing MPLS packets on its transmit ports Ap (with IP destination belonging to advertised IP prefix(es)), and expect to receive frames containing IP packets on its receive ports Bp, as described in Section 4.1.4.4.

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

Results for each test SHOULD be in the form of a table with a row for each of the tested frame sizes.

6.2. Latency Measurement

Latency measurement measures the time taken by the DUT to forward the MPLS packet during various MPLS switching paths such as IP-to-MPLS, MPLS-to-MPLS, or MPLS-to-IP involving an MPLS label stack.

Objective

To obtain the average latency induced by the DUT during MPLS packet forwarding for each of five forwarding operations.

Test Setup

Follow the "Test Setup" guidelines established for each of the five MPLS forwarding operations in Sections 6.1.1 (for IP-to-MPLS), 6.1.2 (for MPLS-to-MPLS), 6.1.3 (for MPLS-to-IP Unlabeled), 6.1.4 (for MPLS-to-IP Aggregate), and 6.1.5 (for MPLS-to-IP PHP), one by one.

Procedure

Please refer to Section 26.2 in RFC 2544 in addition to following the associated procedure for each MPLS forwarding operation in accord with the test setup described earlier:

IP-to-MPLS forwarding	(Push)	Section 6.1.1
MPLS-to-MPLS forwarding	(Swap)	Section 6.1.2
MPLS-to-IP forwarding	(Pop)	Section 6.1.3
MPLS-to-IP forwarding	(Aggregate)	Section 6.1.4
MPLS-to-IP forwarding	(PHP)	Section 6.1.5

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

6.3. Frame-Loss Rate (FLR) Measurement

Frame-Loss Rate (FLR) measurement measures the percentage of MPLS frames that were not forwarded during various switching paths such as IP-to-MPLS (push), MPLS-to-IP (swap), or MPLS-IP (pop) by the DUT under overloaded state.

Please refer to RFC 2544, Section 26.3, for more details.

Objective

To obtain the frame-loss rate, as defined in RFC 1242, for each of the three MPLS forwarding operations of a DUT, throughout the range of input data rates and frame sizes.

Test Setup

Follow the "Test Setup" guidelines established for each of the five MPLS forwarding operations in Sections 6.1.1 (for IP-to-MPLS), 6.1.2 (for MPLS-to-MPLS), 6.1.3 (for MPLS-to-IP Unlabeled), 6.1.4 (for MPLS-to-IP Aggregate), and 6.1.5 (for MPLS-to-IP PHP), one by one.

Procedure

Please refer to Section 26.3 of RFC 2544 [RFC2544] and follow the associated procedure for each MPLS forwarding operation one-by-one in accord with the test setup described earlier:

IP-to-MPLS forwarding	(Push)	Section 6.1.1
MPLS-to-MPLS forwarding	(Swap)	Section 6.1.2
MPLS-to-IP forwarding	(Pop)	Section 6.1.3
MPLS-to-IP forwarding	(Aggregate)	Section 6.1.4
MPLS-to-IP forwarding	(PHP)	Section 6.1.5

A misdirected frame, that is, a frame received on the wrong Bn, is considered lost. If the test tool is capable of checking received MPLS label values, a frame with the wrong MPLS label is considered lost.

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

6.4. System Recovery

Objective

To characterize the speed at which a DUT recovers from an overload condition.

Test Setup

Follow the "Test Setup" guidelines established for each of the five MPLS forwarding operations in Sections 6.1.1 (for IP-to-MPLS), 6.1.2 (for MPLS-to-MPLS), 6.1.3 (for MPLS-to-IP Unlabeled), 6.1.4 (for MPLS-to-IP Aggregate), and 6.1.5 (for MPLS-to-IP PHP), one by one.

Procedure

Please refer to Section 26.5 of RFC 2544 and follow the associated procedure for each MPLS forwarding operation in the referenced sections one-by-one in accord with the test setup described earlier:

IP-to-MPLS forwarding	(Push)	Section 6.1.1
MPLS-to-MPLS forwarding	(Swap)	Section 6.1.2
MPLS-to-IP forwarding	(Pop)	Section 6.1.3
MPLS-to-IP forwarding	(Aggregate)	Section 6.1.4
MPLS-to-IP forwarding	(PHP)	Section 6.1.5

Reporting Format

The result should be reported as per Section 5 and RFC 2544.

6.5. Reset

The "reset" aspects of benchmarking are described in [RFC2544], but these procedures need to be clarified in order to ensure consistency. This document does not specify the reset procedures. These need to be addressed in a separate document and will more generally apply to IP and MPLS test cases.

The text below describes the MPLS forwarding benchmarking-specific setup that will have to be used in conjunction with the procedures from the separate document to make this test case meaningful.

Objective

To characterize the speed at which a DUT recovers from a device or software reset.

Test Setup

Follow the "Test Setup" guidelines established for each of the five MPLS forwarding operations in Sections 6.1.1 (for IP-to-MPLS), 6.1.2 (for MPLS-to-MPLS), 6.1.3 (for MPLS-to-IP Unlabeled), 6.1.4 (for MPLS-to-IP Aggregate), and 6.1.5 (for MPLS-to-IP PHP), one by one.

For this test case, the requirements of LDP and a routing protocol are removed and replaced by static configurations. For the IP-to-MPLS forwarding, static route configurations should be applied. For the MPLS-to-MPLS and MPLS-to-IP, static label configurations must be applied.

For this test, all Graceful Restart features MUST be disabled.

Discussion

This test case is intended to provide insight into how long an MPLS device could take to be fully operational after any of the reset events. It is quite likely that the time an IP/MPLS device takes to become fully operational after any of the reset events may be different from that of an IP-only device.

Modern devices now have many more reset options that were not available when Section 26.6 of RFC 2544 was published. Moreover, different reset events on modern devices may produce different results, hence, needing clarity and consistency in reset procedures beyond what's specified in RFC 2544.

Procedure

Please follow the procedure from the separate document for each MPLS forwarding operation one-by-one:

IP-to-MPLS forwarding	(Push)	Section 6.1.1
MPLS-to-MPLS forwarding	(Swap)	Section 6.1.2
MPLS-to-IP forwarding	(Pop)	Section 6.1.3
MPLS-to-IP forwarding	(Aggregate)	Section 6.1.4
MPLS-to-IP forwarding	(PHP)	Section 6.1.5

Reporting Format

The result should be reported as per Section 5 and as per the separate document.

7. Security Considerations

Benchmarking activities, as described in this memo, are limited to technology characterization using controlled stimuli in a laboratory environment, with dedicated address space and the constraints specified in the sections above.

The benchmarking network topology will be an independent test setup and **MUST NOT** be connected to devices that may forward the test traffic into a production network or misroute traffic to the test management network.

Furthermore, benchmarking is performed on a "black-box" basis, relying solely on measurements observable external to the DUT/SUT (System Under Test).

Special capabilities **SHOULD NOT** exist in the DUT/SUT specifically for benchmarking purposes. Any implications for network security arising from the DUT/SUT **SHOULD** be identical in the lab and in production networks.

There are no specific security considerations within the scope of this document.

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