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MPLS Forwarding Compliance and Performance Requirements
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Abstract

This document provides guidelines for implementors regarding MPLS forwarding and a basis for evaluations of forwarding implementations. Guidelines cover basic MPLS forwarding, forwarding when a deep MPLS label stack is encountered, MPLS UHP operations which require one or more label POP plus a PUSH, guidelines for hashing an MPLS stack and payload for multipath, and conformance and performance requirements for recent pseudowire and MPLS standards.

Status of this Memo

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1. Introduction

The document addresses concerns raised on the MPLS WG mailing list about shortcomings in implementations of MPLS forwarding.

Although this document is informational, the key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" are used. For those who wish to take the advice of this document, these keywords SHOULD be interpreted as described in RFC 2119 [RFC2119]. Similarly, the References section is split into Normative and Informative subsections. In this case references which are normative for forwarding are listed as normative. References which describe signaling only, though normative with respect to signaling, are listed as informative here, as they are informative with respect to MPLS forwarding.

1.1. Apparent Misconceptions

In early generations of forwarding silicon (which may now be behind us), there apparently were some misconceptions about MPLS. The following statements may clear up some of these misconceptions.

1. There are practical reasons to have more than one or two labels in an MPLS label stack. Under some circumstances the label stack can become quite deep. See Section 2.1.

2. The label stack must be considered to be arbitrarily deep. If a the bottom of the label stack cannot be found, but sufficient number of labels exist to forward, an LSR MUST forward the packet. An LSR MUST NOT assume the packet is malformed unless the end of packet is found before bottom of stack. See Section 2.1.

3. In networks where deep label stacks are encountered, they are not rare. Full packet rate performance is required regardless of

label stack depth, except where multiple POP operations are required. See Section 2.1.

4. Research has shown that long bursts of short packets with 40 byte or 44 byte common IP payload sizes in these bursts. This is due to TCP ACK compression [ACK-compression].

   A. A forwarding engine SHOULD, if practical, be able to sustain an arbitarily long sequence of small packets arriving at full interface rate.

   B. If indefinite full packet rate for small packets is not practical, a forwarding engine MUST be able to buffer a long sequence of small packets inbound to the decision engine and sustain full interface rate for some reasonable average packet rate.

   See Section 2.2.

5. For practical reasons, support for pseudowire control word SHOULD be considered mandatory by the implementor and system designer. Deployment of pseudowire control word MAY be considered optional. See Section 2.3.1.

6. For practical reasons, support for adding a pseudowire Flow Label [RFC6391] SHOULD be considered mandatory by the implementor and system designer. Deployment of this features MAY be considered optional. See Section 2.3.2.

7. For practical reasons, support for adding a MPLS Entropy Label [I-D.ietf-mpls-entropy-label] SHOULD be considered mandatory by the implementor and system designer. Deployment of this features MAY be considered optional. See Section 2.3.3.

1.2. Target Audience

This document is intended for multiple audiences: implementor (implementing MPLS forwarding in silicon or in software); systems designer (putting together a MPLS forwarding systems); deployer (running an MPLS network). These guidelines are intended to serve

the following purposes:

1. Explain what to do and what not to do when a deep label stack is encountered. (audience: implementor)

2. Highlight pitfalls to look for when implementing an MPLS forwarding chip. (audience: implementor)

3. Provide a checklist of features and performance specificiations to request. (audience: systems designer, deployer)

4. Provide a set of tests to perform. (audience: systems designer, deployer).

The implementor, systems designer, and deployer have a transitive supplier customer relationship. It is in the best interest of the supplier to review their product against their customer's checklist and customer's customer's checklist if applicable.

2. Forwarding Issues

A brief review of forwarding issues is provided in the subsections that follow. This section provides some background on why some of these requirements exist. The questions to ask of suppliers and testing is covered in the following sections, Section 3 and Section 4.

2.1. Forwarding Basics

Basic MPLS architecture and MPLS encapsulation, and thereforepacket forwarding is defined in [RFC3031] and [RFC3032]. RFC3031 and RFC3032 are somewhat LDP centric. RSVP-TE supports traffic engineering (TE) and fast reroute, features that LDP lacks. The base document for RSVP-TE based MPLSis [RFC3209].

A few RFCs update RFC3032. Those with impact on forwarding include the following.

1. TTL processing is clarified in [RFC3443].

2. The use of MPLS Explicit NULL is modified in [RFC4182].

3. Diffserv is supported by [RFC3270] and [RFC4124]. The "EXP" field is renamed to "Traffic Class" in [RFC5462], removing any misconception that it was available for experimentation or could be ignored.

4. ECN is supported by [RFC5129].

5. The MPLS G-ACh and GAL are defined in [RFC5586].

A few RFCs update RFC3209. Those that are listed as updating RFC3209 generally impact only RSVP-TE signaling. Forwarding is modified by major extension built upon RFC3209. Some of these extensions are discussed in following subsections.

2.1.1. Early Uses of Multiple Label Stack Entries

MPLS deployments in the early part of the prior decade (circa 2000) tended to support either LDP or RSVP-TE. LDP was favored by some for its ability to scale close to the network edges without adding deployment complexity. RSVP-TE was favored where traffic engineering or fast reroute were considered important.

The use of MPLS FRR [RFC4090] added a second label to MPLS traffic, but only when FRR protection was in use.

At least one major service provider made use of LDP over RSVP-TE in their core network in the circa 2000-2005 time frame. LDP supported VPN services to the provider edges. RSVP-TE provided TE and FRR in the core. This yields two labels on nearly all packets in the core. They also used FRR which yields three labels on a large subset of traffic while FRR protection is active. VPNs added yet another label, bringing the label stack depth (with FRR) to four.

2.1.2. MPLS Link Bundling

MPLS Link Bundling was the first RFC to address the need for multiple parallel links between nodes [RFC4201]. MPLS Link Bundling is notable in that it tried not to change MPLS forwarding, except in specifying the "All-Ones" component link. MPLS Link Bundling is seldom if ever deployed. Instead multipath techniques described in

Section 2.3 are used.

2.1.3. MPLS Hierarchy

MPLS hierarchy is defined in [RFC4206]. Although RFC4206 is considered part of GMPLS, the Packet Switching Capable (PSC) portion of the MPLS hierarchy are applicable to MPLS and may be supported in an otherwise GMPLS free implementation. The MPLS PSC hierarchy remains the most likely means of providing further scaling in an RSVP-TE MPLS network, particularly where the network is designed to provide RSVP-TE connectivity to the edges. This is the case for envisioned MPLS-TP networks. The use of the MPLS PSC hierarchy can add as many as four labels to a label stack, though it is likely that only one layer of PSC will be used in the near future.

2.2. Packet Rates

While average packet size of Internet traffic may be large, long sequences of small packets have both been predicted in theory and observed in practice. Traffic compression and TCP ACK compression can conspire to create long sequences of packets of 40-44 bytes in payload length. If carried over Ethernet, the 64 byte minimum payload applies, yielding a packet rate of approximately 150 Mpps (million packets per second) for the duration of the burst. The peak rate is higher for other encapsulations, as high as 250 Mpps.

The loss of some TCP ACK packets are not the primary concern when such a burst occurs. When a burst occurs, any other packets, regardless of packet length are dropped once input buffers are exceeded. Buffers in front of the packet decision engine are often very small.

Internet service providers and content providers generally specify

full rate forwarding with 40 byte payload packets as a requirement. This requirement often can be waived if the provider can be convinced that when long sequence of short packets occur no packets will be dropped.

With adequate buffers before the packet decision engine, an LSR can absorb a long sequence of short packets. Even if the output is slowed to the point where light congestion occurs, the packets,

having cleared the decision process, can make use of larger VOQ or output side buffers and be dealt with according to configured QoS treatment, rather than dropped completely at random.

Packet rate requirements apply regardless of which network tier equipment is deployed in. Whether deployed in the network core or near the network edges, packets must be processed at full line rate or with sufficient buffering prior to the packet decision engine.

2.3. MPLS Multipath Techniques

In any large provider, service providers and content providers, hash based multipath techniques are used in the core. In many of these providers hash based multipath is used in the edge as well and in some cases the metro.

The most common multipath techniques are ECMP applied at the IP forwarding level, Ethernet LAG with inspection of the IP payload, and multipath on links carrying both IP and MPLS, where the IP header is inspected below the MPLS label stack. In most core networks, the vast majority of traffic is MPLS encapsulated.

In order to support an adequately even load distribution across multiple links, IP addresses must be used. Common practice today is to reinspect the IP addresses at each LSR and use the label stack and IP addresses in a hash performed at each LSR.

The use of this technique is so ubiquitous in large core networks that lack of support for multipath makes any product unsuitable for use in large core networks. This will continue to be the case in the near future, even as deployment of MPLS Entropy Label begins to relax the core LSR multipath performance requirements given the existing deployed base of edge equipment without the ability to add an Entropy Label.

A generation of edge equipment supporting the ability to add an MPLS Entropy Label is needed before the performance requirements for core LSR can be relaxed. However, it is likely that two generations of deployment in the future will allow core LSR to support full packet rate only when a relatively small number of MPLS labels need to be

inspected before hashing. For now, don't count on it.

2.3.1. Pseudowire Control Word

Within the core of a network some form of multipath is almost certain to be used. Multipath techniques deployed today are likely to be looking beneath the label stack for an opportunity to hash on IP addresses.

A pseudowire encapsulated at a network edge must have a means to prevent reordering within the core if the pseudowire will be crossing a network core, or any part of a network topology where multipath is used.

Not supporting the ability to encapsulate a pseudowire with a control word may lock a product out from consideration. A pseudowire capability without control word support might be sufficient for applications which are strictly both intra-metro and low bandwidth. However a provider with other applications will very likely not tolerate having equipment which can only support a subset of their pseudowire needs.

2.3.2. Pseudowire Flow Label

Unlike a pseudowire control word, a pseudowire flow label [RFC6391], is required only for relatively large capacity pseudowires. There are many cases where a pseudowire flow label makes sense. Any service such as a VPN which carries IP traffic within a pseudowire can make use of a pseudowire flow label.

Any pseudowire which does not carry a flow label is in effect a single microflow (in [RFC2475] terms). Where multipath makes use of a simple hash (see Section 2.3) the presense of large microflows that consumes 10% of the capacity of a potentially congested link, can upset the traffic balance and in effect reduce the effective capacity of the entire microflow by far more than 10%. Therefore is a network where a significant number of parallel 10 Gb/s links exists, even a 1 Gb/s pseudowire should carry a flow label if possible.

2.3.3. MPLS Entropy Label

The MPLS Entropy Label simplifies flow group identification [I-D.ietf-mpls-entropy-label] in the network core. Prior to the MPLS Entropy Label core LSR needed to inspect the entire label stack and often the IP headers to provide an adequate distribution of traffic when using multipath techniques (see Section 2.3). With the use of MPLS Entropy Label, a hash can be performed closer to network edges, placed in the label stack, and used within the network core.

The MPLS Entropy Label avoid full label stack and payload inspection within the core where performance levels are most difficult to acheive (see Section 2.2). The label stack inspection can be terminated as soon as the first Entropy Label is encounted, which is generally after a small number of labels are inspected.

In order to provide these benefits in the core, LSR closer to the edge must be capable of adding an entropy label. This support may not be required in the access tier, the tier closest to the customer, but is likely to be required in the edge or the border to the network core. LSR peering with external networks will also need to be able to add an Entropy Label.

2.4. MPLS-TP and UHP

MPLS-TP introduces forwarding demands that will be extremely difficult to meet in a core network. Most troublesome is the requirement for Ultimate Hop Popping (UHP, the opposite of Penultimate Hop Popping or PHP). Using UHP opens the possibility of one or more MPLS POP operation plus an MPLS SWAP operation for each packet. The potential for multiple lookups and multiple counter instances per packet exists.

As networks grow and tunneling of LDP LSPs into RSVP-TE LSPs is used, and/or RSVP-TE hierarchy is used, the requrement to perform one or two or more MPLS POP operations plus a MPLS SWAP operation (and possibly a PUSH or two) increases. If MPLS-TP LM (link monitoring) OAM is enabled at each layer, then a packet and byte count must be maintained for each POP and SWAP operation.

3. Questions for Suppliers

The following questions should be asked of a supplier. These questions are grouped into broad categories.

Basic Compliance

Q#1 Can the implementation forward packets with an arbitrarily large stack depth?

Basic Performance

Q#2 Can very small packets be forwarded at full line rate on all interfaces indefinitely?

Q#3 Customers must decide whether to relax the prior requirement and to what extent. If the answer to the prior question is "no", then:

a. What is the smallest packet size where full line rate forwarding can be supported?

b. What is the longest burst of full rate small packets that can be supported?

Q#4 How many POP operations can be supported along with a SWAP operation at full line rate while maintaining per LSP packet and byte counts for each POP and SWAP? This requirement is particularly relevant for MPLS-TP.

Q#5 For a worst case where all packets arrive on one LSP, what is the counter overflow time? Are any means provided to avoid polling all counters at short intervals? This applies to both MPLS and MPLS-TP.

Multipath Capabilities and Performance

Multipath capabilities do not apply to MPLS-TP but apply to MPLS and apply if MPLS-TP is carried in MPLS.

Q#6 How many MPLS labels can be included in a hash based on the MPLS label stack?

Q#7 Is packet rate performance decreased beyond some number of labels?

Q#8 Can the IP addresses below the MPLS stack be used in the hash?

Q#9 At what maximum MPLS label stack depth can Bottom of Stack and an IP header appear without impacting packet rate performance?

Q#10 Are reserved labels included in the label stack hash? They

MUST NOT be included.

Pseudowire Capabilities and Performance

Q#11 Is the pseudowire control word supported?

Q#12 What is the maximum rate of pseudowire encapsulation and decasulation? Apply the same questions as in Based Performance for any packet based pseudowire such as IP VPN or Ethernet.

Q#13 Does inclusion of a pseudowire control word impact performance?

Q#14 Are flow labels supported?

Q#15 If so, what fields are hashed on for the flow label for different types of pseudowires?

Q#16 Does inclusion of a flow label impact performance?

Entropy Label Support and Performance

Q#17 Can an entropy label be added when acting as in ingress LER and can it be removed when acting as an egress LER?

Q#18 If so, what fields are hashed on for the entropy label?

Q#19 Does adding or removing an entropy label impact packet rate performance?

Q#20 Can an entropy label be detected in the label stack, used in the hash, and properly terminate the search for further information to hash on?

Q#21 Does using an entropy label have any negative impact on performance? It should have no impact or a positive impact.

4. Forwarding Compliance and Performance Testing

Packet rate performance of equipment supporting a large number of 10 Gb/s or 100 Gb/s links is not possible using desktop computers or workstations. The use of high end workstations as a source of test traffic was barely viable 20 years ago, but is no longer at all viable. Though custom microcode has been used on specialized router forwarding cards to serve the purpose of generating test traffic and measuring it, for the most part performance testing will require specialized test equipment. There are multiple sources of suitable equipment.

The set of tests listed here do not correspond one-to-one to the set of questions in Section 3. The same categorization is used and these

tests largely serve to validate answers provided the the prior questions, and can also provide answers where a supplier is unwilling to disclose compliance or performance.

Performance testing is the domain of the IETF Benchmark Methodology Working Group (BMWG). Below are brief descriptions of conformance and performance tests. Some very basic tests are specified in [RFC5695] which partially cover only the basic performance test T#2.

The following tests should be performed by the systems designer, or deployer, or performed by the supplier on their behalf if it is not practical for the potential customer to perform the tests directly. These tests are grouped into broad categories.

Basic Compliance

T#1 Test forwarding at a high rate for packets with varying number of label entriess. While packets with more than a dozen label entriess are unlikely to be used in any practical scenario today, it is useful to know if limitations exists.

Basic Performance

T#2 Test packet forwarding at full line rate with small packets.

See [RFC5695]. The most likely case to fail is the smallest packet size.

T#3 If the prior tests did not succeed for all packat sizes, then perform the following tests.

a. Increase the packet size by 4 bytes until a size is found that can be forwarded at full rate.

b. Inject bursts of consecutive small packets into a stream of larger packets. Allow some time for recovery between bursts. Increase the number of packets in the burst until packets are dropped. One way to accomplish this is to use a router with higher priority set on the interfaces on which small packets are sent to it. The router should buffer the lower priority large packets. It is best to inject the small packets to this router on a faster interface (if such a thing exists), or more than one interface.

T#4 Send test traffic where a SWAP operation is required. Also set up multiple LSP carried over other LSP where the device under test (DUT) is the egress of these LSP. Create test packets such that the SWAP operation is performed after POP operations, increasing the number of POP operations until forwarding of small packets at full line rate can no longer be supported. Also check to see at what point the full set of counters can no longer be maintained. This requirement is particularly relevant for MPLS-TP.

T#5 Send all traffic on one LSP and see if the counters become inaccurate. Often counters on silicon are much smaller than the 64 bit counters in IETF MIB. System developers should consider what counter polling rate is necessary to maintain accurate counters and whether those polling rates are practical. Relevant MIBs for MPLS are discussed in [RFC4221] and [RFC6639].

Multipath Capabilities and Performance

Multipath capabilities do not apply to MPLS-TP but apply to MPLS and apply if MPLS-TP is carried in MPLS.

T#6 Send traffic at a rate well exceeding the capacity of a single multipath component link, and where entropy exists only below the top of stack. If only the top label is used this test will fail immediately.

T#7 Move the labels with entropy down in the stack until either the full forwarding rate can no longer be supported or most or all packets try to use the same component link.

T#8 Repeat the two tests above with the entropy contained in IP addresses below the label stack rather than in the label stack.

T#9 Determine whether traffic that contains a pseudowire control word is interpreted as IP traffic. Information in the payload MUST NOT be used in the load balancing if the first nibble of the packet is not 4 or 6 (IPv4 or IPv6).

T#10 Determine whether reserved labels are included in the label stack hash. They MUST NOT be included.

Pseudowire Capabilities and Performance

T#11 Determine whether pseudowire can be set up with a pseudowire label and pseudowire control word added at ingress and the pseudowire label and pseudowire control word removed at egress.

T#12 For pseudowire that contains variable length payload packets, repeat the packet size based performance tests for pseudowire ingress and egress functions.

T#13 Repeat pseudowire performance tests with and without a pseudowire control word.

T#14 Determine whether pseudowire can be set up with a pseudowire label, flow label, and pseudowire control word added at ingress and the pseudowire label, flow label, and pseudowire control word removed at egress.

T#15 Determine which payload fields are used to create the flow label and whether the set of fields and algorithm provide sufficient entropy for load balancing.

T#16 Repeat pseudowire performance tests with flow labels included.

Entropy Label Support and Performance

T#17 Determine whether entropy labels are supported.

T#18 Determine which fields are used to create an entropy label. Labels further down in the stack, including entropy labels further down and IP payload where applicable should be used. Determine whether the set of fields and algorithm provide sufficient entropy for load balancing.

T#19 Repeat performance tests at LSP ingress and egress when entropy labels are added or removed.

T#20 Determine whether an ELI is detected when acting as a midpoint LSR and whether the search for further information on which to base the load balancing is used. Information below the entropy labe MUST NOT be used.

T#21 Repeat performance tests for midpoint LSR with entropy labels found at various label stack depths.

5. IANA Considerations

This memo includes no request to IANA.

6. Security Considerations

This document reviews forwarding behaviour specified elsewhere and points out compliance and performance requirements. As such it introduces no new security requirements or concerns. Knowledge of potential performance shortcomings may serve to help avoid pitfalls, but in very unlikely circumstances such knowledge could in principle be the basis of denial of service. In practice such extreme data and packet rate would be needed to make this type of denial of service extremely unlikely and undetectable denial of service impossible.

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7.1. Normative References

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