LSP Self-Ping

draft-bonica-mpls-self-ping-04

Abstract

LSP Self-ping is a new, light-weight protocol that ingress LSRs can use to verify an LSP's readiness to carry traffic. LSP Self-ping does not consume control plane resources on the egress LSR.

When an ingress LSR executes LSP Self-ping procedures, it constructs a probe message. The probe message is an IP datagram whose destination address represents an interface on the ingress LSR.

The ingress LSR forwards the probe through the LSP under test. If the LSP is ready to forward traffic, the egress LSR receives the probe. Because the probe is addressed to the ingress LSR, the egress LSR forwards the probe back to the ingress. When the ingress LSR receives the probe, it has verified LSP readiness without consuming control plane resources at the egress LSR.

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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1. Introduction

Ingress Label Switching Routers (LSR) can use RSVP-TE [RFC3209] to establish a MPLS Label Switched Paths (LSP) [RFC3032]. The following paragraphs outline RSVP-TE procedures.

The ingress LSR calculates path between itself and an egress LSR. The calculated path can be either strictly or loosely routed. Having calculated a path, the ingress LSR constructs an RSVP PATH message. The PATH message includes an Explicit Route Object (ERO) and the ERO represents the calculated path between the ingress and egress LSRs.

The ingress LSR forwards the PATH message towards the egress LSR, following the path defined by the ERO. Each transit LSR that receives the PATH message executes admission control procedures. If the transit LSR admits the LSP, it sends the PATH message downstream, to the next node in the ERO.
When the egress LSR receives the PATH message, it binds a label to the LSP. The label can be implicit null, explicit null, or non-null. The egress LSR then installs forwarding state (if necessary), and constructs an RSVP RESV message. The RESV message contains a Label Object and the Label Object contains the label that has been bound to the LSP.

The egress LSR sends the RESV message upstream towards the ingress LSR. The RESV message visits the same transit LSRs that the PATH message visited, in reverse order. Each transit LSR binds a label to the LSP, updates its forwarding state and updates the RESV message. As a result, the RESV message contains a Label Object and the Label Object contains the label that has been bound to the LSP. Finally, the transit LSR sends the RESV message upstream, along the reverse path of the LSP.

When the ingress LSR receives the RESV message, it installs forwarding state. Once the ingress LSR installs forwarding state it can forward traffic through the LSP.

Some implementations optimize the procedure described above by allowing LSRs to send RESV messages before installing forwarding state. This optimization is desirable, because it allows LSRs to install forwarding state in parallel, thus accelerating the process of LSP signaling and setup. However, this optimization creates a race condition. When the ingress LSR receives a RESV message, some downstream LSRs may not have installed forwarding state yet. In this case, if the ingress LSR forwards traffic through the LSP, traffic will be black-holed until forwarding state is installed on all of the downstream LSRs.

The ingress LSR can prevent back-holing by verifying the LSPs readiness to carry traffic before forwarding traffic through it. LSP Ping [RFC4379] and BFD [RFC5884] are mechanisms that the ingress LSR could use to verify LSP readiness. However, LSP Ping and BFD consume control plane resource on the egress LSR. During periods of network restoration or reoptimization, control plane resources may be scarce. Therefore, a mechanism that does not consume control plane resources on the egress LSR is required.

LSP Self-ping is a new, light-weight protocol that ingress LSRs can use to verify an LSPs readiness to carry traffic. Unlike LSP Ping, LSP Self-ping does not consume control plane resources on the egress LSR.

When an ingress LSR executes LSP Self-ping procedures, it constructs a probe message. The probe message is an IP datagram whose destination address represents an interface on the ingress LSR.
The ingress LSR forwards the probe through the LSP under test. If the LSP is ready to forward traffic, the egress LSR receives the probe. Because the probe is addressed to the ingress LSR, the egress LSR forwards the probe back to the ingress. When the ingress LSR receives the probe, it has verified LSP readiness without consuming control plane resources at the egress LSR.

While LSP Self-ping does not consume control plane resources at the egress LSR, it cannot detect some failures that can be detected by protocols that consume control plane resources at the egress. For example, LSP Self-ping cannot detect a misrouted LSP. Furthermore, LSP Self-ping cannot be used to verify LSPs that were signaled using LDP independent mode.

2. LSP Self Ping Procedures

In order to verify that an LSP is ready to carry traffic, the ingress LSR creates a short-lived LSP Self-ping session. All session state is maintained locally on the ingress LSR. Session state includes the following:

- **Session-id**: A 32-bit number that identifies the session
- **verification-status**: A boolean variable indicating whether LSP readiness has been verified. The initial value of this variable is FALSE.
- **retries**: The number of times that the ingress LSR probes the LSP before giving up. The initial value of this variable is determined by configuration.
- **retry-timer**: The number of milliseconds that the LSR waits after probing the LSP. The initial value of this variable is determined by configuration.

The ingress LSR executes the following procedure until verification-status equals TRUE or retries is less than 1:

- Format a MPLS Echo Reply [RFC4379] message
- Send the MPLS Echo Reply message through the LSP under test
- Set a timer to expire in retry-timer milliseconds
- Wait until either a) a MPLS Echo Reply message associated with the session returns or b) the timer expires. If an MPLS Echo Reply message associated with the session returns, set verification-status to TRUE. Otherwise, decrement retries. Optionally,
increase the value of retry-timer according to an appropriate back-off algorithm.

As per [RFC4379], the MPLS Echo Reply message is encapsulate in a User Datagram Protocol (UDP) [RFC0768] header. If the protocol messages used to establish the LSP were delivered over IPv4 [RFC0791], the UDP datagram is encapsulated in an IPv4 header. If the protocol messages used to establish the LSP were delivered over IPv6 [RFC2460], the UDP datagram is encapsulated in an IPv6 header.

In either case, message contents are as follows:

- IP Source Address is configurable. By default, it is the address of the egress LSR
- IP Destination Address is the address of the ingress LSR
- IP Time to Live (TTL) / Hop Count is 255
- IP DSCP is configurable. By default, it is equal to CS6 (0x48) [RFC4594]
- UDP Source Port is any port selected from the dynamic range (49152-65535) [RFC6335]
- UDP Destination Port is any port selected from the dynamic range
- MPLS Echo Global Flags are clear (i.e., set to 0)
- MPLS Echo Type is equal to "MPLS Echo Reply" (2)
- MPLS Echo Reply Mode is "Reply via an IPv4/IPv6 UDP packet" (2)
- MPLS Echo Senders Handle is equal to the Session-ID
- MPLS Echo Sequence Number is equal to retries
- MPLS Echo Time Stamp Sent is equal to the current time

The reader should note that the ingress LSR probes the LSP by sending an MPLS Echo Reply message, addressed to itself, through the LSP. The egress LSR forwards the MPLS Echo Reply message back to the ingress LSR, exactly as it would forward any other IP packet.

If the LSP under test is ready to carry traffic, the egress LSR receives the MPLS Echo Reply message. The MPLS Echo Reply message can arrive at the egress LSR with or without an MPLS header, depending on whether the LSP under test executes penultimate hop-
popping procedures. If the MPLS Echo Reply message arrives at the egress LSR with an MPLS header, the egress LSR removes that header.

The egress LSR forwards the MPLS Echo Reply message to its destination, the ingress LSR. The egress LSR forwards the MPLS Echo Reply message exactly as it would forward any other IP packet. If the egress LSR’s most preferred route to the ingress LSR is through an LSP, the egress LSR forwards the MPLS Echo Reply message through that LSP. However, if the egress LSR’s most preferred route to the ingress LSR is not through an LSP, the egress LSR forwards the MPLS Echo Reply message without MPLS encapsulation.

If the ingress LSR receives an MPLS Echo Reply message with Senders Handle equal to the Session-ID, it sets the verification-status to TRUE. The Sequence Number does not have to match the last Sequence Number sent.

When an LSP Self-ping session terminates, it returns the value of verification-status to the invoking protocol. For example, assume that RSVP-TE invokes LSP Self-ping as part of the LSP set-up procedure. If LSP Self-ping returns TRUE, RSVP-TE makes the LSP under test available for forwarding. However, if LSP Self-ping returns FALSE, RSVP-TE takes appropriate remedial actions.

LSP Self-ping fails if all of the following conditions are true:

- The Source Address of the MPLS Echo Reply message is equal to its default value (that is, the address of the egress LSR)
- The penultimate hop pops the MPLS label
- The egress LSR executes Unicast Reverse Path Forwarding (uRPF) procedures

In this scenario and in similar scenarios, the egress LSR discards the MPLS Echo Reply message rather than forwarding it. In such scenarios, the calling application can set the source address to a more appropriate value.

3. Bidirectional LSP Procedures

In order to verify a bidirectional LSP’s readiness to carry traffic, the procedures described in Section 2 are executed twice, once by each LSP endpoint. Each LSP endpoint tests LSP readiness in one direction.
4. Rejected Approaches

In a rejected approach, the ingress LSR uses LSP-Ping, exactly as described in [RFC4379] to verify LSP readiness to carry traffic. This approach was rejected for the following reasons.

While an ingress LSR can control its control plane overhead due to LSP Ping, an egress LSR has no such control. This is because each ingress LSR can, on its own, control the rate of the LSP Ping originated by the LSR, while an egress LSR must respond to all the LSP Pings originated by various ingresses. Furthermore, when an MPLS Echo Request reaches an egress LSR it is sent to the control plane of the egress LSR, which makes egress LSR processing overhead of LSP Ping well above the overhead of its data plane (MPLS/IP forwarding). These factors make LSP Ping problematic as a tool for detecting LSP readiness to carry traffic when dealing with a large number of LSPs.

By contrast, LSP Self-ping does not consume any control plane resources at the egress LSR, and relies solely on the data plane of the egress LSR, making it more suitable as a tool for checking LSP readiness when dealing with a large number of LSPs.

In another rejected approach, the ingress LSR does not verify LSP readiness. Alternatively, it sets a timer when it receives an RSVP RESV message and does not forward traffic through the LSP until the timer expires. This approach was rejected because it is impossible to determine the optimal setting for this timer. If the timer value is set too low, it does not prevent black-holing. If the timer value is set too high, it slows down the process of LSP signalling and setup.

Moreover, the above-mentioned timer is configured on a per-router basis. However, its optimum value is determined by a network-wide behavior. Therefore, changes in the network could require changes to the value of the timer, making the optimal setting of this timer a moving target.

5. IANA Considerations

This document makes no request of IANA.

Note to RFC Editor: this section may be removed on publication as an RFC.
6. Security Considerations

MPLS Echo messages are easily forged. Therefore, an attacker can send the ingress LSR a forged MPLS Echo message, causing the ingress LSR to terminate the LSP Self-ping session prematurely.

7. Acknowledgements

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8. Normative References


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MPLS Flow Identification
draft-bryant-mpls-flow-ident-01

Abstract

This memo discusses the desired capabilities for MPLS flow identification. The key application that needs this is in-band performance monitoring of user data packets.

Status of This Memo

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1. Introduction

This memo discusses the desired capabilities for MPLS flow identification. The key application that needs this is in-band performance monitoring of user data packets.

There is a need to identify flows in MPLS networks for applications such as packet loss and packet delay measurement. A method of loss and delay measurement in MPLS networks was defined in [RFC6374]. When used to measure packet loss [RFC6374] depends on the use of the injected OAM packets are used to designate the beginning and the end of the packet group over which packet loss is being measured. Where the misordering of packets from one group relative to the following group, or misordering of one of the packets being counted relative to the [RFC6374] packet occurs, then an error will occur in the packet loss measurement. In addition, this packet performance system needs to be extended to deal with different granularities of flow and to address a number of the multi-point cases in which a number of ingress LSRs could send to one or more destinations.

Improvements in link and transmission technologies mean that it may be difficult to assess packet loss using active performance
measurement methods with synthetic traffic, due to the very low loss rate in normal operation. That together with more demanding service level requirements mean that network operators need to be able to measure the loss of the actual user data traffic by using passive performance measurement methods. Any technique deployed needs to be transparent to the end user, and it needs to be assumed that they will not take any active part in the measurement process. Indeed it is important that any flow identification technique be invisible to them and that no remnant of the identification of measurement process leak into their network.

Additionally where there are multiple traffic sources, such as in multi-point to point and multi-point to multi-point network environments there needs to be a method whereby the sink can distinguish between packets from the various sources, that is to say, that a multi-point to multi-point measurement model needs to be developed.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Loss Measurement Considerations

Modern networks, if not oversubscribed, normally drop very few packets, thus packet loss measurement is highly sensitive to counter errors. Without some form of coloring or batch marking such as that proposed in [I-D.tempia-ippm-p3m] it may not be possible to achieve the required accuracy in the loss measurement of customer data traffic. Where accuracy better than the data link loss performance of a modern optical network is required, it may be economically advantageous, or even a technical requirement, to include temporal marking.

Where this level of accuracy is required and the traffic between a source-destination pair is subject to ECMP a demarcation mechanism is needed to group the packets into batches. Once a batch is correlated at both ingress and egress, the packet accounting mechanism is then able to operate on the batch of packets which can be accounted for at both the packet ingress and the packet egress. Errors in the accounting are particularly acute in LSPs subjected to ECMP because the network transit time will be different for the various ECMP paths since:

a. The packets may traverse different sets of LSRs.
b. The packets may depart from different interfaces on different line cards on LSRs

c. The packets may arrive at different interfaces on different line cards on LSRs.

A consideration in modifying the identity label (the MPLS label ordinarily used to identify the LSP, Virtual Private Network, Pseudowire etc) to indicate the batch is the impact that this has on the path chosen by the ECMP mechanism. When the member of the ECMP path set is chosen by deep packet inspection a change of batch represented by a change of identity label will have no impact on the ECMP path. Where the path member is chosen by reference to an entropy label [RFC6790] then provided that the entropy label is higher in the stack than the label that is changing the batch identifier again there will be no change to the chosen ECMP path.

ECMP is so pervasive in multi-point to (multi-) point networks that some method of avoiding accounting errors introduced by ECMP needs to be supported.

4. Delay Measurement Considerations

Most of the existing delay measurement methods are active measurement that depend on the extra injected test packet to evaluate the delay of a path. With the active measurement method, the rate, numbers and interval between the injected packets may affect the accuracy of the results. Also, for injected test packets, these may not be co-routed with the data traffic due to ECMP. Thus there exists a requirements to measure the delay of the real traffic. For loss delay, the identity considerations described in Section 3 also apply.

5. Units of identification

The most basic unit of identification is the identity of the node processed the packet on its entry to the MPLS network. However, the required unit of identification may vary depending on the use case for accounting, performance measurement or other types of packet observations. In particular note that there mat be a need to impose identify at several different layers of the MPLS label stack.

This document considers following units of identifications:

- Per source LSR - everything from one source is aggregated.
- Per group of LSPs chosen by an ingress LSR - an ingress LSP aggregates group of LSPs (ex: all LSPs of a tunnel).
- Per LSP - the basic form.
Per flow [RFC6790] within an LSP - fine graining method.

Note that a finer grained identity resolution is needed when there is a need to perform these operations on a flow not readily identified by some other element in the label stack. Such fine grained resolution may be possible by deep packet inspection, but this may not always be possible, or it may be desired to minimise processing costs by doing only in entry to the network, and adding a suitable identifier to the packet for reference by other network elements. An example of such a fine grained case might be traffic from a specific application, or from a specific application from a specific source, particularly if matters related to service level agreement or application performance were being investigated.

We can thus characterize the identification requirement in the following broad terms:

- There needs to be some way for an egress LSR to identify the ingress LSR with an appropriate degree of scope. This concept is discussed further in Section 7.

- There needs to be a way to identify a specific LSP at the egress node. This allows for the case of instrumenting multiple LSPs operate between the same pair of nodes. In such cases the identity of the ingress LSR is insufficient.

- In order to conserve resources such as labels, counters and/or compute cycles it may be desirable to identify an LSP group so that a operation can be performed on the group as an aggregate.

- There needs to be a way to identify a flow within an LSP. This is necessary when investigating a specific flow that has been aggregated into an LSP.

The unit of identification and the method of determining which packets constitute a flow will be application or use-case specific and is out of scope of this memo.

6. Types of LSP

We need to consider a number of types of LSP. The two simplest types to monitor are point to point LSPs and point to multi-point LSPs. The ingress LSR for a point to point LSP, such as those created using the RSVP-TE signalling protocol, or those that conform to the MPLS-TP may be identified by inspection of the top label in the stack, since at any PE or P router on the path this is unique to the ingress-egress pair at every hop at a given layer in the LSP hierarchy. Provided that penultimate hop popping is disabled, the identity of
the ingress LSR of a point to point LSP is available at the egress LSR and thus determining the identity of the ingress LSR must be regarded as a solved problem. Note however that the identity of a flow cannot to be determined without further information.

In the case of a point to multi-point LSP the identity of the ingress LSR may also be inferred from the top label. [Editor’s note - there was discussion of the following sentence amongst the authors and this needs to be looked at in the next version]. However, it may not possible to adequately from the top label alone. In designing any solution it is desirable that a common flow identity solution be used for both point to point and point to multi-point LSP types. Similarly it is desirable that a common method of LSP group identification be used.

[Editor’s note: The following text was in -00, and a review comment asks why. At the time of editing I cannot remember the context. If the original authors cannot remember why by the next version, it will be deleted] In the above cases, an explicit non-null label is needed to provide context at the egress LSR. This is widely supported MPLS feature.

A more interesting case, and the core purpose of this memo, is the case of a multi-point to point LSP. In this case the same label is normally used by multiple ingress or upstream LSRs and hence source identification is not possible by inspection of the top label by egress LSRs. It is therefore necessary for a packet to be able to explicitly convey any of the identity types described in Section 5.

Similarly, in the case of a multi-point to multi-point LSP the same label is normally used by multiple ingress or upstream LSRs and hence source identification is not possible by inspection of the top label by egress LSRs. The various types of identity described in Section 5 are again needed. Note however, that the scope of the identity may be constrained to be unique within the set of multi-point to multi-point LSPs terminating on any common node.

7. Network Scope

The scope of identification can be constrained to the set of flows that are uniquely identifiable at an ingress LSR, or some aggregation thereof. There is no question of an ingress LSR seeking assistance from outside the MPLS protocol domain.

In any solution that constrains itself to carrying the required identity in the MPLS label stack rather than in some different associated data structure, constraints on the label stack size imply that the scope of identity reside within that MPLS domain. For
similar reasons the identity scope of a component of an LSP should be constrained to the scope of that LSP.

8. Backwards Compatibility

In any network it is unlikely that all LSRs will have the same capability to support the methods of identification discussed in this memo. It is therefore an important constraint on any identity solution that it is backwards compatible with deployed MPLS equipment to the extent that deploying the new feature will not disable anything that currently works on a legacy equipment.

This is particularly the case when the deployment is incremental or when the feature is not required for all LSRs or all LSPs. Thus in broad the flow identification design MUST support the co-existence of LSRs that can and cannot identify the traffic components described in Section 5. In addition the identification of the traffic components described in Section 5 MUST be an optional feature that is disabled by default. As a design simplification, a solution MAY require that all egress LSRs of a point to multipoint or a multi-point to multipoint LSP support the identification type in use so that a single packet can be correctly processed by all egress devices. The corollary of this last point is that either all egress LSRs are enabled to support the required identity type, or none of them are.

9. Dataplane

There is a huge installed base of MPLS equipment, typically this type of equipment remains in service for an extended period of time, and in many cases hardware constraints mean that it is not possible to upgrade its dataplane functionality. Changes to the MPLS data plane are therefore expensive to implement, add complexity to the network, and may significantly impact the deployability of a solution that requires such changes. For these reasons, the MPLS designers have set a very high bar to changes to the MPLS data plane, and only a very small number have been adopted. Hence, it is important that the method of identification must minimize changes to the MPLS data plane. Ideally method(s) of identification that require no changes to the MPLS data plane should be given preferential consideration. If a method of identification makes a change to the data plane is chosen it will need to have a significant advantage over any method that makes no change, and the advantage of the approach will need to be carefully evaluated and documented. If a change is necessary to the MPLS data plane proves necessary, it should be (a) be as small a change as possible and (b) be a general purpose method so as to maximise its use for future applications. It is imperative that, as far as can be foreseen, any necessary change made to the MPLS data
plane does not impose any foreseeable future limitation on the MPLS data plane.

Stack size is an issue with many MPLS implementations both as a result of hardware limitations, and due to the impact on networks and applications where a large number of small payloads need to be transported. In particular one MPLS payload may be carried inside another. For example one LSP may be carried over another LSP, or a PW or similar multiplexing construct may be carried over an LSP and identification may be required at both layers. Of particular concern is the implementation of low cost edge LSRs that for cost reasons have a significant limit on the number of Label Stack Elements (LSEs) that they can impose or dispose. Therefore, any method of identity MUST NOT consume an excessive number of unique labels, and MUST NOT result in an excessive increase in the size of the label stack.

The MPLS data plane design provides two types of special purpose labels: the original 16 reserved labels and the much larger set of special purpose labels defined in [RFC7274]. The original reserved labels need one LSE, and the newer [RFC7274] special purpose labels need two LSEs. Given the tiny number of original reserved labels, it is core to the MPLS design philosophy that this scarce resource is only used when it is absolutely necessary. Using a single LSE reserved or special purpose label to encode flow identity thus requires two stack entries, one for the reserved label and one for the flow identity. The larger set of [RFC7274] labels requires two labels stack entries for the special purpose label itself and hence a total of three label stack entries to encode the flow identity.

The use of special purpose labels (SPL) [RFC7274] as part of a method to encode the identity information therefore has a number of undesirable implications for the data plane and hence whilst a solution may use SPL(s), methods that do not require SPLs need to be carefully considered.

10. Control Plane

Any flow identity design should both seek to minimise the complexity of the control plane and should minimise the amount of label co-ordination needed amongst LSRs.

11. Manageability Considerations

This will be provided in a future version of this document.
12. Privacy Considerations

The inclusion of originating and/or flow information in a packet provides more identity information and hence potentially degrades the privacy of the communication. Recent IETF concerns on pervasive monitoring would lead it to prefer a solution that does not degrade the privacy of user traffic below that of an MPLS network not implementing the flow identification feature. The minimizing the scope of the identity indication can be useful in minimizing the observability of the flow characteristics.

13. Security Considerations

Any solution to the flow identification needs must not degrade the security of the MPLS network below that of an equivalent network not deploying the specified identity solution. Propagation of identification information outside the MPLS network imposing it must be disabled by default. Any solution should provide for the restriction of the identity information to those components of the network that need to know it. It is thus desirable to limit the knowledge of the identity of an endpoint to only those LSRs that need to participate in traffic flow.

14. IANA Considerations

EDITOR’S NOTE: This section may be removed on publication

This memo has no IANA considerations.

15. Acknowledgements

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16. References

16.1. Normative References


16.2. Informative References

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Abstract

In draft-bryant-mpls-synonymous-flow-labels the concept of MPLS synonymous flow labels (SFL) was introduced. This document describes a control protocol that runs over an associated control header to request, withdraw and extend the lifetime of such labels.

Status of This Memo

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1. Introduction

In [draft-bryant-mpls-synonymous-flow-labels] the concept of MPLS synonymous flow labels (SFL) was introduced. This document describes a simple control protocol that runs over an associated control header to request, withdraw and extend the lifetime of such labels. In [draft-bryant-mpls-RFC63740-over-udp] it is shown how to run this over UDP transport.

2. 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 [RFC2119].

3. SFL Control

This section describes the process by which the RFC6374 Querier requests SFLs, the process by which the RFC6374 Responder sends them to the Querier, and the process for managing the SFL lifetime. SFL Control Messages are carried over the SFL Control ACH. The SFL ACH is carried over a Pseudowire(PW) in place of the PW Control Word (CW), over an MPLS LSP using the GAL, or over some other mutually agreed path. Similarly the response may be returned over a PW, over a bidirectional LSP or over some other mutually agreed path. See Section 4.
3.1. SFL Control Message

The format of an SFL Control message, which follows the Associated Channel Header (ACH), is as follows:

```
+----------------------------------+
| 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 |
+----------------------------------+
| Version | Flags | Control Code | Message Length |
+----------------------------------+
| Session Identifier | SFL Batch |
+----------------------------------+
| Lifetime (seconds) | Num SFL |
+----------------------------------+
| SFL 0 | LFlags |
+----------------------------------+
| SFL n | LFlags |
+----------------------------------+
| Forwarding Equivalence Class (FEC) |
+----------------------------------+
```

Figure 1: SFL Control Message Format

Reserved fields MUST be set to 0 and ignored upon receipt. The possible values for the remaining fields are as follows:

Version          Protocol version. Set to zero in this specification.
Flags            Message control flags.
Control Code     Code identifying the query or response type.
Message Length   Total length of this message in bytes.
Session Identifier Set arbitrarily by the querier and used as a message handle.
SFL Batch        Used where the SFLs for this Session Identifier managed across multiple SFL Control Messages. A given set of SFLs MUST be retained in the same batch.
Lifetime         The lifetime in seconds of the SFLs in this message. In a Query message it is the requested lifetime. In a Response message it is the lifetime that the SFLs have been allocated for by the Responder. The Querier MUST
NOT use an SFL after expiry of its lifetime, a Responder MUST make the SFL available for at least its lifetime.

Num SFL The number of SFLs in this SFL Batch. This MUST be constant for the lifetime of the batch.

SFL n The n’th SFL carried in this TLV. This is an MPLS label which is a component of a label stack entry as defined in Section 2.1 of [RFC3032]. The position of a label within a batch is constant for the lifetime of the batch. Enumeration starts at zero.

LFlags The set of flags associated with the immediately preceding SFL. See below.

FEC The Forwarding Equivalence Class that the SFLs in this TLV correspond to. This is encoded as per Section 3.4.1 of [RFC5036].

Flags: The format of the Flags field is shown below.

```
+-----+
| R 0 0 0 |
+-----+
```

SFL Control Message Flag

R: Query/Response indicator. Set to 0 for a Query and 1 for a Response.

0: Set to zero by the Sender and ignored by the Receiver.

Control Code: Set as follows according to whether the message is a Query or a Response as identified by the R flag.

For a Query:

Request This indicates that the responder is requested to allocate the set of SFLs marked with the R LFlag in this Message.

Refresh This indicates that the responder is requested to refresh the set of SFLs marked with the V LFlag in this Message.

Withdraw This indicates that the querier will no longer use the set of SFLs marked with the V Lflag and the responder may expire their lifetime.
For a Response:

Grant  This indicates that the responder allocated the set of SFLs marked with the A LFlag in this Message.

Refresh-Ack  This indicates that the responder has refreshed the set of SFLs marked with the V LFlag in this Message, and the lifetime is now as indicated by the lifetime field.

Withdraw-Ack  This indicates that the responder has received the Withdraw message and will withdraw the SFLs

SFL-Unable  The Responder was unable to satisfy the SFL Request. The details of the failure can be determined by comparing the Request and Grant messages.

Further error codes are for future study.

The LFlags field is defined as follows:

```
0                   1
0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|1|2|3|        MBZ    |
|              |   |   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: LFLAGS Bit Definition

Where:

0 (Valid (V))  The Label value of the corresponding SFL is valid. In an SFL Request setting the V Lflag indicates a request for the specified label value. Where an SFL has a valid flag clear in a request message this indicates that any SFL value is acceptable.

1 (Request (R))  Indicates to the Querier that this member of the SFL batch is requested. Where a value is specified in the request, but the Responder is unable honour that request, no SFL is allocated and the corresponding A flag MUST be cleared.

2 (Allocated (A))  Indicates to the Querier that this SFL was allocated.
3 (Withdraw (W)) Indicates to the Responder that this SFL is to be withdrawn and to the Querier that the withdrawal has been carried out.

MBZ MUST be sent as zero and ignored on receive.

A flag value of one is true/set and a flag value of zero is false/clear. The use of these bits is described in more detail in the following sub-sections.

3.2. SFL Control Procedures

3.2.1. Request/Grant

To request a batch of SFLs the Querier constructs an SFL Control Request, encapsulates it in an SFL Control ACH and sends it to the Responder via an appropriate path. It sets the Control Message Flag to Query and the Control Code to Request. It chooses a session identifier as a handle for this transaction and as a way of binding this batch of SFLs to other operations that will use members of this SFL batch. Since members of the batch are treated as a group, the SFL Batch identifier is used to identify different SFL batches used in conjunction with the same session identifier.

The requested lifetime is set. This is the number of seconds from the time of the query to the time when the batch of SFLs will expire unless refreshed.

The Num SFL field is set to the SFL batch size.

Each SFL is set as follows: if a specific value is requested (for example for continuity across system restarts) this is written into the SFV n field and the V LFlag set. Otherwise, and including spare SFLs where an allocation is not requested, the label value is set to zero and the V LFlag is cleared. For each SFL entry where an allocation is requested the R LFlag is set. All other LFlags are cleared.

The Forwarding Equivalence Class (FEC) is set to the FEC for which the SFLs are requested.

The Message Length is determined and filled in.

The Responder proceeds as follows:

It sets the control Message Flag to Response and initially sets the Control Code to Grant.
For each SFL with an R flag set, it determines whether it can honour
the request, if so sets the A Lflag, and if the SFL value in the
query was zero it overwrites it with the allocated SFL label value.
In all other cases it leaves the SFL value and LFlag unchanged.

The lifetime field is updated with the lifetime of the SFLs if this
is different from the requested lifetime.

All other fields in the Query message are left unchanged and the
message is sent back to the Querier using the signaled or previously
agreed message path.

Where the offered lifetime is other than the requested lifetime the
Querier may accept the proposed value, or withdraw the SFLs and
attempt to negotiate a new set of SFLs with a different lifetime.

If the Responder is unable to allocate all of the requested SFLs it
MUST respond with a response code of SFL-Unable. The Querier MUST
determine whether the allocated SFLs were adequate for its purposes
and MUST send a withdraw if there are not adequate. A Querier MUST
NOT attempt to hoard labels in the hope that the residual labels
needed may become available in the future.

A Querier MUST wait a configured time (suggested wait of 60 seconds)
before reattempting negotiation for a resource. Any failure to
negotiate the required resources MUST be notified through the
management interface of both Querier and Responder.

A Querier MUST NOT send an expired SFL to a Responder since to do so
may invalidate another SFL operation.

3.2.2. Refresh

To request the lifetime refresh of a batch of SFLs the Querier
constructs an SFL Refresh Request, encapsulates it in an SFL Control
ACH and sends it to the Responder via an appropriate path. It sets
the Control Message Flag to Query and the Control Code to Refresh.
It uses the session identifier and the SFL Batch identifier that it
used to request this SFL batch.

The requested lifetime is set. This is the number of seconds from
the time of the query to the time when the batch of SFLs will expire
unless refreshed.

The Num SFL field is set to the SFL batch size.
Each SFL is set as follows: the allocated SFL label value is written into the SFL n field and the V LFlag set. All other LFlags are cleared.

The Forwarding Equivalence Class (FEC) is set to the FEC for which the SFLs are requested.

The Message Length is determined and filled in.

The Responder proceeds as follows:

It sets the control Message Flag to Response and sets the Control Code to Refresh-Ack.

It sets the lifetime to the lifetime of the SFL.

All other fields in the Query message are left unchanged and the message is sent back to the Querier using the signaled or previously agreed message path.

Where the offered lifetime is other than the requested lifetime the Querier may accept the proposed value, or withdraw the SFLs and attempt to negotiate a new set of SFLs with a different lifetime.

A Querier MUST wait a configured time (suggested wait of 60 seconds) before reattempting negotiation for a resource. Any failure to negotiate the required resources MUST be notified through the management interface of both Querier and Responder.

3.2.3. Withdraw

To request the withdrawal of some or all of a batch of SFLs the Querier constructs an SFL Withdraw Request, encapsulates it in an SFL Control ACH and sends it to the Responder via an appropriate path. It sets the Control Message Flag to Query and the Control Code to Withdraw. It uses the session identifier and the SFL Batch identifier that it used to request this SFL batch.

The requested lifetime is set to zero.

The Num SFL field is set to the SFL batch size.

Each SFL being withdrawn is set as follows: the allocated SFL label value is written into the SFL n field and the V and W LFlags set. All other LFlags are cleared.

The Forwarding Equivalence Class (FEC) is set to the FEC for which the SFLs are requested.
The Message Length is determined and filled in.

The Responder proceeds as follows:

It sets the control Message Flag to Response and sets the Control Code to Withdraw-Ack.

All other fields in the Query message are left unchanged and the message is sent back to the Querier using the signaled or previously agreed message path.

A Querier MUST wait a configured time (suggested wait of 60 seconds) before reattempting a Withdraw request. No more than three Withdraw requests should be made.

3.2.4. Timer Accuracy

The lifetime of SFLs is expected to be sufficiently long that there are no significant constraints on timer accuracy. A node should be conservative in its assumptions concerning the lifetime of an SFL. A Querier MUST stop using a SFL significantly before the expiry of its lifetime and a Responder must maintain an SFL in active operation significantly beyond nominal expiry. A margin of the order of minutes is RECOMMENDED.

4. Return Path

Where the LSP is a mulit-point to point, or multi-point to multi-point MPLS LSP (or other MPLS construct) the RFC6374 Address TLV MUST be included in Query packet, even if the response is requested in-band, since this is needed to provide the necessary return address for this request.

5. Manageability Considerations

This may be provided in a future version of this memo.

6. Privacy Considerations

The inclusion of originating and/or flow information in a packet provides more identity information and hence potentially degrades the privacy of the communication. Whilst the inclusion of the additional granularity does allow greater insight into the flow characteristics it does not specifically identify which node originated the packet other than by inspection of the network at the point of ingress, or inspection of the control protocol packets. This privacy threat may be mitigated by encrypting the control protocol packets, regularly
changing the synonymous labels and by concurrently using a number of such labels.

7. Security Considerations

It is assumed that this protocol is run in a well managed MPLS network with strict access controls preventing unwanted parties from generating MPLS OAM packets. The control protocol described in this memo thus introduced no additional MPLS security vulnerabilities.

8. IANA Considerations

As per the IANA considerations in [RFC5586], IANA is requested to allocate the following Channel Types in the "MPLS Generalized Associated Channel (G-ACh) Types" registry:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>TLV Follows</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0XXX</td>
<td>SFL Control</td>
<td>No</td>
<td>This</td>
</tr>
</tbody>
</table>

A value of 0x60 is suggested.

9. Acknowledgements

TBD

10. Normative References


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draft-chandra-mpls-enhanced-frr-bypass-01

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Abstract

This document defines RSVP-TE extensions to facilitate refresh-interval independent FRR facility protection.

Conventions used in this document

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 RFC-2119 [RFC2119].

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1. Introduction

The facility backup protection mechanism is one of two methods discussed in [RFC4090] for enabling the fast reroute of traffic onto backup LSP tunnels in 10s of milliseconds, in the event of a failure. This document discusses a few shortcomings with some of the refresh-interval reliant procedures proposed for this method in [RFC4090]. These shortcomings come to the fore under scaled conditions and get highlighted even further when large RSVP-TE refresh intervals are used. The RSVP-TE extensions defined in this document will enhance the facility backup protection mechanism by making the corresponding procedures refresh-interval independent.

2. Motivation

Standard RSVP [RFC2205] maintains state via the generation of RSVP Path/Resv refresh messages. Refresh messages are used to both synchronize state between RSVP neighbors and to recover from lost RSVP messages. The use of Refresh messages to cover many possible failures has resulted in a number of operational problems. One problem relates to RSVP control plane scaling due to periodic refreshes of Path and Resv messages, another relates to the reliability and latency of RSVP signaling. An additional problem is the time to clean up the stale state after a tear message is lost. For more on these problems see Section 1 of [RFC2961]. All these problems adversely affect RSVP control plane scalability. RSVP-TE inherited all these problems from standard RSVP.
Procedures specified in [RFC2961] address the above mentioned problems by eliminating dependency on refreshes for state synchronization and for recovering from lost RSVP messages, and by eliminating dependency on refresh timeout for stale state cleanup. Implementing these procedures allows to improve RSVP-TE control plane scalability.

However, the procedures specified in [RFC2961] do not fully address stale state cleanup for facility backup protection [RFC4090], as facility backup protection still depends on refresh timeouts for stale state cleanup. Thus [RFC2961] is insufficient to address the problem of stale state cleanup when facility backup protection is used.

The procedures specified in this document, in combination with [RFC2961], eliminate facility backup protection dependency on refresh timeouts for stale state cleanup. These procedures, in combination with [RFC2961], fully address the above mentioned problem of RSVP-TE stale state cleanup, including the cleanup for facility backup protection.

The procedures specified in this document assume reliable delivery of RSVP messages, as specified in [RFC2961]. Therefore this document makes support for [RFC2961] a pre-requisite.

3. Problem Description

![Example Topology]

Figure 1: Example Topology
In the topology illustrated in Figure 1, consider a large number of LSPs from A to D transiting B and C. Assume that refresh interval has been configured to be large of the order of minutes and refresh reduction extensions are enabled on all routers.

Also assume that node protection has been configured for the LSPs and the LSPs are protected by each router in the following way:

- A has made node protection available using bypass LSP A -> E -> C; A is the Point of Local Repair (PLR) and C is Node Protecting Merge Point (NP-MP)
- B has made node protection available using bypass LSP B -> F -> D; B is the PLR and D is the NP-MP
- C has made link protection available using bypass LSP C -> B -> F -> D; C is the PLR and D is the Link Protecting Merge Point (LP-MP)

In the above condition, assume that B-C link fails. The following is the sequence of events that is expected to occur for all protected LSPs under normal conditions.

1. B performs local repair and re-directs LSP traffic over the bypass LSP B -> F -> D.
2. B also creates backup state for the LSP and triggers sending of backup LSP state to D over the bypass LSP B -> F -> D.
3. D receives backup LSP states and merges the backups with the protected LSPs.
4. As the link on C over which the LSP states are refreshed has failed, C will no longer receive state refreshes. Consequently the protected LSP states on C will time out and C will send tear down message for all LSPs.

While the above sequence of events has been described in [RFC4090], there are a few problems for which no mechanism has been specified explicitly.

- If the protected LSP on C times out before D receives signaling for the backup LSP, then D would receive PathTear from C prior to receiving signaling for the backup LSP, thus resulting in deleting the LSP state. This would be possible at scale even with default refresh time.
- If upon the link failure C is to keep state until its timeout, then with long refresh interval this may result in a large amount of stale state on C. Alternatively, if upon the link failure C is to delete the state and send PathTear to D, this would result in deleting the state on D, thus deleting the LSP. D needs a reliable mechanism to determine whether it is MP or not to overcome this problem.

- If head-end A attempts to tear down LSP after step 1 but before step 2 of the above sequence, then B may receive the tear down message before step 2 and delete the LSP state from its state database. If B deletes its state without informing D, with long refresh interval this could cause (large) buildup of stale state on D.

- If B fails to perform local repair in step 1, then B will delete the LSP state from its state database without informing D. As B deletes its state without informing D, with long refresh interval this could cause (large) buildup of stale state on D.

The purpose of this document is to provide solutions to the above problems which will then make it practical to scale up to a large number of protected LSPs in the network.

4. Solution Aspects

The solution consists of five parts.

- Enhance the facility protection method defined in [RFC4090] by introducing an MP determination mechanism that enables PLR to signal availability of link or node protection to the MP. See section 4.1 for more details.

- Handle upstream link or node failures by cleaning up LSP states if the node has not found itself as MP through the MP determination mechanism. See section 4.2 for more details.

The combination of "path state" maintained as Path State Block (PSB) and "reservation state" maintained as Reservation State Block (RSB) forms an individual LSP state on an RSVP-TE speaker.

- Introduce extensions to enable a router to send tear down message to downstream router that enables the receiving router to conditionally delete its local state. See section 4.3 for more details.
- Enhance facility protection by allowing a PLR to directly send
tear down message to MP without requiring the PLR to either have a
working bypass LSP or have already signaled backup LSP state. See
section 4.4 for more details.

- Introduce extensions to enable the above procedures to be
backward compatible with routers along the LSP path running
implementation that do not support these procedures. See section
4.5 for more details.

4.1. Signaling Protection availability in Path RRO Flags

This section specifies a mechanism to allow the PLR to inform the MP
if local protection is available. This mechanism relies on a
combination of rules around the propagation of RRO flags carried in
PATH messages (Section 4.1.2) and a targeted Node-ID Hello session
(Section 4.1.3).

4.1.1. PLR Behavior

As per the procedures specified in RFC 4090, when a protected LSP
comes up and if the "local protection desired" flag is set in the
SESSION_ATTRIBUTE object, each node along the LSP path attempts to
make local protection available for the LSP.

- If the "node protection desired" flag is set, then the node tries
to become a PLR by attempting to create a NP-bypass LSP to the
NNhop node avoiding the Nhop node on protected LSP path. In case
node protection could not be made available after some time out,
the node attempts to create a LP-bypass LSP to Nhop node avoiding
only the link that protected LSP takes to reach Nhop

- If the "node protection desired" flag is not set, then the PLR
attempts to create a LP-bypass LSP to Nhop node avoiding the link
that the protected LSP takes to reach Nhop

With regard to the PLR procedures described above and that are
specified in RFC 4090, this document specifies the following
recommendations involving addresses selection, and additional PLR
procedures involving RRO flags carried in PATH message as well as
the initiation of Node-ID based Hello sessions.

- While selecting the destination address of the bypass LSP, the
PLR SHOULD attempt to select the router ID of the NNhop or Nhop
node. If the PLR and the MP are in same area, then the PLR may
utilize the TED to determine the router ID from the interface
address in RRO (if NodeID is not included in RRO). If the PLR and the MP are in different IGP areas, then the PLR SHOULD use the NodeID address of NNhop MP if included in the RRO of RESV. If the NP-MP in a different area has not included NodeID in RRO, then the PLR SHOULD use NP-MP’s interface address present in the RRO. The PLR SHOULD use its router ID as the source address of the bypass LSP. The PLR SHOULD also include its router ID as the NodeID in PATH RRO unless configured explicitly not to include NodeID.

In parallel to the attempt made to create NP-bypass or LP-bypass, the PLR SHOULD initiate a Node-ID based Hello session to the NNhop or Nhhop node respectively to establish the RSVP-TE signaling adjacency. This Hello session is used to track the state of the adjacency, including detection of adjacency failure.

- If the NP-bypass LSP comes up, then the PLR SHOULD set the "local protection available" and "NP available" RRO flags and triggers PATH to be sent.

- If the LP-bypass LSP comes up, then the PLR SHOULD set the "local protection available" RRO flag and triggers PATH to be sent.

- After signaling protection availability, if the PLR finds that the protection becomes unavailable then it SHOULD attempt to make protection available. The PLR SHOULD wait for a time out before resetting RRO flags relating to protection availability and triggering PATH downstream. On the other hand, the PLR need not wait for a time out to set RRO flags relating to protection availability and immediately trigger PATH downstream.

4.1.2. Remote Signaling Adjacency

A NodeID based RSVP-TE Hello session is one in which NodeID is used in source and destination address fields in RSVP Hello. [RFC4558] formalizes NodeID based Hello messages between two routers. This document extends NodeID based RSVP Hello session to track the state of RSVP-TE neighbor that is not directly connected by at least one interface. In order to apply NodeID based RSVP-TE Hello session between any two routers that are not immediate neighbors, the router that supports the extensions defined in the document SHOULD set TTL to 255 in the NodeID based Hello messages exchanged between PLR and MP.

In the rest of the document the term "signaling adjacency", or "remote signaling adjacency" refers specifically to the RSVP-TE signaling adjacency.
4.1.3. PATH RRO flags Propagation

As each node along the LSP path can make protection available, propagating PATH immediately due to change in RRO flags on any upstream node would increase control plane message load. So whenever a node receives PATH, it SHOULD check if the only change is in RRO flags. If the change is only in PATH RRO flags, then the node SHOULD decide whether to propagate the PATH based on the following rule.

- If "NP desired" flag is set and "NP available" flag has changed in Phop’s RRO flags, then PATH is triggered.
- In all other cases the change is not propagated.

4.1.4. MP Behavior

When the NNhop or Nhop node receives the triggered PATH with RRO flag(s) set, the node SHOULD check the presence of remote signaling adjacency with PLR (this check is needed to detect network being partitioned). If the flags are set and the RSVP-TE signaling adjacency is present, the node concludes that protection has been made available at the PLR. If the PLR has included NodeID in PATH RRO, then that NodeID is the remote neighbor address. Otherwise, the PLR’s interface address in RRO will be the remote neighbor address. If the "NP available" flag is set by PPhop node, then it is NP-MP. Otherwise, it concludes it is LP-MP.

4.1.5. "Remote" state on MP

Once a router concludes it is MP, it SHOULD create a remote path state for the LSP. The "remote" state is identical to the protected LSP path state except for the difference in HOP object. The HOP object corresponding to the "remote" path state contains the address of remote node signaling adjacency with PLR.

The MP SHOULD consider the "remote" path state automatically deleted if:

- NP-MP later receives a PATH with "NP available" flag reset in PLR’s RRO flags, or
- LP-MP later receives PATH with "local protection available" flag reset in PLR’s RRO flags, or
- Node signaling adjacency with PLR goes down, or

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- MP receives backup LSP signaling from PLR or
- MP receives PathTear, or
- MP deletes the LSP state on local policy or exception event

Unlike the normal path state that is either locally generated on Ingress or created from PATH message from Phop node, the "remote" path state is not signaled explicitly from PLR. The purpose of "remote" path state is to enable the PLR to explicitly tear down path and reservation states corresponding to the LSP by sending tear message for the "remote" path state. Such message tearing down "remote" path state is called "Remote PathTear."

The scenarios in which "Remote" PathTear is applied are described in Section 4.4 - Remote State Teardown.

4.2. Impact of Failures on LSP State

This section describes the procedures for routers on the LSP path for different kinds of failures. The procedures described on detecting RSVP control plane adjacency failures do not impact the RSVP-TE graceful restart mechanisms ([RFC3473], [RFC5063]). If the router executing these procedures act as helper for neighboring router, then the control plane adjacency will be declared as having failed after taking into account the grace period extended for neighbor by the helper.

It should be noted that even though this section and the subsequent sections of the document mention "link failure" and "node failure" separately involving upstream or downstream of a protected LSP, a router implementing the procedures specified in the document need not have a mechanism to distinguish between these two types of failures. Optionally, a router MAY run Node-ID based RSVP-TE signaling adjacency with immediate neighbors to distinguish between these two types of failures.

4.2.1. Non-MP Behavior on Phop Link/Node Failure

When a router detects Phop link or Phop node failure and the router is not an MP for the LSP, then it SHOULD send Conditional PathTear (refer to Section "Conditional PathTear" below) and delete PSB and RSB states corresponding to the LSP.
4.2.2. LP-MP Behavior on Phop Link Failure

When the Phop link for an LSP fails on a router that is LP-MP for the LSP, the LP-MP SHOULD retain PSB and RSB states corresponding to the LSP till the occurrence of any of the following events.

- Node-ID signaling adjacency with Phop PLR goes down, or
- MP receives normal or "Remote" PathTear for PSB, or
- MP receives ResvTear RSB.

4.2.3. LP-MP Behavior on Phop Node Failure

When a router that is LP-MP for an LSP detects Phop node failure from Node-ID signaling adjacency state, the LP-MP SHOULD send normal PathTear and delete PSB and RSB states corresponding to the LSP.

4.2.4. NP-MP Behavior on Phop Link/Node Failure

When a router that is NP-MP for an LSP detects Phop link failure, or Phop node failure from Node-ID signaling adjacency, the router SHOULD retain PSB and RSB states corresponding to the LSP till the occurrence of any of the following events.

- Remote Node-ID signaling adjacency with PPhop PLR goes down, or
- MP receives normal or "Remote" PathTear for PSB, or
- MP receives ResvTear for RSB.

4.2.5. NP-MP Behavior on PLR Link Failure

If the PLR link that is not attached to NP-MP fails and if NP-MP receives Conditional PathTear from the Phop node, then the MP SHOULD retain PSB and RSB states corresponding to the LSP till the occurrence of any of the following events.

- Remote Node-ID signaling adjacency with PPhop PLR goes down, or
- MP receives normal or "Remote" PathTear for PSB, or
- MP receives ResvTear for RSB.
Receiving Conditional PathTear from the Phop node will not impact the "remote" state from the PLR. Note that Phop node would send Conditional PathTear if it was not an MP.

In the example topology in Figure 1, assume C & D are NP-MP for PLRs A & B respectively. Now when A-B link fails, as B is not MP and its Phop link signaling adjacency has failed, B will delete LSP state (this behavior is required for unprotected LSPs - Section 4.2.1). In the data plane, that would require B to delete the label forwarding entry corresponding to the LSP. So if B’s downstream nodes C and D continue to retain state, it would not be correct for D to continue to assume itself as NP-MP for PLR B.

The mechanism that enables D to stop considering itself as NP-MP and delete "remote" path state is given below.

1. When C receives Conditional PathTear from B, it decides to retain LSP state as it is NP-MP of PLR A. C also SHOULD check whether Phop B had previously signaled availability of node protection. As B had previously signaled NP availability in its PATH RRO flags, C SHOULD reset "local protection available" and "NP available" on RRO flags corresponding to B and trigger PATH to D.
2. When D receives triggered PATH, it realizes that it is no longer NP-MP and so deletes the "remote" path state. D does not propagate PATH further down because the only change is in PATH RRO flags of B.

4.2.6. Phop Link Failure on a Node that is LP-MP and NP-MP

A router may be both LP-MP as well as NP-MP at the same time for Phop and PPhop nodes respectively of an LSP. If Phop link fails on such node, the node SHOULD retain PSB and RSB states corresponding to the LSP till the occurrence of any of the following events.

- Both Node-ID signaling adjacencies with Phop and PPhop nodes go down, or
- MP receives normal or "Remote" PathTear for PSB, or
- MP receives ResvTear for RSB.
4.2.7. Phop Node Failure on Node that is LP-MP and NP-MP

If a router that is both LP-MP and NP-MP detects Phop node failure, then the node SHOULD retain PSB and RSB states corresponding to the LSP till the occurrence of any of the following events.

- Remote Node-ID signaling adjacency with PPhop PLR goes down, or
- MP receives normal or "Remote" PathTear for PSB, or
- MP receives ResvTear for RSB.

4.3. Conditional Path Tear

In the example provided in the Section 4.2.5 "NP-MP Behavior on PLR link failure", B deletes PSB and RSB states corresponding to the LSP once B detects its link to Phop went down as B is not MP. If B were to send PathTear normally, then C would delete LSP state immediately. In order to avoid this, there should be some mechanism by which B can indicate to C that B does not require the receiving node to unconditionally delete the LSP state immediately. For this, B SHOULD add a new optional object called CONDITIONS object in PathTear. The new optional object is defined in Section 4.3.3. If node C also understands the new object, then C SHOULD delete LSP state only if it is not an NP-MP - in other words C SHOULD delete LSP state if there is no "remote" PLR state on C.

4.3.1. Sending Conditional Path Tear

A router that is not an MP for an LSP SHOULD delete PSB and RSB states corresponding to the LSP if Phop link or Phop Node-ID signaling adjacency goes down (Section 4.2.1). The router SHOULD send Conditional PathTear if the following are also true.

- Ingress has requested node protection for the LSP, and
- PathTear is not received from upstream node

4.3.2. Processing Conditional Path Tear

When a router that is not an NP-MP receives Conditional PathTear, the node SHOULD delete PSB and RSB states corresponding to the LSP, and process Conditional PathTear by considering it as normal PathTear. Specifically, the node SHOULD NOT propagate Conditional PathTear downstream but remove the optional object and send normal PathTear downstream.
When a node that is an NP-MP receives Conditional PathTear, it SHOULD NOT delete LSP state. The node SHOULD check whether the Phop node previously set "NP available" flag in PATH RRO flags. If the flag had been set previously by Phop, then the node SHOULD clear "local protection available" and "NP available" flags in Phop’s RRO flags and trigger PATH downstream.

If Conditional PathTear is received from a neighbor that has not advertised support (refer to Section 4.5) for the new procedures defined in this document, then the node SHOULD consider the message as normal PathTear. The node SHOULD propagate normal PathTear downstream and delete LSP state.

4.3.3. CONDITIONS object

As any implementation that does not support Conditional PathTear SHOULD ignore the new object but process the message as normal PathTear without generating any error, the Class-Num of the new object SHOULD be 10bbbbbb where ‘b’ represents a bit (from Section 3.10 of [RFC2205]).

The new object is called as "CONDITIONS" object that will specify the conditions under which default processing rules of the RSVP-TE message SHOULD be invoked.

The object has the following format:

```
+---------------------------------------------+   +---+
|          Length               |  Class    |     C-type    |
+---------------------------------------------+ ---+---+
|                         Reserved                     |   M   |
+---------------------------------------------+---+
```

Length
This contains the size of the object in bytes and should be set to eight.

Class
TBD

C-type
1
M bit

This bit indicates that the message SHOULD be processed based on the condition whether the receiving node is Merge Point or not.

4.4. Remote State Teardown

If the Ingress wants to tear down the LSP because of a management event while the LSP is being locally repaired at a transit PLR, it would not be desirable to wait till backup LSP signaling to perform state cleanup. To enable LSP state cleanup when the LSP is being locally repaired, the PLR SHOULD send "remote" PathTear message instructing the MP to delete PSB and RSB states corresponding to the LSP.

Consider node C in example topology (Figure 1) has gone down and B locally repairs the LSP.

1. Ingress A receives a management event to tear down the LSP.
2. A sends normal PathTear to B.
3. To enable LSP state cleanup, B SHOULD send "remote" PathTear with destination IP address set to that of D used in Node-ID signaling adjacency with D, and HOP object containing local address used in Node-ID signaling adjacency.
4. B then deletes PSB and RSB states corresponding to the LSP.
5. On D there would be a remote signaling adjacency with B and so D SHOULD accept the remote PathTear and delete PSB and RSB states corresponding to the LSP.

4.4.1. PLR Behavior on Local Repair Failure

If local repair fails on the PLR after a failure, then this should be considered as a case for cleaning up LSP state from PLR to the Egress. PLR would achieve this using "remote" PathTear to clean up state from MP. If MP has retained state, then it would propagate PathTear downstream thereby achieving state cleanup. Note that in the case of link protection, the PathTear would be directed to LP-MP node IP address rather than the Nhopt interface address.

4.4.2. PLR Behavior on Resv RRO Change

When a router that has already made NP available detects a change in the RRO carried in RESV message, and if the RRO change indicates
that the router’s former NP-MP is no longer present in the LSP path, then the router SHOULD send "Remote" PathTear directly to its former NP-MP.

In the example topology in Figure 1, assume A has made node protection available and C has concluded it is NP-MP. When the B-C link fails then implementing the procedure specified in Section 4.2.4 of this document, C will retain state till: remote NodeID control plane adjacency with A goes down, or PathTear or ResvTear is received for PSB or RSB respectively. If B also has made node protection available, B will eventually complete backup LSP signaling with its NP-MP D and trigger RESV to A with RRO changed. The new RRO of the LSP carried in RESV will not contain C. When A processes the RESV with a new RRO not containing C - its former NP-MP, A SHOULD send "Remote" PathTear to C. When C receives a "Remote" PathTear for its PSB state, C will send normal PathTear downstream to D and delete both PSB and RSB states corresponding to the LSP. As D has already received backup LSP signaling from B, D will retain control plane and forwarding states corresponding to the LSP.

4.4.3. LSP Preemption during Local Repair

If an LSP is preempted when there is no failure along the path of the LSP, the node on which preemption occurs would send PathErr and ResvTear upstream and only delete the forwarding state and RSB state corresponding to the LSP. But if the LSP is being locally repaired upstream of the node on which the LSP is preempted, then the node SHOULD delete both PSB and RSB states corresponding to the LSP and send normal PathTear downstream.

4.4.3.1. Preemption on LP-MP after Phop Link failure

If an LSP is preempted on LP-MP after its Phop or incoming link has already failed but the backup LSP has not been signaled yet, then the node SHOULD send normal PathTear and delete both PSB and RSB states corresponding to the LSP. As the LP-MP has retained LSP state because the PLR would signal the LSP through backup LSP signaling, preemption would bring down the LSP and the node would not be LP-MP any more requiring the node to clean up LSP state.

4.4.3.2. Preemption on NP-MP after Phop Link failure

If an LSP is preempted on NP-MP after its Phop link has already failed but the backup LSP has not been signaled yet, then the node SHOULD send normal PathTear and delete PSB and RSB states corresponding to the LSP. As the NP-MP has retained LSP state
because the PLR would signal the LSP through backup LSP signaling, preemption would bring down the LSP and the node would not be NP-MP any more requiring the node to clean up LSP state.

Consider B-C link goes down on the same example topology (Figure 1). As C is NP-MP for PLR A, C will retain LSP state.

1. The LSP is preempted on C.
2. C will delete RSB state corresponding to the LSP. But C cannot send PathErr or ResvTear to PLR A because backup LSP has not been signaled yet.
3. As the only reason for C having retained state after Phop node failure was that it was NP-MP, C SHOULD send normal PathTear to D and delete PSB state also. D would also delete PSB and RSB states on receiving PathTear from C.
4. B starts backup LSP signaling to D. But as D does not have the LSP state, it will reject backup LSP PATH and send PathErr to B.
5. B will delete its reservation and send ResvTear to A.

4.5. Backward Compatibility Procedures

The "Enhanced FRR facility protection" referred below in this section refers to the set of changes that have been proposed in previous sections. Any implementation that does not support them has been termed as "existing implementation". Of the proposed extensions, signaling protection using RRO flags is expected to be backward compatible and can work safely irrespective of whether the refresh time is small or arbitrarily long. This is because the existing implementations would not send error or tear down message in response to the flags in PATH RRO but would simply ignore and propagate them. On the other hand, changes proposed relating to LSP state cleanup namely Conditional and remote PathTear require support from other nodes along the LSP path. So procedures that fall under LSP state cleanup category SHOULD be turned on only if all nodes involved in the node protection FRR i.e. PLR, MP and intermediate node in the case of NP, support the extensions. Note that for LSPs requesting only link protection, the PLR and the LP-MP should support the extensions.
4.5.1. Detecting Support for Enhanced FRR Facility Protection

An implementation supporting the FRR facility protection extensions specified in previous sections SHOULD set a new flag "Enhanced facility protection" in CAPABILITY object in Hello messages.

- As nodes supporting the extensions SHOULD initiate Node Hellos with adjacent nodes, a node on the path of protected LSP can determine whether its Phop or Nhop neighbor supports FRR enhancements from the Hello messages sent by the neighbor.

- If a node attempts to make node protection available, then the PLR SHOULD initiate remote Node-ID signaling adjacency with NNhop. If the NNhop (a) does not reply to remote node Hello message or (b) does not set "Enhanced facility protection" flag in CAPABILITY object in the reply, then the PLR can conclude that NNhop does not support FRR extensions.

- If node protection is requested for an LSP and if (a) PPhop node has not set "local protection available" and "NP available" flags in its RRO flags or (b) PPhop node has not initiated remote node Hello messages, then the node SHOULD conclude that PLR does not support FRR extensions. The details are described in the "Procedures for backward compatibility" section below.

The new flag that will be introduced to CAPABILITY object is specified below.

```
+----------------------------------+-+-+-+
|                   Length          | Class-Num(134)|  C-Type  (1)  |
+----------------------------------+-+-+-+
|                    Reserved       |E|T|R|S|
+----------------------------------+-+-+-+
```

E bit

Indicates that the sender supports Enhanced FRR facility protection

Any node that sets the new E-bit is set in its CAPABILITY object MUST also set Refresh-Reduction-Capable bit in common header of all RSVP-TE messages.
4.5.2. Procedures for backward compatibility

The procedures defined hereafter are performed on a subset of LSPs that traverse a node, rather than on all LSPs that traverse a node. This behavior is required to support backward compatibility for a subset of LSPs traversing nodes running existing implementations.

4.5.2.1. Lack of support on Downstream Node

- If the Nhop does not support enhanced facility protection FRR, then the node SHOULD reduce the "refresh period" in TIME_VALUES object carried in PATH to default small refresh default value.

- If node protection is requested and the NNhop node does not support the enhancements, then the node SHOULD reduce the "refresh period" in TIME_VALUES object carried in PATH to a small refresh default value.

If the node reduces the refresh time from the above procedures, it SHOULD also not send remote PathTear or Conditional PathTear messages.

Consider the example topology in Figure 1. If C does not support scalability improvements, then:

- A and B SHOULD reduce the refresh time to default value of 30 seconds and trigger PATH

- If B is not an MP and if Phop link of B fails, B cannot send Conditional PathTear to C but SHOULD time out PSB state from A normally. This would be accomplished if A would also reduce the refresh time to default value. So if C does not support enhanced facility protection, then Phop B and PPhop A SHOULD reduce refresh time to a small default value.

4.5.2.2. Lack of support on Upstream Node

- If Phop node does not support enhanced facility protection, then the node SHOULD reduce the "refresh period" in TIME_VALUES object carried in RESV to default small refresh time value.

- If node protection is requested and the Phop node does not support the enhancements, then the node SHOULD reduce the "refresh period" in TIME_VALUES object carried in PATH to default value.
- If node protection is requested and PPhop node does not support the enhancements, then the node SHOULD reduce the "refresh period" in TIME_VALUES object carried in RESV to default value.

- If the node reduces the refresh time from the above procedures, it SHOULD also not execute MP determination procedures.

4.5.2.3. Incremental Deployment

The backward compatibility procedures described in the previous subsections imply that a router supporting the FRR extensions specified in this document can apply the procedures specified in the document either in the downstream or upstream direction of an LSP, depending on the capability of the routers downstream or upstream in the LSP path.

- FRR extensions and procedures are enabled for downstream Path, PathTear and ResvErr messages corresponding to an LSP if link protection is requested for the LSP and the Nhop node supports the extensions.

- FRR extensions and procedures are enabled for downstream Path, PathTear and ResvErr messages corresponding to an LSP if node protection is requested for the LSP and both Nhop & NNhop nodes support the extensions.

- FRR extensions and procedures are enabled for upstream PathErr, Resv and ResvTear messages corresponding to an LSP if link protection is requested for the LSP and the Phop node supports the extensions.

- FRR extensions and procedures are enabled for upstream PathErr, Resv and ResvTear messages corresponding to an LSP if node protection is requested for the LSP and both Phop and PPhop nodes support the extensions.

For example, if implementation supporting the FRR extensions specified in this document is deployed on all routers in particular region of the network and if all the LSPs in the network request node protection, then the FRR extensions will only be applied for the LSP segments that traverse the particular region. This will aid incremental deployment of these extensions and also allow reaping the benefits of the extensions in portions of the network where it is supported.
5. Security Considerations

This document extends the applicability of Node-ID based Hello session between immediate neighbors. The Node-ID based Hello session between PLR and NP-MP may require the two routers to exchange Hello messages with non-immediate neighbor. So, the implementations SHOULD provide the option to configure Node-ID neighbor specific or global authentication key to authentication messages received from Node-ID neighbors. The network administrator MAY utilize this option to enable RSVP-TE routers to authenticate Node-ID Hello messages received with TTL greater than 1.

6. IANA Considerations

6.1. New Object - CONDITIONS

[RFC2205] defines the Class-Number name space for RSVP objects. The name space is managed by IANA.

IANA registry: RSVP Parameters
Subsection: Class Names, Class Numbers, and Class Types

A new RSVP object using a Class-Number of form 10bbbbbb called the "CONDITIONS" object is defined in Section 4.3 of this document. The Class-Number is TBD.

6.2. New CAPABILITY Object value

[RFC5063] defines the name space for RSVP Capability Object Values. The name space is managed by IANA.

IANA registry: RSVP PARAMETERS
Subsection: Capability Object Values

A new Capability flag called "Enhanced FRR facility protection" is defined in Section 4.5 of this document. The bit number for this flag is TBD.

7. Normative References


8. Acknowledgments

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Abstract

This document describes requirements, architecture and solutions for MPLS-TP Shared Ring Protection (MSRP) in the ring topology for point-to-point (P2P) services. The mechanism of MSRP is illustrated and how it satisfies the requirements in RFC 5654 for optimized ring protection is analyzed.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

As described in 2.5.6.1 of [RFC5654], Ring Protection of MPLS-TP requirements, several service providers have expressed much interest in operating MPLS-TP in ring topologies and require a high-level survivability function in these topologies. In operational transport network deployment, MPLS-TP networks are often constructed with ring topologies. It calls for an efficient and optimized ring protection mechanism to achieve simple operation and fast, sub 50 ms, recovery performance.

The requirements for MPLS-TP [RFC5654] state that recovery mechanisms which are optimized for ring topologies could be further developed if it can provide the following features:

a. Minimize the number of OAM entities for protection

b. Minimize the number of elements of recovery

c. Minimize the required label number

d. Minimize the amount of control and management-plane transactions during maintenance operation

e. Minimize the impact on information exchange during protection if a control plane is supported

This document specifies MPLS-TP Shared-Ring Protection mechanisms that can meet all those requirements on ring protection listed in [RFC5654].

The basic concepts and architecture of Shared-Ring protection mechanism are specified in this document. This document focuses on the solutions for point-to-point transport paths. While the basic
concepts may also apply to point-to-multipoint transport paths, the solution for point-to-multipoint transport paths is under study and will be presented in a separate document.

2. Requirements for MPLS-TP Ring Protection

The requirements for MPLS-TP ring protection are specified in [RFC5654]. This document elaborates on the requirements in detail.

2.1. Recovery of Multiple Failures

MPLS-TP is expected to be used in carrier grade metro networks and backbone transport networks to provide mobile backhaul, business services etc., in which the network survivability is very important. According to R106 B in [RFC5654], MPLS-TP recovery mechanisms in a ring SHOULD protect against multiple failures. The following text provides some more detailed illustration about "multiple failures". In metro and backbone networks, a single risk factor often affects multiple links or nodes. Some examples of risk factors are given as follows:

- multiple links use fibers in one cable or pipeline
- Several nodes share one power supply system
- Weather sensitive micro-wave system

Once one of the above risk factors happens, multiple links or nodes failures may occur simultaneously and those failed links or nodes may be located on a single ring as well as on interconnected rings. Ring protection against multiple failures should cover both multiple failures on a single ring and multiple failures on interconnected rings.

2.2. Smooth Upgrade from Linear Protection to Ring Protection

It is beneficial for service providers to upgrade the protection scheme from linear protection to ring protection in their MPLS-TP network without service interruption. In-service insertion and removal of a node on the ring should also be supported. Therefore, the MPLS-TP ring protection mechanism is supposed to be developed and optimized for compliance with this smooth upgrading principle.

2.3. Configuration Complexity

Ring protection can reduce the dependency of configuration on the quantity of services, thus will simplify the network protection configuration and operation effort. This is because the ring
protection makes use of the characteristics of ring topology and mechanisms on the section layer. While in the application scenarios of deploying linear protection in ring topology MPLS-TP network, the configuration of protection has a close relationship with the quantities of services carried. Especially in some large metro networks with more than ten thousands of services in the access nodes, the LSP linear protection capabilities of the metro core nodes needs to be large enough to meet the network planning requirements, which also leads to the complexity of network protection configurations and operations.

3. Terminology and Notation

The following syntax will be used to describe the contents of the label stack:

1. The label stack will be enclosed in square brackets ("[]").

2. Each level in the stack will be separated by the ’|’ character. It should be noted that the label stack may contain additional layers. However, we only present the layers that are related to the protection mechanism.

3. If the Label is assigned by Node X, the Node Name is enclosed in bracket ("()")

4. Shared Ring Protection Architecture

4.1. Ring Tunnel

This document introduces a new logical layer of the ring for shared ring protection in MPLS-TP networks. As shown in Figure 1, the new logical layer consists of ring tunnels which provides a server layer for the LSPs traverse the ring. Once a ring tunnel is established, the configuration, management and protection of the ring are all performed at the ring tunnel level. One port can carry multiple ring tunnels, while one ring tunnel can carry multiple LSPs.
Figure 1. The logical layers of the ring

The label stack used in MPLS-TP Shared Ring Protection mechanism is shown as below:

```
+------------------+-+------------------+
| Ring tunnel Label | | LSP Label          |
+------------------+-+------------------+
| PW Label          | | Payload           |
+------------------+-+------------------+
```

Figure 2. Label stack used in MPLS-TP Shared Ring Protection

4.1.1. Establishment of Ring Tunnel

The Ring tunnels are established based on the exit node. The exit node is the node where traffic leaves the ring. LSPs which have the same exit node on the ring share the same ring tunnels. In other words, all the LSPs that traverse the ring and exit from the same node share the same working ring tunnel and protection ring tunnel. For each exit node, four ring tunnels are established:

- one clockwise working ring tunnel, which is protected by the anticlockwise protection ring tunnel
- one anticlockwise protection ring tunnel
- one anticlockwise working ring tunnel, which is protected by the clockwise protection ring tunnel
- one clockwise protection ring tunnel
The structure of the protection tunnels are determined by the selected protection mechanism. This will be detailed in subsequent sections.

As shown in Figure 3, LSP 1, LSP 2 and LSP 3 enter the ring from Node E, Node A and Node B, respectively, and all leave the ring at Node D. To protect these LSPs that traverse the ring, a clockwise working ring tunnel (RcW_D) via E->F->A->B->C->D, and its anticlockwise protection ring tunnel (RaP_D) via D->C->B->A->F->E->D are established, Also, an anti-clockwise working ring tunnel (RaW_D) via C->B->A->F->E->D, and its clockwise protection ring tunnel (RcP_D) via D->E->F->A->B->C->D are established. For simplicity Figure 3 only shows RcW_D and RaP_D. A similar provisioning should be applied for any other node on the ring. In summary, for each node in Figure 3 when acting as exit node, the ring tunnels are created as follows:

- To Node A: RcW_A, RaW_A, RcP_A, RaP_A
- To Node B: RcW_B, RaW_B, RcP_B, RaP_B
- To Node C: RcW_C, RaW_C, RcP_C, RaP_C
- To Node D: RcW_D, RaW_D, RcP_D, RaP_D
- To Node E: RcW_E, RaW_E, RcP_E, RaP_E
- To Node F: RcW_F, RaW_F, RcP_F, RaP_F
Through these working and protection ring tunnels, LSPs which enter the ring from any node can reach any exit nodes on the ring, and are protected from failures on the ring.

4.1.2. Label Assignment and Distribution

The ring tunnel labels are downstream-assigned labels as defined in [RFC3031]. The ring tunnel labels can be either configured statically, provisioned by a controller, or distributed dynamically via a control protocol.

4.1.3. Forwarding Operation

When an MPLS-TP transport path, such as an LSP, enters the ring, the ingress node on the ring pushes the working ring tunnel label according to the exit node and sends the traffic to the next hop. The transit nodes on the working ring tunnel swap the ring tunnel labels and forward the packets to the next hop. When the packet arrives at the exit node, the exit node pops the ring tunnel label and forwards the packets based on the inner LSP label and PW label. Figure 4 shows the label operation in the MPLS-TP shared ring protection mechanism. Assume that LSP1 enters the ring at Node A and exits from Node D, and the following label operations are executed.
1. Ingress node: Packets of LSP1 arrive at Node A with a label stack [LSP1] and is supposed to be forwarded in the clockwise direction of the ring. The clockwise working ring tunnel label RcW_D will be pushed at Node A, the label stack for the forwarded packet at Node A is changed to [RcW_D(B)|LSP1].

2. Transit nodes: In this case, Node B and Node C forward the packets by swapping the working ring tunnel labels. For example, the label [RcW_D(B)|LSP1] is swapped to [RcW_D(C)|LSP1] at Node B.

3. Exit node: When the packet arrives at Node D (i.e. the exit node) with label stack [RcW_D(D)|LSP1], Node D pops RcW_D(D), and subsequently deals with the inner labels of LSP1.

4. All the LSPs that exit from the same node share the same set of ring tunnel labels.

   +---+#####[RaP_D(F)]#####++---+  LSP1
   | F |---------------------| A | +--
   +---+*****[RcW_D(A)]*****++---+
   /    */             */    
[RaP_D(E)]/*/ [RaW_D(F)] [RaW_D(B)]/*/ [RaP_D(A)]
/                  
+---     +---
| E |     | B |    
+---     +---
/>          */   
[RaP_D(D)]/>    [RxW_D(C)]/> [RaP_D(B)]
/>               */   
+---*****[RcW_D(D)]*****++---+  LSP1
+--- | D |---------------------| C | +--
+---#####[RaP_D(C)]#####++---+

   -----physical links    ***** RcW_D    ##### RaP_D

4.2. Failure Detection

The MPLS-TP section layer OAM is used to monitor the connectivity between each two adjacent nodes on the ring using the mechanisms defined in [RFC6371]. Protection switching is triggered by the failure detected on the ring by the OAM mechanisms.

Two end ports of a link form a Maintenance Entity Group (MEG), and an MEG end point (MEP) function is installed in each ring port. CC-V OAM packets are periodically exchanged between each pair of MEPs to
monitor the link health. Three or more consecutive CC-V packets losses will be interpreted as a link failure.

A node failure is regarded as the failure of two links attached to that node. The two nodes adjacent to the failed node detect the failure in the links that are connected to the failed node.

4.3. Ring Protection

Taking the topology in Figure 4 as example, the LSP1 enters the ring at Node A and leaves the ring at Node D. In normal state, LSP 1 is carried by clockwise working ring tunnel (RcW_D) through the path A->B->C->D, the label operation is:

\[\text{[LSP1]}(\text{original data traffic carried by LSP 1}) \rightarrow \text{[RcW}_D(B) | \text{LSP1]}(\text{Node A}) \rightarrow \text{[RcW}_D(C) | \text{LSP1]}(\text{Node B}) \rightarrow \text{[RcW}_D(D) | \text{LSP1]}(\text{Node C}) \rightarrow \text{[LSP1]}(\text{data traffic carried by LSP 1})\].

Then at node D the packet will be forwarded based on label stack of LSP1.

The following sections describes the protection mechanisms used in ring topology.

4.3.1. Wrapping

With the wrapping mechanism, the protection ring tunnel is a closed ring identified by the exit node. As shown in Figure 4, the RaP_D is the anticlockwise protection ring tunnel for the clockwise working ring tunnel RcW_D. As specified in the following sections, the closed ring protection tunnel can protect both the link failure and the node failure.

4.3.1.1. Wrapping for Link Failure

When a link failure between Node B and Node C occurs, both Node B and Node C detect the failure via OAM mechanism. Node B switches the clockwise working ring tunnel (RcW_D) to the anticlockwise protection ring tunnel (RaP_D) and Node C switches anticlockwise protection ring tunnel(RaP_D) to the clockwise working ring tunnel(RcW_D). The data traffic which enters the ring at Node A and exits at Node D follows the path A->B->A->F->E->D->C->D. The label operation is:

\[\text{[LSP1]}(\text{Original data traffic}) \rightarrow \text{[RcW}_D(B) | \text{LSP1]}(\text{Node A}) \rightarrow \text{[RaP}_D(A) | \text{LSP1]}(\text{Node B}) \rightarrow \text{[RaP}_D(F) | \text{LSP1]}(\text{Node A}) \rightarrow \text{[RaP}_D(E) | \text{LSP1]}(\text{Node F}) \rightarrow \text{[RaP}_D(D) | \text{LSP1]}(\text{Node E}) \rightarrow \text{[RaP}_D(C) | \text{LSP1]}(\text{Node D}) \rightarrow \text{[RcW}_D(D) | \text{LSP1]}(\text{Node C}) \rightarrow \text{[LSP1]}(\text{data traffic exits the ring})\].
4.3.1.2. Wrapping for Node Failure

When Node B fails, Node A detects the failure between A and B and switches the clockwise work ring tunnel (RcW_D) to the anticlockwise protection ring tunnel (RaP_D), Node C detects the failure between C and B and switches the anticlockwise protection ring tunnel (RaP_D) to the clockwise working ring tunnel (RcW_D). The data traffic which enters the ring at Node A and exits at Node D follows the path A→F→E→D→C→D. The label operation is:

[LSP1](original data traffic carried by LSP 1) →
[RaP_D(F)]LSP1(NodeA) → [RaP_D(E)]LSP1(NodeF) →
[RaP_D(D)]LSP1(NodeE) → [RaP_D(C)]LSP1(NodeD) → [RcW_D(D)]LSP1
(NodeC) → [LSP1](data traffic carried by LSP 1).
4.3.2. Short Wrapping

With the traditional wrapping protection scheme, Protection switching is executed at both nodes detecting the failure, consequently the traffic will be wrapped twice. This mechanism will cause additional latency and bandwidth consumption when traffic is switched to the protection path.

With short wrapping protection, data traffic switching is executed only at the upstream node detecting the link failure, and exits the ring in the protection ring tunnel at the exit node. This scheme can reduce the additional latency and bandwidth consumption when traffic is switched to the protection path.

In the traditional wrapping solution, the protection ring tunnel is a closed ring in normal state, while in the short wrapping solution, the protection ring tunnel is ended at the exit node, which is similar to the working ring tunnel. Short wrapping is easy to implement in shared ring protection because both the working and protection ring tunnels are terminated on the exit nodes. Figure 7 shows the clockwise working ring tunnel and the anticlockwise protection ring tunnel with node D as the exit node.

As shown in Figure 7, in normal state, LSP 1 is carried by the clockwise working ring tunnel (RcW_D) through the path A->B->C->D. When a link failure between Node B and Node C occurs, Node B switches The working ring tunnel RcW_D to the protection ring tunnel RaP_D in

Figure 6. Wrapping for node failure
the opposite direction. The difference occurs in the protection ring tunnel at exit node. In short wrapping protection, Rap_D ends in Node D and then traffic will be forwarded based on the LSP labels. Thus with short wrapping mechanism, LSP1 will follow the path A->B->A->F->E->D when link failure between Node B and Node C happens. For node failure, the protection with short wrapping is similar to the mechanism with link failure.

```
+---+#####[RaP_D(F)]#####+---+
| F |---------------------| A | +-- LSP1
+-----+---------------------+

[RaP_D(E)]/#/[RcW_D(F)]    [RcW_D(B)]*\#RaP_D(A)
  #/          #/          */#
  +---+      +---+      +---+
  | E |      | B |      | C |
  +---+      +---+      +---+

[RaP_D(D)]/#\     [RcW_D(C)]*x#RaP_D(B)
  #\             
  +-----[RcW_D(D)]+++++---+
LSP1   +-- | D |-------------------| C |
      +---+              +---+

----- physical links     xxxxx Failure Link
***** RcW_D     ###### RaP_D
```

Figure 7. Short wrapping for link failure

4.3.3. Steering

In ring topology, each working ring tunnel is associated with a protection ring tunnel in the opposite direction, and every node can obtain the ring topology either by configuration or via some topology discovery mechanism. When a failure occurs in the ring, the nodes that detect the failure will transmit the failure information in the opposite direction of the failure hop by hop on the ring. When a node receives the message that identifies a failure, it can quickly determine the location of the fault by using the topology information that is maintained by the node, then it can determine whether the LSPs entering the ring locally need to switchover or not. For LSPs that needs to switchover, it will switch the LSPs from the working ring tunnels to its corresponding protection ring tunnels.

As shown in Figure 8, LSP1 enters the ring from Node A while LSP2 enters the ring from Node B, and both of them have the same destination node D.

In the normal state, LSP 1 is carried by the clockwise working ring tunnel (RcW_D) through the path A->B->C->D, the label operation is:
[LSP1] -> [RcW_D(B)|LSP1](NodeA) -> [RcW_D(C)|LSP1](NodeB) -> [RcW_D(D)|LSP1](NodeC) -> [LSP1] (data traffic carried by LSP 1).

LSP2 is carried by the clockwise working ring tunnel (RcW_D) through the path B->C->D, the label operation is:
[LSP2] -> [RcW_D(C)|LSP2](NodeB) -> [RcW_D(D)|LSP2](NodeC) -> [LSP2] (data traffic carried by LSP 1).

If the link between nodes C and D fails, according to the fault detection and distribution mechanisms, Node D will find out that there is a failure in the link between C and D, and it will update the link state of its ring topology, changing the link between C and D from normal to fault. In the direction that opposite to the failure position, Node D will send the state report message to Node E, informing Node E of the fault between C and D, and E will update the link state of its ring topology accordingly, changing the link.
between C and D from normal to fault. In this way, the state report message is sent hop by hop in the clockwise direction. Similar to Node D, Node C will send the failure information in the anti-clockwise direction.

When Node A receives the failure report message and updates the link state of its ring topology, it is aware that there is a fault on the clockwise working ring tunnel to node D (RcW_D), and LSP 1 enters the ring locally and is carried by this ring tunnel, thus Node A will decide to switch the LSP1 onto the anticlockwise protection ring tunnel to node D (RaP_D). After the switchover, LSP1 will follow the path A->F->E->D, the label operation is: [LSP1] -> [RaP_D(F)|LSP1](NodeA) -> [RaP_D(E)|LSP1](NodeF) -> [RaP_D(D)|LSP1](NodeE) -> [LSP1] (data traffic carried by LSP 1).

The same also apply to the operation of LSP2. When Node B updates the link state of its ring topology, and finds out that the working ring tunnel RcW_D has failed, it will switch the LSP2 to the anticlockwise protection tunnel RaP_D. After the switchover, LSP2 goes through the path B->A->F->E->D, and the label operation is: [LSP2] -> [RaP_D(A)|LSP2](NodeB) -> [RaP_D(F)|LSP2](NodeA) -> [RaP_D(E)|LSP2](NodeF) -> [RaP_D(D)|LSP2](NodeE) -> [LSP2] (data traffic carried by LSP 2).

Then assume the link between nodes A and B breaks down, as shown in Figure 9. Similar to the above failure case, Node B will detect a fault in the link between A and B, and it will update the link state of its ring topology, changing the link state between A and B from normal to fault. The state report message is sent hop by hop in the clockwise direction, notifying every node that there is a fault between node A and B, and every node updates the link state of its ring topology. As a result, Node A will detect a fault in the working ring tunnel to node D, and switch LSP1 to the protection ring tunnel, while Node B determine that the working ring tunnel for LSP2 still works fine, and will not perform the switchover.
4.4. Interconnected Ring Protection

4.4.1. Interconnected Ring Topology

Interconnected ring topology is often used in MPLS-TP networks. This document will discuss two typical interconnected ring topologies:

1. Single-node interconnected rings

In single-node interconnected rings, the connection between the two rings is through a single node. Because the interconnection node is in fact a single point of failure, this topology should be avoided in real transport networks. Figure 10 shows the topology of single-node interconnected rings. Node C is the interconnection node between Ring1 and Ring2.

2. Dual-node interconnected rings

In dual-node interconnected rings, the connection between the two rings is through two nodes. The two interconnection nodes belong to both interconnected rings. This topology can recover from one interconnection node failure.

Figure 9. Steering operation and protection switching (2)
Figure 10 shows the topology of single-node interconnected rings. Node C is the interconnection node between Ring1 and Ring2.

![Diagram of single-node interconnected rings]

Figure 10. Single-node interconnected rings

Figure 11 shows the topology of dual-node interconnected rings. Nodes C and Node D are the interconnection nodes between Ring1 and Ring2.

![Diagram of dual-node interconnected rings]

Figure 11. Dual-node interconnected rings

4.4.2. Interconnected Ring Protection Mechanisms

Interconnected rings can be regarded as two independent rings. Ring protection switching protocol operates on each ring independently. Failure in one ring only triggers protection switching on the ring itself and does not affect the other ring. Protection switching in a single ring is same as the one described in section 4.3.

The service LSPs that traverse the interconnected rings via the interconnection nodes MUST use different ring tunnels in different rings. On the interconnection node, the ring tunnel label used in the source ring will be popped, and the ring tunnel label of destination ring will be pushed.
For the protected interconnection node in dual-node interconnected ring, the service LSPs in the interconnection nodes should use the same LSP label. So any interconnection node can terminate a source ring tunnel and push a destination ring tunnel according to the service LSP label.

Two interconnection nodes can be managed as a virtual interconnection node group. Each ring should assign ring tunnels to the virtual interconnection node group. The interconnection nodes in the group should terminate the working ring tunnel in each ring. The protection ring tunnel is an open ring to switch with the working ring tunnel at the nodes that detect the fault and ends at the egress node.

When the service traffic passes through the interconnection node, the direction of the working ring tunnels in each ring for this service traffic should be the same. For example, if the working ring tunnel follows the clockwise direction in Ring1, the working ring tunnel for the same service traffic in Ring2 also follows the clockwise direction when the service leaves Ring1 and enters Ring2.

4.4.3. Ring Tunnels in Interconnected Rings

The same ring tunnels as described in section 4.1 are used in each ring of the interconnected rings. Note that ring tunnels to the virtual interconnection node group will be established by each ring of the interconnected rings, i.e.:

- one clockwise working ring tunnel to the virtual interconnection node group
- one anticlockwise protection ring tunnel to the virtual interconnection node group
- one anticlockwise working ring tunnel to the virtual interconnection node group
- one clockwise protection ring tunnel to the virtual interconnection node group

These ring tunnels will terminated at all nodes in the virtual interconnection node group.

For example, all the ring tunnels on Ring1 of Figure 12 are established as follows:

- To Node A: R1cW_A, R1aW_A, R1cP_A, R1aP_A
To Node B: R1cW_B, R1aW_B, R1cP_B, R1aP_B
To Node C: R1cW_C, R1aW_C, R1cP_C, R1aP_C
To Node D: R1cW_D, R1aW_D, R1cP_D, R1aP_D
To Node E: R1cW_E, R1aW_E, R1cP_E, R1aP_E
To Node F: R1cW_F, R1aW_F, R1cP_F, R1aP_F
To the virtual interconnection node group (including Node F and Node A): R1cW_F&A, R1aW_F&A, R1cP_F&A, R1aP_F&A;

All the ring tunnels established in Ring2 in Figure 12 are provisioned as follows:
To Node A: R2cW_A, R2aW_A, R2cP_A, R2aP_A
To Node F: R2cW_F, R2aW_F, R2cP_F, R2aP_F
To Node G: R2cW_G, R2aW_G, R2cP_G, R2aP_G
To Node H: R2cW_H, R2aW_H, R2cP_H, R2aP_H
To Node I: R2cW_I, R2aW_I, R2cP_I, R2aP_I
To Node J: R2cW_J, R2aW_J, R2cP_J, R2aP_J
To the virtual interconnection node group (including Node F and Node A): R2cW_FandA, R2aW_FandA, R2cP_FandA, R2aP_FandA
4.4.4. Interconnected Ring Switching Procedure

As shown in Figure 12, for the service traffic LSP1 which enters Ring1 at Node D and exits Ring1 at Node F and continues to enter Ring2 at Node F and exits Ring2 at Node I, the protection scheme is described below.

In normal state, LSP1 follows R1cW_F&A in Ring1 and R2cW_I in Ring2. The label used for the working ring tunnel R1cW_F&A in Ring1 is popped and the label used for the working ring tunnel R2cW_I will be pushed based on the inner label lookup at the interconnection node F. The working path that the service traffic LSP1 follows is: LSP1→R1cW_F&A (D→E→F)→R2cW_I(F→G→H→I)→LSP1.
In case of link failure, for example, when a failure occurs on the link between Node F and Node E, Nodes F and E will detect the failure and execute protection switching as described in 2.2.1.1. The path that the service traffic LSP1 follows after switching change to LSP1->R1cW_F&A(D->E)->R1aP_F&A(E->D->C->B->A->F)->R1cW_F(F)->R2cW_I(F->G->H->I)->LSP1.

In case of a non interconnection node failure, for example, when the failure occurs at Node E in Ring1, Nodes F and E will detect the failure and execute protection switching as described in 2.2.1.2. The path that the service traffic LSP1 follows after switching becomes: LSP1->R1cW_F&A(D)->R1aP_F&A(D->C->B->A->F)->R1cW_F(F)->R2cW_I(F->G->H->I).

In case of an interconnection node failure, for example, when the failure occurs at the interconnection Node F. Nodes E and A in Ring1 will detect the failure, and execute protection switching as described in 2.2.1.2. Nodes G and A in Ring2 will also detect the failure, and execute protection switching. The path that the service traffic LSP1 follows after switching is: LSP1->R1cW_F&A(D->E)->R1aP_F&A(E->D->C->B->A)->R1cW_A(A)->R2aP_I(A->J->I)->LSP1.

4.4.5. Interconnected Ring Detection Mechanism

As show in Figure 13, the service traffic LSP1 traverses A->B-C in Ring1 and C->G->H->I in Ring2. Node C and Node D are the interconnection nodes. When both the link between Node C and Node G and the link between Node C and Node D fail, the ring tunnel from Node C to Node I in Ring 2 becomes unreachable. However, Node D is still available, and LSP1 can still reach Node I.
In order to achieve this, the interconnection nodes need to know the ring topology of each ring so that they can judge whether a node is reachable. This judgment is based on the knowledge of each ring topology and the fault location as described in section 3.4. The ring topology can be obtained from the NMS or topology discovery mechanisms. The fault location can be obtained by transmitting the fault information around the ring. The nodes that detect the failure will transmit the fault information in the opposite direction node by node in the ring. When the interconnection node receives the message that informs the failure, it will quickly calculate the location of the fault by the topology information that is maintained by itself and determines whether the LSPs entering the ring at itself can reach the destination. If the destination node is reachable, the LSP will exit the source ring and enter the destination ring. If the destination node is not reachable, the LSP will switch to the anticlockwise protection ring tunnel.

In Figure 13, Node C determines that the ring tunnel to Node I is unreachable, the service traffic LSP1 for which the destination node on the ring tunnel is Node I should switch to the protection LSP (R1aP_C&D) and consequently the service traffic LSP1 traverses the interconnected rings at Node D. Node D will remove the ring tunnel label of Ring1 and add the ring tunnel label of Ring2.

5. Ring Protection Coordination Protocol

5.1. RPS Protocol

The MSRP protection operation MUST be controlled with the help of the Ring Protection Switch Protocol (RPS). The RPS processes in the each of the individual ring nodes that form the ring SHOULD communicate using the G-ACh channel.

The RPS protocol MUST carry the ring status information and RPS requests, i.e., automatically initiated and externally initiated, between the ring nodes.

Each node on the ring MUST be uniquely identified by assigning it a node ID. The maximum number of nodes on the ring supported by the RPS protocol is 127. The node ID SHOULD be independent of the order in which the nodes appear on the ring. The node ID is used to identify the source and destination nodes of each RPS request.

Each node SHOULD have a ring map containing information about the sequence of the nodes around the ring. The method of configuring the nodes with the ring maps is TBD.

When no protection switches are active on the ring, each node MUST dispatch periodically RPS requests to the two adjacent nodes, indicating No Request (NR). When a node determines that a protection switching is required, it MUST send the appropriate RPS request in both directions.

\[
\begin{align*}
+----+ A->B & (NR) & +----+ B->C & (NR) & +----+ C->D & (NR) \\
\hline
\text{(NR)F<-A} & +----+ & \text{(NR)A<-B} & +----+ & \text{(NR)B<-C} & +----+
\end{align*}
\]

Figure 14. RPS communication between the ring nodes in case of no failures in the ring

A destination node is a node that is adjacent to a node that identified a failed span. When a node that is not the destination node receives an RPS request and it has no higher priority local request, it MUST transfer in the same direction the RPS request as received. In this way, the switching nodes can maintain direct RPS protocol communication in the ring.

\[
\begin{align*}
+----+ C->B & (SF) & +----+ B->C & (SF) & +----+ C->B & (SF) \\
\hline
\text{(SF)C<-B} & +----+ & \text{(SF)C<-B} & +----+ & \text{(SF)B<-C} & +----+
\end{align*}
\]

Figure 15. RPS communication between the ring nodes in case of failure between nodes B and C
Note that in the case of a bidirectional failure such as a cable cut, the two adjacent nodes detect the failure and send each other an RPS request in opposite directions.

- In rings utilizing the wrapping protection. When the destination node receives the RPS request it MUST perform the switch from/to the working ring tunnels to/from the protection ring tunnels if it has no higher priority active RPS request.

- In rings utilizing the steering protection. When a ring switch is required, any node MUST perform the switches if its added/dropped traffic is affected by the failure. Determination of the affected traffic SHOULD be performed by examining the RPS requests (indicating the nodes adjacent to the failure or failures) and the stored ring maps (indicating the relative position of the failure and the added traffic destined towards that failure).

When the failure has cleared and the Wait-to-Restore (WTR) timer has expired, the nodes sourcing RPS requests MUST drop their respective switches (tail end) and MUST source an RPS request carrying the NR code. The node receiving from both directions such RPS request (head end) MUST drop its protection switches.

A protection switch MUST be initiated by one of the criteria specified in Section 3.2. A failure of the RPS protocol or controller MUST NOT trigger a protection switch.

Ring switches MUST be preempted by higher priority RPS requests. For example, consider a protection switch that is active due to a manual switch request on the given span, and another protection switch is required due to a failure on another span. Then an RPS request MUST be generated, the former protection switch MUST be dropped, and the latter protection switch established.

MSRP mechanism SHOULD support multiple protection switches in the ring, resulting the ring being segmented into two or more separate segments. This may happen when several RPS requests of the same priority exist in the ring due to multiple failures or external switch commands.

Proper operation of the MSRP mechanism relies on all nodes having knowledge of the state of the ring (nodes and spans) so that nodes do not preempt existing RPS request unless they have a higher-priority RPS request. In order to accommodate ring state knowledge, during a protection switch the RPS requests MUST be sent in both directions.
5.1.1. Transmission and Acceptance of RPS Requests

A new RPS request MUST be transmitted immediately when a change in
the transmitted status occurs.

The first three RPS protocol messages carrying new RPS request SHOULD
be transmitted as fast as possible. For fast protection switching
within 50 ms, the interval of the first three RPS protocol messages
SHOULD be 3.3 ms. The successive RPS requests SHOULD be transmitted
with the interval of 5 seconds.

5.1.2. RPS PDU Format

Figure 16 depicts the format of an RPS packet that is sent on the
G-ACh. The Channel Type field is set to indicate that the message is
an RPS message. The ACH MUST NOT include the ACH TLV Header
[RFC5586] meaning that no ACH TLVs can be included in the message.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 1|0 0 0 0|0 0 0 0 0 0 0 0|    RPS Channel Type (TBD)     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Dest Node ID  | Src Node ID   |   Request     |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 16. G-ACh RPS Packet Format

The following fields MUST be provided:

- **Destination Node ID**: The destination node ID MUST always be set to
  value of the node ID of the adjacent node. Valid destination node
  ID values are 1-127.

- **Source node ID**: The source node ID MUST always be set to the value
  of the node ID generating the RPS request. Valid source node ID
  values are 1-127.

- **RPS request code**: A code consisting of four bits as specified
  below:
5.1.3. Ring Node RPS States

Idle state: A node is in the idle state when it has no RPS request and is sourcing and receiving NR code to/from both directions.

Switching state: A node not in the idle or pass-through states is in the switching state.

Pass-through state: A node is in the pass-through state when its highest priority RPS request is a request not destined to it or sourced by it. The pass-through is bidirectional.

5.1.3.1. Idle State

A node in the idle state MUST source the NR request in both directions.

A node in the idle state MUST terminate RPS requests flow in both directions.

A node in the idle state MUST block the traffic flow on protection LSPs/tunnels in both directions.

5.1.3.2. Switching State

A node in the switching state MUST source RPS request to adjacent node with its highest RPS request code in both directions when it detects a failure or receives an external command.

A node in the switching state MUST terminate RPS requests flow in both directions.
As soon as it receives an RPS request from the short path, the node to which it is addressed MUST acknowledge the RPS request by replying with the RR code on the short path, and with the received RPS request code on the long path.

This rule refers to the unidirectional failure detection: the RR SHOULD be issued only when the node does not detect the failure condition (i.e., the node is a head end), that is, it is not applicable when a bidirectional failure is detected, because, in this case, both nodes adjacent to the failure will send an RPS request for the failure on both paths (short and long).

The following switches MUST be allowed to coexist:

- LP and LF
- FS and FS
- SF and SF
- FS and SF

When multiple MS RPS requests over different spans exist at the same time, no switch SHOULD be executed and existing switches MUST be dropped. The nodes MUST signal, anyway, the MS RPS request code.

Multiple EXER requests MUST be allowed to coexist in the ring.

A node in a ring switching state that receives the external command LP for the affected span MUST drop its switch and MUST signal NR for the locked span if there is no other RPS request on another span. Node still SHOULD signal relevant RPS request for another span.

5.1.3.3. Pass-through State

When a node is in a pass-through state, it MUST transfer the received RPS Request in the same direction.

When a node is in a pass-through state, it MUST enable the traffic flow on protection ring tunnels in both directions.

5.1.4. RPS State Transitions

All state transitions are triggered by an incoming RPS request change, a WTR expiration, an externally initiated command, or locally detected MPLS-TP section failure conditions.
RPS requests due to a locally detected failure, an externally initiated command, or received RPS request shall pre-empt existing RPS requests in the prioritized order given in Section 3.1.2, unless the requests are allowed to coexist.

5.1.4.1. Transitions Between Idle and Pass-through States

The transition from the idle state to pass-through state MUST be triggered by a valid RPS request change, in any direction, from the NR code to any other code, as long as the new request is not destined to the node itself. Both directions move then into a pass-through state, so that, traffic entering the node through the protection Ring tunnels are transferred transparently through the node.

A node MUST revert from pass-through state to the idle state when it detects NR codes incoming from both directions. Both directions revert simultaneously from the pass-through state to the idle state.

5.1.4.2. Transitions Between Idle and Switching States

Transition of a node from the idle state to the switching state MUST be triggered by one of the following conditions:

- A valid RPS request change from the NR code to any code received on either the long or the short path and destined to this node
- An externally initiated command for this node
- The detection of an MPLS-TP section layer failure at this node

Actions taken at a node in the idle state upon transition to switching state are:

- For all protection switch requests, except EXER and LP, the node MUST execute the switch
- For EXER, and LP, the node MUST signal appropriate request but not execute the switch

A node MUST revert from the switching state to the idle state when it detects NR codes received from both directions.

- At the tail end: When a WTR time expires or an externally initiated command is cleared at a node, the node MUST drop its switch, transit to the Idle State and signal the NR code in both directions.
o At the head end: Upon reception of the NR code, from both directions, the head-end node MUST drop its switch, transition to Idle State and signal the NR code in both directions.

5.1.4.3. Transitions Between Switching States

When a node that is currently executing any protection switch receives a higher priority RPS request (due to a locally detected failure, an externally initiated command, or a ring protection switch request destined to it) for the same span, it MUST update the priority of the switch it is executing to the priority of the received RPS request.

When a failure condition clears at a node, the node MUST enter WTR condition and remain in it for the appropriate time-out interval, unless:

o A different RPS request with a higher priority than WTR is received

o Another failure is detected

o An externally initiated command becomes active

The node MUST send out a WTR code on both the long and short paths.

When a node that is executing a switch in response to incoming SF RPS request (not due to a locally detected failure) receives a WTR code (unidirectional failure case), it MUST send out RR code on the short path and the WTR on the long path.

5.1.4.4. Transitions Between Switching and Pass-through States

When a node that is currently executing a switch receives an RPS request for a non-adjacent span of higher priority than the switch it is executing, it MUST drop its switch immediately and enter the pass-through state.

The transition of a node from pass-through to switching state MUST be triggered by:

o An equal priority, a higher priority, or an allowed coexisting externally initiated command

o The detection of an equal priority, a higher priority, or an allowed coexisting automatic initiated command
The receipt of an equal, a higher priority, or an allowed coexisting RPS request destined to this node

5.2. RPS State Machine

5.2.1. Initial States

<table>
<thead>
<tr>
<th>State</th>
<th>Signaled RPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Idle</td>
<td>NR</td>
</tr>
<tr>
<td>Working: no switch</td>
<td></td>
</tr>
<tr>
<td>Protection: no switch</td>
<td></td>
</tr>
<tr>
<td><strong>B</strong> Pass-trough</td>
<td>N/A</td>
</tr>
<tr>
<td>Working: no switch</td>
<td></td>
</tr>
<tr>
<td>Protection: pass through</td>
<td></td>
</tr>
<tr>
<td><strong>C</strong> Switching - LP</td>
<td>LP</td>
</tr>
<tr>
<td>Working: no switch</td>
<td></td>
</tr>
<tr>
<td>Protection: no switch</td>
<td></td>
</tr>
<tr>
<td><strong>D</strong> Idle - LW</td>
<td>NR</td>
</tr>
<tr>
<td>Working: no switch</td>
<td></td>
</tr>
<tr>
<td>Protection: no switch</td>
<td></td>
</tr>
<tr>
<td><strong>E</strong> Switching - FS</td>
<td>FS</td>
</tr>
<tr>
<td>Working: switched</td>
<td></td>
</tr>
<tr>
<td>Protection: switched</td>
<td></td>
</tr>
<tr>
<td><strong>F</strong> Switching - SF</td>
<td>SF</td>
</tr>
<tr>
<td>Working: switched</td>
<td></td>
</tr>
<tr>
<td>Protection: switched</td>
<td></td>
</tr>
<tr>
<td><strong>G</strong> Switching - MS</td>
<td>MS</td>
</tr>
<tr>
<td>Working: switched</td>
<td></td>
</tr>
<tr>
<td>Protection: switched</td>
<td></td>
</tr>
<tr>
<td><strong>H</strong> Switching - WTR</td>
<td>WTR</td>
</tr>
<tr>
<td>Working: switched</td>
<td></td>
</tr>
<tr>
<td>Protection: switched</td>
<td></td>
</tr>
<tr>
<td><strong>I</strong> Switching - EXER</td>
<td>EXER</td>
</tr>
<tr>
<td>Working: no switch</td>
<td></td>
</tr>
<tr>
<td>Protection: no switch</td>
<td></td>
</tr>
</tbody>
</table>
5.2.2. State transitions When Local Request is Applied

In the state description below 'O' means that new local request will be rejected because of exiting request.

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Idle)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>D (Idle - LW)</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>F (Switching - SF)</td>
</tr>
<tr>
<td></td>
<td>Recover from SF</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>G (Switching - MS)</td>
</tr>
<tr>
<td></td>
<td>Clear</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>WTR expires</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>EXER</td>
<td>I (Switching - EXER)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Pass-trough)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>B (Pass-trough)</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>O - if current state is due to LP sent by another node</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>E (Switching - FS) - otherwise</td>
</tr>
<tr>
<td></td>
<td>Recover from SF</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>O - if current state is due to LP, SF or FS sent by another node</td>
</tr>
<tr>
<td></td>
<td>Clear</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>WTR expires</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>EXER</td>
<td>O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (Switching - LP)</td>
<td>LP</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Recover from SF</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Clear</td>
<td>A (Idle) - if there is no failure in the ring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F (Switching - SF) - if there</td>
</tr>
<tr>
<td>Initial state</td>
<td>New request</td>
<td>New state</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>D (Idle - LW)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td>LW</td>
<td></td>
<td>N/A - if on the same span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D (Idle - LW) - if on another span</td>
</tr>
<tr>
<td>FS</td>
<td></td>
<td>O - if on the same span</td>
</tr>
<tr>
<td>SF</td>
<td></td>
<td>E (Switching - FS) - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O - if on the addressed span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F (Switching - SF) - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recover from SF N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MS O - if on the same span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G (Switching - MS) - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clear A (Idle) - if there is no failure on the addressed span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F (Switching - SF) - if there is a failure on this span</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (Switching - FS)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td>LW</td>
<td></td>
<td>O - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D (Idle - LW) - if on the same span</td>
</tr>
<tr>
<td>FS</td>
<td></td>
<td>N/A - if on the same span</td>
</tr>
<tr>
<td>SF</td>
<td></td>
<td>E (Switching - FS) - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O - if on the addressed span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E (Switching - FS) - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recover from SF N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MS O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clear A (Idle) - if there is no failure in the ring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F (Switching - SF) - if there is a failure at this node</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B (Pass-trough) - if there is a failure at another node</td>
</tr>
</tbody>
</table>
a failure at another node

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (Switching - SF)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>O - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D (Idle - LW) - if on the same span</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>N/A - if on the same span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F (Switching - SF) - if on another span</td>
</tr>
<tr>
<td>Recover from SF</td>
<td></td>
<td>H (Switching - WTR)</td>
</tr>
<tr>
<td>MS</td>
<td>N/A</td>
<td>G (Switching - MS) - if on another span</td>
</tr>
<tr>
<td>Clear</td>
<td>N/A</td>
<td>A</td>
</tr>
<tr>
<td>WTR expires</td>
<td>N/A</td>
<td>A</td>
</tr>
<tr>
<td>EXER</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>G (Switching - MS)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>O - if on another span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D (Idle - LW) - if on the same span</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>F (Switching - SF)</td>
</tr>
<tr>
<td>Recover from SF</td>
<td>N/A</td>
<td>N/A - if on the same span</td>
</tr>
<tr>
<td>MS</td>
<td>N/A</td>
<td>G (Switching - MS) - if on another span</td>
</tr>
<tr>
<td>Clear</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>WTR expires</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>EXER</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (Switching - WTR)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>D (Idle - W)</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>F (Switching - SF)</td>
</tr>
<tr>
<td>Recover from SF</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>MS</td>
<td>G (Switching - MS)</td>
<td></td>
</tr>
<tr>
<td>Clear</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>WTR expires</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>
EXER

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (Switching - EXER) LP</td>
<td>C (Switching - LP)</td>
<td></td>
</tr>
<tr>
<td>LW</td>
<td>D (Idle - W)</td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>E (Switching - FS)</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>F (Switching - SF)</td>
<td></td>
</tr>
<tr>
<td>Recover from SF</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>G (Switching - MS)</td>
<td></td>
</tr>
<tr>
<td>Clear</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>WTR expires</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>EXER</td>
<td>N/A - if on the same span</td>
<td></td>
</tr>
<tr>
<td>I (Switching - EXER)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2.3. State Transitions When Remote Request is Applied

The priority of a remote request does not depend on the side from which the request is received.

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Idle) LP</td>
<td>C (Switching - LP)</td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>E (Switching - FS)</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>F (Switching - SF)</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>G (Switching - MS)</td>
<td></td>
</tr>
<tr>
<td>WTR</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>EXER</td>
<td>I (Switching - EXER)</td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>NR</td>
<td>A (Idle)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Pass-trough) LP</td>
<td>C (Switching - LP)</td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>N/A - cannot happen when there is LP request in the ring</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>N/A - cannot happen when there is LP request in the ring</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>N/A - cannot happen when there is LP, FS or SF request in the ring</td>
<td></td>
</tr>
<tr>
<td>WTR</td>
<td>N/A - cannot happen when there is LP, FS or SF request in the ring</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (Switching - LP)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>N/A - cannot happen when there is LP request in the ring</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>N/A - cannot happen when there is LP request in the ring</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>N/A - cannot happen when there is LP request in the ring</td>
</tr>
<tr>
<td></td>
<td>WTR</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>EXER</td>
<td>N/A - cannot happen when there is LP request in the ring</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>D (Idle - LW)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>F (Switching - SF)</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>G (Switching - MS)</td>
</tr>
<tr>
<td></td>
<td>WTR</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>EXER</td>
<td>I (Switching - EXER)</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>D (Idle - LW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state</th>
<th>New request</th>
<th>New state</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (Switching - FS)</td>
<td>LP</td>
<td>C (Switching - LP)</td>
</tr>
<tr>
<td></td>
<td>FS</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>SF</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>N/A - cannot happen when there is FS request in the ring</td>
</tr>
<tr>
<td></td>
<td>WTR</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>EXER</td>
<td>N/A - cannot happen when there is FS request in the ring</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>E (Switching - FS)</td>
</tr>
<tr>
<td>Initial state</td>
<td>New request</td>
<td>New state</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>-----------</td>
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<tr>
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</tr>
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<tr>
<td></td>
<td>MS</td>
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<td>H (Switching - WTR)</td>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>I (Switching - EXER)</td>
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5.2.4. State Transitions When Request Addresses to Another Node is Received

The priority of a remote request does not depend on the side from which the request is received.

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<td></td>
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<tr>
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<td>B (Pass-trough)</td>
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<tr>
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<td>N/A</td>
<td>N/A</td>
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<td>B (Pass-trough)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>B (Pass-trough) - otherwise</td>
</tr>
<tr>
<td></td>
<td>SF</td>
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<td></td>
<td></td>
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<td></td>
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<td>N/A</td>
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</tr>
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<td>MS</td>
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</tr>
<tr>
<td></td>
<td>WTR</td>
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</tr>
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<td>EXER</td>
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6. IANA Considerations

The Channel Types for the Generic Associated Channel are allocated from the IANA PW Associated Channel Type registry defined in [RFC4446] and updated by [RFC5586].

IANA is requested to allocate a further Channel Type as follows:

- TBA   Ring Protection Switching (RPS)

Note to RFC Editor: this section may be removed on publication as an RFC.

7. Security Considerations

This document does not by itself raise any particular security considerations.

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9. Normative References


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Abstract

The concept of "make-before-break (MBB)" while rerouting MPLS RSVP-TE tunnels is discussed in [RFC3209]. In the procedure that is outlined, the behavior of downstream label assignment for the new LSP (new tunnel instance) is not well defined. As a general practice, a different label is assigned by each downstream router and advertised to the upstream router in the RESV message for the new LSP; this results in a separate end-to-end data-plane path for the new LSP (with the exception of PHP LSPs or UHP LSP with explicit label on the last hop). This practice allows independent end to end LSP path data-plane verification for each tunnel instance. The consequence of this practice is that the label entry gets added/deleted in the LFIB at every non-ingress router along the LSP path during MBB. Also, the ingress router would need to update all the applications using this LSP when switching to the new tunnel instance, as the new tunnel instance uses different outgoing label. This in turn may also cause other elements of the network which are dependent on the LSP to do the update.

Such network churn can be avoided/minimized if the same label can be re-used (kept intact) wherever it is affecting neither the routing functionalities nor the data path verification of each instance. In addition, whenever label is reused, the setup time for the new tunnel instance would be faster because there is no need for the transit routers along the path of the new LSP to wait for the new LFIB entry to be added. This document proposes a set of procedures to facilitate label reuse when there is a total or partial path overlap between the two tunnel instances during MBB.
1. Introduction

MPLS RSVP-TE make-before-break (MBB) procedure is defined in [RFC3209]. The behavior of downstream label assignment for the new LSP (new tunnel instance) is not well-defined in this procedure. In most MBB implementations, a different label is assigned by each downstream router and advertised to upstream router in the RESV message for the new Label Switched Path (LSP). This means a separate end-to-end data-plane path for the new tunnel instance (with the exception of PHP LSPs or UHP LSPs with explicit NULL label at the last hop). Although this allows for independent end-to-end path verification for each tunnel instance, it requires an LFIB entry add/delete at every non-ingress router along the path of the LSP during MBB even if the paths for the new tunnel instance and the old tunnel instance might be partially or totally overlapping. Label reuse under partial or total overlap condition reduces unnecessary LFIB update, reduces the possibility of errors and improves network convergence latency. In cases where there is a total overlap of paths between the two tunnel instances and the label is reused at each hop along the overlapping path, the necessity of data plane verification for the new tunnel instance is no longer needed.

1.1. Common LSP MBB triggers

The MBB procedure can be triggered because of a change to any property of the RSVP-TE tunnel. The most common case is a change to the bandwidth requirement, especially with the widely implemented auto-bandwidth feature, which dynamically adjusts the LSP bandwidth based on traffic-monitoring feedback. With CSPF commonly used to compute path to meet the new bandwidth requirements, it is possible that the existing path is still one of the best paths which can satisfy the new requirements. This provides the opportunity to reuse labels to maximize the benefits described. If given the choice and the goal of selecting the best path is not the highest priority, CSPF can also prefer the existing path to other possible paths to take full advantage of the label reuse as long as the requirements are still met by the existing path.

2. Recommended conditions for label reuse

The notion of "Label reuse" can be applied for both point-to-point (P2P) LSP and point-to-multipoint (P2MP) LSP, but due to the complexity of P2MP and many possible variations of the solutions, this document will only focus on the recommendations for P2P LSPs.
Labels can be reused when the primary paths of the two tunnel instances have complete overlap starting from a certain point in the paths and going all the way to the egress router of the LSP. The best case scenario is complete overlap of the two paths end to end; in which case there is no need for any label changes and LFIB updates, both in the transit as well as in the ingress routers. In this scenario there is also no need to perform data plane verification for the new tunnel instance. For the case where the two paths overlaps only from a certain transit router (rather than from the ingress), label reuse starts at that router and continues all the way to the egress router. In this case the existing data plane verification method can still be used to verify new tunnel instance as before. Data traversing on either instance will take a different label path from the ingress to this transit router and from then on the traffic will merge into the shared label switched path towards the egress router.

The conditions under which label reuse can be applied are as following:

- Egress router of LSP: Reuse-label functionality can always be applied.
- Transit routers of the LSP: For any given transit router of P2P LSP, label can be reused if the following conditions are met:
  a) Downstream label received is the same
  b) NHOP is the same
- Ingress router of the LSP: When the same conditions as listed under transit router are met, instead of no label change, there is no need for ingress route update for LSP to applications depending on it.

The label reuse procedure starts from the egress of the LSP as RESV traverses upstream towards the ingress of the LSP; it terminates at the first transit router where paths of the two tunnel instances diverge towards the ingress of the LSP or at the transit router which doesn’t support label reuse.

3. Control of label-reuse behavior

3.1. Enable/Disable label-reuse capability

This document recommends enabling "label-reuse" capability by default. Allow it to be disabled if needed by changing configuration.
3.2. Prefer overlapping path to facilitate label-reuse

In order to take full advantage of the label-reuse capability, path computation for the new tunnel instance may seek to maximize path overlap. This can be achieved through two approaches.

- The first approach is to select from the best paths available the path which has the most path overlap with the existing path starting from the egress router.

- The second approach is to prefer the existing path if it still satisfies the new requirement, even though it might not be the best path.

The choice between the approaches is a matter of local computation policy and can be different for different types of MBB trigger.

4. IANA Considerations

This document makes no request for IANA action.

5. Security Considerations

This document does not introduce new security issues.

6. Acknowledgements

The authors wish to thank Vishnu Pavan Beeram for his input, feedback, and helpful suggestions.

7. Normative References


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Abstract

This document describes Hierarchical SDN (HSDN), an architectural solution to scale the Data Center (DC) and Data Center Interconnect (DCI) networks to support tens of millions of physical underlay endpoints, while efficiently handling both Equal Cost Multi Path (ECMP) load-balanced traffic and any-to-any end-to-end Traffic Engineered (TE) traffic. HSDN achieves massive scale using surprisingly small forwarding tables in the network nodes. HSDN introduces a new paradigm for both forwarding and control planes, in that all paths in the network are pre-established in the forwarding tables and the labels can identify entire paths rather than simply destinations. The HSDN forwarding architecture is based on four main concepts: 1. Dividing the DC and DCI in a hierarchically-partitioned structure; 2. Assigning groups of Underlay Border Nodes in charge of forwarding within each partition; 3. Constructing HSDN MPLS label stacks to identify endpoints and paths according to the HSDN structure; and 4. Forwarding using the HSDN MPLS labels.

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1. Introduction

With the growth in the demand for cloud services, the end-to-end cloud network, which includes Data Center (DC) and Data Center Interconnect (DCI) networks, has to scale to support millions to tens of millions of underlay network endpoints. These endpoints can be bare-metal servers, virtualized servers, or physical and virtualized network functions and appliances.

The scalability challenge is twofold: 1. Being able to scale using low-cost network nodes while achieving high resource utilization in the network; and 2. Being able to scale at low operational and computational complexity while supporting both Equal-Cost Multi-Path (ECMP) load-balanced traffic and any-to-any Traffic Engineering (TE) traffic.

Being able to scale at low cost requires to avoid the potential explosion of the routing tables in the network nodes as the number of underlay network endpoints increases. Current commodity switches have relatively small routing and forwarding tables. For example, the typical Forwarding Information Base (FIBs) and Label Forwarding Information Base (LFIBs) tables in current low-cost network nodes contain 16K or 32K entries. These small sizes are clearly insufficient to support entries for all the endpoints in the hyper-scale cloud. Address aggregation is used to ameliorate the problem, but the scalability challenges remain, since the dynamic and elastic environment in the DC/cloud often brings the need to handle finely granular prefixes in the network in order to support Virtual Machine (VM) and Virtualized Network Function (VNF) mobility.

Other factors contribute to the FIB/LFIB explosion. For example, in a typical DC using a fat Clos topology, even the support of ECMP load balancing may become an issue if the individual outgoing paths belonging to an ECMP group carry different outgoing labels, since a single destination may contribute multiple entries in the tables.

Another key scalability issue to resolve is the complexity of certain desired functions that should be supported in the network, the most prominent one being TE. Currently, any-to-any server-to-server TE in the DC/DCI is simply unfeasible, as path computation and bandwidth allocation at scale, an NP-complete problem, becomes rapidly unmanageable. Furthermore, the forwarding state needed in the network nodes for TE tunnels contributes in a major way to the explosion of the LFIBs, since each TE tunnel corresponds to an entry in the tables.

Other major scalability issues are related to the efficient creation, management, and use of tunnels, for example the configuration of
Many additional scalability issues in terms of operational and computational complexity need to be resolved in order to scale the control plane and the network state. In particular, the controller-centric approach of Software Defined Networks (SDNs), which is increasingly being accepted as "the way to build the next generation clouds," still needs to be demonstrated to be scalable to the levels required in the hyper-scale DC and cloud.

Finally, the underlay network architecture should offer certain capabilities to facilitate the support of the demands of the overlay network.

In this document, we present Hierarchical SDN (HSDN), a set of solutions for all these scalability challenges in the underlay network, both in the forwarding and in the control plane.

Although HSDN can be used with any forwarding technology, including IPv4 and IPv6, it has been designed to leverage Multi Protocol Label Switching (MPLS)-based forwarding [RFC3031], using label stacks [RFC3032] constructed according to the HSDN structure. This document therefore describes MPLS-based HSDN. The HSDN underlay network is suited to support any Layer 2 or Layer 3 virtualized overlay network technology. In this document, we assume a MPLS-based overlay technology using a Virtual Network (VN) Label, which is encapsulated in the HSDN label stack. However the description can be easily generalized to any overlay technology, such as BGP/MPLS IP VPNs [RFC4364], EVPN [RFC7432], VXLAN [RFC7348], NVGRE [I-D.sridharan-virtualization-nvgre], Geneve [I-D.draft-gross-geneve], and other technologies.

HSDN achieves massive scale using surprisingly small LFIBs in the network nodes, while supporting both ECMP load-balanced traffic and any-to-any end-to-end TE traffic. HSDN also brings important simplifications in the control plane and in the architecture of the SDN controller.

The HSDN architecture and operation is characterized by two fundamental properties. First, all paths in the network are pre-established in the forwarding tables. Second, the HSDN labels can identify entire paths or groups of paths rather than simply destinations.

These two properties radically simplify establishing and handling tunnels. In addition to optimally handling both ECMP and Non-Equal Cost Multi Path load balancing, HSDN enables any-to-any, end-to-end, server-to-server TE at scale. With HSDN, the "cost" of establishing a
tunnel is essentially eliminated, since the "tunnels" are pre-established in the network, and the TE task becomes one of path assignment and bandwidth allocation to the flows. As a larger portion of the traffic can be engineered effectively, the network can be run at a higher utilization using comparatively smaller buffers at the nodes.

The HSDN forwarding architecture in the underlay network is based on four main concepts: 1. Dividing the DC and DCI in a hierarchically-partitioned structure; 2. Assigning groups of Underlay Border Nodes in charge of forwarding within each partition; 3. Constructing HSDN MPLS label stacks to identify the end points according to the HSDN structure; and 4. Forwarding using the HSDN MPLS labels.

HSDN is designed to allow the physical decoupling of control and forwarding, and have the LFIBs configured by a controller according to a full SDN approach. The controller-centric approach is described in this document.

However, HSDN is also meant to support the traditional distributed routing and label distribution protocol approach to distribute the labels. This hybrid approach may be particularly useful during technology migration. The use of BGP Labeled Unicast (BGP-LU) for label distribution and LFIB configuration in a HSDN architecture is described in [I-D.fang-idr-bgplu-for-hsdn].

1.1. Terminology

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 RFC 2119 [RFC2119].

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGP</td>
<td>Border Gateway Protocol</td>
</tr>
<tr>
<td>BGP-LU</td>
<td>Border Gateway Protocol Labeled Unicast</td>
</tr>
<tr>
<td>DC</td>
<td>Data Center</td>
</tr>
<tr>
<td>DCGW</td>
<td>DC Gateway (Border Leaf)</td>
</tr>
<tr>
<td>DCI</td>
<td>Data Center Interconnect</td>
</tr>
<tr>
<td>DID</td>
<td>Destination Identifier</td>
</tr>
<tr>
<td>ECMP</td>
<td>Equal Cost MultiPathing</td>
</tr>
<tr>
<td>FIB</td>
<td>Forwarding Information Base</td>
</tr>
<tr>
<td>HSDN</td>
<td>Hierarchical SDN</td>
</tr>
<tr>
<td>LDP</td>
<td>Label Distribution Protocol</td>
</tr>
<tr>
<td>LFIB</td>
<td>Label Forwarding Information Base</td>
</tr>
<tr>
<td>LN</td>
<td>Leaf Node</td>
</tr>
<tr>
<td>MPLS</td>
<td>Multi-Protocol Label Switching</td>
</tr>
<tr>
<td>PID</td>
<td>Path Identifier</td>
</tr>
</tbody>
</table>

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In this document, we also use the following terms.

- **End device**: A physical device attached to the DC/DCI network. Examples of end devices include bare metal servers, virtualized servers, network appliances, etc.

- **Level**: A layer in the hierarchy of underlay partitions in the HSDB architecture.

- **Overlay Network (ON)**: A virtualized network that provides Layer 2 or Layer 3 virtual network services to multiple tenants. It is implemented over the underlay network.

- **Path Label (PL)**: A label used for MPLS-based HSDN forwarding in the underlay network.

- **Row**: A row of racks where end devices reside in a DC.

- **Tier**: One of the layers of network nodes in a multi-layer Clos-based topology.

- **Underlay Network (UN)**: The physical network that provides the connectivity among physical end devices. It provides transport for the overlay network traffic.

- **Underlay Partition (UP)**: A logical portion of the underlay network designed according to the HSDN architecture. Underlay partitions are arranged in a hierarchy consisting of multiple levels.

- **VN Label (VL)**: A label carrying overlay network traffic. It is encapsulated in the underlay network in a stack of path labels constructed according to the HSDN forwarding scheme.
1.2. DC and DCI Reference Model

Here we show the typical structure of the DC and DCI, which we use in the rest of this document to describe the HSDN architecture. We also introduce a few commonly used terms to assist in the explanation.

Figure 1 illustrates multiple DCs interconnected by the DCI/WAN.

Figure 2 below illustrates the typical structure of a Clos-based DC fabric.
Figure 2. Typical Clos-based DC fabric topology.

Note: Not all nodes and links are shown in Figure 2.

The DC fabric shown in Figure 2 uses what is known as a spine and leaf architecture with a multi-stage Clos-based topology interconnecting multiple tiers of network nodes. The DC Gateways (DCGWs) connect the DC to the DCI/WAN. The DCGW connect to the Spine Nodes (SNs), which in turn connect to the Leaf Nodes (LFs). The Leaf Nodes connect to the Top-of-Rack switches (ToRs). Each ToR typically resides in a rack (hence the name) accommodating a number of servers connected to their respective ToR. The servers may be bare metal or virtualized.

Each tier of switches and the connectivity between switches is designed to offer a desired capacity and provide sufficient bandwidth to the servers and end devices.

Figure 2 is not meant to represent the precise topology of the DC. In fact, the precise topology and connectivity between the tiers of switches depends on the specific design of the DC. More or less tiers of switches (spines or leaves) or asymmetric topologies, not shown in the figure, may be used. A precise description of the possible
topologies and related design criteria is out of the scope of this
document.

What is relevant for this document is the fact that a typical large-
scale DC topology does not have all the tiers fully connected to the
adjacent tier (i.e., not all network nodes in a tier are necessarily
connected to all network nodes in the adjacent tiers). This is
especially true for the tiers closer to the endpoints, and is due to
the sheer number of connections and devices (in other words, in a
large, fat Clos there are too many network nodes in some tiers for
all network nodes to connect to one another), and to the physical
constraints of the DC (i.e., the network nodes may be located
physically apart in separate rooms or buildings, and full
connectivity may become too costly).

The actual connectivity is typically organized following an
aggregation/multiplexing connectivity architecture that consolidates
traffic from the edges into the leafs and spines, while allowing for
over-subscription in order to strike a reasonable trade-off between
cost and available capacity. The connectivity between each tier uses
some form of shuffle-exchange topology that attempts to "mix" the
available paths while taking in account the physical constraints.

The key observation is that it is impractical, uneconomical, and
ultimately unnecessary to use a fully connected Clos-based topology
in a large scale DC. Because of the physical constraints, the
topology of a large DC is not a flat, fully-connected, multi-layer
Clos, but rather has some form of hierarchy. The HSDN architecture
recognizes this fact, and uses it to dramatically simplify forwarding
and control planes using an approach that is also hierarchical.

2. Requirements

2.1. MPLS-Based HSDN Design Requirements

The following are the key design requirements for MPLS-based HSDN
solutions.

1) MUST support millions to tens of millions of underlay network
   endpoints in the DC/DCI.

2) MUST use very small LFIB sizes (e.g., 16K or 32K LFIB entries) in
   all network nodes.

3) MUST support both ECMP load-balanced traffic and any-to-any, end-
   to-end, server-to-server TE traffic.

4) MUST support ECMP traffic load balancing using a single forwarding
entry in the LFIBs per ECMP group.

5) MUST require IP lookup only at the network edges.

6) MUST support encapsulation of overlay network traffic, and support any network virtualization overlay technology.

7) MUST support control plane using both full SDN controller approach, and traditional distributed control plane approach using any label distribution protocols.

2.2. Hardware Requirements

The following are the hardware requirements to support HSDN.

1) The server NICs MUST be able to push a HSDN label stack consisting of as many path labels as levels in the HSDN hierarchical partition (e.g., 3 path labels).

2) The network nodes MUST support MPLS forwarding.

3) The network nodes MUST be able perform ECMP load balancing on packets carrying a label stack consisting of as many path labels as levels in the HSDN hierarchical partition, plus one or more VN label/header for the overlay network (e.g., 3 path labels + 1 VN label/header).

3. HSDN Architecture - Forwarding Plane

As mentioned above, a primary design requirement for HSDN is to enable scalability of the forwarding plane to tens of millions of network endpoints using very small LFIB sizes in all network nodes in the DC/DCI, while supporting both ECMP and any-to-any server-to-server TE traffic.

The driving principle of the HSDN forwarding plane is "divide and conquer" by partitioning the forwarding task into local and independent forwarding. When designed properly, such an approach enables extreme horizontal scaling of the DC/DCI.

HSDN is based on four concepts:

1) Dividing the underlay network in a hierarchy of partitions;
2) Assigning groups of Underlay Partition Border Nodes (UPBN) to each partition, in charge of forwarding within the corresponding partition;
3) Constructing HSDN label stacks for the endpoint Forward Equivalency Classes (FECs) in accordance with the underlay network
4) Configuring the LFIBs in all network nodes and forwarding using the label stacks.

As explained below, the HSDN label stacks can be used to identify entire paths to each endpoint, rather than simply the destination endpoint itself. As a matter of fact, the HSDN solution is meant to be configured with all possible paths in the network pre-established in the LFIBs in the network nodes. In this case, a FEC per path to each endpoint is defined. However, because of the way the HSDN architecture is designed, the required local number of entries in the LFIB of each network node remains surprisingly small.

In this section, we explain in detail each of these concepts. Scalability analysis for both ECMP load-balanced and TE traffic is presented in Section 4. In Section 5, we describe a possible label stack assignment scheme for HSDN.

3.1. Hierarchical Underlay Partitioning

HSDN is based on dividing the DC/DCI underlay network into logical partitions arranged in a multi-level hierarchy.

The HSDN hierarchical partitioning is illustrated in Figure 3.
The hierarchy consists of multiple levels of Underlay Partitions (UPs). For simplicity, we describe HSDN using three levels of partitioning, but more or less levels can be used, depending on the size and architecture of the overall network, using similar design principles (as shown below, three levels of partitions are sufficient to achieve scalability to tens of millions servers using very small LFIBs).

The levels of partitions are nested into a hierarchical structure. At each level, the combination of all partitions covers the entire DC/DCI topology. In general, within each level, the UPs do not overlap, although there may be design scenarios in which overlapping UPs within a level may be used. The top level (Level 0) consists of a single underlay partition UP0 (the HSDN concept can be extended to multi-partitioned Level 0).

We use the following naming convention for the UPs:

- Partitions at Level i are referred to as UPi (e.g., UP0 for Level 0, UP1 for Level 1, UP2 for Level 2, and so on).

- Within each level, partitions are identified by a rightmost sequential number (starting from 1) referring to the corresponding level and a set of sequential number(s) for each partition in a
higher level that the specific partition is nested into.

For example, at Level 1, there are N partitions, referred to as UP1-1 to UP1-N.

Similarly, at Level 2, there are M partitions for each Level 1 partitions, for a total of N\times M partitions. For example, the Level 2 partitions nested into Level 1 partition UP1-1 are UP2-1-1 to UP2-1-M, while the ones nested into UP1-N are UP2-N-1 to UP2-N-M.

Note that for simplicity in illustrating the partitioning, we assume a symmetrical arrangement of the partitions, where the number of partitions nested into each partition at a higher level is the same (e.g., all UP1 partitions have M UP2 partitions). In practice, this is rarely the case, and the naming convention can be adapted accordingly for different numbers of partitions nesting into each higher level partition (e.g., partition UP1-1 has M1 UP2 partitions, partition UP1-2 has M2 UP2 partitions, and so on).

The following considerations complete the description of Figure 3.

- The servers (bare metal or virtualized) are attached to the bottom UP level (in our case, Level 2). A similar naming convention as the one used for the partitions may be used.

- In Figure 3, we also show an additional Overlay Level. This corresponds to the virtualized overlay network (if any) providing Virtual Networks (VN) connecting Virtual Machines (VMs) and other overlay network endpoints. Overlay network traffic is encapsulated by the HSDN underlay network. As mentioned in the Introduction, the HSDN underlay network is suited to support any Layer 2 or Layer 3 virtualized overlay network technology, such as BGP/MPLS IP VPNs [RFC4364], EVPN [RFC7432], VXLAN [RFC7348], NVGRE [I-D.sridharan-virtualization-nvgre], Geneve [I-D.draft-gross-geneve], and other technologies. A full description of the encapsulation of these technologies into the HSDN underlay label stack is out of scope of this document and will be addressed in a separate document.

The UPs are designed to contain one or more tiers of switches in the DC topology or nodes in the DCI. The key design criteria in defining the partitions at each layer is that they need to follow the "natural" connectivity implemented in the DC/DCI topology. An example is given below to further clarify how the partitions are designed.

3.2. Underlay Partition Border Nodes

Once the HSDN hierarchical partitioning is defined, Underlay
Partition Border Nodes (UPBNs) are assigned to each UP. This is illustrated in Figure 4.

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Figure 4. UPBNs, UBPGs, and label stack assignment.

The UPBNs serve as the connecting nodes between adjacent partitions. As such, the UPBNs belong to two partitions in adjacent levels in the hierarchy and they constitute the entry points for traffic from the higher level partition destined to the corresponding lower level partition (and vice-versa, they are the exit points for traffic from a lower level partition to a higher level partition). As such, they constitute the forwarding end destinations within each partition.

In order to provide sufficient capacity and support traffic load balancing between the levels in the hierarchy, multiple UPBNs are assigned to each partition. The UPBNs for each partition are grouped into an Underlay Partition Border Group (UPBG). As shown below, using an appropriate Label Stack Assignment scheme all UPBNs in a UPBG can
be made identical for ECMP traffic forwarding (i.e., the ECMP entries in the LFIBs in all UPBNs in a UPBG are identical). Thus, for ECMP traffic load balancing, all UPBNs belong to the same FEC as far as the higher level partition is concerned. For TE traffic, a desired UPBN within a UPBG group may need to be specified, and thus the UPBNs in a UPBG are not forwarding-wise equivalent.

In practice, the UPs are designed by finding the most advantageous way to partition the DC Clos-based topology and the DCI topology. As mentioned above, the connectivity of any large-scale DC is not fully flat, but rather contains some sort of hierarchical organization. Recognizing the hierarchy of the physical connectivity is an important starting point in the design of the partitions.

Within the DC, the UPBNs in each level are subsets of the network nodes in one of the tiers that form the multi-stage Clos architecture.

In general, in addition to the UPBNs, the UPs may internally contain tiers of network nodes that are not UPBNs. A specific design example to further illustrate the HSDN partitioning is provided below.

As explained in more detail below, for forwarding purposes, by partitioning the DC/DCI in this manner and using HSDN forwarding, the UPBNs need to have entries in their LFIBs only to reach destinations in the two partitions to which they belong to (i.e., their own corresponding lower-level partition and the higher-layer partition to which they nested to). The network nodes inside the UPs only need to have entries in their LFIB to reach the destinations in their partition.

Similarly, in order to establish all possible paths in the entire network, the UPBNs need to have entries in their LFIBs only for all possible paths to the destinations in the two partitions to which they belong to.

From these considerations, a first design heuristic for choosing the partitioning structure is to keep the number of partitions nested at each level into the higher level relatively small for all levels. For the lowest level, the number of endpoints (servers) in each partition should also be kept to manageable levels.

Clearly, the design tradeoff is between the size and the number of partitions at each level. Although finding the optimal design choice may require a little trial-and-error computation of different options, fortunately, for most practical deployments, it is relatively simple to find a good tradeoff that achieves the desired scalability to millions or tens of millions of endpoints.
3.2.1. UPBN and UPBG Naming Convention

We use a similar naming convention for the UPBNs and UPBGs as the one used for the UPs:

- UPBNi is a UPBN between partitions at Level(i) and Level(i-1). Similarly for UPBG.

- Within each level, the UPBNs are identified by a set of sequential number(s) equal to the corresponding sequential number(s) of the corresponding partition within that level.

For example, at Level 1, UPBN1-1 corresponds to partition UP1-1, and connects UP0 with UP1-1. UPBN1-N corresponds to partition UP1-N and connects UP0 with UP1-N, and so on. Similarly for UPBG.

At Level 2, UPBN2-1-1 corresponds to partition UP2-1-1 and connects UP1-1 with UP2-1-1, and so on. Similarly for UPBG.

Note that the UPBNs within an UPBGs can be further distinguished using an appropriate naming convention (for example, using an additional sequential number within the UPBG), which for simplicity is not shown here. This more granular naming convention is needed to configure the paths and the TE tunnels.

3.2.2. HSDN Label Stack

In MPLS-Based HSDN, an MPLS label stack is defined and used for forwarding. The key notion in HSDN is that the label stack is defined and the labels are assigned in accordance with the hierarchical partitioned structure defined above.

The label stack, shown in Figure 4 above, is constructed as follows.

- The label stack contains as many Path Labels (PLs) as levels in the partitioning hierarchy.

- Each PL in the label stack is associated to a corresponding level in the partition hierarchy and is used for forwarding at that level.

In the scenario of Figure 4, PL0 is associated to Level 0 and is used to forward to destinations in UP0, PL1 is associated to Level 1 and is used to forward to destinations in any UP1 partitions, and PL2 is associated to Level 2 and is used to forward to destinations in any UP2 partitions.

- A VN Label (VL) is also shown in the label stack in Figure 4. This
A label is associated to the Overlay Level and is used to forward in the overlay network. The VL is simply encapsulated in the label stack and transported in the HSDN underlay network. As mentioned above, the HSDN underlay network is suited to support any Layer 2 or Layer 3 virtualized overlay network technology, and thus the VL may be a label, a tag, or some other identifier, depending on the overlay technology used. The details of the VL encapsulation and processing for different overlay technologies are out of scope of this document.

Each endpoint in the DC/DCI is identified by a corresponding label stack. For a given endpoint, the label stack is constructed in such a way that the PLO specifies the UP1 to which the endpoint is attached to, the PL1 specifies the UP2 to which the endpoint is attached to, and the PL2 specifies the FEC in the UP2 corresponding to the endpoint.

The labels in the HSDN label stack can identify entire paths, rather than simply the end destination within the corresponding partition. This can be used to bring dramatic simplifications in handling tunnels and TE traffic in particular, as further explained below.

A scheme to assign the PL labels in the HSDN label stack is described below.

3.2.3. HSDN Design Example

We use an example to further explain the HSDN design criteria to define the hierarchically-partitioned structure of the DC/DCI. We use the same design example in the Scalability Analysis section below to show the LFIB sizing with ECMP and TE traffic.

To summarize some of the design heuristics for the HSDN underlay partitions:

- The UPs should be designed to follow the "natural" connectivity topology in the DC/DCI.
- The number of partitions at each level nested into the higher level should be relatively small (since they are FEC entries in the LFIBs in the network nodes in the corresponding levels).
- The number of endpoints (servers) in each partition in the lowest level should be relatively small (since they are FEC entries in the LFIBs in the network nodes in the lowest level).
- The number of levels should be kept small (since it corresponds to the number of path labels in the stack).
- The number of tiers in each partition in each level should be kept small. This is due to the multiplicative fanout effect for TE traffic (explained below), which has a major impact on the LFIB size needed to support any-to-any server-to-server TE.

The HSDN forwarding plane design consists in finding the best tradeoff among these conflicting objectives. Although the optimal design choices ultimately depend on the specific deployment, fortunately, it is generally rather straightforward to identify design choices that can support scalability to millions or tens of millions of servers.

Here we describe a design example to illustrate that a three-level HSDN hierarchy is sufficient to scale the DC/DCI to tens of millions of servers.

With three levels, a possible design choice for the UP1s is to have each UP1 correspond to a DC. With this choice, the UP0 corresponds to the DCI and the UPBN1s are the DCGWs in each DC (the UPBG1s group the DCGWs in each DC).

Once the UP1s are chosen this way, a possible design choice for the UP2s is to have each UP2 correspond to a group of racks, where each group of racks may correspond to a portion of a row of racks, an entire row of racks, or multiple rows of racks. The specific best choice of how many racks should be in a group of racks corresponding to each UP2 ultimately depends on the specific connectivity in the DC and the number of servers per racks.

While precise numbers depend on the specific technologies used in each deployment, here and in the Scalability Analysis section below we want to give some ideas of the scaling capabilities of HSDN. For this purpose, we use some hypothetical yet reasonable numbers to characterize the partitioning design example.

Assume the following: a) 20 DCs connected via the DCI/WAN; b) 50 servers per rack; c) 20 racks per group of racks; d) 50 groups of racks per DC.

With these numbers, there are 500K servers per DC, for a total of 10M underlay network endpoints in the DC/DCI.

In the HSDN structure in this example, there are 20 UP1s, 500 UP2s per UP1, and 1000 servers per UP2.

3.3. MPLS-Based HSDN Forwarding

The hierarchically partitioned structure and the corresponding label
stack are used in HSDN to scale the forwarding plane horizontally while using LFIBs of surprising small sizes in the network nodes.

As explained above, each label in the HSDN label stack is associated with one of the levels in the hierarchy and is used to forward to destinations in the underlay partitions at that level.

With HSDN, by superimposing a hierarchically-partitioned structure and using a label stack constructed according to such a structure, we are able to impose a forwarding scheme that is aggregated by construction. This translates in dramatic reductions in the size of the LFIBs in the network nodes, since each node only needs to know a limited portion of the forwarding space.

HSDN supports any label assignment scheme to generate the labels in the label stack. However, if a label assignment scheme that is consistent with the HSDN structure is used, additional simplifications of the LFIBs and the control plane can be achieved.

In Section 5 below, we present one example of such a scheme, where the labels in the label stack represent the "physical" location of the endpoint, expressed according to the HSDN structure. For TE traffic, the labels represent a specific path towards the desired destination through the HSDN structure.

In the Scalability Analysis section and in the Control Plane section below we assume that such a Label Assignment scheme is used.

In the rest of this section, we describe the life of a packet in the HSDN DC/DCI. We use the specific design example described in Section 3.2.3 above to help in the explanation, but of course the forwarding would be similar for other design choices.

### 3.3.1 Non-TE Traffic

We first describe the behavior for ECMP load-balanced, non-TE traffic. In the HSDN DC/DCI, for a packet that needs to be forwarded to a specific endpoint in the underlay network, the outer label PL0 specifies which UP1 contains the endpoint. Let’s refer to this UP1 as UP1-a. For ECMP traffic, the PL0 binding is with a FEC corresponding to the UPBG1-a associated with UP1-a. Note that all the endpoints reachable via UP1-a are forwarded using the same FEC entry for Level 0 in the hierarchical partitioning.

Once the packet reaches one of the network nodes UPBN1-a in the UPBG1-a group (the upstream network nodes perform ECMP load balancing, thus the packet may enter UP1-a via any of the UPBN1-a nodes), the PL0 is popped and the PL1 is used for forwarding in the
UP1-a (to be precise, because of penultimate hop popping, it is the network node immediately upstream of the chosen UPBN1-a that pops the label P0).

The PL1 is used within UP1-a to reach the UP2 which contains the endpoint. Let’s refer to this UP2 as UP2-a. In the UP2 network nodes the PL1 binding is with a FEC corresponding to the UPBG2-a associated with UP2-a. Similarly as above, note that all the endpoints reachable via UP2-a are forwarded using the same FEC entry for Level 1 in the hierarchical partitioning.

Once the packet reaches one of the network nodes UPBN2-a in the UPBG2-a group (once again, the upstream network nodes perform ECMP load balancing, so the packet may transit to any of the UPBN2-a nodes), the PL1 is popped and the PL2 is used for the rest of the forwarding (again, to be precise, the penultimate network node upstream of UPBN2-a is the one popping the PL1 label).

The PL2 is used within UP2-a to reach the desired endpoint. Note that the UPBN2 nodes and the network nodes in the UP2s have entries in their LFIBs only to reach endpoints within their UP2. They can reach endpoints in other UP2s by using a FEC entry corresponding to the UP2 containing the destination endpoint, identified by PL1.

The following two observations help in further clarifying the forwarding operation above.

- The PL0 is used for forwarding from the source to the UPBN1-a. For a packet originating from an endpoint attached to a certain UP2, say UP2-b, nested to a different UP1, say UP1-b, PL0 is used for forwarding in all network nodes that the packet transits until it reaches the UPBN1-a. This includes network nodes in UP2-b and UP1-b (i.e., "on the way out" from UP2). It also includes one of the UPBN1-b nodes.

  It is important to note, however, that the PL0 is not popped at the UPBN1-b, since it is used for forwarding to the destination UPBN1-a.

- It should be pointed out that, in order to achieve route optimization, not all packets need to use the entire HSDN label stack and thus not all packets carry a three-label MPLS stack. For example, a packet originating from the endpoint in UP2-b and destined to an endpoint in the same UP2-b should not be forwarded all the way to the highest level in the hierarchy and back, but should be forwarded to the desired endpoint at the first node in the UP2 that contains an entry to that desired endpoint. In other words, the packet only needs PL2 to be properly forwarded, since
it should never "go out" of UP2.

To optimize the label assignment and forwarding scheme, a single "turn around" label value can be used to identify traffic that needs to be kept within the partition once the corresponding UPBN is reached. For example, a packet destined to an endpoint in the same UP2-b of the originating server that needs to only reach the UPBN2-b, may carry a PL1 corresponding to the "turn around" label value and a PL2 corresponding to the desired endpoint within UP2, and does not need a PL0.

Similarly, a packet originating from the endpoint in UP2-b and destined to an endpoint in a different UP2 nested in the same UP1-b only needs PL1 and PL2 to be forwarded.

In the case of ECMP load-balanced non-TE traffic, the labels in the HSDN label stack identify ECMP groups for each destination in the corresponding partition. In this way, at each node in the partition, the outgoing label is the same for all paths belonging to the same ECMP group. A label allocation scheme for this is described below.

3.3.1 TE Traffic

Handling TE traffic in the hyper-scale DC/DCI presents major scalability challenges, since each TE tunnel contributes one entry in the forwarding tables, and the TE path and bandwidth allocation computation is a NP-complete problem.

HSDN introduces radical simplifications in establishing and handling tunnels, and in supporting TE in particular.

In HSDN, all paths in the network can be pre-established in the LFIBs. Because of the way the HSDN architecture is constructed, the number of entries that have to be stored in the local LFIB in each network node remains surprisingly small.

In this case, the labels in the HSDN stack identify entire paths, or groups of paths, to each destination in each partition, rather than just the destination itself.

With HSDN, since the "cost" of establishing a tunnel is essentially eliminated (all "tunnels" are pre-established in the network), and the TE task becomes one of path assignment and bandwidth allocation to the flows. Furthermore, the hierarchical structure of HSDN makes it possible to devise algorithms and heuristics for path and bandwidth allocation computation that operate largely independently in each partition, and are therefore computationally feasible even at large scale. A description of such algorithms is out of scope of this
document. As a larger portion of the traffic can be engineered effectively, the network can be run at a higher utilization using comparatively smaller buffers at the nodes.

Since all paths can be accommodated in the LFIBs, HSDN makes it possible to support "TE Max Case" with small LFIB sizes. In TE Max Case, all sources are connected to all destinations (e.g., server to server) with TE tunnels, the tunnels using all possible distinct paths in the network. TE Max Case gives therefore an upper bound to the number of TE tunnels (and consequently, LFIB entries) in the network.

The fact that the LFIBs remain relatively small even when all possible paths are configured is the consequence of two desirable properties of HSDN.

First, since in HSDN the individual UPs are designed in such a way to be relatively small, the number of paths in each partition can be kept to a manageable number.

Second, the hierarchical structure of HSDN makes it possible to use the partitioning astutely to break the "TE Fanout Multiplicative Effect," which defines the number of paths to a destination, and can easily contribute to the LFIB explosion as the number of hops and the fanout of each hop to each destination in the network increases. As explained below, with the hierarchical structure, the TE Fanout Multiplicative Effect is only multiplicative within each level in the hierarchy. Thus, by properly designing the partitioning, the multiplicative effect can be kept to a manageable level.

In the case of TE traffic, the processing of the different labels in the label stack is similar to what described above for ECMP load-balanced non-TE traffic. However, the labels are bound to FECs identifying a specific path within each UPs that is traversed.

4. Scalability Analysis

In this section, we compute the maximum size of the LFIBs for non-TE/ECMP traffic and any-to-any server-to-server TE traffic.

4.1. LFIB Sizing - ECMP

For ECMP traffic, at each level, all destinations belonging to the same partition at a lower level are forwarded using the same FEC entry in the LFIB, which identifies the destination UPBG for that level, or the destination endpoint at the lower level. Since the UPs are designed in such a way to keep the number of destinations small in all UPs, and the network nodes only need to know how to reach...
destinations in their own UP and in the adjacent UP at the higher level in the hierarchy, this translate to the fact that hyper scale of the DC/DCI can be achieved with very small LFIB sizes in all the individual network nodes.

The worst case for the LFIB size occurs at one of the network nodes that serve as UPBNs for one of the levels of UPs in the hierarchy. The level where the LFIB size occurs depend on the specific choice of the partitioning design.

4.2. LFIB Sizing - TE

As noted above, TE traffic may add a considerable number of entries to LFIB, since it creates one new FEC per TE tunnel to each destination.

HSDN provides a solution to this problem, and in fact, HSDN can support any-to-any server-to-server "TE Max Case" with small LFIB sizes.

In a Clos Topology (the analysis can be extended to generic topologies), the number of paths in a UP with N destination can be easily computed. The number of paths (and the maximum number of LFIB entries) is equal to the products of the switch fanout in each tier traversed from the source to the destination in that UP. This is the "TE Fanout Multiplicative Effect" mentioned above, which is illustrated in Figure 5. Accordingly:

Total # LFIB Entries for TE Max Case = N * F1 * F2 * ... * F(M-1)

Where Fi is the fanout of a switch in each tier traversed to the destination, M is the number of tiers in the UP, and N is the number of destinations in the UP.

Once again, by properly designing the UPs, the TE Fanout Multiplicative Effect can be kept under control, since the path computation is local for each of the UPs. HSDN breaks the multiplicative effect, since the TE Fanout Multiplicative Effect is multiplicative only within each UP, rather than in the entire network, and the "multiplication" restarts at each level of the hierarchy.
5. HSDN Label Stack Assignment Scheme

HSDN can use any scheme to assign the labels in the label stack. However, if a label assignment scheme which assigns labels in a way consistent with the HSDN structure, important simplifications can be achieved in the control plane and in the LFIBs.

For non-TE FECs, the HSDN label assignment scheme assigns labels according to the "physical" location of the endpoint in the HSDN structure. Continuing our design example from above, for an endpoint X in UP2-a, PL0 would identify the DC in which the endpoint is located, PL1 would identify the group of racks in which the endpoint is located within the DC, and PL2 would identify the endpoint within
the group of servers within the DC.

For TE FECs, the HSDN label assignment scheme assigns labels to identify a specific path in each UP that is traversed. In our example, for a specific TE tunnel to endpoint X, PL0 would identify the specific path that should be followed in the DCI, PL1 would identify the path that should be followed within the DC to reach the group of racks, and PL2 would identify the path to reach the endpoint within the group of racks (if there are multiple paths).

In order to assign labels to both non-TE traffic and TE traffic, HSDN uses a label format in which the labels are divided into two logical sub-fields, one identifying the destination within the UP, called Destination Identifier (DID), and one identifying the path, called Path Identifier (PID). The Path Identifier is only relevant for TE traffic, and can be zero for non-TE traffic. The HSDN Label format is illustrated in Figure 6.

```
0  d  19
+-----------------------------------------------+
|  Destination Identifier |     Path Identifier    |
+-----------------------------------------------+
|<-------- d bits -------->|<-----(20-d bits)------>|
LSB                                               MSB
```

Figure 6. HSDN Label format.

Depending on the LFIB configuration, the two MSBs may be reserved for identifying the layer (i.e., whether the label is PL0, PL1, or PL2) to resolve ambiguity (not shown in Figure 6). Note, however, that this is not strictly necessary and the same function of identifying the layer can be achieved by simply allocating "turn around" entries in the nodes, so an individual node always sees the same label in the stack.

By properly designing the UPs, this label assignment scheme can support the desired scalability and the support of end-to-end TE traffic.

Note that by using this type of label assignment scheme important benefits can be achieved, including:

- The LFIBs become rather "static," since the FECs are tied to "physical" locations and paths, which change infrequently. This simplifies the use of the SDN approach to configure the LFIBs via
a controller.

- All paths in each ECMP group use the same outgoing labels. This guarantees that a single LFIB entry can be used for each ECMP group.

The label stack needs to be imposed at the entry points. For an endpoint, this implies that the server NIC must be able to push a three-label stack of path labels (in addition to possibly push one additional VL label for the overlay network).

6. HSDN Architecture - Control Plane

HSDN has been designed to support the controller-centric SDN approach in a scalable fashion. HSDN also supports the traditional distributed control plane approach.

HSDN introduces important simplifications in the control plane and in the network state as well.

6.1. The SDN approach

In the controller-centric SDN approach, the SDN controller configures the LFIBs in all the network nodes. With HSDN, the hierarchical partitioned structure offers a natural framework for a distributed implementation of the SDN controller, since the control plane in each UP is largely independent from other UPs.

For example, a possible architecture uses a SDN controller for each UP. Such SDN partition controller is in charge of configuring the LFIBs in the network nodes in the corresponding UP.

The SDN partition controller may also be in charge of TE computation. With proper design of the UPs, TE path computation algorithms which perform partition-local computation while approach global optimality can be used.

6.2. Distributed control plane

HSDN can also use the traditional distributed routing protocol approach to distribute HSDN labels. An example using BGP-LU [RFC3107] is presented in [I-D.fang-idr-bgplu-for-hsdn].

7. Security Considerations

When the SDN approach is used, the protocols used to configure the LFIBs in the network nodes MUST be mutually authenticated.
For general MPLS/GMPLS security considerations, refer to [RFC5920].

Given the potentially very large scale and the dynamic nature in the cloud/DC environment, the choice of key management mechanisms need to be further studied.

To be completed.

8. IANA Considerations

TBD.

9. References

9.1 Normative References


9.2 Informative References


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Relayed Echo Reply mechanism for LSP Ping
draft-ietf-mpls-lsp-ping-relay-reply-07

Abstract

In some inter autonomous system (AS) and inter-area deployment scenarios for RFC 4379 "Label Switched Path (LSP) Ping and Traceroute", a replying LSR may not have the available route to the initiator, and the Echo Reply message sent to the initiator would be discarded resulting in false negatives or complete failure of operation of LSP Ping and Traceroute. This document describes extensions to LSP Ping mechanism to enable the replying Label Switching Router (LSR) to have the capability to relay the Echo Response by a set of routable intermediate nodes to the initiator. This document updates RFC 4379.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at http://datatracker.ietf.org/drafts/current/.

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This Internet-Draft will expire on September 8, 2015.
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1. Introduction

This document describes the extensions to the Label Switched Path (LSP) Ping as specified in [RFC4379], by adding a relayed echo reply mechanism which could be used to detect data plane failures for the inter autonomous system (AS) and inter-area LSPs. The extensions are to update the [RFC4379]. Without these extensions, the ping functionality provided by [RFC4379] would fail in many deployed inter-AS scenarios, since the replying LSR in one AS may not have the available route to the initiator in the other AS. The mechanism in this document defines a new message type referred as "Relayed Echo Reply message", and a new TLV referred as "Relay Node Address Stack TLV".

This document is also to update [RFC4379], include updating of Echo Request sending procedure in section 4.3 of [RFC4379], Echo Request receiving procedure in section 4.4 of [RFC4379], Echo Reply sending procedure in Section 4.5 of [RFC4379], Echo Reply receiving procedure in section 4.6 of [RFC4379].

1.1. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Motivation

LSP Ping [RFC4379] defines a mechanism to detect the data plane failures and localize faults. The mechanism specifies that the Echo Reply should be sent back to the initiator using an UDP packet with the IPv4/ IPv6 address of the originating LSR. This works in administrative domains where IP addresses reachability are allowed among LSRs, and every LSR is able to route back to the originating LSR. However, in practice, this is often not the case due to intra-provider routing policy, route hiding, and network address translation at autonomous system border routers (ASBR). In fact, it is almost uniformly the case that in inter-AS scenarios, it is not
allowed the distribution or direct routing to the IP addresses of any of the nodes other than the ASBR in another AS.

Figure 1 demonstrates a case where one LSP is set up between PE1 and PE2. If PE1’s IP address is not distributed to AS2, a traceroute from PE1 directed to PE2 could fail if the fault exists somewhere between ASBR2 and PE2. Because P2 cannot forward packets back to PE1 given that it is a routable IP address in AS1 but not routable in AS2. In this case, PE1 would detect a path break, as the Echo Reply messages would not be received. Then localization of the actual fault would not be possible.

Note that throughout the document, routable address means that it is possible to route an IP packet to this address using the normal information exchanged by the IGP operating in the AS.

\[\begin{align*}
\text{PE1} & \quad \text{P1} \quad \text{ASBR1} \quad \text{ASBR2} \quad \text{P2} \quad \text{PE2} \\
\text{----------------} & \quad \text{----------------} & \quad \text{----------------} & \quad \text{----------------} & \quad \text{----------------} \\
\text{AS1} & \quad \text{AS2} & \quad \text{LSP} \\
\end{align*}\]

**Figure 1: Simple Inter-AS LSP Configuration**

A second example that illustrates how [RFC4379] would be insufficient would be the inter-area situation in a seamless MPLS architecture [I-D.ietf-mpls-seamless-mpls] as shown below in Figure 2. In this example LSRs in the core network would not have IP reachable route to any of the ANs. When tracing an LSP from one AN to the remote AN, the LSR1/LSR2 node could not make a response to the Echo Request either, like the P2 node in the inter-AS scenario in Figure 1.
This document describes extensions to the LSP Ping mechanism to facilitate a response from the replying LSR, by defining a mechanism that uses a relay node (e.g., ASBR) to relay the message back to the initiator. Every designated or learned relay node must be reachable to the next relay node or to the initiator. Using a recursive approach, relay node could relay the message to the next relay node until the initiator is reached.

The LSP Ping relay mechanism in this document is defined for unicast case. How to apply the LSP Ping relay mechanism in multicast case is out of the scope.

3. Extensions

[RFC4379] describes the basic MPLS LSP Ping mechanism, which defines two message types, Echo Request and Echo Reply message. This document defines a new message, Relayed Echo Reply message. This new message is used to replace Echo Reply message which is sent from the replying LSR to a relay node or from a relay node to another relay node.

A new TLV named Relay Node Address Stack TLV is defined in this document, to carry the IP addresses of the possible relay nodes for the replying LSR.

In addition, MTU (Maximum Transmission Unit) Exceeded Return Code is defined to indicate to the initiator that one or more TLVs will not be returned due to MTU size.

It should be noted that this document focuses only on detecting the LSP which is set up using a uniform IP address family type. That is,
all hops between the source and destination node use the same address family type for their LSP ping control planes. This does not preclude nodes that support both IPv6 and IPv4 addresses simultaneously, but the entire path must be addressable using only one address family type. Supporting for mixed IPv4-only and IPv6-only is beyond the scope of this document.

3.1. Relayed Echo Reply message

The Relayed Echo Reply message is a UDP packet, and the UDP payload has the same format with Echo Request/Reply message. A new message type is requested from IANA.

New Message Type:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>MPLS Relayed Echo Reply</td>
</tr>
</tbody>
</table>

The use of TCP and UDP port number 3503 is described in [RFC4379] and has been allocated by IANA for LSP Ping messages. The Relayed Echo Reply message will use the same port number.

3.2. Relay Node Address Stack

The Relay Node Address Stack TLV is an optional TLV. It MUST be carried in the Echo Request, Echo Reply and Relayed Echo Reply messages if the echo reply relayed mechanism described in this document is required. Figure 3 illustrates the TLV format.

```
0                   1                    2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Type            |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Initiator Source Port | Reply Add Type | Reserved |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Source Address of Replying Router (0, 4, or 16 octects) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Destination Address Pointer |  Number of Relayed Addresses |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Stack of Relayed Addresses                                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Relay Node Address Stack TLV
- Type: to be assigned by IANA. A value should be assigned from 32768-49161 as suggested by [RFC4379] Section 3.
- Length: the length of the value field in octets.
- Initiator Source Port: the source UDP port that the initiator uses in the Echo Request message, and also the port that is expected to receive the Echo Reply message.
- Reply Address Type: address type of replying router. This value also implies the length of the address field as shown below.

<table>
<thead>
<tr>
<th>Type#</th>
<th>Address Type</th>
<th>Address Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Null</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>IPv4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>IPv6</td>
<td>16</td>
</tr>
</tbody>
</table>
- Reserved: This field is reserved and MUST be set to zero.
- Source Address of Replying Router: source IP address of the originator of Echo Reply or Replay Echo Reply message.
- Destination Address Pointer: an integer entry number used as the destination address of the Reply or Relayed Reply message. The entry on the top of the Stack of Relayed Addresses will have value 1.
- Number of Relayed Addresses: an integer indicating the number of relayed addresses in the stack.
- Stack of Relayed Addresses: a list of relay node addresses.

The format of each relay node address is as below:

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-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```

<table>
<thead>
<tr>
<th>Type#</th>
<th>Address Type</th>
<th>Address Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Null</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>IPv4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>IPv6</td>
<td>16</td>
</tr>
</tbody>
</table>
Reserved: The two fields are reserved and MUST be set to zero.

K bit: if the K bit is set to 1, then this sub-TLV MUST be kept in Relay Node Address Stack during TLV compress process described in section 4.2.

Having the K bit set in the relay node address entry causes that entry to be preserved in the Relay Node Address Stack TLV for the entire traceroute operation. A responder node MAY set the K bit to ensure its relay node address entry remains as one of the relay nodes in the Relay Node Address Stack TLV. The address with K bit set will always be a relay node address for the Relayed Echo Reply, see section 4.3.

Relayed Address: this field specifies the node address, either IPv4 or IPv6.

3.3. MTU Exceeded Return Code

Return Code is defined to indicate that one or more TLVs were omitted from the Reply or Relay-Reply message to avoid exceeding the message’s effective MTU size. These TLVs MAY be included in an Errored TLV’s Object with their lengths set to 0 and no value. The return sub-code MUST be set to the value that otherwise would have been sent.

<table>
<thead>
<tr>
<th>MTU Exceeded Return Code:</th>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TBD</td>
<td>One or more TLVs not returned due to MTU size</td>
</tr>
</tbody>
</table>

4. Procedures

4.1. Sending an Echo Request

In addition to the procedures described in section 4.3 of [RFC4379], a Relay Node Address Stack TLV MUST be carried in the Echo Request message to facilitate the relay functionality.

When the Echo Request is first sent by the initiator included a Relay Node Address Stack TLV, the TLV MUST contain the initiator address as the only entry of the stack of relayed addresses, the destination address pointer set to this entry, and the source address of the replying router set to null. The source UDP port field MUST be set to the source UDP port. Note that the first relay node address in the stack will always be the initiator’s address.
4.2. Receiving an Echo Request

An LSR that does not recognize the Relay Node Address Stack TLV, SHOULD ignore it as per section 3 of [RFC4379].

In addition to the processes in section 4.4 of [RFC4379], the procedures of the Relay Node Address Stack TLV are defined here.

Upon receiving a Relay Node Address Stack TLV in an Echo Request message, the receiver updates the "Source Address of Replying Router". The address MUST be same as the source IP address of Relay Echo Reply (section 4.3) or Echo Reply message (section 4.5) being sent.

Those address entries with K bit set to 1 MUST be kept in the stack. The receiver MUST check the addresses of the stack in sequence from bottom to top to find the last address in the stack with the K bit set (or the top of the stack if no K bit was found). The receiver then checks the stack beginning with this entry, proceeding towards the bottom to find the first routable address IP address. The Destination Address Pointer MUST be set to this entry. Address entries below the first routable IP address MUST be deleted. At least one address entries of the replying LSR MUST be added at the bottom of the stack. A second or more address entries MAY also be added if necessary, depending on implementation. The final address added MUST be an address that is reachable through the interface that the Echo Request Message would have been forwarded if it had not TTL expired at this node. The updated Relay Node Address Stack TLV MUST be carried in the response message.

If the replying LSR is configured to hide its routable address information, the address entry added in the stack MUST be a NIL entry with Address Type set to NULL.

If a node spans two addressing domains (with respect to this message) where nodes on either side may not be able to nodes in the other domain, then the final address added MUST set the K bit. K bit applies in the case of a NULL address, to serve as a warning to the initiator that further Echo Request messages may not result in receiving Echo Reply messages.

If the full reply message would exceed the MTU size, the Relay Node Address Stack TLV MUST be returned back in the Echo Reply message. Some other TLV(s) MUST be dropped.
4.3. Originating an Relayed Echo Reply

The Destination Address determined in section 4.2 is used as the next relay node address. If the resolved next relay node address is not routable, then sending of Relayed Echo Reply or Echo Reply will fail.

If the first IP address in the Relay Node Address Stack TLV is not the next relay node address, the replying LSR SHOULD send a Relayed Echo Reply message to the next relay node. The processing of Relayed Echo Reply is the same with the procedure of the Echo Reply described in Section 4.5 of [RFC4379], except the destination IP address and the destination UDP port. The destination IP address of the Relayed Echo Reply is set to the next relay node address from the Relay Node Address Stack TLV, and both the source and destination UDP port are set to 3503. The updated Relay Node Address Stack TLV described in section 4.2 MUST be carried in the Relayed Echo Reply message.

4.4. Relaying an Relayed Echo Reply

Upon receiving an Relayed Echo Reply message with its own address as the destination address in the IP header, the relay node MUST determine the next relay node address as described in section 4.3, with the modification that the location of the received Destination Address is used instead of the bottom of stack in the algorithm. The destination address in Relay Node Address Stack TLV will be updated with the next relay node address. Note that unlike section 4.2 no changes are made to the Stack of Relayed Addresses.

If the next relay node address is not the first one in the address list, i.e., another intermediate relay node, the relay node MUST send an Relayed Echo Reply message to the determined upstream node with the payload unchanged other than the Relay Node Address Stack TLV. The TTL SHOULD be copied from the received Relay Echo Reply and decremented by 1.

4.5. Sending an Echo Reply

The Echo Reply is sent in two cases:

1. When the replying LSR receives an Echo Request, and the first IP address in the Relay Node Address Stack TLV is the next relay node address (section 4.3), the replying LSR would send an Echo Reply to the initiator. In addition to the procedure of the Echo Reply described in Section 4.5 of [RFC4379], the updated Relay Node Address Stack TLV described in section 4.2 MUST be carried in the Echo Reply.

2. When the intermediate relay node receives a Relayed Echo Reply, and the first IP address in the Relay Node Address Stack TLV is the
next relay node address (section 4.4), the intermediate relay node would send the Echo Reply to the initiator, and update the Message Type field from type of Relayed Echo Reply to Echo Reply. The updated Relay Node Address Stack TLV described in section 4.4 MUST be carried in the Echo Reply. The destination IP address of the Echo Reply is set to the first IP address in the stack, and the destination UDP port would be copied from the Initiator Source Port field of the Relay Node Address Stack TLV. The source UDP port should be 3503. The TTL of the Echo Reply SHOULD be copied from the received Relay Echo Reply and decremented by 1.

4.6. Sending Subsequent Echo Requests

During a traceroute operation, multiple Echo Request messages are sent. Each time the TTL is increased, the initiator MUST copy the Relay Node Address Stack TLV received in the previous Echo Reply to the next Echo Request.

4.7. Impact to Traceroute

Source IP address in Echo Reply and Relay Echo Reply is to be of the address of the node sending those packets, not the original responding node. Then the traceroute address output module will print the source IP address as below:

```c
    if (Relay Node Address Stack TLV exists) {
        Print the Source Address of Replying Router in Relay Node Address Stack TLV;
    } else {
        Print the source IP address of Echo Reply message;
    }
```

5. LSP Ping Relayed Echo Reply Example

Considering the inter-AS scenario in Figure 4 below. AS1 and AS2 are two independent address domains. In the example, an LSP has been created between PE1 to PE2, but PE1 in AS1 is not reachable by P2 in AS2.
When performing LSP traceroute on the LSP, the first Echo Request sent by PE1 with outer-most label TTL=1, contains the Relay Node Address Stack TLV with PE1’s address as the first relayed address.

After processed by P1, P1’s interface address facing ASBR1 without the K bit set will be added in the Relay Node Address Stack TLV address list following PE1’s address in the Echo Reply.

PE1 copies the Relay Node Address Stack TLV into the next Echo Request when receiving the Echo Reply.

Upon receiving the Echo Request, ASBR1 checks the address list in the Relay Node Address Stack TLV, and determines that PE1’s address is the next relay address. Then deletes P1’s address, and adds its interface address facing ASBR2 with the K bit set. As a result, there would be PE1’s address followed by ASBR1’s interface address facing ASBR2 in the Relay Node Address Stack TLV of the Echo Reply sent by ASBR1.

PE1 then sends an Echo Request with outer-most label TTL=3, containing the Relay Node Address Stack TLV copied from the received Echo Reply message. Upon receiving the Echo Request message, ASBR2 checks the address list in the Relay Node Address Stack TLV, and determines ASBR1’s interface address is the next relay address in the stack TLV. ASBR2 adds its interface address facing P2 with the K bit set. Then ASBR2 sets the next relay address as the destination address of the Relayed Echo Reply, and sends the Relayed Echo Reply to ASBR1.

Upon receiving the Relayed Echo Reply from ASBR2, ASBR1 checks the address list in the Relay Node Address Stack TLV, and determines that PE1’s address is the next relay node. Then ASBR1 sends an Echo Reply to PE1.

For the Echo Request with outer-most label TTL=4, P2 checks the address list in the Relay Node Address Stack TLV, and determines that ASBR2’s interface address is the next relay address. Then P2 sends
an Relayed Echo Reply to ASBR2 with the Relay Node Address Stack TLV containing four addresses, PE1’s, ASBR1’s interface address, ASBR2’s interface address and P2’s interface address facing PE2 in sequence.

Then according to the process described in section 4.4, ASBR2 sends the Relayed Echo Reply to ASBR1. Upon receiving the Relayed Echo Reply, ASBR1 sends an Echo Reply to PE1. And as relayed by ASBR2 and ASBR1, the Echo Reply would finally be sent to the initiator PE1.

For the Echo Request with outer-most label TTL=5, the Echo Reply would relayed to PE1 by ASBR2 and ASBR1, similar to the case of TTL=4.

The Echo Reply from the replying node which has no IP reachable route to the initiator is thus transmitted to the initiator by multiple relay nodes.

6. Security Considerations

The Relayed Echo Reply mechanism for LSP Ping creates an increased risk of DoS by putting the IP address of a target router in the Relay Node Address Stack. These messages then could be used to attack the control plane of an LSR by overwhelming it with these packets. A rate limiter SHOULD be applied to the well-known UDP port on the relay node as suggested in [RFC4379]. The node which acts as a relay node SHOULD validate the relay reply against a set of valid source addresses and discard packets from untrusted border router addresses. An implementation SHOULD provide such filtering capabilities.

If an operator wants to obscure their nodes, it is RECOMMENDED that they may replace the replying node address that originated the Echo Reply with blank address in Relay Node Address Stack TLV.

Other security considerations discussed in [RFC4379], are also applicable to this document.

7. Backward Compatibility

When one of the nodes along the LSP does not support the mechanism specified in this document, the node will ignore the Relay Node Address Stack TLV as described in section 4.2. Then the initiator may not receive the Relay Node Address Stack TLV in Echo Reply message from that node. In this case, an indication should be reported to the operator, and the Relay Node Address Stack TLV in the next Echo Request message should be copied from the previous Echo Request, and continue the ping process. If the node described above is located between the initiator and the first relay node, the ping process could continue without interruption.
8. IANA Considerations

IANA is requested to assign one new Message Type, one new TLV and one Return Code.

8.1. New Message Type

This document requires allocation of one new message type from "Multi-Protocol Label Switching (MPLS) Label Switched Paths (LSPs) Ping Parameters" registry, the "Message Type" registry:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>MPLS Relayed Echo Reply</td>
</tr>
</tbody>
</table>

The value should be assigned from the "Standards Action" range (0-191), and using the lowest free value within this range.

8.2. New TLV

This document requires allocation of one new TLV from "Multi-Protocol Label Switching (MPLS) Label Switched Paths (LSPs) Ping Parameters" registry, the "TLVs" registry:

<table>
<thead>
<tr>
<th>Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>Relay Node Address Stack TLV</td>
</tr>
</tbody>
</table>

A suggested value should be assigned from "Standards Action" range (32768-49151) as suggested by [RFC4379] Section 3, using the first free value within this range.

8.3. MTU Exceeded Return Code

This document requires allocation of MTU Exceeded return code from "Multi-Protocol Label Switching (MPLS) Label Switched Paths (LSPs) Ping Parameters" registry, the "Return Codes" registry:

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>One or more TLVs not returned due to MTU size</td>
</tr>
</tbody>
</table>

The value should be assigned from the "Standards Action" range (0-191), and using the lowest free value within this range.
9. Acknowledgement

The authors would like to thank Carlos Pignataro, Xinwen Jiao, Manuel Paul, Loa Andersson, Wim Henderickx, Mach Chen, Thomas Morin, Gregory Mirsky, Nobo Akiya and Joel M. Halpern for their valuable comments and suggestions.

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11. References

11.1. Normative References


11.2. Informative References

[I-D.ietf-mpls-seamless-mpls]

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Entropy labels for source routed stacked tunnels

draft-kini-mpls-spring-entropy-label-03

Abstract

Source routed tunnel stacking is a technique that can be leveraged to provide a method to steer a packet through a controlled set of segments. This can be applied to the Multi Protocol Label Switching (MPLS) data plane. Entropy label (EL) is a technique used in MPLS to improve load balancing. This document examines and describes how ELs are to be applied to source routed stacked tunnels.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at http://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on September 4, 2015.
1. Introduction

The source routed stacked tunnels paradigm is leveraged by techniques such as Segment Routing (SR) [I-D.filsfils-spring-segment-routing] to steer a packet through a set of segments. This can be directly applied to the MPLS data plane, but it has implications on label stack depth.

Clarifying statements on label stack depth have been provided in [RFC7325] but they do not address the case of source routed stacked MPLS tunnels as described in [I-D.gredler-spring-mpls] or
[I-D.filsfils-spring-segment-routing] where deeper label stacks are more prevalent.

Entropy label (EL) [RFC6790] is a technique used in the MPLS data plane to provide entropy for load balancing. When using LSP hierarchies there are implications on how [RFC6790] should be applied. One such issue is addressed by [I-D.ravisingh-mpls-el-for-seamless-mpls] but that is when different levels of the hierarchy are created at different LSRs. The current document addresses the case where the hierarchy is created at a single LSR as required by source stacked tunnels.

A use-case requiring load balancing with source stacked tunnels is given in Section 3. A recommended solution is described in Section 4 keeping in consideration the limitations of implementations when applying [RFC6790] to deeper label stacks. Options that were considered to arrive at the recommended solution are documented for historical purposes in Section 5.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

Although this document is not a protocol specification, the use of this language clarifies the instructions to protocol designers producing solutions that satisfy the requirements set out in this document.

2. Abbreviations and Terminology

   EL - Entropy Label
   ELI - Entropy Label Identifier
   ELC - Entropy Label Capability
   SR - Segment Routing
   ECMP - Equal Cost Multi Paths
   MPLS - Multiprotocol Label Switching
   SID - Segment Identifier
   RLD - Readable Label Depth
3. Use-case requiring multipath load balancing in source stacked tunnels

Traffic-engineering (TE) is one of the applications of MPLS and is also a requirement for source stacked tunnels. Consider the topology shown in Figure 1. Let's say the LSR P1 has a limitation that it can only look four labels deep in the stack to do multipath decisions. All other transit LSRS in the figure can read deep label stacks and the LSR S can insert as many <ELI, EL> pairs as needed. The LSR S requires data to be sent to LSR D along a traffic-engineered path that goes over the link L1. Good load balancing is also required across equal cost paths (including parallel links). To engineer traffic along a path that takes link L1, the label stack that LSR S creates consists of a label to the node SID of LSR P3, stacked over the label for the adjacency SID of link L1 and that in turn is stacked over the label to the node SID of LSR D. For simplicity let's assume that all LSRS use the same label space for source stacked tunnels. Let \( L_{N-P} \) denote the label to be used to reach the node SID of LSR P. Let \( L_{A-Ln} \) denote the label used for the adjacency SID for link Ln. The LSR S must use the label stack \(<L_{N-P3}, L_{A-L1}, L_{N-D}>\) for traffic-engineering. However, to achieve good load balancing over the equal cost paths P2-P4-D, P2-P5-D and the parallel links L3, L4, a mechanism such as Entropy labels [RFC6790] should be adapted for source stacked tunnels. Multiple ways to apply entropy labels were considered and are documented in Section 5 along with their tradeoffs. A recommended solution is described in Section 4.
4. Recommended EL solution for SPRING

The solution described in this section follows [RFC6790].

An LSR may have a limitation in its ability to read and process the label stack in order to do multipath load balancing. This limitation expressed in terms of the number of label stack entries that the LSR can read is henceforth referred to as the Readable Label Depth (RLD) capability of that LSR. If an EL does not occur within the RLD of an LSR in the label stack of the MPLS packet that it receives, then it would lead to poor load balancing at that LSR. The RLD of an LSR is a characteristic of the forwarding plane of that LSR’s implementation and determining it is outside the scope of this document.

In order for the EL to occur within the RLD of LSRs along the path corresponding to a label stack, multiple <ELI, EL> pairs MAY be inserted in the label stack as long as the tunnel’s label below which they are inserted are advertised with entropy label capability enabled. The LSR that inserts <ELI, EL> pairs MAY have limitations on the number of such pairs that it can insert and also the depth at which it can insert them. If due to any limitation, the inserted ELs are at positions such that an LSR along the path receives an MPLS packet without an EL in the label stack within that LSR’s RLD, then the load balancing performed by that LSR would be poor. Special attention should be paid when a forwarding adjacency LSP (FA-LSP) [RFC4206] is used as a link along the path of a source stacked LSP, since the labels of the FA-LSP would additionally count towards the depth of the label stack when calculating the appropriate positions to insert the ELs. The recommendations for inserting <ELI, EL> pairs are:

- An LSR that is limited in the number of <ELI, EL> pairs that it can insert SHOULD insert such pairs deeper in the stack.
- An LSR SHOULD try to insert <ELI, EL> pairs at positions so that for the maximum number of transit LSRs, the EL occurs within the RLD of the incoming packet to that LSR.
- An LSR SHOULD try to insert the minimum number of such pairs while trying to satisfy the above criteria.

A sample algorithm to insert ELs is shown below. Implementations can choose any algorithm as long as it follows the above recommendations.
Initialize the current EL insertion point to the bottommost label in the stack that is EL-capable while (local-node can push more <ELI,EL> pairs OR insertion point is not above label stack) {
    insert an <ELI,EL> pair below current insertion point
    move new insertion point up from current insertion point until
    ((last inserted EL is below the RLD) AND (RLD > 2)
    AND
    (new insertion point is EL-capable))
    set current insertion point to new insertion point
}

Figure 2: Algorithm to insert <ELI, EL> pairs in a label stack

When this algorithm is applied to the example described in Section 3 it will result in ELs being inserted in two positions, one below the label L_N-D and another below L_N-P3. Thus the resulting label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D, ELI, EL>

The RLD can be advertised via protocols and those extensions would be described in separate documents [I-D.xu-isis-mpls-elc] and [I-D.xu-ospf-mpls-elc].

The recommendations above are not expected to bring any additional OAM considerations beyond those described in section 6 of [RFC6790]. However, the OAM requirements and solutions for source stacked tunnels are still under discussion and future revisions of this document will address those if needed.

5. Options considered

5.1. Single EL at the bottom of the stack of tunnels

In this option a single EL is used for the entire label stack. The source LSR S encodes the entropy label (EL) below the labels of all the stacked tunnels. In the example described in Section 3 it will result in the label stack at LSR S to look like <L_N-P3, L_A-L1, L_N-D, ELI, EL> <remaining packet header>. Note that the notation in [RFC6790] is used to describe the label stack. An issue with this approach is that as the label stack grows due an increase in the number of SIDs, the EL goes correspondingly deeper in the label stack. Hence transit LSRs have to access a larger number of bytes in the packet header when making forwarding decisions. In the example described in Section 3 the LSR P1 would poorly load-balance traffic on the parallel links L3, L4 since the EL is below the RLD of the packet received by P1. A load balanced network design using this approach must ensure that all intermediate LSRs have the capability
to traverse the maximum label stack depth as required for that application that uses source routed stacking.

In the case where the hardware is capable of pushing a single <ELI, EL> pair at any depth, this option is the same as the recommended solution in Section 4.

This option was discounted since there exist a number of hardware implementations which have a low maximum readable label depth. Choosing this option can lead to a loss of load-balancing using EL in a significant part of the network but that is a critical requirement in a service provider network.

5.2. An EL per tunnel in the stack

In this option each tunnel in the stack can be given its own EL. The source LSR pushes an <ELI, EL> before pushing a tunnel label when load balancing is required to direct traffic on that tunnel. In the example described in Section 3, the source LSR S encoded label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D, ELI, EL> where all the ELs can be the same. Accessing the EL at an intermediate LSR is independent of the depth of the label stack and hence independent of the specific application that uses source stacking on that network. A drawback is that the depth of the label stack grows significantly, almost 3 times as the number of labels in the label stack. The network design should ensure that source LSRs should have the capability to push such a deep label stack. Also, the bandwidth overhead and potential MTU issues of deep label stacks should be accounted for in the network design.

In the case where the RLD is the minimum value (3) for all LSRs, all LSRs are EL capable and the LSR that is inserting <ELI, EL> pairs has no limit on how many it can insert then this option is the same as the recommended solution in Section 4.

This option was discounted due to the existence of hardware implementations that can push a limited number of labels on the label stack. Choosing this option would result in a hardware requirement to push two additional labels per tunnel label. Hence it would restrict the number of tunnels that can form a LSP and constrain the types of LSPs that can be created. This was considered unacceptable.

5.3. A re-usable EL for a stack of tunnels

In this option an LSR that terminates a tunnel re-uses the EL of the terminated tunnel for the next inner tunnel. It does this by storing the EL from the outer tunnel when that tunnel is terminated and re-inserting it below the next inner tunnel label during the label swap
The LSR that stacks tunnels SHOULD insert an EL below the outermost tunnel. It SHOULD NOT insert ELs for any inner tunnels. Also, the penultimate hop LSR of a segment MUST NOT pop the ELI and EL even though they are exposed as the top labels since the terminating LSR of that segment would re-use the EL for the next segment.

In Section 3 above, the source LSR S encoded label stack would be $<L_{N-P3}, ELI, EL, L_{A-L1}, L_{N-D}>$. At P1 the outgoing label stack would be $<L_{N-P3}, ELI, EL, L_{A-L1}, L_{N-D}>$ after it has load balanced to one of the links L3 or L4. At P3 the outgoing label stack would be $<L_{N-D}, ELI, EL>$. At P2 the outgoing label stack would be $<L_{N-D}, ELI, EL>$ and it would load balance to one of the nexthop LSRs P4 or P5. Accessing the EL at an intermediate LSR (e.g. P1) is independent of the depth of the label stack and hence independent of the specific use-case to which the stacked tunnels are applied.

This option was discounted due to the significant change in label swap operations that would be required for existing hardware.

5.3.1. EL at top of stack

A slight variant of the re-usable EL option is to keep the EL at the top of the stack rather than below the tunnel label. In this case each LSR that is not terminating a segment should continue to keep the received EL at the top of the stack when forwarding the packet along the segment. An LSR that terminates a segment should use the EL from the terminated segment at the top of the stack when forwarding onto the next segment.

This option was discounted due to the significant change in label swap operations that would be required for existing hardware.

5.4. ELs at readable label stack depths

In this option the source LSR inserts ELs for tunnels in the label stack at depths such that each LSR along the path that must load balance is able to access at least one EL. Note that the source LSR may have to insert multiple ELs in the label stack at different depths for this to work since intermediate LSRs may have differing capabilities in accessing the depth of a label stack. The label stack depth access value of intermediate LSRs must be known to create such a label stack. How this value is determined is outside the scope of this document. This value can be advertised using a protocol such as an IGP. For the same Section 3 above, if LSR P1 needs to have the EL within a depth of 4, then the source LSR S encoded label stack would be $<L_{N-P3}, ELI, EL, L_{A-L1}, L_{N-D}, ELI, EL>$ where all the ELs would typically have the same value.
In the case where the RLD has different values along the path and the LSR that is inserting <ELI, EL> pairs has no limit on how many pairs it can insert, and it knows the appropriate positions in the stack where they should be inserted, then this option is the same as the recommended solution in Section 4.

A variant of this solution was selected which balances the number of labels that need to be pushed against the requirement for entropy.

6. Acknowledgements

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7. IANA Considerations

This memo includes no request to IANA.

8. Security Considerations

This document does not introduce any new security considerations beyond those already listed in [RFC6790].

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Label Distribution Using ARP
draft-kompella-mpls-larp-02

Abstract

This document describes extensions to the Address Resolution Protocol to distribute MPLS labels for IPv4 and IPv6 host addresses. Distribution of labels via ARP enables simple plug-and-play operation of MPLS, which is a key goal of the MPLS Fabric architecture.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

The term "server" will be used in this document to refer to an ARP/L-ARP server; the term "host" will be used to refer to a compute server or other device acting as an ARP/L-ARP client.

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 April 30, 2015.
1. Introduction

This document describes extensions to the Address Resolution Protocol (ARP) [RFC0826] to advertise label bindings for IP host addresses. While there are well-established protocols, such as LDP, RSVP and BGP, that provide robust mechanisms for label distribution, these protocols tend to be relatively complex, and often require detailed configuration for proper operation. There are situations where a simpler protocol may be more suitable from an operational standpoint. An example is the case where an MPLS Fabric is the underlay technology in a Data Centre, here, MPLS tunnels originate from host machines. The host thus needs a mechanism to acquire label bindings to participate in the MPLS Fabric, but in a simple, plug-and-play
manner. Existing signaling/routing protocols do not always meet this need. Labeled ARP (L-ARP) is a proposal to fill that gap.

[TODOMPLS-FABRIC] describes the motivation for using MPLS as the fabric technology.

1.1. Approach

ARP is a nearly ubiquitous protocol; every device with an Ethernet interface, from hand-helds to hosts, have an implementation of ARP. ARP is plug-and-play; ARP clients do not need configuration to use ARP. That suggests that ARP may be a good fit for devices that want to source and sink MPLS tunnels, but do so in a zero-config, plug-and-play manner, with minimal impact to their code.

The approach taken here is to create a minor variant of the ARP protocol, labeled ARP (L-ARP), which is distinguished by a new hardware type, MPLS-over-Ethernet. Regular (Ethernet) ARP (E-ARP) and L-ARP can coexist; a device, as an ARP client, can choose to send out an E-ARP or an L-ARP request, depending on whether it needs Ethernet or MPLS connectivity. Another device may choose to function as an E-ARP server and/or an L-ARP server, depending on its ability to provide an IP-to-Ethernet and/or IP-to-MPLS mapping.

2. Overview of Ethernet ARP

In the most straightforward mode of operation [RFC0826], ARP queries are sent to resolve "directly connected" IP addresses. The ARP query is broadcast, with the Target Protocol Address field (see Section 5 for a description of the fields in an ARP message) carrying the IP address of another node in the same subnet. All the nodes in the LAN receive this ARP query. All the nodes, except the node that owns the IP address, ignore the ARP query. The IP address owner learns the MAC address of the sender from the Source Hardware Address field in the ARP request, and unicasts an ARP reply to the sender. The ARP reply carries the replying node’s MAC address in the Source Hardware Address field, thus enabling two-way communication between the two nodes.

A variation of this scheme, known as "proxy ARP" [RFC2002], allows a node to respond to an ARP request with its own MAC address, even when the responding node does not own the requested IP address. Generally, the proxy ARP response is generated by routers to attract traffic for prefixes they can forward packets to. This scheme requires the host to send ARP queries for the IP address the host is trying to reach, rather than the IP address of the router. When there is more than one router connected to a network, proxy ARP enables a host to automatically select an exit router without running
any routing protocol to determine IP reachability. Unlike regular ARP, a proxy ARP request can elicit multiple responses, e.g., when more than one router has connectivity to the address being resolved. The sender must be prepared to select one of the responding routers.

Yet another variation of the ARP protocol, called ‘Gratuitous ARP’ [RFC2002], allows a node to update the ARP cache of other nodes in an unsolicited fashion. Gratuitous ARP is sent as either an ARP request or an ARP reply. In either case, the Source Protocol Address and Target Protocol Address contain the sender’s address, and the Source Hardware Address is set to the sender’s hardware address. In case of a gratuitous ARP reply, the Target Hardware Address is also set to the sender’s address.

3. L-ARP Protocol Operation

The L-ARP protocol builds on the proxy ARP model, and also leverages gratuitous ARP model for asynchronous updates.

In this memo, we will refer to L-ARP clients (that make L-ARP requests) and L-ARP servers (that send L-ARP responses). In Figure 1, H1, H2 and H3 are L-ARP clients, and T1, T2 and T3 are L-ARP servers. T is a member of the MPLS Fabric that may not be an L-ARP server. Within the MPLS Fabric, the usual MPLS protocols (IGP, LDP, RSVP-TE) are run. Say H1, H2 and H3 want to establish MPLS tunnels to each other (for example, they are using BGP MPLS VPNs as the overlay virtual network technology). H1 might also want to talk to a member of the MPLS Fabric, say T.

```
H1 --- T1           T4
  \ .  MPLS .
   \ .  .
    \ .  Fabric
H2 --- T2           T3 --- H3
     .  .  .  .
```

Figure 1

3.1. Basic Operation

A node (say H1) that needs an MPLS tunnel to a destination (say H3) broadcasts over all its interfaces an L-ARP query with the Target Protocol Address set to H3. A node that has reachability to H3 (such as T1 or T2) sends an L-ARP reply with the Source Hardware Address set to a locally-allocated MPLS label plus its Ethernet MAC address.
After receiving one or more L-ARP replies, H1 can select either T1 or T2 to send MPLS packets that are destined to H3. As described later, the L-ARP response may contain certain parameters that enable the client to make an informed choice of the routers.

As with standard ARP, the validity of the MPLS label obtained using L-ARP is time-bound. The client should periodically resend its L-ARP requests to obtain the latest information, and time out entries in its ARPs cache if such an update is not forthcoming. Once an L-ARP server has advertised a label binding, it MUST NOT change the binding until expiry of the binding’s validity time.

The mechanism defined here is simplistic; see Section 4.

3.2. Asynchronous operation

The preceding sections described a request-response based model. In some cases, the L-ARP server may want to asynchronously update its clients. L-ARP uses the gratuitous ARP model [RFC2002] to “push” such changes.

In a pure “push” model, a device may send out updates for all prefixes it knows about. This naive approach will not scale well. This memo specifies a mode of operation that is somewhere between “push” and “pull” model. An L-ARP server does not advertise any binding for a prefix until at least one L-ARP client expresses interest in that prefix (by initiating an L-ARP query). As long as the server has at least one interested client for a prefix, the server sends unsolicited (aka gratuitous, though the term is less appropriate in this context) L-ARP replies when a prefix’s reachability changes. The server will deem the client’s interest in a prefix to have ceased when it does not hear any L-ARP queries for some configured timeout period.

3.3. Client-Server Synchronization

In an L-ARP reply, the server communicates several pieces of information to the client: its hardware address, the MPLS label, Entropy Label capability and metric. Since ARP is a stateless protocol, it is possible that one of these changes without the client knowing, which leads to a loss of synchronization between the client and the server. This loss of synchronization can have several bad effects.

If the server’s hardware address changes or the MPLS label is repurposed by the server for a different purpose, then packets may be sent to the wrong destination. The consequences can range from suboptimally routed packets to dropped packets to packets being
delivered to the wrong customer, which may be a security breach. This last may be the most troublesome consequence of loss of synchronization.

If a destination transitions from entropy label capable to entropy label incapable (an unlikely event) without the client knowing, then packets encapsulated with entropy labels will be dropped. A transition in the other direction is relatively benign.

If the metric changes without the client knowing, packets may be suboptimally routed. This may be the most benign consequence of loss of synchronization.

3.4. Applicability

L-ARP can be used between a host and its Top-of-Rack switch in a Data Center. L-ARP can also be used between a DSLAM and its aggregation switch going to the B-RAS. More generally, L-ARP can be used between an "access node" and its first hop MPLS-enabled device in the context of Seamless MPLS [reference]. In all these cases, L-ARP can handle the presence of multiple connections between the access device and its first hop devices.

ARP is not a routing protocol. The use of L-ARP should be limited to cases where the L-ARP client has a small number of one-hop connections to L-ARP servers. The presence of a complex topology between the L-ARP client and server suggests the use of a different protocol.

3.5. Backward Compatibility

Since L-ARP uses a new hardware type, it is backward compatible with "regular" ARP. ARP servers and clients MUST be able to send out, receive and process ARP messages based on hardware type. They MAY choose to ignore requests and replies of some hardware types; they MAY choose to log errors if they encounter hardware types they do not recognize; however, they MUST handle all hardware types gracefully. For hardware types that they do understand, ARP servers and clients MUST handle operation codes gracefully, processing those they understand, and ignoring (and possibly logging) others.

4. For Future Study

The L-ARP specification is quite simple, and the goal is to keep it that way. However, inevitably, there will be questions and features that will be requested. Some of these are:
1. Keeping L-ARP clients and servers in sync. In particular, dealing with:
   A. client and/or server restart
   B. lost packets
   C. timeouts

2. Withdrawing a response.

3. Dealing with scale.

4. If there are many servers, which one to pick?

5. How can a client make best use of underlying ECMP paths?

6. and probably many more.

In all of these, it is important to realize that, whenever possible, a solution that places most of the burden on the server rather than on the client is preferable.

5. L-ARP Message Format

![L-ARP Packet Format](image)
Hardware Type: MPLS-over-Ethernet. The value of the field used here is [HTYPE-MPLS-TBD]. To start with, we will use the experimental value HW_EXP2 (256).

Protocol Type: IPv4/IPv6. The value of the field used here is 0x0800 to resolve an IPv4 address and 0x86DD to resolve an IPv6 address.

Hardware Length: the value of the field used here is 6.

Protocol Address Length: for an IPv4 address, the value is 4; for an IPv6 address, it is 16.

Operation Code: set to 1 for request, 2 for reply, and 10 for ARP-NAK. Other op codes may be used, but this is not anticipated at this time.

Source Hardware Address: In an L-ARP message, Source Hardware Address is the 6 octets of the sender’s MAC address.

Source Protocol Address: In an L-ARP message, this field carries the sender’s IP address.

Target Hardware Address: In an L-ARP query message, Target Hardware Address is the all-ones Broadcast MAC address; in an L-ARP reply message, it is the client’s MAC address.

Target Protocol Address: In an L-ARP message, this field carries the IP address for which the client is seeking an MPLS label.

Label Stack: In an L-ARP request, this field is empty. In an L-ARP reply, this field carries the MPLS label stack in the format below.

Attribute TLV: In an L-ARP request, this field is empty. In an L-ARP reply, this field carries attributes for the MPLS label stack in the format below.

Figure 3 describes the format of MPLS Label Stack carried in L-ARP. Figure 4 describes the format of Attribute TLV carried in L-ARP.
MPLS Label Stack: This field contains the MPLS label stack for the client to use to get to the target. Each label is 3 octets; the Length is 3*(number of labels). This field is valid only in an L-ARP request message.

E-bit: Entropy Capability

This field indicates whether the label stack of MPLS data packets sent with the label in this advertisement can contain Entropy Label or not. If this flag is set, the client has the option of inserting ELI and EL as specified in [RFC6790]. The client can choose not to insert ELI/EL pair, if it does not support Entropy Labels, or the local policy does not permit the client to insert ELI/EL. If this flag is clear, the client must not insert ELI/EL into the label stack when sending packets with the advertised L-ARP label.

Z These bits are not used, and SHOULD be set to zero on sending and ignored on receipt.

If other parameters are deemed useful in the L-ARP reply, they will be added as needed.
6. Security Considerations

TODO

7. IANA Considerations

TODO

8. Acknowledgments

Many thanks to Shane Amante for his detailed comments and suggestions. Many thanks to the team in Juniper prototyping this work for their suggestions on making this variant workable in the context of existing ARP implementations. Thanks too to Luyuan Fang, Alex Semenyaka and Dmitry Afanasiev for their comments and encouragement.

9. Normative References


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Abstract

This document describes the use of the MPLS control and data planes on ring topologies. It describes the special nature of rings, and proceeds to show how MPLS can be effectively used in such topologies. It describes how MPLS rings are configured, auto-discovered and signaled, as well as how the data plane works. Companion documents describe the details of discovery and signaling for specific protocols.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

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1.  Introduction

Rings are a very common topology in transport networks. A ring is the simplest topology offering link and node resilience. Rings are nearly ubiquitous in access and aggregation networks. As MPLS increases its presence in such networks, and takes on a greater role in transport, it is imperative that MPLS handles rings well; this is not the case today.
This document describes the special nature of rings, and the special needs of MPLS on rings. It then shows how these needs can be met in several ways, some of which involve extensions to protocols such as IS-IS [RFC5305], OSPF [RFC3630], RSVP-TE [RFC3209] and LDP [RFC5036].

1.1. Definitions

A (directed) graph $G = (V, E)$ consists of a set of vertices (or nodes) $V$ and a set of edges (or links) $E$. An edge is an ordered pair of nodes $(a, b)$, where $a$ and $b$ are in $V$. (In this document, the terms node and link will be used instead of vertex and edge.)

A ring is a subgraph of $G$. A ring consists of a subset of $n$ nodes $(R_i, 0 \leq i < n)$ of $V$. The directed edges $(R_i, R_{i+1})$ and $(R_{i+1}, R_i)$, $0 \leq i < n-1$ must be a subset of $E$ (note that index arithmetic is done modulo $n$). We define the direction from node $R_i$ to $R_{i+1}$ as "clockwise" (CW) and the reverse direction as "anticlockwise" (AC). As there may be several rings in a graph, we number each ring with a distinct ring ID RID.

![Ring with 8 nodes](image)

Figure 1: Ring with 8 nodes

The following terminology is used for ring LSPs:

Ring ID (RID): A non-zero number that identifies a ring; this is unique in some scope of a Service Provider’s network. An RID of 0 means the node is a "promiscuous" node.

Node index: A logical numbering of nodes in a ring, from zero upto one less than the ring size. Used purely for exposition in this document.

Ring master: The ring master initiates the ring identification process. Mastership is indicated in the IGP by a two-bit field.

Ring neighbors: Nodes whose indices differ by one (modulo ring size).
Ring links: Links that connect ring neighbors.

Bypass links: Links that connect non-neighboring ring nodes.

Ring direction: A two-bit field in the IGP indicating the direction of a link. The choices are:

- UN: 00 undefined link
- CW: 01 clockwise ring link
- AC: 10 anticlockwise ring link
- BY: 11 bypass link

Ring Identification: The process of discovering ring nodes, ring links, link directions, and bypass links.

The following notation is used for ring LSPs:

- \( R_k \): A ring node with index \( k \). \( R_k \) has AC neighbor \( R_{(k-1)} \) and CW neighbor \( R_{(k+1)} \).
- \( RL_k \): A (unicast) Ring LSP anchored on node \( R_k \).
- \( CL_{jk} (AL_{jk}) \): A label allocated by \( R_j \) for \( RL_k \) in the CW (AC) direction.
- \( P_{jk} (Q_{jk}) \): A Path (Resv) message sent by \( R_j \) for \( RL_k \).

2. Motivation

A ring is the simplest topology that offers resilience. This is perhaps the main reason to lay out fiber in a ring. Thus, effective mechanisms for fast failover on rings are needed. Furthermore, there are large numbers of rings. Thus, configuration of rings needs to be as simple as possible. Finally, bandwidth management on access rings is very important, as bandwidth is generally quite constrained here.

The goals of this document are to present mechanisms for improved MPLS-based resilience in ring networks (using ideas that are reminiscent of Bidirectional Line Switched Rings), for automatic bring-up of LSPs, better bandwidth management and for auto-hierarchy. These goals can be achieved using extensions to existing IGP and MPLS signaling protocols, using central provisioning, or in other ways.
3. Theory of Operation

Say a ring has ring ID RID. The ring is provisioned by choosing one or more ring masters for the ring and assigning them the RID. Other nodes in the ring may also be assigned this RID, or may be configured as "promiscuous". Ring discovery then kicks in. When each ring node knows its CW and AC ring neighbors and its ring links, and all bypass links have been identified, ring identification is complete.

Once ring identification is complete, each node signals one or more ring LSPs RL_i. RL_i, anchored on node R_i, consists of two counter-rotating unicast LSPs that start and end at R_i. A ring LSP is "multipoint": any node R_j can use RL_i to send traffic to R_i; this can be in either the CW or AC directions, or both (i.e., load balanced). Both of these counter-rotating LSPs are "active"; the choice of direction to send traffic to R_i is determined by policy at the node where traffic is injected into the ring. The default is to send traffic along the shortest path. Bidirectional connectivity between nodes R_i and R_j is achieved by using two different ring LSPs: R_i uses RL_j to reach R_j, and R_j uses RL_i to reach R_i.

3.1. Provisioning

The goal here is to provision rings with the absolute minimum configuration. The exposition below aims to achieve that using auto-discovery via a link-state IGP (see Section 4). Of course, auto-discovery can be overridden by configuration. For example, a link that would otherwise be classified by auto-discovery as a ring link might be configured not to be used for ring LSPs.

3.2. Ring Nodes

Ring nodes have a loopback address, and run a link-state IGP and an MPLS signaling protocol. To provision a node as a ring node for ring RID, the node is simply assigned that RID. A node may be part of several rings, and thus may be assigned several ring IDs.

To simplify ring provisioning even further, a node N may be made "promiscuous" by being assigned an RID of 0. A promiscuous node listens to RIDs in its IGP neighbors' link-state updates. If N hears a non-zero RID from a neighbor, it joins that ring by taking on that RID. However, if N hears more than one non-zero RID from its neighbors, N remains in promiscuous mode. In many situations, the use of promiscuous mode means that only one or two nodes in the ring needs to be provisioned; everything else is auto-discovered.
A ring node indicates in its IGP updates the ring LSP signaling protocols it supports. This can be LDP and/or RSVP-TE. Ideally, each node should support both.

### 3.3. Ring Links and Directions

Ring links must be MPLS-capable. They are by default unnumbered, point-to-point (from the IGP point of view) and "auto-bundled". The last attribute means that parallel links between ring neighbors are considered as a single link, without the need for explicit configuration for bundling (such as a Link Aggregation Group). Note that each component may be advertised separately in the IGP; however, signaling messages and labels across one component link apply to all components. Parallel links between a pair of ring nodes is often the result of having multiple lambdas or fibers between those nodes.

A ring link is not provisioned as belonging to the ring; it is discovered to belong to ring RID if both its adjacent nodes belong to RID. A ring link's direction (CW or AC) is also discovered; this process is initiated by the ring's ring master. Note that the above two attributes can be overridden by provisioning if needed; it is then up to the provisioning system to maintain consistency across the ring.

#### 3.3.1. Bypass Links

Bypass links are discovered once ring nodes, ring links and directions have been established. As defined earlier, bypass links are links joining non-neighboring ring nodes; often, this may be the result of optically bypassing ring nodes. The use of bypass links will be described in a future version of this document.

### 3.4. Ring LSPs

Ring LSPs are not provisioned. Once a ring node R_i knows its RID, its ring links and directions, it kicks off ring LSP signaling automatically. R_i allocates CW and AC labels for each ring LSP RL_k. R_i also initiates the creation of RL_i. As the signaling propagates around the ring, CW and AC labels are exchanged. When R_i receives CW and AC labels for RL_k from its ring neighbors, primary and fast reroute (FRR) paths for RL_k are installed at R_i. More details are given in Section 5.

For RSVP-TE LSPs, bandwidths may be signaled in both directions. However, these are not provisioned either; rather, one does "reverse call admission control". When a service needs to use an LSP, the ring node where the traffic enters the ring attempts to increase the
bandwidth on the LSP to the egress. If successful, the service is admitted to the ring.

3.5. Installing Primary LFIB Entries

In setting up RL_k, a node R_j sends out two labels: CL_jk to R_j-1 and AL_jk to R_j+1. R_j also receives two labels: CL_j+1,k from R_j+1, and AL_j-1,k from R_j-1. R_j can now set up the forwarding entries for RL_k. In the CW direction, R_j swaps incoming label CL_jk with CL_j+1,k with next hop R_j+1; these allow R_j to act as LSR for RL_k. R_j also installs an LFIB entry to push CL_j+1,k with next hop R_j+1 to act as ingress for RL_k. Similarly, in the AC direction, R_j swaps incoming label AL_jk with AL_j-1,k with next hop R_j-1 (as LSR), and an entry to push AL_j-1,k with next hop R_j-1 (as ingress).

Clearly, R_k does not act as ingress for its own LSPs. However, if these LSPs use UHP, then R_k installs LFIB entries to pop CL_k,k for packets received from R_k-1 and to pop AL_k,k for packets received from R_k+1.

3.6. Installing FRR LFIB Entries

At the same time that R_j sets up its primary CW and AC LFIB entries, it can also set up the protection forwarding entries for RL_k. In the CW direction, R_j sets up an FRR LFIB entry to swap incoming label CL_jk with AL_j-1,k with next hop R_j-1. In the AC direction, R_j sets up an FRR LFIB entry to swap incoming label AL_jk with CL_j+1,k with next hop R_j+1. Again, R_k does not install FRR LFIB entries in this manner.

3.7. Protection

In this scheme, there are no protection LSPs as such -- no node or link bypasses, no standby LSPs, no detours, and no LFA-type protection. Protection is via the "other" direction around the ring, which is why ring LSPs are in counter-rotating pairs. Protection works in the same way for link, node and ring LSP failures.

If a node R_j detects a failure from R_j+1 -- either all links to R_j+1 fail, or R_j+1 itself fails, R_j switches traffic on all CW ring LSPs to the AC direction using the FRR LFIB entries. If the failure is specific to a single ring LSP, R_j switches traffic just for that LSP. In either case, this switchover can be very fast, as the FRR LFIB entries can be preprogrammed. Fast detection and fast switchover lead to minimal traffic loss.
R_j then sends an indication to R_j-1 that the CW direction is not working, so that R_j-1 can similarly switch traffic to the AC direction. These indications propagate AC until each traffic source on the ring AC of the failure uses the AC direction. Thus, within a short period, traffic will be flowing in the optimal path, given that there is a failure on the ring. This contrasts with (say) bypass protection, where until the ingress recomputes a new path, traffic will be suboptimal.

One point to note is that when a ring node, say R_j, fails, RL_j is clearly unusable. However, the above protection scheme will cause a traffic loop: R_j-1 detects a failure CW, and protects by sending CW traffic on RL_j back all the way to R_j+1, which in turn sends traffic to R_j-1, etc. There are three proposals to avoid this:

1. Each ring node acting as ingress sends traffic with a TTL of at most 2*n, where n is the number of nodes in the ring.

2. A ring node sends protected traffic (i.e., traffic switched from CW to AC or vice versa) with TTL just large enough to reach the egress.

3. A ring node sends protected traffic with a special purpose label below the ring LSP label. A protecting node first checks for the presence of this label; if present, it means that the traffic is looping and MUST be dropped.

It is recommended that (2) be implemented. The other methods are optional.

4. Autodiscovery

4.1. Overview

Auto-discovery proceeds in three phases. The first phase is the announcement phase. The second phase is the mastership phase. The third phase is the ring identification phase.
In what follows, we refer to a ring Type-Length-Value (TLV). This is a new TLV that contains an RID and associated flags. A ring link TLV is a ring TLV that appears as a sub-TLV of a traffic engineering TLV (TE TLV) of each link that is identified as a ring link or a bypass link. For IS-IS, the TE TLV is the extended reachability TLV; for OSPF, it is the Link TLV in the opaque TE LSA. A ring node TLV is a ring TLV that appears as a sub-TLV of a "node TLV" once for each ring this node is participating in. In IS-IS, the node TLV is the Router ID TLV; in OSPF, it is a new top-level TLV of the TE LSA. The ring direction field is ignored in ring node TLVs.

```
+--------+--------+                  +--------+--------+                  +--------+--------+
| Type (TBD) | Length = 8 | Ring ID (4 octets) ... | | Type (TBD) | Length = 8 | Ring ID (4 octets) ... |
| ... (RID continued) | Ring Flags (2 octets) | ... (RID continued) | Ring Flags (2 octets) |
```

**IS-IS Ring TLV Format**
OSPF Ring TLV Format

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
|MV|RD|SP|OP|M| MBZ |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
MV: Mastership Value
RD: Ring Direction
SP: Signaling Protocols (10 = RSVP-TE; 01 = LDP)
OP: OAM Protocols (10 = BFD; 01 = EFM)
M : Elected Master (0 = no, 1 = yes)
```

Ring Flags Format

4.2. Ring Announcement Phase

Each node participating in an MPLS ring is assigned an RID; in the example, RID = 17. A node is also provisioned with a mastership value. Each node advertises a ring node TLV for each ring it is participating in, along with the associated flags. It then starts timer T1.

A node in promiscuous mode doesn’t advertise any ring node TLVs. If it hears exactly one non-zero RID from its IGP neighbors, it joins that ring, and sends one ring node TLV with that RID. If it hears more than one RID from its IGP neighbors, it doesn’t join any rings, and withdraws any ring node TLVs it may have advertised.

The announcement phase allows a ring node to discover other ring nodes in the same ring so that a ring master can be elected and ring links be identified.
4.3. Mastership Phase

When timer T1 fires, a node enters the mastership phase. In this phase, each ring node N starts timer T2 and checks if it is master. If it is the node with the lowest loopback address of all nodes with the highest mastership values, N declares itself master by re-advertising its ring node TLV with the M bit set.

When timer T2 fires, each node examines the ring node TLVs from all other nodes in the ring to identify the ring master. There should be exactly one; if not, each node restarts timer T2 and tries again. The nodes that set their M bit should be extra careful in advertising their M bit in subsequent tries.

4.4. Ring Identification Phase

When there is exactly one ring master M, M enters the Ring Identification Phase. M indicates that it has successfully completed this phase by advertising ring link TLVs. This is the trigger for M’s CW neighbor to enter the Ring Identification Phase. This phase passes CW until all ring nodes have completed ring identification.

In the Ring Identification Phase, a node X that has two or more IGP neighbors that belong to the ring picks one of them to be its CW ring neighbor. If X is the ring master, it also picks a node as its AC ring neighbor. If there are exactly two such nodes, this step is trivial. If not, X computes a ring that includes all nodes that have completed the Ring Identification Phase (as seen by their ring link TLVs) and further contains the maximal number of nodes that belong to the ring. Based on that, X picks a CW neighbor and inserts ring link TLVs with ring direction CW for each link to its CW neighbor; X also inserts a ring link TLV with direction AC for each link to its AC neighbor. Then, X determines its bypass links. These are links connected to ring nodes that are not ring neighbors. X advertises ring link TLVs for bypass links by setting the link direction to "bypass link".

4.5. Ring Changes

A future version of this document will specify how ring changes are detected and handled.

5. Ring Signaling

A future version of this document will specify details about ring LSP signaling.
6. Ring OAM

Each ring node should advertise in its ring node TLV the OAM protocols it supports. Each ring node is expected to run a link-level OAM over each ring and bypass link. This should be an OAM protocol that both neighbors agree on. The default hello time is 3.3 millisecond.

Each ring node also sends OAM messages over each direction of its ring LSP. This is a multi-hop OAM to check LSP liveness; typically, BFD would be used for this. The node chooses the hello interval; the default is once a second.

7. Security Considerations

It is not anticipated that either the notion of MPLS rings or the extensions to various protocols to support them will cause new security loopholes. As this document is updated, this section will also be updated.

8. Acknowledgments

Many thanks to Pierre Bichon whose exemplar of self-organizing networks and whose urging for ever simpler provisioning led to the notion of promiscuous nodes.

9. IANA Considerations

There are no requests as yet to IANA for this document.

10. References

10.1. Normative References


10.2. Informative References


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Abstract

This document describes extensions to Resource ReSerVation Protocol - Traffic Engineering for the set up of multi-path Traffic Engineered Label Switched Paths (LSPs) in Multi Protocol Label Switching (MPLS) and Generalized MPLS networks, i.e., LSPs that conform to traffic engineering constraints, but follow multiple independent paths from source to destination.

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1. Introduction

In selecting a protocol for setting up and signaling "tunnel" Labeled Switched Paths (LSPs) in Multi Protocol Label Switching (MPLS) and Generalized MPLS (GMPLS) networks, one first chooses whether one wants Equal Cost Multi-Path (ECMP) load balancing or Traffic Engineering (TE). For the former, one uses the Label Distribution Protocol (LDP) ([RFC5036]); for the latter, the Resource ReSerVation Protocol - Traffic Engineering (RSVP-TE) ([RFC3209]). [Two other criteria, the need for fast protection and the desire for less configuration, are no longer the deciding factors they used to be, thanks to "IP fast reroute" ([RFC5286]) and "RSVP-TE automesh" ([RFC4972])].

This document describes how one can set up a tunnel LSP that has both ECMP and TE characteristics using RSVP-TE. The techniques described in this document can be used to create a "Multipath LSP" (MLSP) to a destination, that consists of several "sub-LSPs", each potentially taking a different path through the network to the destination. The techniques can also be used to create a single MLSP to multiple equivalent destinations (such as equidistant BGP nexthops announcing a common set of reachable addresses), such that each destination is served by one or more sub-LSPs.

There are several alternatives to choose from when considering MLSPs. One is whether the ingress Label Switching Router (LSR) computes (or otherwise obtains) the full path for each sub-LSP, or whether LSRs along the various paths can compute paths further downstream (using techniques such as "loose hop expansion", as in [RFC5152]). Another is whether the various paths that make up the MLSP have equal cost (or distance) from ingress to egress (i.e., ECMP), whether they may have differing costs. Finally, one can choose whether to terminate a multi-path LSP on a single egress or on several equivalent egresses. For now, the first of each of these alternatives is assumed; future work can explore other choices.

1.1. Terminology

The term Multipath LSP, or MLSP, will be used to denote the (logical) container LSP from an ingress LSR to one or more egress LSR(s). An MLSP is the unit of configuration and management.

An MLSP consists of one or more "sub-LSPs". A sub-LSP consists of a single path from the ingress of the MLSPs to one of its egresses. A sub-LSP is the unit of signaling of an MLSP. An Explicit Route Object (ERO) will be used to define the path of a sub-LSP.

The "downstream links" of an MLSP Z at LSR X is the union of the
downstream links of all sub-LSPs of Z traversing X. Similarly, the "upstream links" of an MLSP Z at LSR X is the union of upstream links of all sub-LSPs of Z traversing X.

The agent that takes the configuration parameters of a tunnel and computes the corresponding paths is called the Path Computation Agent (PCA). The PCA is responsible for acquiring the tunnel configuration, computing the paths of the sub-LSPs, and, if the PCA is not co-located with the ingress, informing the ingress about the tunnel and the EROs for the sub-LSPs.

1.2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].
2. Theory of Operation

2.1. Multi-path Label Switched Paths

An MLSP is configured with various constraints associated with TE LSPs, such as destination LSR(s), bandwidth (on a per-class basis, if desired), link colors, Shared Risk Link Groups, etc. [Auto-mesh techniques ([RFC4972]) can be used to reduce configuration; this is not described further here.] In addition, parameters specifically related to MLSPs, such as how many (or the maximum number of) sub-LSPs to create, whether traffic should be split equally across sub-LSPs or not, etc. may also be specified. This configuration lives on the PCA, which is responsible for computing the paths (i.e., the EROs) for the various sub-LSPs. The PCA informs the ingress LSR about the MLSP and the constituent sub-LSPs, including EROs and bandwidths.

The PCA uses the configuration parameters to decide how many sub-LSPs to compute for this MLSP, what paths they should take, and how much bandwidth each sub-LSP is responsible for. Each sub-LSP MUST meet all the constraints of the MLSP (except bandwidth). The bandwidths (per-class, if applicable) of all the sub-LSPs MUST add up to the bandwidth of the MLSP. A Path Computation Element ([RFC4655]) that is multi-path LSP-aware may be used as the PCA.

Having computed (or otherwise obtained) the paths of all the sub-LSPs, the ingress A then signals the MLSP by signaling all the individual sub-LSPs across the MPLS/GMPLS network. To do this, the ingress first picks an MLSP ID, a 16-bit number that is unique in the context of the ingress. This ID is used in an ASSOCIATION object that is placed in each sub-LSP to let all transit LSRs know that the sub-LSPs belong to the same MLSP.

If multiple sub-LSPs of the same MLSP pass through LSR Y, and Y has downstream links YP, YQ and YR for the various sub-LSPs, then Y has to load balance incoming traffic for the MLSP across the three downstream links in proportion to the sum of the bandwidths of the sub-LSPs going to each downstream (see Figure 1).

One must distinguish carefully between the signaled bandwidth of a sub-LSP, a static value capturing the expected or maximum traffic on the sub-LSP, and the instantaneous traffic received on a sub-LSP, a constantly varying quantity. Suppose there are three sub-LSPs traversing Y, with bandwidths 10Gbps, 20Gbps and 30Gbps, going to P, Q and R respectively. Suppose further Y receives some traffic over each of these sub-LSPs. Y must balance this received traffic over the three downstream links YP, YQ and YR in the ratio 1:2:3.
2.2. ECMP

An example network illustrating ECMP. Assume that paths AMB, AXYPTB, AXYQTB, AXYRB and AXSB all have the same path length (cost).

Figure 1: Example Network Topology

In an IP or LDP network, incoming traffic arriving at A headed for B will be split equally between M and X at A. Similarly, traffic for B arriving at Y will be split equally among P, Q and R. If the traffic arriving at A for B is 120Gbps, then the AMB path will carry 60Gbps, the paths AXYPTB, AXYQTB and AXYRB will each carry 10Gbps, and the AXSB path will carry 30Gbps. We’ll call this "IP-style" load balancing.

Note: all load balancing is subject to the overriding requirement of mapping the same "flow" to the same downstream. (What constitutes a "flow" is beyond the scope of this document.) This requirement takes precedence over all attempts to balance traffic among downstreams. Thus, the statements above (e.g., "the AMB path will carry 60Gbps") are to be interpreted as ideal targets, not hard requirements, of load balancing.

One can simulate the IP or LDP ECMP behavior with TE-based ECMP by creating an MLSP with five sub-LSPs S1 through S5 taking paths AMB, AXYPTB, AXYQTB, AXYRB and AXSB, with bandwidths 60Gbps, 10Gbps, 10Gbps, 10Gbps and 30Gbps, respectively.

With such an arrangement, the MB link carries 60Gbps while the RB link carries just 10Gbps. If one wishes instead to carry equal amounts of traffic on the links incoming to B, then one could arrange the sub-LSPs S1 to S5 to have bandwidths 30Gbps, 15Gbps, 15Gbps, 30Gbps and 30Gbps, respectively. In this case, the bandwidth on each of the four links going to B is 30Gbps, illustrating some of the capabilities of TE-based ECMP.

Staying with this example, A has one sub-LSP of bandwidth 30Gbps to M and four sub-LSPs of total bandwidth 90Gbps through X. Thus, A should
load balance traffic in the ratio 1:3 between the AM and the AX links. Similarly, X has three sub-LSPs of total bandwidth 60Gbps to Y and one sub-LSP of bandwidth 30Gbps to S, so X should load balance traffic 2:1 between Y and S. Y has a sub-LSP of bandwidth 15Gbps to each of P and Q and one sub-LSP of bandwidth 30Gbps to R, so Y should load balance traffic 1:1:2 among P, Q and R, respectively. Thus, in general, TE-based ECMP does not assume equal distribution of traffic among downstream LSRs, unlike IP- or LDP-style ECMP.

---U---
--L--  --P-- | --V-- |
/    \  /    \ /    \\  /  \\ \\
A  S---Q---T---W---B
  /  \  /  \  /  \\  /  \\ \\
--M--  --R-- | --X-- |
       |
---Y---

Another example network illustrating 30 ECMP paths between A and B.

Figure 2: Another Network Topology

In Figure 2, there are potentially 2x3x5=30 ECMP paths between A and B. With IP or LDP, exploiting all these paths is straightforward, and doesn’t need a lot of state. With an MLSP as seen so far, this would require 30 sub-LSPs to achieve equivalent load balancing. This suggests that a different approach is needed to efficiently achieve IP-style load balancing with TE LSPs. To this end, we introduce the notion of "equi-bandwidth" (EB) sub-LSPs and EB MLSPs. A sub-LSP is equi-bandwidth if its "E" bit is set (see Section 3.1.1). An MLSP is equi-bandwidth if all of its sub-LSPs are equi-bandwidth.

If a set of EB sub-LSPs of the same MLSP traverse an LSR S, say to downstream links SP, SQ and SR, then S MUST attempt to load balance traffic received on these EB sub-LSPs equally among the links SP, SQ and SR, independent of how many sub-LSPs go over each of these links. Furthermore, S MUST redistribute traffic received from each of its upstream LSRs, and SHOULD redistribute all traffic received from upstream as a whole. One can do the former by signaling the same label to each of its upstream LSRs; one can do the latter by signaling the same label to all upstream LSRs (see Section 3.2). For example, in Figure 2, if L sends 12Gbps of traffic to S and M sends 18Gbps to S, S can redistribute L’s traffic by sending 4Gbps to each of P, Q and R; and can similarly send 6Gbps of M’s traffic to each of P, Q and R. Alternatively, S can load balance the aggregate 30Gbps of traffic received from L and M to each of P, Q and R, thus sending 10Gbps to each. EB sub-LSPs have an added benefit of not requiring
unequal load balancing across links, which may pose problems for some hardware.

Given the notion of EB sub-LSPs and EB MLSPs, A can signal an EB MLSP Z comprised of five EB sub-LSPs E1 through E5 with the following paths: ALSPTUB, AMSQTVB, ALSRTWB, AMSPTXB and ALSQTYB (respectively). Then, A has two downstream links for the five sub-LSPs, AL and AM, between which A will load balance equally. Similarly, S has three downstream links, SP, SQ and SR; and T has five downstreams, TU, TV, TW, TX and TY. Thus the load balancing behavior of the MLSP will replicate IP load balancing. The state required for an EB MLSP to achieve IP-style load balancing is somewhat greater than for LDP LSPs, but significantly less than that for multiple "regular" TE LSPs, or for a non-EB MLSP.

2.3. Discussion

Some of the power of TE-based ECMP was illustrated in the above examples. Another is ability to request that all sub-LSPs avoid links colored red. If in the example network in Figure 1, the QT link is colored red but all other links are not, then there are four ECMP paths that satisfy these constraints, and the traffic distribution among them will naturally be different than it would without the link color constraint.

One can also ask whether an MLSP with sub-LSPs is any better than N "regular" LSPs from the same ingress to the same egress. Here are some benefits of an MLSP:

1. With an MLSP, there is a single entity to provision, manage and monitor, versus N separate entities in the case of LSPs. A consequence of this is that with an MLSP, changes in topology can be dealt with easily and autonomously by the ingress LSR, by adding, changing or removing sub-LSPs to rebalance traffic, while maintaining the same TE constraints. With individual LSPs, such changes would require changes in configuration, and thus are harder to automate.

2. An ingress LSR, knowing that an MLSP is for load balancing, can decide on an optimum number of sub-LSPs, and place them appropriately across the network to optimize load balancing. On the other hand, an ingress LSR asked to create N independent LSPs will do so without regard to whether N is a good number of equal cost paths, and, more importantly, may place several of the N LSPs on the same path, defeating the purpose of load balancing.

3. The EB sub-LSP mechanism will, in many cases, result in far fewer sub-LSPs than independent LSPs and thus less control plane state.
4. Finally, an MLSP will usually have less data plane state than N independent LSPs: whenever multiple sub-LSPs traverse a link, a single label will be used for all of them, whereas if multiple LSPs traverse a link, each will need a separate label.

2.4. The Capabilities of TE-based Load Balancing

Definition: Let G=(V, E) be a directed graph (or network), and let A and B in V be two nodes in G. Let T be the traffic arriving at A destined for B. T is said to be "IP-style" load balanced if for every node X on a shortest path from A to B, the portion of T arriving at X is split equally among all nodes Yi that are adjacent to X and are on a shortest path from X to B.

Theorem: An MLSP can accurately mimic IP-style load balancing between any two nodes in any network.

Proof: left to the reader.

Corollary: MLSPs provide a strictly more powerful load balancing mechanism than IP-style load balancing.
3. Operation of MLSPs

3.1. Signaling MLSPs

Sub-LSPs of an MLSP are tied together using ASSOCIATION objects. ASSOCIATION objects have a new Association Type for MLSPs (TBD). The Association ID is chosen by the ingress of the MLSP; the Association Source is the loopback address of the ingress of the MLSP. All sub-LSPs containing an ASSOCIATION object with a given Association Source and Type belong to the same MLSP.

3.1.1. Indicating Equi-bandwidth (EB) nature

A sub-LSP is considered equi-bandwidth if its Path message carries the optional LSP_ATTRIBUTES object ([RFC5420]) with an EBC (equi-bandwidth capability) flag in the Attribute Flags TLV. The bit number for the EBC flag is yet to be assigned by IANA.

3.2. Label Allocation

A LSR S that receives Path messages for several sub-LSPs of the same MLSP from the same upstream LSR SHOULD allocate the same label for all the sub-LSPs. This simplifies load balancing for the aggregate traffic on those sub-LSPs. If the sub-LSPs are EB sub-LSPs, then S SHOULD allocate the same label for all EB sub-LSPs of the same MLSP that pass through S, regardless of which upstream LSR they come from. This allows S to load balance the aggregate traffic received on the MLSP, as all the MLSP traffic arrives at S with the same label. However, an LSR that can achieve the load balancing requirements independent of label allocation strategies is free to do so.

3.3. Bandwidth Accounting

Since MLSPs are traffic engineered, there needs to be strict bandwidth accounting, or admission control, on every link that an MLSP traverses. For non-EB sub-LSPs, this is straightforward, and analogous to regular TE LSPs. However, for EB sub-LSPs, two new procedures are needed, one for signaling bandwidth, and the other for admission control. First, for a given MLSP Z, an LSR X MUST ensure (via signaling) that the total incoming bandwidth of EB sub-LSPs of MLSP Z is divided equally among all the downstream links of X which at least one of the EB sub-LSPs traverses. Second, LSR X MUST ensure that, for each upstream link of X, there is sufficient bandwidth to accommodate all EB sub-LSPs of MLSP Z that traverse that link.

Let’s take the example of Figure 2, with MLSP Z having five EB sub-LSPs E1 to E5, and say that MLSP Z is configured with a bandwidth of 30Gbps. Here are some of the steps involved.
1. LSR A, being the ingress, has no upstream links. A has two downstream links, AL and AM. Three EB sub-LSPs of MLSP Z traverse AL, and two traverse AM. A MUST signal a total of 15Gbps for the sub-LSPs to L, and a total of 15Gbps for the sub-LSPs to M. The required bandwidth may be divided up among the sub-LSPs to L (similarly, to M) in any manner so long as the total is 15Gbps. For example, A can signal sub-LSP E1 with 15Gbps, and sub-LSPs E3 and E5 with 0 bandwidth.

2. LSR L has one upstream link AL with three EB sub-LSPs with a total bandwidth of 15Gbps. L MUST ensure that 15Gbps is available for the AL link. If this bandwidth is not available, L MUST send a PathErr on ALL of the EB sub-LSPs on the AL link. Let’s assume that the AL link has sufficient bandwidth.

3. Next, it is up to L to decide how to divide the incoming 15Gbps among the three downstream EB sub-LSPs to S. Say L signals sub-LSP E1 with 15Gbps, and the others with 0 bandwidth.

4. LSR S has two upstream links: LS with three EB sub-LSPs with a total bandwidth of 15Gbps, and MS with two EB sub-LSPs with a total bandwidth of 15Gbps. S MUST ensure that 15Gbps is available for each of the LS and MS links. S has thus a total incoming bandwidth of 30Gbps on MLSP Z. S has to divide this equally among its downstream links SP, SQ and SR, yielding 10Gbps each. S MUST ensure that the total bandwidth requested on the SP link for sub-LSPs E1 and E4 is 10Gbps. S may choose to signal these sub-LSPs with 5Gbps each. Similarly for the SQ and SR links.

There are two important points to note here. One is that the bandwidth reservation (TSpec) for a given EB sub-LSP can (and usually will) change hop-by-hop. The second is that as new EB sub-LSPs are signaled for an MLSP, the bandwidth reservations for existing EB sub-LSPs belonging to the same MLSP may have to be updated. To minimize these updates, it is RECOMMENDED that the first EB sub-LSP on a link be signaled with the total required bandwidth (as far as is known), and later sub-LSPs on the same link be signaled with 0 bandwidth.

3.4. MLSP Data Plane Actions

Traffic intended to be sent over an MLSP is determined at the ingress LSR by means outside the scope of this document, and at transit LSRs by the label(s) assigned by the transit LSR to its upstream LSRs. In the case of non-EB sub-LSPs, this traffic is load balanced across downstream links in the ratio of the bandwidths of the sub-LSPs that comprise the MLSP. In the case of EB sub-LSPs, the traffic belonging to an MLSP from an upstream LSR (or better still, the aggregate
traffic for the MLSP from all upstream LSRs) is load balanced equally among all downstream links.

As noted above, the overriding concern is that flows are mapped to the same downstream link (except when the MLSP or some constituent sub-LSPs are changing); this is typically done by hashing fields that define a flow, and mapping hash results to different downstream LSRs. Hash-based load balancing typically assumes that the numbers of flows is sufficiently large and the bandwidth per flow is reasonably well-balanced so that the results of hashing yields reasonable traffic distribution.

Entropy labels ([RFC6790] and [RFC6391]) can be used to improve load balancing at intermediate nodes.
4. Manageability

TBD
5. Security Considerations

This document introduces no new security concerns in the setup and signaling of LSPs using RSVP-TE, or in the use of the RSVP protocol. [RFC2205] specifies the message integrity mechanisms for RSVP signaling. These mechanisms apply to RSVP-TE signaling of MLSPs described in this document, and are highly recommended pending newer integrity mechanisms for RSVP.
6. Acknowledgments

The author would like to thank the Routing Protocol group at Juniper Networks for their questions, comments and encouragement for this proposal. While many participated, special thanks go to Yakov Rekhter, John Drake and Rahul Aggarwal. Many thanks too to John for suggesting the use of ASSOCIATION objects.
7. IANA Considerations

IANA is requested to assign the following:

A new Association Type for MLSP. This Association Type is to be used for ASSOCIATION objects with C-Type 1 (IPv4 Source) and 2 (IPv6 Source).

A new flag in the Attribute Flags TLV in the LSP_ATTRIBUTES object ([RFC5420]: a bit number for the EBC (equi-bandwidth capability) to indicate that a specific sub-LSP is an equi-bandwidth sub-LSP.
8. References

8.1. Normative References


8.2. Informative References


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Bidirectional Forwarding Detection (BFD) Directed Return Path
draft-mirsky-mpls-bfd-directed-03

Abstract

Bidirectional Forwarding Detection (BFD) is expected to monitor bi-
directional paths. When a BFD session monitors in its forward
direction an explicitly routed path there is a need to be able to
direct egress BFD peer to use specific path as reverse direction of
the BFD session.

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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1. Introduction

RFC 5880 [RFC5880], RFC 5881 [RFC5881], and RFC 5883 [RFC5883] established the BFD protocol for IP networks and RFC 5884 [RFC5884] set rules of using BFD asynchronous mode over IP/MPLS LSPs. All standards implicitly assume that the egress BFD peer will use the shortest path route regardless of route being used to send BFD control packets towards it. As result, if the ingress BFD peer sends its BFD control packets over explicit path that is diverging from the best route, then reverse direction of the BFD session is likely not to be on co-routed bi-directional path with the forward direction of the BFD session. And because BFD control packets are not guaranteed to cross the same links and nodes in both directions detection of Loss of Continuity (LoC) defect in forward direction may demonstrate positive negatives.

This document defines the extension to LSP Ping [RFC4379], BFD Reverse Path TLV, and proposes that it to be used to instruct the
egress BFD peer to use explicit path for its BFD control packets associated with the particular BFD session. The TLV will be allocated from the TLV and sub-TLV registry defined by RFC 4379 [RFC4379]. As a special case, forward and reverse directions of the BFD session can form bi-directional co-routed associated channel.

1.1. Conventions used in this document

1.1.1. Terminology

BFD: Bidirectional Forwarding Detection

MPLS: Multiprotocol Label Switching

LSP: Label Switching Path

LoC: Loss of Continuity

1.1.2. 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 [RFC2119].

2. Problem Statement

BFD is best suited to monitor bi-directional co-routed paths. In most cases, given stable environments, the forward and reverse direction between two nodes is likely to be co-routed, this fulfilling the implicit BFD requirements. If BFD is used to monitor unidirectional explicitly routed paths, e.g. MPLS-TE LSPs, its control packets in forward direction would be in-band using the mechanism defined in [RFC5884] and [RFC5586]. But the reverse direction of the BFD session would still follow the shortest path route and that might lead to the following problems detecting failures on the unidirectional explicit path:

- failure detection on the reverse path cannot be interpreted as bi-directional failure and thus trigger, for example, protection switchover of the forward direction;

- if reverse direction is in Down state, the head-end node would not receive indication of forward direction failure from its egress peer.

To address these challenges the egress BFD peer should be instructed to use specific path for its control packets.
3. Direct Reverse BFD Path

3.1. Case of MPLS Data Plane

LSP ping, defined in [RFC4379], uses BFD Discriminator TLV [RFC5884] to bootstrap a BFD session over an MPLS LSP. This document defines a new TLV, BFD Reverse Path TLV, that MUST contain a single sub-TLV that can be used to carry information about reverse path for the specified in BFD Discriminator TLV session.

3.1.1. BFD Reverse Path TLV

The BFD Reverse Path TLV is an optional TLV within the LSP ping protocol. However, if used, the BFD Discriminator TLV MUST be included in an Echo Request message as well. If the BFD Discriminator TLV is not present when the BFD Reverse Path TLV is included, then it MUST be treated as malformed Echo Request, as described in [RFC4379].

The BFD Reverse Path TLV carries the specified path that BFD control packets of the BFD session referenced in the BFD Discriminator TLV are required to follow. The format of the BFD Reverse Path TLV is as presented in Figure 1.

```
+-----------------+-+-----------------+
| BFD Reverse Path TLV Type |          Length          |
|-----------------+-----------------+
| Reverse Path    |
+-----------------+-----------------+
```

Figure 1: BFD Reverse Path TLV

BFD Reverse Path TLV Type is 2 octets in length and value to be assigned by IANA.

Length is 2 octets in length and defines the length in octets of the Reverse Path field.

Reverse Path field contains a sub-TLV. Any Target FEC sub-TLV, already or in the future defined, from IANA sub-registry Sub-TLVs for TLV Types 1, 16, and 21 of MPLS LSP Ping Parameters registry MAY be used in this field. Only one sub-TLV MUST be included in the Reverse Path TLV. If more than one sub-TLVs are present in the Reverse Path field, then it must be treated as malformed Echo Request.
TLV, then only the first sub-TLV MUST be used and the rest MUST be silently discarded.

If the egress LSR fails to establish the BFD session because path specified in the Reverse Path TLV is not known, the egress MAY establish the BFD session over IP network [RFC5884] and MAY send Echo Reply with the Reverse Path TLV received and the return code set to "Failed to establish the BFD session". The specified reverse path was not found" (TBD4) Section 3.4. If the egress LSR cannot find path specified in the Reverse Path TLV and does not establish BFD session per RFC 5884, it MUST send Echo Reply with the Reverse Path TLV received and the return code set to "Failed to establish the BFD session. The specified reverse path was not found".

3.1.2. Segment Routing Tunnel sub-TLV

With MPLS data plane explicit path can be either Static or RSVP-TE LSP, or Segment Routing tunnel. In case of Static or RSVP-TE LSP [RFC7110] defined sub-TLVs to identify explicit return path. For the Segment Routing with MPLS data plane case a new sub-TLV is defined in this document as presented in Figure 2.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| SegRouting MPLS sub-TLV Type |          Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Label Stack Element                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Label Stack Element                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Label Stack Element                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Label Stack Element                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

Figure 2: Segment Routing MPLS Tunnel sub-TLV
```

The Segment Routing Tunnel sub-TLV Type is two octets in length, and will be allocated by IANA.

The Segment Routing Tunnel sub-TLV MAY be used in Reply Path TLV defined in [RFC7110]

3.2. Case of IPv6 Data Plane

IPv6 can be data plane of choice for Segment Routed tunnels [I-D.previdi-6man-segment-routing-header]. In such networks the BFD Reverse Path TLV described in Section 3.1.1 can be used as well. IP networks, unlike IP/MPLS, do not require use of LSP ping with BFD.
Discriminator TLV[RFC4379] to bootstrap BFD session. But to specify reverse path of a BFD session in IPv6 environment the BFD Discriminator TLV MUST be used along with the BFD Reverse Path TLV. The BFD Reverse Path TLV in IPv6 network MUST include sub-TLV.

```
|  SegRouting IPv6 sub-TLV Type |          Length             |
+-------------------------------+-----------------------------|
| IPv6 Prefix                   |
+-------------------------------+-----------------------------|
| IPv6 Prefix                   |
+-------------------------------+-----------------------------|
```

Figure 3: Segment Routing IPv6 Tunnel sub-TLV

3.3. Bootstrapping BFD session with BFD Reverse Path over Segment Routed tunnel

As discussed in [I-D.kumarkini-mpls-spring-lsp-ping] introduction of Segment Routing network domains with MPLS dataplane adds three new sub-TLVs that may be used with Target FEC TLV. Section 6.1 addresses use of new sub-TLVs in Target FEC TLV in LSP ping and LSP traceroute. For the case of LSP ping the [I-D.kumarkini-mpls-spring-lsp-ping] states that:

"Initiator MUST include FEC(s) corresponding to the destination segment.

Initiator MAY include FECs corresponding to some or all of segments imposed in the label stack by the initiator to communicate the segments traversed."

When LSP ping is used to bootstrap BFD session this document updates this and defines that LSP Ping MUST include the FEC corresponding to the destination segment and SHOULD NOT include FECs corresponding to some or all of segment imposed by the initiator. Operationally such restriction would not cause any problem or uncertainty as LSP ping
with FECs corresponding to some or all segments or traceroute may precede the LSP ping that bootstraps the BFD session.

3.4. Return Codes

This document defines the following Return Codes:

- Failed to establish the BFD session. The specified reverse path was not found, failed to establish the BFD session. When a specified reverse path is not available at the egress LSR, an Echo Reply with the return code set to "Failed to establish the BFD session. The specified reverse path was not found." MAY be sent back to the initiator. (Section 3.1.1)

4. Use Case Scenario

In network presented in Figure 4 node A monitors two tunnels to node H: A-B-C-D-G-H and A-B-E-F-G-H. To bootstrap BFD session to monitor the first tunnel, node A MUST include BFD Discriminator TLV with Discriminator value N and MAY include BFD Reverse Path TLV that references H-G-D-C-B-A tunnel. To bootstrap BFD session to monitor the second tunnel, node A MUST include BFD Discriminator TLV with Discriminator value M and MAY include BFD Reverse Path TLV that references H-G-F-E-B-A tunnel.

```
C--------D
|         |
A-------B     G-----H
|         |
E--------F
```

Figure 4: Use Case for BFD Reverse Path TLV

If an operator needs node H to monitor path to node A, e.g. H-G-D-C-B-A tunnel, then by looking up list of known Reverse Paths it MAY find and use existing BFD sessions.

5. IANA Considerations

5.1. TLV

The IANA is requested to assign a new value for BFD Reverse Path TLV from the "Multiprotocol Label Switching Architecture (MPLS) Label Switched Paths (LSPs) Ping Parameters - TLVs" registry, "TLVs and sub-TLVs" sub-registry.
Table 1: New BFD Reverse Type TLV

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (TBD1)</td>
<td>BFD Reverse Path TLV</td>
<td>This document</td>
</tr>
</tbody>
</table>

5.2. Sub-TLV

The IANA is requested to assign two new sub-TLV types from "Multiprotocol Label Switching Architecture (MPLS) Label Switched Paths (LSPs) Ping Parameters - TLVs" registry, "Sub-TLVs for TLV Types 1, 16, and 21" sub-registry.

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (TBD2)</td>
<td>Segment Routing MPLS Tunnel sub-TLV</td>
<td>This document</td>
</tr>
<tr>
<td>X (TBD3)</td>
<td>Segment Routing IPv6 Tunnel sub-TLV</td>
<td>This document</td>
</tr>
</tbody>
</table>

Table 2: New Segment Routing Tunnel sub-TLV

5.3. Return Codes

The IANA is requested to assign a new Return Code value from the "Multi-Protocol Label Switching (MPLS) Label Switched Paths (LSPs) Ping Parameters" registry, "Return Codes" sub-registry, as follows using a Standards Action value.

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (TBD4)</td>
<td>Failed to establish the BFD session. The specified reverse path was not found.</td>
<td>This document</td>
</tr>
</tbody>
</table>

Table 3: New Return Code

6. Security Considerations

Security considerations discussed in [RFC5880], [RFC5884], and [RFC4379], apply to this document.
7. Acknowledgements

8. Normative References

[I-D.kumarkini-mpls-spring-lsp-ping]

[I-D.previdi-6man-segment-routing-header]


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Abstract

This document specifies G-ACh based Residence Time Measurement and how it can be used by time synchronization protocols being transported over MPLS domain.

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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1. Introduction

Time synchronization protocols, Network Time Protocol version 4 (NTPv4) [RFC5905] and Precision Time Protocol (PTP) Version 2 [IEEE.1588.2008] can be used to synchronize clocks across network domains. In some scenarios calculation of time packet of time...
synchronization protocol spends within a node, called Residence Time, can improve accuracy of clock synchronization. This document defines new Generalized Associated Channel (G-ACh) that can be used in Multi-Protocol Label Switching (MPLS) network to measure Residence Time over Label Switched Path (LSP). Mechanisms for transport of time synchronization protocol packets over MPLS are out of scope in this document.

1.1. Conventions used in this document

1.1.1. Terminology

- **MPLS**: Multi-Protocol Label Switching
- **ACH**: Associated Channel
- **TTL**: Time-to-Live
- **G-ACh**: Generic Associated Channel
- **GAL**: Generic Associated Channel Label
- **NTP**: Network Time Protocol
- **ppm**: parts per million
- **PTP**: Precision Time Protocol
- **LSP**: Label Switched Path
- **LSR**: Label Switching Router
- **OAM**: Operations, Administration, and Maintenance
- **RSO**: RTM Set Object
- **RTM**: Residence Time Measurement
- **IGP**: Internal Gateway Protocol

1.1.2. 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 [RFC2119].
2. Residence Time Measurement

Packet Loss and Delay Measurement for MPLS Networks [RFC6374] can be used to measure one-way or two-way end-to-end propagation delay over LSP or PW. But these metrics are insufficient for use in some applications, for example, time synchronization across a network as defined in the Precision Time Protocol (PTP). PTPv2 [IEEE.1588.2008] uses "residence time", the time it takes for a PTPv2 event packet to transit a node. Residence times are accumulated in the correctionField of the PTP event messages or of the associated follow-up messages (or Delay_Resp message associated with the Delay_Req message) in case of two-step clocks (detailed discussion in Section 7). The residence time values are specific to each output PTP port and message.

This accumulated residence time MAY then be applied to correct the propagated time for node delays, effectively making these nodes transparent.

This document proposes mechanism to accumulate packet residence time from all LSRs that support the mechanism across a particular LSP.

3. G-ACh for Residence Time Measurement

RFC 5586 [RFC5586] and RFC 6423 [RFC6423] extended applicability of PW Associated Channel (ACH) [RFC5085] to LSPs. G-ACh provides a mechanism to transport OAM and other control messages. Processing by arbitrary transit LSRs can be triggered through controlled use of the Time-to-Live (TTL) value. In a way that is analogous to PTP operations, the packet residence time can be handled by the RTM capable node either as "one-step clock" or as a "two-step clock".

The packet format for Residence Time Measurement (RTM) is presented in Figure 1
Figure 1: G-ACh packet format for Residence Time Measurement

- The Version field is set to 0, as defined in RFC 4385 [RFC4385].
- The Reserved field MUST be set to 0 on transmit and ignored on receipt.
- The RTM G-ACh field, value to be allocated by IANA, identifies the packet as such.
- The Scratch Pad field is 8 octets in length. The first RTM-capable LSR MUST initialize the Scratch Pad field, it SHOULD set it to zero value. The Scratch Pad is used to accumulate the residence time spent in each RTM capable LSR transited by the packet on its path from ingress LSR to egress LSR. Its format is IEEE double precision and its units are nanoseconds. Note: depending on one-step or two-step operation (Section 7), the residence time might be related to the same packet carried in the Value field or to a packet carried in a different RTM packet.
- The Type field identifies the type of Value that the TLV carries. IANA will be asked to create a sub-registry in Generic Associated Channel (G-ACh) Parameters Registry called "MPLS RTM TLV Registry".
- The Length field contains the number of octets of the Value field.
- The optional Value field may be used to carry a packet of a given time synchronization protocol. If packet data is carried in the RTM message, then this is identified by Type accordingly. The data MAY be NTP [RFC5905] or PTP [IEEE.1588.2008]. It is important to note that the packet may be authenticated or encrypted and carried over MPLS LSP edge to edge unchanged while...
residence time being accumulated in the Scratch Pad field. Sub-TLVs MAY be included in the Value field.

- The TLV MUST be included in the RTM message, even if the length of the Value field is zero.

### 3.1. PTP Packet Sub-TLV

Figure 2 presents format of a PTP sub-TLV that MUST be precede every PTP packet carried in RTM TLV.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type              |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Flags     | Resv  |PTPType|           Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Port ID                            |
|                                                               |
|                               +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+|
|                               |           Sequence ID         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: PTP Sub-TLV format

where Flags field has format

```
0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|S|  Reserved   |
+-+-+-+-+-+-+-+-+
```

Figure 3: Flags field format for Residence Time Measurement

- The Type field identifies PTP sub-TLV defined in the Table 19 Values of messageType field in [IEEE.1588.2008].
- The Length field of the PTP sub-TLV contains the number of octets of the Value field and MUST be 20.
- The Flags field currently defines one bit, the S-bit, that defines whether or not the current message has been processed by a 2-step node, where the flag is cleared if the message has been handled exclusively by 1-step nodes and there is no follow-up message, and set if there has been at least one 2-step node and a follow-up message is forthcoming.
The PTPType indicates the type of PTP packet carried in the TLV. PTPType is the messageType field of the PTPv2 packet whose values are defined in the Table 19 [IEEE.1588.2008].

The 10 octets long Port ID field contains the identity of the source port. The Sequence ID is the sequence ID of the PTP message carried in the Value field of the message.

4. Control Plane Theory of Operation

The operation of RTM depends upon TTL expiry to deliver an RTM packet from one RTM capable interface to the next along the path from ingress LSR to egress LSR, which means that an LSR with RTM capable interfaces needs to be able to compute a TTL which will cause the expiry of an RTM packet at the next LSR with RTM capable interfaces.

However, because of Equal Cost Multipath, labels distributed by LDP do not necessarily instantiate a single path between a given ingress/egress LSR pair but rather MAY create a graph in which different flows will take different paths through this network. This means one doesn’t necessarily know the path that RTM packets will take or even if they all take the same path. So, in an environment in which not all interfaces in an IGP domain support RTM, it is effectively impossible to use TTL expiry to deliver RTM packets and hence RTM cannot be used for LSPs instantiated using LDP, if multi-pathing is in use and not all LSRs are RTM-capable. In the special but important case of environment in which all interfaces in an IGP domain support RTM, setting the TTL to 1 will always cause the expiry of an RTM packet on the next RTM capable downstream LSR and hence in such an environment, RTM can be used for LSPs instantiated using LDP.

Also, if it is possible and desirable, multi-path forwarding may be disabled, at least for the set of packets that includes RTM.

Generally speaking, RTM is more useful for an LSP instantiated using RSVP-TE [RFC3209] because the LSP’s path can be determined.

4.1. RTM Capability

Note that RTM capability of a node is with respect to the pair of interfaces that will be used to forward an RTM packet. In general, the ingress interface of this pair must be able to capture the arrival time of the packet and encode it in some way such that this information will be available to the egress interface.

The supported modes (1-step verses 2-step) of any pair of interfaces is then determined by the capability of the egress interface. In both cases, the egress interface implementation MUST be able to
determine the precise departure time of the same packet and determine from this, and the arrival time information from the corresponding ingress interface, the difference representing the residence time for the packet.

An interface with the ability to do this and update the associated correctionField in real-time (i.e. while the packet is being forwarded) is said to be 1-step capable.

Hence while both ingress and egress interfaces are required to support RTM, for the pair to be RTM-capable, it is the egress interface that determines whether or not the node is 1-step or 2-step capable with respect to the interface-pair.

The RTM capability used in the sub-TLV shown in Figure 4 is thus associated with the egress port of the node making the advertisement, while the ability of any pair of interfaces that includes this egress interface to support any mode of RTM depends on the ability of that interface to record packet arrival time in some way that can be conveyed to and used by that egress interface.

When an IGP is used to carry the above defined RTM capability sub-TLV, the implementation MUST associate the advertisement with the interface that has the ability used to determine its supported RTM capabilities, and MUST NOT propagate this sub-TLV via any interface that does not have the associated ingress ability described in this section.

4.2. RTM Capability Sub-TLV

The format for the RTM Capabilities sub-TLV is presented in Figure 4

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type(TBA5)          |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| RTM |                       Reserved                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: RTM Capability sub-TLV

- Type value will be assigned by IANA from appropriate registries.
- Length MUST be set to 4.
- RTM is a three-bit long bit-map field with values defined as follows:
* 0b001 - one-step RTM supported;
* 0b010 - two-step RTM supported;
* 0b100 - reserved.

Reserved field must be set to all zeroes on transmit and ignored on receipt.

[RFC4202] explains that "the Interface Switching Capability Descriptor describes switching capability of an interface. For bi-directional links, the switching capabilities of an interface are defined to be the same in either direction. I.e., for data entering the node through that interface and for data leaving the node through that interface". That principle SHOULD be applied when a node advertises RTM Capability.

A node that supports RTM MUST be able to act in two-step mode and MAY also support one-step RTM mode. Detailed discussion of one-step and two-step RTM modes in Section 7.

### 4.3. RTM Capability Advertisement in OSPFv2

The capability to support RTM on a particular link advertised in the OSPFv2 Extended Link Opaque LSA [I-D.ietf-ospf-prefix-link-attr] as RTM Capability sub-TLV, presented in Figure 4, of the OSPFv2 Extended Link TLV.

Type value will be assigned by IANA from the OSPF Extended Link TLV Sub-TLVs registry that will be created per [I-D.ietf-ospf-prefix-link-attr] request.

### 4.4. RTM Capability Advertisement in OSPFv3

The capability to support RTM on a particular link in OSPFv3 can be advertised by including an RTM Capability sub-TLV defined in Section 4.3 in the following TLVs defined in [I-D.ietf-ospf-ospf-v3-lsa-extend] Intra-Area-Prefix TLV, IPv6 Link-Local Address TLV, or IPv4 Link-Local Address TLV when these are included in E-Link-LSA.

### 4.5. RTM Capability Advertisement in IS-IS

The RTM capability logically belongs to a group of parameters characterized as "generic information not directly related to the operation of the IS-IS protocol" [RFC6823]. Hence the capability to process RTM messages can be advertised by including RTM Capability sub-TLV in GENINFO TLV [RFC6823].
With respect to the Flags field of the GENINFO TLV:

- The S bit MUST be cleared to prevent the RTM Capability sub-TLV from leaking between levels.
- The D bit of the Flags field MUST be cleared as well.
- The I bit and the V bit MUST be set accordingly depending on whether RTM capability being advertised for IPv4 or IPv6 interface of the node.

Application ID (TBA6) will be assigned from the Application Identifiers for TLV 251 IANA registry. The RTM Capability sub-TLV, presented in Figure 4, MUST be included in GENINFO TLV in Application Specific Information.

4.6. RSVP-TE Control Plane Operation to Support RTM

Though RTM capability is per interface throughout this document we will refer to an LSR as RTM capable LSR when:

- ingress LSR’s LSP interface is RTM capable;
- transit LSR’s ingress and egress interfaces for the given LSP are RTM capable;
- egress LSR’s egress interface is RTM capable.

An ingress LSR that wishes to perform RTM along a path through an MPLS network to an egress LSR verifies that the selected egress LSR has an interface that supports RTM via the egress LSR’s advertisement of the RTM Capability sub-TLV. In the Path message that the ingress LSR uses to instantiate the LSP to that egress LSR it places initialized Record Route and RTM Set Objects Section 4.7, which tell the egress LSR that RTM is desired for this LSP.

In the Resv message that the egress LSR sends in response to the received Path message, it includes initialized Record Route and RTM Set Objects (RSO). The RTM Set Object contains an ordered list, from egress LSR to ingress LSR, of the RTM capable LSRs along the LSP’s path. Each such LSR will use the ID of the first LSR in the RTM Set Object in conjunction with the Record Route Object to compute the hop count to its downstream LSR with reachable RTM capable interface. It will also insert its ID at the beginning of the RTM Set Object before forwarding the Resv upstream.

After the ingress LSR receives the Resv, it MAY begin sending RTM packets to the first RTM capable LSR on the LSP’s path. Each RTM
packet has its Scratch Pad field initialized and its TTL set to expire on that first subsequent RTM capable LSR.

It should be noted that RTM can also be used for LSPs instantiated using [RFC3209] in an environment in which all interfaces in an IGP support RTM. In this case the RTM Set Object MAY be omitted.

4.7. RTM_SET Object

RTM capable interfaces can be recorded via RTM_SET object (RSO). The RTM Set Class is TBA7. Currently one C_Type is defined, Type TBA8 RTM Set. The RTM_SET object format presented in Figure 5

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                             |
|                                                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: RTM Set object format

The contents of a RTM_SET object are a series of variable-length data items called sub-objects. The sub-objects are defined in Section 4.7.1 below.

The RSO can be present in both RSVP Path and Resv messages. If a Path message contains multiple RSOs, only the first RSO is meaningful. Subsequent RSOs SHOULD be ignored and SHOULD NOT be propagated. Similarly, if in a Resv message multiple RSOs are encountered following a FILTER_SPEC before another FILTER_SPEC is encountered, only the first RSO is meaningful. Subsequent RSOs SHOULD be ignored and SHOULD NOT be propagated.

4.7.1. RSO Sub-objects

The RTM Set object contains an ordered list, from egress LSR to ingress LSR, of the RTM capable LSRs along the LSP’s path.

The contents of a RTM_SET object are a series of variable-length data items called sub-objects. Each sub-object has its own Length field. The length contains the total length of the sub-object in bytes, including the Type and Length fields. The length MUST always be a multiple of 4, and at least 8 (smallest IPv4 sub-object).

Sub-objects are organized as a last-in-first-out stack. The first sub-object relative to the beginning of RSO is considered the top.
The last sub-object is considered the bottom. When a new sub-object is added, it is always added to the top.

Three kinds of sub-objects for RSO are currently defined.

4.7.1.1. IPv4 Sub-object

```
+------------------+-+------------------+-+
| Type | Length | Flags |
+------------------+-+------------------+-+
| IPv4 address     |
+------------------+-+------------------+-+
```

Figure 6: IPv4 sub-object format

Type

0x01 IPv4 address

Length

The Length contains the total length of the sub-object in bytes, including the Type and Length fields. The Length is always 8.

IPv4 address

A 32-bit unicast host address.

Flags

TBD

4.7.1.2. IPv6 Sub-object

```
+------------------+-+------------------+-+
| Type | Length | Flags |
+------------------+-+------------------+-+
| IPv6 address     |
+------------------+-+------------------+-+
```

Figure 7: IPv6 sub-object format
Type

0x02 IPv6 address

Length

The Length contains the total length of the sub-object in bytes, including the Type and Length fields. The Length is always 20.

IPv6 address

A 128-bit unicast host address.

Flags

TBD

4.7.1.3.  Unnumbered Interface Sub-object

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type</td>
<td>Length</td>
<td>Flags</td>
</tr>
<tr>
<td></td>
<td>Router ID</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interface ID</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: IPv4 sub-object format

Type

0x03 Unnumbered interface

Length

The Length contains the total length of the sub-object in bytes, including the Type and Length fields. The Length is always 12.

Router ID

The Router ID interpreted as discussed in the Section 2 of RFC 3447 [RFC3477].

Interface ID
The identifier assigned to the link by the LSR specified by the Router ID.

Flags

TBD

5. Data Plane Theory of Operation

After instantiating an LSP for a path using RSVP-TE [RFC3209] as described in Section 4.6 or if this is the special case of homogeneous RTM-capable IP/MPLS domain discussed in the last paragraph of Section 4, ingress LSR MAY begin sending RTM packets to the first downstream RTM capable LSR on that path. Each RTM packet has its Scratch Pad field initialized and its TTL set to expire on the next downstream RTM-capable LSR. Each RTM-capable LSR on the explicit path receives an RTM packet and records the time at which it receives that packet at its ingress interface as well as the time at which it transmits that packet from its egress interface; this should be done as close to the physical layer as possible to ensure precise accuracy in time determination. The RTM-capable LSR determines the difference between those two times; for 1-step operation, this difference is determined just prior to or while sending the packet, and the RTM-capable egress interface adds it to the value in the Scratch Pad field of the message in progress. Note, for the purpose of calculating a residence time, a common free running clock synchronizing all the involved interfaces may be sufficient, as, for example, 4.6 ppm accuracy leads to 4.6 nanosecond error for residence time on the order of 1 millisecond.

For 2-step operation, the difference between packet arrival time (at an ingress interface) and subsequent departure time (from an egress interface) is determined at some later time prior to sending a subsequent follow-up message, so that this value can be used to update the correctionField in the follow-up message.

See Section 7 for further details on the difference between 1-step and 2-step operation.

The RTM capable LSR also sets the RTM packet’s TTL to expire on the next downstream RTM capable LSR.

The last RTM-capable LSR on the LSP MAY then use the value in the Scratch Pad field to perform time correction, if there is no follow-up message. For example, the egress LSR may be a PTP Boundary Clock synchronized to a Master Clock and will use the value in the Scratch Pad Field to update PTP’s correctionField.
6. Applicable PTP Scenarios

The proposed approach can be directly integrated in a PTP network based on delay request-response mechanism. The RTM capable LSR nodes act as end-to-end transparent clocks, and typically boundary clocks, at the edges of the MPLS network, use the value in the Scratch Pad field to update the correctionField of the corresponding PTP event packet prior to performing the usual PTP processing.

7. One-step Clock and Two-step Clock Modes

One-step mode refers to the mode of operation where an egress interface updates the correctionField value of an original event message. Two-step mode refers to the mode of operation where this update is made in a subsequent follow-up message.

Processing of the follow-up message, if present, requires the downstream end-point to wait for the arrival of the follow-up message in order to combine correctionField values from both the original (event) message and the subsequent (follow-up) message. In a similar fashion, each 2-step node needs to wait for the correct follow-up message, if there is one, in order to update that follow-up message (as opposed to creating a new one. Hence the first node that uses 2-step mode MUST do two things:

1. Mark the original event message to indicate that a follow-up message will be forthcoming (this is necessary in order to

   Let any subsequent 2-step node know that there is already a follow-up message, and

   Let the end-point know to wait for a follow-up message;

2. Create a follow-up message in which to put the RTM determined as an initial correctionField value.

IEEE 1588v2 [IEEE.1588.2008] defines this behavior for PTP messages.

Thus, for example, with reference to the PTP protocol, the PTPType field identifies whether the message is a Sync message, Follow_up message, Delay_Req message, or Delay_Resp message. The 10 octet long Port ID field contains the identity of the source port, that is, the specific PTP port of the boundary clock connected to the MPLS network. The Sequence ID is the sequence ID of the PTP message carried in the Value field of the message.

PTP messages also include a bit that indicates whether or not a follow-up message will be coming. This bit - once it is set by a
2-step mode device - must stay set accordingly until the original and follow-up message are combined by an end-point (such as a boundary clock).

Thus, an RTM packet, containing residence time information relating to an earlier packet, also contains information identifying that earlier packet.

For compatibility with PTP, RTM (when used for PTP packets) must behave in a similar fashion. To do this, a 2-step RTM capable egress interface will need to examine the S-bit in the Flags field of the PTP sub-TLV (for RTM messages that indicate they are for PTP) and - if it is clear (set to zero), it MUST set it and create a follow-up PTP Type RTM message. If the S bit is already set, then the RTM capable node MUST wait for the RTM message with the PTP type of follow-up and matching originator and sequence number to make the corresponding residence time update to the Scratch Pad field.

In practice an RTM operating according to two-step clock behaves like a two-steps transparent clock.

A 1-step capable RTM node MAY elect to operate in either 1-step mode (by making an update to the Scratch Pad field of the RTM message containing the PTP even message), or in 2-step mode (by making an update to the scratch pad of a follow-up message when its presence is indicated), but MUST NOT do both.

Two main subcases can be identified for an RTM node operating as a two-step clock:

A) If any of the previous RTM capable node or the previous PTP clock (e.g. the BC connected to the first LSR), is a two-step clock, the residence time is added to the RTM packet that has been created to include the associated PTP packet (i.e. follow-up message in the downstream direction), if the local RTM-capable LSR is also operating as a two-step clock. This RTM packet carries the related accumulated residence time and the appropriate values of the Sequence Id and Port Id (the same identifiers carried in the packet processed) and the Two-step Flag set to 1.

Note that the fact that an upstream RTM-capable node operating in the two-step mode has created a follow-up message does not require any subsequent RTM capable LSR to also operate in the 2-step mode, as long as that RTM-capable LSR forwards the follow-up message on the same LSP on which it forwards the corresponding previous message.
A one-step capable RTM node MAY elect to update the RTM follow-up message as if it were operating in two-step mode, however, it MUST NOT update both messages.

A PTP event packet (sync) is carried in the RTM packet in order for an RTM node to identify that residence time measurement must be performed on that specific packet.

To handle the residence time of the Delay request message on the upstream direction, an RTM packet must be created to carry the residence time on the associated downstream Delay Resp message.

The last RTM node of the MPLS network in addition to update the correctionField of the associated PTP packet, must also properly handle the two-step flag of the PTP packets.

B) When the PTP network connected to the MPLS and RTM node, operates in one-step clock mode, the associated RTM packet must be created by the RTM node itself. The associated RTM packet including the PTP event packet needs now to indicate that a "follow up" message will be coming.

The last RTM node of the LSP, modeif it receives an RTM message with a PTP payload indicating a follow-up message will be forthcoming, must generate a follow-up message and properly set the two-step flag of the PTP packets.

8. IANA Considerations

8.1. New RTM G-ACh

IANA is requested to reserve a new G-ACh as follows:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBA1</td>
<td>Residence Time Measurement</td>
<td>This document</td>
</tr>
</tbody>
</table>

Table 1: New Residence Time Measurement

8.2. New RTM TLV Registry

IANA is requested to create sub-registry in Generic Associated Channel (G-ACh) Parameters Registry called "MPLS RTM TLV Registry". All code points in the range 0 through 127 in this registry shall be allocated according to the "IETF Review" procedure as specified in [RFC5226]. Remaining code points are allocated according to the
table below. This document defines the following new values RTM TLV type s:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reserved</td>
<td>This document</td>
</tr>
<tr>
<td>1</td>
<td>No payload</td>
<td>This document</td>
</tr>
<tr>
<td>2</td>
<td>PTPv2</td>
<td>This document</td>
</tr>
<tr>
<td>3</td>
<td>NTP</td>
<td>This document</td>
</tr>
<tr>
<td>4-127</td>
<td>Reserved</td>
<td>IETF Consensus</td>
</tr>
<tr>
<td>128 - 191</td>
<td>Reserved</td>
<td>First Come First Served</td>
</tr>
<tr>
<td>192 - 255</td>
<td>Reserved</td>
<td>Private Use</td>
</tr>
</tbody>
</table>

Table 2: RTM TLV Type

8.3. New RTM Sub-TLV Registry

IANA is requested to create sub-registry in MPLS RTM TLV Registry, requested in Section 8.2, called "MPLS RTM Sub-TLV Registry". All code points in the range 0 through 127 in this registry shall be allocated according to the "IETF Review" procedure as specified in [RFC5226]. Remaining code points are allocated according to the table below. This document defines the following new values RTM sub-TLV types:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reserved</td>
<td>This document</td>
</tr>
<tr>
<td>1</td>
<td>PTP 2-step</td>
<td>This document</td>
</tr>
<tr>
<td>2-127</td>
<td>Reserved</td>
<td>IETF Consensus</td>
</tr>
<tr>
<td>128 - 191</td>
<td>Reserved</td>
<td>First Come First Served</td>
</tr>
<tr>
<td>192 - 255</td>
<td>Reserved</td>
<td>Private Use</td>
</tr>
</tbody>
</table>

Table 3: RTM Sub-TLV Type

8.4. RTM Capability sub-TLV

IANA is requested to assign a new type for RTM Capability sub-TLV from future OSPF Extended Link TLV Sub-TLVs registry as follows:
8.5. IS-IS RTM Application ID

IANA is requested to assign a new Application ID for RTM from the Application Identifiers for TLV 251 registry as follows:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBA3</td>
<td>RTM</td>
<td>This document</td>
</tr>
</tbody>
</table>

Table 5: IS-IS RTM Application ID

8.6. RTM_SET Object RSVP Class Number, Class Type and Sub-object Types

IANA is requested to assign a new Class Number for RTM_SET object as follows:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBA4</td>
<td>RTM_SET object</td>
<td>This document</td>
</tr>
</tbody>
</table>

Table 6: RTM_SET object Class

IANA is requested to assign a new Class Type for RTM_SET object as follows:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBA5</td>
<td>RTM Set</td>
<td>This document</td>
</tr>
</tbody>
</table>

Table 7: RTM_SET object Class Type

IANA requested to create new sub-registry for sub-object types of RTM_SET object as follows:
### Table 8: RTM_SET object sub-object types

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Reserved</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>IPv4 address</td>
<td>This document</td>
</tr>
<tr>
<td>2</td>
<td>IPv6 address</td>
<td>This document</td>
</tr>
<tr>
<td>3</td>
<td>Unnumbered interface</td>
<td>This document</td>
</tr>
<tr>
<td>4-127</td>
<td>Reserved</td>
<td>IETF Consensus</td>
</tr>
<tr>
<td>128-191</td>
<td>Reserved</td>
<td>First Come First Served</td>
</tr>
<tr>
<td>192-255</td>
<td>Reserved</td>
<td>Private Use</td>
</tr>
</tbody>
</table>

9. Security Considerations

Routers that support Residence Time Measurement are subject to the same security considerations as defined in [RFC5586].

In addition - particularly as applied to use related to PTP - there is a presumed trust model that depends on the existence of a trusted relationship of at least all PTP-aware nodes on the path traversed by PTP messages. This is necessary as these nodes are expected to correctly modify specific content of the data in PTP messages and proper operation of the protocol depends on this ability.

As a result, the content of the PTP-related data in RTM messages that will be modified by intermediate nodes cannot be authenticated, and the additional information that must be accessible for proper operation of PTP 1-step and 2-step modes MUST be accessible to intermediate nodes (i.e. - MUST NOT be encrypted in a manner that makes this data inaccessible).

While it is possible for a supposed compromised LSR to intercept and modify the G-ACh content, this is an issue that exists for LSRs in general - for any and all data that may be carried over an LSP - and is therefore the basis for an additional presumed trust model associated with existing LSPs and LSRs.

The ability for potentially authenticating and/or encrypting RTM and PTP data that is not needed by intermediate RTM/PTP-capable nodes is for further study.

Security requirements of time protocols are provided in RFC 7384 [RFC7384].
10. Acknowledgements

TBD

11. References

11.1. Normative References

[I-D.ietf-ospf-ospfv3-lsa-extend]

[I-D.ietf-ospf-prefix-link-attr]

[IEEE.1588.2008]


11.2. Informative References


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Abstract

This document defines RSVP-TE signaling extensions that reduce the amount of RSVP signaling required for Fast Reroute (FRR) procedures and subsequently improve the scalability of the RSVP-TE signaling when undergoing FRR convergence post a link or node failure. Such extensions allow the RSVP message exchange between the Point of Local Repair (PLR) and the Merge Point (MP) to be independent of the number of protected LSPs traversing between them (e.g. when bypass LSP FRR protection is used). The new signaling extensions are fully backwards compatible with nodes that do not support them.

Status of This Memo

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1. Introduction

Fast Reroute (FRR) procedures defined in [RSVP-TE-FRR] describe the mechanism for the Point of Local Repair (PLR) to reroute traffic and signaling of a protected RSVP-TE LSP onto the bypass tunnel in the event of a TE link or node failure. These signaling procedures are performed individually for each affected LSP and can lead to scalability and latency issues when the failure event affects a large number of protected LSPs between the same PLR and MP.

In a scaled deployment, a single P node acting as a PLR may host tens of thousands of protected RSVP-TE LSPs egressing the same link, and likewise, act as a Merge Point (MP) for similar number of LSPs ingressing the same link. In the event of the failure of the link or neighbor node, the RSVP-TE control plane of PLR and MP becomes busy rerouting protected LSPs signaling over the bypass tunnel(s) in one direction, and merging signaling of received messages over bypass tunnels in the other direction, respectively. At the same time, head-end PE nodes that are notified of the local repair, attempt to (re)converge affected RSVP-TE LSPs over newly computed paths, possibly traversing the same P node. As a result, the RSVP-TE control plane at the PLR and MP becomes overwhelmed by the FRR processing overhead following link or node failure while also competing for CPU processing power with other control plane protocol(s) (e.g. IGP) also undergoing convergence.

The extensions defined in this document enable a MP to become aware of the PLR’s bypass assignment and allow FRR procedures between PLR and MP to be signaled and processed on groups of LSPs.

1.1. Summary FRR LSP Groups

The PLR creates and manages Summary FRR LSP groups (Bypass_Group_Identifiers) and shares them with the MP via signaling. Protected LSPs sharing the same egress link and bypass assignment are grouped together and are assigned the same group. The MP maintains the PLR group assignments learned via signaling, and acknowledges the group assignments via signaling. Once the PLR receives the acknowledgement, FRR signaling can now be group based.

1.2. Terminology

In this document, the key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" are to be interpreted as described in BCP 14, RFC 2119 [RFC2119].
2. Bypass Tunnel Assignment Coordination

This document defines a new subobject in RSVP RECORD_ROUTE object, SUMMARY_FRR_BYPASS_ASSIGNMENT, to extend RSVP-TE for summary fast-reroute signaling. This object is backward compatible with LSRs that do not recognize it (see section 4.4.5 in [RSVP-TE]).

2.1. SUMMARY_FRR_BYPASS_ASSIGNMENT RECORD_ROUTE subobject

When used within an RSVP Path message, the SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is used to inform the MP of the bypass tunnel being used by the PLR and the assigned Summary FRR Bypass_Group_Identifier for the protected LSP. When used within a RSVP Resv message, the SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is used by the MP to acknowledge the PLR’s bypass tunnel assignment, and indicate support for this extension.

The IPv4 SUMMARY_FRR_BYPASS_ASSIGNMENT subobject has the following format:

```
0                   1                   2                   3
+-------------------+-------------------+-------------------+-------------------+
|       Type       |      Length      |    Bypass_Tunnel_ID    |                  |
+-------------------+-------------------+-------------------+-------------------+
|                    |                  |                      |                  |
+-------------------+-------------------+-------------------+-------------------+
|   Bypass_Source_IPv4_Address   |                  |                  |                  |
+-------------------+-------------------+-------------------+-------------------+
|                    |                  |                      |                  |
+-------------------+-------------------+-------------------+-------------------+
|    Bypass_Destination_IPv4_Address       |                  |                  |                  |
+-------------------+-------------------+-------------------+-------------------+
|                    |                  |                      |                  |
+-------------------+-------------------+-------------------+-------------------+
|    Bypass_Group_Identifier       |                  |                  |                  |
+-------------------+-------------------+-------------------+-------------------+
|                    |                  |                      |                  |
+-------------------+-------------------+-------------------+-------------------+
| Summary_FRR_PLR_Generation_Identifier |                  |                  |                  |
+-------------------+-------------------+-------------------+-------------------+
```

Type: 8 bits

(TBD-1) IPv4 Summary FRR Bypass Assignment

Length: 8 bits

The Length contains the total length of the subobject in bytes, including the Type and Length fields.

Bypass_Tunnel_ID: 16 bits

The bypass tunnel identifier.
Bypass_Source_IPv4_Address: 32 bits
The bypass tunnel source IPV4 address.

Bypass_Destination_IPv4_Address: 32 bits
The bypass tunnel destination IPV4 address.

Bypass_Group_Identifier: 32 bits
The bypass tunnel group identifier.

Summary_FRR_PLR_Generation_Identifier
The PLR generation identifier.

The IPv6 SUMMARY_FRR_BYPASS_ASSIGNMENT subobject has the following format:

```
0                   1                   2                   3
+-------------------+-------------------+-------------------+-------------------|
|       Type        |      Length       |    Bypass_Tunnel_ID|
|                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------|
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------|
|       Bypass_Source_IPv6_Address|
+-------------------+-------------------+-------------------+-------------------|
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------|
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------|
|       Bypass_Destination_IPv6_Address|
+-------------------+-------------------+-------------------+-------------------|
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------|
|  Bypass_Group_Identifier|
+-------------------+-------------------+-------------------+-------------------|
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
|                   |                   |                   |
+-------------------+-------------------+-------------------+-------------------|
|  Summary_FRR_PLR_Generation_Identifier|
+-------------------+-------------------+-------------------+-------------------|
```

Type: 8 bits

(TBD-2) IPv6 Summary FRR Bypass Assignment

Length: 8 bits

The length contains the total length of the subobject in bytes, including the Type and Length fields.

Bypass_Tunnel_ID: 16 bits

The bypass tunnel identifier.

Bypass_Source_IPv6_Address: 128 bits

The bypass tunnel source IPv4 address.

Bypass_Destination_IPv6_Address: 128 bits

The bypass tunnel destination IPv4 address.

Bypass_Group_Identifier: 32 bits

The bypass tunnel group identifier.

Summary_FRR_PLR_Generation_Identifier

The PLR generation identifier.

2.2. Bypass Tunnel Assignment Signaling Procedure

Before Summary FRR procedures can be used, a handshake MUST be completed between the PLR and MP. This handshake is performed using RECORD_ROUTE subobject SUMMARY_FRR_BYPASS_ASSIGNMENT within both the RSVP Path and Resv messages.

The PLR assigns a bypass tunnel and Bypass_Group_Identifier for each protected LSP. The same Bypass_Group_Identifier is used for the set of protected LSPs that share the same bypass tunnel and traverse the same egress link and are not already rerouted. The PLR also generates a generation identifier (per LSP) that is used by the PLR to later match the last sent subobject and eliminate timing issues.
The PLR MUST generate a new generation identifier (per LSP) each time the SUMMARY_FRR_BYPASS_ASSIGNMENT subobject contents change; for example, when PLR changes the bypass tunnel assignment.

The PLR notifies the MP of the bypass tunnel assignment via adding a SUMMARY_FRR_BYPASS_ASSIGNMENT subobject to the RSVP Path message RECORD_ROUTE object for the protected LSP using procedure described in section 2.2.1.

The MP acknowledges the PLR’s assignment by echoing back the received SUMMARY_FRR_BYPASS_ASSIGNMENT subobject within the RSVP Resv message RECORD_ROUTE object.

The PLR considers the protected LSP as Summary FRR capable only if the SUMMARY_FRR_BYPASS_ASSIGNMENT subobjects within the sent RSVP Path message RECORD_ROUTE and the received RSVP Resv message RECORD_ROUTE match exactly. If a matching subobject does not exist, or is later absent in a subsequent refresh, the PLR MUST consider the protected LSP as not Summary FRR capable.

2.2.1. PLR Path Signaling Procedure

The SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is added to the RECORD_ROUTE object by each PLR in the RSVP Path message of the protected LSP to record the bypass tunnel assignment. This subobject is updated every time the PLR updates the bypass tunnel assignment (which triggers an RSVP Path change message). The SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is added in the RECORD_ROUTE object prior to adding the node’s IP address. A node MUST NOT add a SUMMARY_FRR_BYPASS_ASSIGNMENT subobject without also adding the node’s IPv4 or IPv6 subobject.
2.2.2. MP Signaling Procedure

Upon receiving an RSVP Path message with RECORD_ROUTE object, the MP processes all (there may be multiple PLRs for a single MP) SUMMARY_FRR_BYPASS_ASSIGNMENT subobjects with a matching Bypass Destination address.

The MP first ensures the existence of the bypass tunnel and that the Bypass_Group_Identifier is not already active. That is, an LSP cannot join a group that is already active.

The MP builds a mirrored Summary FRR Group database per PLR, which is determined using the Bypass_Source_Address field. For each SUMMARY_FRR_BYPASS_ASSIGNMENT subobject that is successfully processed, the MP mirrors the received SUMMARY_FRR_BYPASS_ASSIGNMENT subobject in the RSVP Resv message RECORD_ROUTE object. Each SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is added in the RECORD_ROUTE object prior to adding the node’s IP address. A node MUST NOT add a SUMMARY_FRR_BYPASS_ASSIGNMENT subobject without also adding an IPv4 or IPv6 subobject.

When forwarding an RSVP Path message downstream, the MP MAY remove any/all SUMMARY_FRR_BYPASS_ASSIGNMENT subobjects with a matching Bypass_Destination_Address.

2.2.3. PLR Resv Signaling Procedure

Upon receiving an RSVP Resv message with RECORD_ROUTE object, the PLR checks if the expected SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is present. If present, and matches the last SUMMARY_FRR_BYPASS_ASSIGNMENT subobject sent within the RSVP Path message RECORD_ROUTE, then the MP has acknowledged the bypass assignment and the LSP is now ready for Summary FRR. If a matching SUMMARY_FRR_BYPASS_ASSIGNMENT subobject is not present, the LSP remains not ready for Summary FRR.

When forwarding an RSVP Resv message upstream, the PLR MAY remove any/all SUMMARY_FRR_BYPASS_ASSIGNMENT subobjects with a matching Bypass_Source_Address.

3. Post FRR Trigger Signaling

Upon detection of the fault (egress link or node failure) the PLR first performs the object modification procedures described by section 6.4.3 of [RSVP-TE-FRR] for all affected protected LSPs. For Summary FRR LSPs assigned to the same bypass tunnel a common RSVP_HOP and SENDER_TEMPLATE MUST be used.
The PLR MUST first signal non-Summary FRR LSPs over the bypass tunnel before signaling the Summary FRR LSPs. This is needed to allow for the case when the PLR has recently changed a bypass assignment which the MP may not have processed the change yet.

A new object SUMMARY_FRR_BYPASS_ACTIVE is defined and sent within the RSVP Path and Resv messages of the bypass tunnel for reroute signaling of Summary FRR LSPs.
3.1. SUMMARY_FRR_BYPASS_ACTIVE object

When sent within an RSVP Path message, the SUMMARY_FRR_BYPASS_ACTIVE object is used to inform the MP (bypass tunnel destination) that one or more groups of protected LSPs that are being protected by the bypass tunnel are being rerouted and refreshed.

When sent within an RSVP Resv message, the SUMMARY_FRR_BYPASS_ACTIVE object is used to refresh one or more groups of LSPs that have been rerouted through the bypass tunnel.

The SUMMARY_FRR_BYPASS_ACTIVE object has the following format:

SUMMARY_FRR_BYPASS_ACTIVE Class = TBD (of the form 11bbbbbb)
Class = SUMMARY_FRR_BYPASS_ACTIVE Class, C_Type = 1 (TBD)

RSVP_HOP_Object: Class 3, as defined by [RSVP]
Replacement HOP object to be applied to all LSPs associated with each of the following Bypass_Group_Identifiers

Bypass_Group_Identifier: 32 bits

Bypass_Group_Identifier field from the RECORD_ROUTE object SUMMARY_FRR_BYPASS_ASSIGNMENT subobject(s) corresponding to all LSPs that the bypass headend (PLR) advertised this specific Bypass_Group_Identifier for. One or more Bypass_Group_Identifiers may be included.

3.2. PLR Summary FRR Path Signaling Procedure

An individual RSVP Path message for each Summary FRR LSP is not signaled.
To reroute Summary FRR LSPs via the bypass tunnel, the PLR adds the SUMMARY_FRR_BYPASS_ACTIVE object in the RSVP Path message of the bypass tunnel.

The RSVP_HOP_Object field of the SUMMARY_FRR_BYPASS_ACTIVE object is set to the common RSVP_HOP that was used during section 3.

For each affected Summary FRR group, its group identifier is added to the SUMMARY_FRR_BYPASS_ACTIVE object.

3.3. MP Summary FRR Path Signaling Procedure

Upon receiving an RSVP Path message with a SUMMARY_FRR_BYPASS_ACTIVE object, the MP performs normal merging processing for each LSP associated with each Bypass_Group_Identifier, as if it received individual RSVP Path messages for each Summary FRR LSP.

For each Summary FRR LSP being merged, the MP first modifies the Path state as follows:

1. The RSVP_HOP object is copied from the SUMMARY_FRR_BYPASS_ACTIVE RSVP_HOP_Object field.

2. The SENDER_TEMPLATE object SrcAddress field is copied from the bypass tunnel SENDER_TEMPLATE object. For the case where PLR is also the headend, and SENDER_TEMPLATE SrcAddress of the protected LSP and bypass tunnel are the same, the MP MUST use the modified HOP Hop Address field instead.

3. The ERO object is modified as per section 6.4.4. of [RSVP-TE-FRR]

4. The TIME_VALUES object is copied from the bypass tunnel RSVP Path message.

Once the above modifications are completed, the MP then performs the merge processing as per [RSVP-TE-FRR].

A failure during merge processing of any individual rerouted LSP MUST result in an RSVP Path Error message and the LSP MUST not be removed from the Bypass_Group -- this is to cover the case where the RSVP Path Error message doesn’t reach the PLR and the RSVP Path Error message may need to be resigaled.

3.4. MP Summary FRR Resv Signaling Procedure

An individual RSVP Resv message for each successfully merged Summary FRR LSP is not signaled.
The SUMMARY_FRR_BYPASS_ACTIVE object from the bypass tunnel RSVP Path message is copied into the RSVP Resv message of the bypass tunnel and signaled.

3.5. Refreshing Summary FRR Active LSPs

Refreshing of Summary FRR active LSPs is performed while refreshing the bypass tunnel itself.

Upon receiving the bypass tunnel RSVP Resv refresh (either normal full refresh message, or using [RSVP-SUMMARY-REFRESH] mechanism), the PLR MUST consider all Summary FRR LSPs associated with each Bypass_Group_Identifier listed in the SUMMARY_FRR_BYPASS_ACTIVE object to have their Resv state also refreshed. The TIMES_VALUE of the bypass tunnel RSVP Resv message is used to calculate the lifetimes.

Upon receiving the bypass tunnel RSVP Path refresh (either normal full refresh message, or using [RSVP-SUMMARY-REFRESH] mechanism), the MP MUST consider all Summary FRR LSPs associated with each Bypass_Group_Identifier listed in the SUMMARY_FRR_BYPASS_ACTIVE object to have their Path state also refreshed. The TIMES_VALUE of the bypass tunnel RSVP Path message is used to calculate the lifetimes. If a merge was previously unsuccessful and the Summary FRR LSP is being refreshed, the MP MUST re-signal the RSVP Path Error message.

3.6. Changing Summary FRR Active LSPs

When a change to a Summary FRR active LSP is required, the protected LSP association with the currently FRR active Bypass_Group_Identifier MUST be withdrawn. This is accomplished by removing the appropriate SUMMARY_FRR_BYPASS_ASSIGNMENT subobject from the RECORD_ROUTE object and signaling this in the RSVP Path or Resv change message.

Once disassociated from the Bypass_Group_Identifier, the protected rerouted LSP is no longer refreshed as per section 3.5, and MUST be refreshed independently (either normal full refresh message, or using [RSVP-SUMMARY-REFRESH] mechanism).
4. Compatibility

The new SUMMARY_FRR_BYPASS_ACTIVE object is to be defined with a class number in the form 11bbbbbb, which ensures compatibility with non-supporting nodes. Per [RSVP], nodes not supporting this extension will ignore the object but forward it, unexamined and unmodified, in all messages.

The new SUMMARY_FRR_BYPASS_ASSIGNMENT RECORD_ROUTE subobject, as per section 4.4.5. of [RSVP-TE], if not recognized SHOULD be ignored and forwarded.

5. Security Considerations

This document introduces new RSVP subobjects. Thus in the event of the interception of a signaling message, slightly more could be deduced about the state of the network than was previously the case.

6. IANA Considerations

IANA is requested to administer assignment of new values for the namespace defined in this document and summarized in this section.

IANA maintains a name space for RSVP-TE TE parameters "Resource Reservation Protocol (RSVP) Parameters" (see http://www.iana.org/assignments/rsvp-parameters). From the registries in this namespace "Route Record" types, allocation of two new RECORD_ROUTE object sub-types (IPv4 and IPv6) for the new SUMMARY_FRR_BYPASS_ASSIGNMENT subobject are required.

A new RSVP Class (of the form 11bbbbbb) and C-type for the new SUMMARY_FRR_BYPASS_ACTIVE object is required.

7. References

7.1. Normative References


May 2005.


7.2. Informative References

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Abstract

This document defines a framework for a YANG data model for configuring and managing label switched paths, including the signaling protocols, traffic engineering, and operational aspects based on carrier and content provider operational requirements.

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1. Introduction

This document describes a YANG [RFC6020] data model for MPLS and traffic engineering, covering label switched path (LSP) configuration, as well as signaling protocol configuration. The model is intended to be vendor-neutral, in order to allow operators to manage MPLS in heterogeneous environments with routers supplied by multiple vendors. The model is also intended to be readily mapped to existing implementations, however, to facilitate support from as large a set of routing hardware and software vendors as possible.

1.1. Goals and approach

The focus area of the first version of the model is to set forth a framework for MPLS, with hooks into which information specific to various signaling-protocols can be added. The framework is built around functionality from a network operator perspective rather than a signaling protocol-centric approach. For example, a traffic-engineered LSP will have configuration relating to its path computation method, regardless of whether it is signaled with RSVP-TE or with segment routing. Thus, rather than creating separate per-signaling protocol models and trying to stitch them under a common umbrella, this framework focuses on functionality, and adds signaling protocol-specific information under it where applicable.

This model does not (in the current iteration) aim to be feature complete (i.e., cover all possible aspects or features of MPLS). Rather its development is driven by examination of actual production configurations in use across a number of operator network deployments.

Configuration items that are deemed to be widely available in existing major implementations are included in the model. Those configuration items that are only available from a single implementation are omitted from the model with the expectation they will be available in companion modules that augment the current model. This allows clarity in identifying data that is part of the vendor-neutral model.

Where possible, naming in the model follows conventions used in available standards documents, and otherwise tries to be self-explanatory with sufficient descriptions of the intended behavior. Similarly, configuration data value constraints and default values,
where used, are based on recommendations in current standards
documentation. Since implementations vary widely in this respect,
this version of the model specifies only a limited set of defaults
and ranges with the expectation of being more prescriptive in future
versions based on actual operator use.

Note that this version of the model is a work-in-progress in several
respects. Although we present a complete framework for MPLS and
traffic engineering from an operational perspective, some signaling
protocol configuration will be completed in future revisions. In
addition, operational state data for MPLS LSPs is not included in
this version, but will be added in the next revision.

2. Model overview

The overall MPLS model is defined across several YANG modules and
submodules but at a high level is organized into 3 main sections:

- global -- configuration affecting MPLS behavior which exists
  independently of the underlying signaling protocol or label
  switched path configuration.

- signaling protocols -- configuration specific to signaling
  protocols used to setup and manage label switched paths.

- label switched paths -- configuration specific to instantiating
  and managing individual label switched paths.

The top level of the model is shown in the tree view below:

```
+---rw mpls!
    +---rw global
        | ... 
        +---rw signaling-protocols
            | ... 
            +---rw lsps
                ... 
```

2.1. MPLS global overview

The global section of the framework provides configuration control
for MPLS items which exist independently of an individual label
switched path or signaling protocol. These standalone items are
applicable to the entire logical routing device, and establish
fundamental configuration such as specific device interfaces where
MPLS forwarding will be permitted. Timers are also specified which
determine the length of time an LSP must be present before considered
viable for forwarding use (mpls-lsp-install-delay), and the length of
time between LSP teardown and removal of the LSP from the network
element’s forwarding information base (mpls-lsp-cleanup-delay).
Also specified are the name to value mappings of MPLS administrative
groups (mpls-admin-groups).

    +-rw mpls!
      +-rw global
        +-rw mpls-interfaces* [interface-name]
          |  +-rw interface-name            string
          |  +-rw interface-admin-groups*  -> /mpls/global/...
        +-rw mpls-lsp-install-delay?   uint16
        +-rw mpls-lsp-cleanup-delay?   uint16
        +-rw mpls-admin-groups* [admin-group-name]
          +-rw admin-group-name     string
          +-rw admin-group-value?   uint32

2.2. Signaling protocol overview

The signaling protocol section of the framework provides
configuration elements for configuring three major methods of
signaling label switched paths: RSVP, segment routing, and label
distribution protocol (LDP). Configuration of RSVP is centered
around interfaces on the device which participate in the protocol. A
key focus is to expose common RSVP configuration parameters which are
used to enhance scale and reliability (refresh-reduction, refresh-
reduction-reliable). From the same principles, configuration is
available to configure the sensitivity of IGP flooding events upon
bandwidth change on an RSVP interface (ted-update-threshold). Also
specified are options to configure RSVP soft-preemption (soft-
preemption), and for MPLS protection (link-protection).

Containers for specifying signaling via segment routing and LDP are
also present. Specific subelements will be added for those
protocols, as well as for BGP labeled unicast, in the next revision.
2.3. LSP overview

This part of the framework contains LSP information. At the high level, LSPs are split into three categories: traffic-engineering-capable (constrained-path), non-traffic-engineered determined by the IGP (unconstrained-path), and hop-by-hop configured (static).

The first two categories, constrained-path and unconstrained-path are the ones for which multiple signaling protocols exist, and are organized in protocol-specific and protocol-independent sections. For example, traffic-engineered, constrained path, LSPs may be set up using RSVP-TE or segment routing, and unconstrained LSPs that follow the IGP path may be signaled with LDP or with segment routing. IGP-determined LSPs may also be signaled by RSVP but this usage is not considered in the current version of the model.

A portion of the data model for constrained path traffic-engineered LSPs is shown below:
Similarly, the partial model for non-traffic-engineered, or IGP-based, LSPs is shown below:

```mermaid
graph LR
  A[---rw mpls!]
  B[---rw lsps]
  C[---rw unconstrained-path]
  D[---rw path-setup-protocol]
  E[---rw ldp!]
  F[---rw segment-routing!]
```

3. Example use cases

3.1. Traffic engineered p2p LSP signaled with RSVP

A possible scenario may be the establishment of a mesh of traffic-engineered LSPs where RSVP signaling is desired, and the LSPs use a local constrained path calculation to determine their path. These LSPs would fall into the category of a constrained-path LSP. The LSP will specify the path setup method as RSVP inside the path-setup container, indicating the LSP desires RSVP signaling. The LSP would be configured as locally-computed under the path-computation-method container, specifying the use of cspf (use-cspf). Additional attributes such as bandwidth (explicit or auto), protection style, and placement constraints are available in the path-attributes container.

The structure to support these is shown in the constrained-path portion of the data model below:
3.2. Traffic engineered LSP signaled with SR

A possible scenario may be the establishment of disjoint paths in a network where there is no requirement for per-LSP state to be held on midpoint nodes within the network, or RSVP-TE is unsuitable (as described in [I-D.ietf-spring-segment-routing-mpls] and [I-D.shakir-rtgwg-sr-performance-engineered-lsps]). Such LSPs fall in the constrained-path category. Similar to any other traffic engineered LSPs, the path computation method must be specified. Path attributes, such as the as lsp-placement-constraints (expressed as administrative groups) or metric must be defined. Finally, the path must be specified in a signaling-protocol specific manner appropriate for SR. The same configuration elements from the tree above apply in this case, except that path setup is done by the head-end by building a label stack, rather than signaled.
3.3. IGP-congruent LDP-signaled LSP

A possible scenario may be the establishment of a full mesh of LSPs. When traffic engineering is not an objective, no constraints are placed on the end-to-end path, and the best-effort path can be setup using LDP signaling simply for label distribution. The LSPs follow IGP-computed paths, and fall in the unconstrained-path category in the model. Protocol-specific configuration pertaining to the signaling protocol used, such as the FEC definition and metrics assigned are in the path-setup-protocol portion of the model.

The relevant part of the model for this case is shown below:

```
+--rw mpls!
  +--rw lsps
    +--rw unconstrained-path
      +--rw path-setup-protocol
        +--rw ldp!
          +--rw tunnel
            +--rw tunnel-type? mplst:tunnel-type
            +--rw ldp-type? enumeration
          +--rw p2p-lsp
          |  +--rw fec-address* inet:ip-prefix
          +--rw p2mp-lsp
          +--rw mp2mp-lsp
```

A common operational issue encountered when using LDP is traffic blackholing under the following scenario: when an IGP failure occurs, LDP is not aware of it as these are two protocols running independently, resulting in traffic blackholing at the IGP failure point even though LDP is up and running. "LDP-IGP synchronization" [RFC5443] can be used to cost out the IGP failing point/segment to avoid the blackholing issue. The LDP-IGP synchronization function will be incorporated in a future version of this document.

Note that targeted LDP sessions are not discussed in this use case, and will be incorporated as a separate use case in a future version of this document.

4. Security Considerations

MPLS configuration has a significant impact on network operations, and as such any related protocol or model carries potential security risks.

YANG data models are generally designed to be used with the NETCONF protocol over an SSH transport. This provides an authenticated and secure channel over which to transfer BGP configuration and
operational data. Note that use of alternate transport or data encoding (e.g., JSON over HTTPS) would require similar mechanisms for authenticating and securing access to configuration data.

Most of the data elements in the configuration model could be considered sensitive from a security standpoint. Unauthorized access or invalid data could cause major disruption.

5. IANA Considerations

This YANG data model and the component modules currently use a temporary ad-hoc namespace. If and when it is placed on redirected for the standards track, an appropriate namespace URI will be registered in the IETF XML Registry“ [RFC3688]. The MPLS YANG modules will be registered in the "YANG Module Names" registry [RFC6020].

6. YANG modules

The modules and submodules comprising the MPLS configuration and operational model are currently organized as depicted below.

```
+-------+
| MPLS  |
+-------+

+--------+       +--------+       +--------+
| TE LSPs |       | IGP-based LSPs |       | static LSPs |
+--------+       +--------+       +--------+

+--------+       +--------+       +--------+
| RSVP   |       | SEGMENT |       | LDP    |
+--------+       +--------+       +--------+

The base MPLS module includes submodules describing the three different types of support LSPs, i.e., traffic-engineered (constrained-path), IGP congruent (unconstrained-path), and static. The signaling protocol specific parts of the model are described in separate modules for RSVP, segment routing, and LDP. As mentioned earlier, support for BGP labeled unicast is also planned in a future revision.
A module defining various reusable MPLS types is included, and these modules also make use of the standard Internet types, such as IP addresses, as defined in RFC 6991 [RFC6991].

6.1. MPLS base modules

```yang
<CODE BEGINS> file mpls.yang
module mpls {
    yang-version "1";
    // namespace
    namespace "http://openconfig.net/yang/mpls";
    prefix "mpls";

    // import some basic types
    import mpls-types { prefix mplst; }
    import mpls-rsvp { prefix rsvp; }
    import mpls-sr { prefix sr; }
    import mpls-ldp { prefix ldp; }

    // include submodules
    include mpls-te;
    include mpls-igp;
    include mpls-static;

    // meta
    organization "OpenConfig working group";
    contact
        "OpenConfig working group
         netopenconfig@googlegroups.com";
    description
        "This module provides data definitions for configuration of
         Multiprotocol Label Switching (MPLS) and associated protocols for
         signaling and traffic engineering.
         
         RFC 3031: Multiprotocol Label Switching Architecture
         
         The MPLS / TE data model consists of several modules and
         submodules as shown below. The top-level MPLS module describes
         the overall framework. Three types of LSPs are supported:
         
         i) traffic-engineered (or constrained-path)"
```
ii) IGP-congruent (LSPs that follow the IGP path)

iii) static LSPs which are not signaled

The structure of each of these LSP configurations is defined in corresponding submodules. Companion modules define the relevant configuration and operational data specific to key signaling protocols used in operational practice.
type identityref {
  base mplst:path-setup-protocol;
}  
description "path setup protocol to use with the LSP";
}

grouping mpls-administrative-groups {
  description
  "global level definitions for MPLS link admin groups";
  list mpls-admin-groups {
    key admin-group-name;
    description "configuration of value to name mapping for mpls
    affinities/admin-groups";
    leaf admin-group-name { 
      type string;
      description "name for mpls admin-group";
    }
    leaf admin-group-value { 
      type uint32;
      description "value for mpls admin-group";
    }
  }
}

// TODO: this should be made a reference to an interface in the
// interfaces model
// TODO - should probably have as key the interface name, also
// need an easy way to specify all interfaces and to exclude
// interfaces.
list mpls-interfaces {
  key interface-name;
  description "interfaces for which MPLS is enabled";
  leaf interface-name { 
    type string;
  }
}

leaf-list interface-admin-groups {
  type leafref {
    path "/mpls:mpls/mpls:global/mpls:mpls-admin-groups/
    + "mpls:admin-group-name";
    description
    "list of configured admin-groups on the interface";
  }
}

leaf mpls-lsp-install-delay {
  type uint16 {
    range 0..3600;
  }
  units seconds;
  description "delay the use of newly installed lsp for a
  specified amount of time.";
}

leaf mpls-lsp-cleanup-delay {
  type uint16;
  units seconds;
  description "delay the removal of old lsp for a specified
  amount of time";
}
}

container mpls {
  presence "top-level container for MPLS config and operational
  state";
  description "Anchor point for mpls configuration and operational
data";
  container global {
    description "general mpls configuration across LSP and tunnel
types";
    uses mpls-global;
    uses mpls-administrative-groups;
  }
  container signaling-protocols {
}
description "top-level signaling protocol configuration";

uses rsvp:rsvp-global;
uses sr:sr-global;
uses ldp:ldp-global;
}

container lsps {
    description "LSP definitions and configuration";

    container constrained-path {
        description "traffic-engineered LSPs supporting different path computation and signaling methods";

        uses mpls-te-global;
        uses path-definitions;

        list label-switched-path {
            key signaled-name;
            description "list of defined TE LSPs";

            uses te-lsp-common;
            uses te-lsp-setup;
        }
    }

    container unconstrained-path {
        description "LSPs that use the IGP-determined path, i.e., non traffic-engineered, or non constrained-path";

        uses igp-lsp-common;
        uses igp-lsp-setup;
    }

    container static-lsps {
        description "statically configured LSPs, without dynamic signaling";

        uses static-lsp-main;
    }
}

// augment statements

// rpc statements
<CODE BEGINS> file mpls-types.yang
module mpls-types {
    yang-version "1";
    // namespace
    namespace "http://openconfig.net/yang/mpls-types";
    prefix "mplst";

    // meta
    organization "OpenConfig working group";
    contact
        "OpenConfig working group
          netopenconfig@googlegroups.com";
    description
        "General types for MPLS / TE data model";
    revision "2015-02-01" {
        description
            "Initial revision";
        reference "TBD";
    }

    // extension statements
    // feature statements
    // identity statements

    // using identities rather than enum types to simplify adding new
    // signaling protocols as they are introduced and supported

    identity path-setup-protocol {
        description "base identity for supported MPLS signaling
                      protocols";
    }

    identity path-setup-rsvp {
        base path-setup-protocol;
    }
</CODE ENDS>
typedef percentage {
  type uint8 {
    range "0..100";
  }
  description "Integer indicating a percentage value";
}

typedef mpls-label {
  type union {
    type uint32 {
      range 16..1048575;
    }
  }
  type enumeration {
    enum IPV4_EXPLICIT_NULL {
      value 0;
      description "valid at the bottom of the label stack, indicates that stack must be popped and packet forwarded based on IPv4 header";
    }
    enum ROUTER_ALERT {
      value 1;
      description "allowed anywhere in the label stack except the bottom, local router delivers packet to the local CPU when this label is at the top of the stack";
    }
    enum IPV6_EXPLICIT_NULL {
      value 2;
      description "valid at the bottom of the label stack, indicates that stack must be popped and packet forwarded based on IPv6 header";
    }
  }
}
enum IMPLICIT_NULL {
    value 3;
    description "assigned by local LSR but not carried in packets";
}

enum ENTROPY_LABEL_INDICATOR {
    value 7;
    description "Entropy label indicator, to allow an LSR to distinguish between entropy label and application labels RFC 6790";
}

description "type for MPLS label value encoding";
reference "RFC 3032 - MPLS Label Stack Encoding";

typedef tunnel-type {
    type enumeration {
        enum P2P {
            description "point-to-point label-switched-path";
        }
        enum P2MP {
            description "point-to-multipoint label-switched-path";
        }
        enum MP2MP {
            description "multipoint-to-multipoint label-switched-path";
        }
    }
    description "defines the tunnel type for the LSP";
}

// grouping statements
// data definition statements
// augment statements
// rpc statements
// notification statements
6.2. MPLS LSP submodules

```yang
<CODE BEGINS> file mpls-te.yang
submodule mpls-te {
    yang-version "1";
    belongs-to "mpls" {
        prefix "mpls";
    }

    // import some basic types
    import ietf-inet-types { prefix inet; }
    import mpls-types { prefix mplst; }
    import mpls-rsvp { prefix rsvp; }
    import mpls-sr { prefix sr; }

    // meta
    organization "OpenConfig working group";

    contact
        "OpenConfig working group
        netopenconfig@googlegroups.com";

    description
        "Configuration related to constrained-path LSPs and traffic
        engineering. These definitions are not specific to a particular
        signaling protocol or mechanism (see related submodules for
        signaling protocol-specific configuration).";

    revision "2014-07-07" {
        description
            "Initial revision";
        reference "TBD";
    }

    // extension statements

    // feature statements

    // identity statements
```

// using identities for path comp method, though enums may also
// be appropriate if we decided these are the primary computation
// mechanisms in future.
identity path-computation-method {
    description "base identity for supported path computation
    mechanisms";
}

identity locally-computed {
    base path-computation-method;
    description "indicates a constrained-path LSP in which the
    path is computed by the local LER";
}

identity externally-queried {
    base path-computation-method;
    description "constrained-path LSP in which the path is
    obtained by querying an external source, such as a PCE server";
}

identity explicitly-defined {
    base path-computation-method;
    description "constrained-path LSP in which the path is
    explicitly specified as a collection of strict or/and loose
    hops";
}

// typedef statements
typedef mpls-hop-type {
    type enumeration {
        enum LOOSE {
            description "loose hop in an explicit path";
        }
        enum STRICT {
            description "strict hop in an explicit path";
        }
    }
    description "enumerated type for specifying loose or strict
    paths";
}

typedef te-metric-type {
    type union {
        type enumeration {
            enum IGP {
                description "set the LSP metric to track the underlying
                IGP metric";
            }
        }
    }
}

typedef cspf-tie-breaking {
    type enumeration {
        enum RANDOM {
            description "CSPF calculation selects a random path among multiple equal-cost paths to the destination";
        }
        enum LEAST_FILL {
            description "CSPF calculation selects the path with greatest available bandwidth";
        }
        enum MOST_FILL {
            description "CSPF calculation selects the path with the least available bandwidth";
        }
    }
    default RANDOM;
    description "type to indicate the CSPF selection policy when multiple equal cost paths are available";
}

typedef mpls-protection-style {
    type enumeration {
        enum UNPROTECTED {
            description "no protection is desired for the lsp";
        }
        enum LINK-PROTECTION-REQUESTED {
            description "link protection is desired for the lsp";
        }
        enum LINK-NODE-PROTECTION-REQUESTED {
            description "node and link protection is desired for the lsp";
        }
    }
    default UNPROTECTED;
    description "Specifies the protection type for the LSP";
}

// grouping statements

grouping te-lsp-common {
description "common definitions for traffic-engineered LSPs";

leaf signaled-name {
    type string;
    description "LSP name, also carried in signaling messages when appropriate";
}

leaf lsp-description {
    type string;
    description "optional text description for the LSP";
}

container path-computation-method {
    description "select and configure the way the LSP path is computed";

    leaf path-computation {
        type identityref {
            base path-computation-method;
        }
        description "path computation method to use with the LSP";
    }

    uses te-lsp-comp-explicit;
    uses te-lsp-comp-queried;
    uses te-lsp-comp-local;
}

container path-attributes {
    description "general path attribute settings for TE-LSP tunnels";

    // XXX - no, this is also there for LDP - also removed the reference to "igp metric" as this is going to be confusing, // unless we mandate for the LSP to have the same metric as the Igp, which is going to be hard with some vendors // implementations.
    leaf metric {
        type te-metric-type;
        description "LSP metric, either explicit or IGP";
    }

    container bandwidth {
        description "bandwidth specification for the LSP";

        choice lsp-bandwidth {
            default explicit;
        }
    }
}
description "select how bandwidth for the LSP will be
specified and managed";
case explicit {
  leaf set-bandwidth {
    type uint32;
    description "set bandwidth explicitly, e.g., using
offline calculation";
  }
}
case auto {
  container auto-bandwidth {
    presence "presence of this container indicates
auto-bandwidth is enabled for the LSP";

description "configure auto-bandwidth operation in
which devices automatically adjust bandwidth to meet
requirements";

  leaf min-bw {
    type uint32;
    description "set the minimum bandwidth in Mbps for an
auto-bandwidth LSP";
  }

  leaf max-bw {
    type uint32;
    description "set the maximum bandwidth in Mbps for an
auto-bandwidth LSP";
  }

  leaf adjust-interval {
    type uint32;
    description "time in seconds between adjustments to
LSP bandwidth";
  }

  leaf adjust-threshold {
    type mplst:percentage;
    description "percentage difference between the LSP’s
specified bandwidth and its current bandwidth
allocation -- if the difference is greater than the
specified percentage, auto-bandwidth adjustment is
triggered";
  }
}

ccontainer overflow {

  presence "presence of this element indicates overflow
is configured for the lsp

description "configuration for mpls lsp bandwidth overflow adjustment"

leaf overflow-threshold {
    type mplst:percentage;
    description "bandwidth percentage change to trigger an overflow event"
}

leaf trigger-event-count {
    type uint16;
    description "number of consecutive overflow sample events needed to trigger an overflow adjustment"
}

container underflow {
    presence
    "presence of this element indicates underflow is configured for the lsp"

description "configuration for mpls lsp bandwidth underflow adjustment"

leaf underflow-threshold {
    type mplst:percentage;
    description "bandwidth percentage change to trigger and underflow event"
}

leaf trigger-event-count {
    type uint16;
    description "number of consecutive underflow sample events needed to trigger an underflow adjustment"
}

container lsp-placement-constraints {
    description
"constraints on lsp routing such as admin-groups";

container admin-groups {
  description
  "Include/Exclude constraints for link affinities";

  list exclude-groups {
    key admin-group-name;
    description
    "list of admin-groups to exclude in path calculation";

    leaf admin-group-name {
      type leafref {
        path "mpls/global/mpls-admin-groups/" +
        "admin-group-name";
      }
      description
      "name of the admin group -- references a defined admin group";
    }
  }

  list include-all-groups {
    key admin-group-name;
    description
    "list of admin-groups of which all must be included";

    leaf admin-group-name {
      type leafref {
        path "mpls/global/mpls-admin-groups/" +
        "admin-group-name";
      }
      description
      "name of the admin group -- references a defined admin group";
    }
  }

  list include-any-groups {
    key admin-group-name;
    description
    "list of admin-groups of which one must be included";

    leaf admin-group-name {

type leafref {
    path "/mpls/global/mpls-admin-groups/" +
    "admin-group-name";
}

description
"name of the admin group -- references a defined
admin group";
}
}
}
}

container protection {
    description "failure protection properties for the LSP";

    leaf protection-style-requested {
        type mpls-protection-style {
        }
        description "style of mpls frr protection desired. both
facility backup and one-to-one are options";
    }
    }
}

// TODO - note that this is only currently defined for
// RSVP-like entities
grouping te-lsp-comp-explicit {
    description "definitions for LSPs in which hops are explicitly
specified";

    container explicit-path {
        description "LSP with explicit path specification";

        leaf path-name {
            type leafref {
                path "/mpls/lsps/constrained-path/" +
                "path-information/path/path-name";
                require-instance true;
            }
            description "reference to a defined path";
        }
    }
}

grouping te-lsp-comp-queried {
    description "definitions for LSPs computed by querying a remote
service, e.g., PCE server";

    container implicit-path {
        description "LSP with implicit path specification";

        leaf path-name {
            type leafref {
                path "/mpls/lsps/constrained-path/" +
                "path-information/path/path-name";
                require-instance true;
            }
            description "reference to a defined path";
        }
    }
}

// TODO - note that this is only currently defined for
// RSVP-like entities

container queried-path {
  description "LSP with path queried from an external server";
  
  leaf path-computation-server {
    type inet:ip-address;
    description "Address of the external path computation server";
  }
}

grouping te-lsp-comp-local {
  description "definitions for locally-computed LSPs";
  
  container locally-computed {
    description "LSP with path computed by local ingress LSR";
    
    leaf use-cspf {
      type boolean;
      description "Flag to enable CSPF for locally computed LSPs";
    }
    leaf cspf-tiebreaker {
      type cspf-tie-breaking;
      description "Determine the tie-breaking method to choose between equally desirable paths during CSFP computation";
    }
  }
}

grouping path-definitions {
  description "describe path configuration for specifying LSP hops";
  
  container path-information {
    description "common information for MPLS path definition";
    
    list path {
      key path-name;
      description "specification of LSP path";
      
      leaf path-name {
        type string;
        description "identifier for the LSP path";
      }
    }
  }
}
list hop {
    key address;
    description "specification of the strict and loose hops in
    the path";

    leaf address {
        type inet:ip-address;
        description "router hop for the LSP path";
    }

    leaf type {
        type mpls-hop-type;
        description "strict or loose hop";
    }
}

grouping te-lsp-setup {
    description "signaling protocol configuration for traffic
    engineered LSPs";

    container path-setup {
        description "select and configure the signaling method for
        the LSP";

        // uses path-setup-common;
        uses rsvp:te-lsp-rsvp-setup;
        uses sr:te-lsp-sr-setup;
    }
}

grouping mpls-te-global {
    description "global level defintions for mpls traffic
    engineered LSPs";
}

// data definition statements
// augment statements
// rpc statements
// notification statements
<CODE BEGINS> file mpls-igp.yang
submodule mpls-igp {
  yang-version "1";
  belongs-to "mpls" {
    prefix "mpls";
  }

  // import some basic types
  import mpls-ldp { prefix ldp; }
  import mpls-sr { prefix sr; }

  // meta
  organization "OpenConfig working group";

  contact
    "OpenConfig working group
     netopenconfig@googlegroups.com";

  description
    "Configuration generic configuration parameters for IGP-congruent LSPs";

  revision "2014-07-07" {
    description
      "Initial revision";
    reference "TBD";
  }

  // extension statements
  // feature statements
  // identity statements
  // typedef statements
  // grouping statements

  grouping igp-lsp-common {

<CODE ENDS>
description "common definitions for IGP-congruent LSPs";

// container path-attributes {
//  description "general path attribute settings for IGP-based
//  LSPs";
//}
}

grouping igp-lsp-setup {
  description "signaling protocol definitions for IGP-based LSPs";

  container path-setup-protocol {
    description "select and configure the signaling method for
    the LSP";

    // uses path-setup-common;
    uses ldp:igp-lsp-ldp-setup;
    uses sr:igp-lsp-sr-setup;
  }
}

// data definition statements
// augment statements
// rpc statements
// notification statements
}

<CODE ENDS>

<CODE BEGINS> file mpls-static.yang
submodule mpls-static {
  yang-version "1";

  belongs-to "mpls" {
    prefix "mpls";
  }

  // import some basic types
  import mpls-types {prefix mplst; }

import ietf-inet-types { prefix inet; }

// meta
organization "OpenConfig working group";

contact
 "OpenConfig working group
 netopenconfig@googlegroups.com";

description
 "Defines static LSP configuration";

revision "2015-02-01" {
 description
 "Initial revision";
 reference "TBD";
 }

// extension statements

// feature statements

// identity statements

// typedef statements

// grouping statements

grouping static-lsp-common {
 description "common definitions for static LSPs";

leaf next-hop {
 type inet:ip-address;
 description "next hop IP address for the LSP";
 }

leaf incoming-label {
 type mplst:mpls-label;
 description "label value on the incoming packet";
 }

leaf push-label {
 type mplst:mpls-label;
 description "label value to push at the current hop for the LSP";
 }
}
grouping static-lsp-main {
    description "grouping for top level list of static LSPs";
}

list label-switched-path {
    key name;
    description "list of defined static LSPs";

    leaf name {
        type string;
        description "name to identify the LSP";
    }

    // TODO: separation into ingress, transit, egress may help
    // to figure out what exactly is configured, but need to
    // consider whether implementations can support the
    // separation
    container ingress {
        description "Static LSPs for which the router is an
                    ingress node";

        uses static-lsp-common;
    }

    container transit {
        description "static LSPs for which the router is a
                    transit node";

        uses static-lsp-common;
    }

    container egress {
        description "static LSPs for which the router is a
                    egress node";

        uses static-lsp-common;
    }
}

// data definition statements
// augment statements
// rpc statements
// notification statements
6.3. MPLS signaling protocol modules

<CODE BEGINS> file mpls-rsvp.yang
module mpls-rsvp {
    yang-version "1";
    // namespace
    namespace "http://openconfig.net/yang/rsvp";
    prefix "rsvp";
    // import some basic types
    import ietf-inet-types { prefix inet; }
    import mpls-types { prefix mplst; }

    // meta
    organization "OpenConfig working group";
    contact
        "OpenConfig working group
        netopenconfig@googlegroups.com";
    description
        "Configuration for RSVP signaling, including global protocol
        parameters and LSP-specific configuration for constrained-path
        LSPs";
    revision "2014-07-07" {
        description
            "Initial revision";
        reference "TBD";
    }

    // extension statements
    // feature statements
    // identity statements
    // typedef statements
    // grouping statements

}
grouping rsvp-global {
  description "Global RSVP protocol configuration";
}

container rsvp {
  description "RSVP global signaling protocol configuration";

  // interfaces, bw percentages, hello timers, etc goes here"

  list interfaces {
    key interface-name;
    description "list of per-interface RSVP configurations";

    // TODO: update to interface ref -- move to separate
    // augmentation.
    leaf interface-name {
      type string;
      description "references a configured IP interface";
    }

    leaf hello-interval {
      type uint16 {
        range 0..60000;
      }
      units milliseconds;
      description "set the interval in ms between RSVP hello
      messages";
    }

    // TODO: confirm that the described semantics are supported
    // on various implementations. Finer grain configuration
    // will be vendor-specific
    leaf refresh-reduction {
      type boolean;
      default true;
      description "enables all RSVP refresh reduction message
      bundling, RSVP message ID, reliable message delivery
      and summary refresh";
      reference "RFC 2961 RSVP Refresh Overhead Reduction
      Extensions";
    }

    leaf refresh-reduction-reliable {
      type boolean;
      default true;
      description "enables RSVP refresh reduction reliable
      delivery and message_ID";
      reference "RFC 2961 RSVP Refresh Overhead Reduction
      Extensions";
    }
  }
}
leaf subscription {
    type mplst:percentage;
    description "percentage of the interface bandwidth that RSVP can reserve"
}

leaf ted-update-threshold {
    type mplst:percentage;
    description "percentage of interface bandwidth change that triggers an update event into the IGP TED"
}

// TODO: this may need to be moved to common TE LSP config
container link-protection {
    description "link-protection (NHOP) related configuration";
    presence "presence of this container indicates facility protection is configured on the interface"

    leaf link-protection-only {
        type boolean;
        default false;
        description "disables node protection on this interface, and forces only link protection"
    }

    leaf bypass-optimize-interval {
        type uint16;
        units seconds;
        description "interval between periodic optimization of the bypass LSPs";
        // note: this is interface specific on juniper
        // on iox, this is global. need to resolve.
    }

    // to be completed, things like enabling link protection,
    // optimization times, etc.
}

container soft-preemption {
    description "options relating to RSVP soft preemption";
    presence "presence of this container enables RSVP soft preemption on a node"

    leaf soft-preemption-timeout {
        type uint16 {
        }
    }
}
range 0..300;
}
default 0;
description "timeout value for soft preemption to revert
to hard preemption";
}
}
}
grouping te-tunnel-rsvp {
    description "definitions for RSVP-signaled LSP tunnel types,
e.g., applicable to point-to-point LSPs";
}
container tunnel {
    description "contains configuration stanzas for different LSP
tunnel types (P2P, P2MP, etc.)";
    leaf tunnel-type {
        type mplst:tunnel-type;
        description "specifies the type of LSP, e.g., P2P or P2MP";
    }
    container p2p-lsp {
        when "tunnel-type = 'P2P'" {
            description "container active when LSP tunnel type is
point to point";
        }
    }
    description "properties of point-to-point tunnels";
    leaf destination {
        type inet:ip-address;
        description "destination egress node for the LSP";
    }
    leaf tunnel-local-id {
        type union {
            type uint32;
            type string;
        }
        description "locally significant optional identifier for the
LSP; may be a numerical or string value";
    }
    leaf soft-preemption {
        type boolean;
        description "enables RSVP soft-preemption on this LSP";
        default false;
// p2p-lsp

container p2mp-lsp {
  when "tunnel-type = 'P2MP'" {
    description "container is active when LSP tunnel type is point to multipoint";
  }

  description "properties of point-to-multipoint tunnels";

  leaf-list destination {
    type inet:ip-address;
    description "list of destinations / egress nodes for the multipoint LSP tunnel";
  }
}

grouping te-lsp-rsvp-setup {
  description "data definitions for RSVP-signalled LSPs";

  container rsvp {
    presence "Presence of this container sets the LSP to use RSVP signaling";

    description "Configuration for RSVP-signalled TE LSPs";

    container path-specification {
      description "Definition of primary/backup paths for purpose of signaling the LSP";
    }

    leaf setup-priority {
      type uint8 {
        range 0..7;
      }
      default 7;
      description "preemption priority during LSP setup, lower is higher priority; default 7 indicates that LSP will not preempt established LSPs during setup";
    }

    leaf hold-priority {
      type uint8 {

range 0..7;
} default 0;
description "preemption priority once the LSP is established,
lower is higher priority; default 0 indicates that other LSPs
will not preempt the LSPs once established";
}

leaf retry-timer {
  type uint16 {
    range 1..600;
  }
  units seconds;
  description "sets the time between attempts to establish the
LSP";
}
//TODO: add other RSPV parms: optimize delay, switchover delay,
// etc.
// include tunnel (p2p, p2mp, etc).
uses te-tunnel-rsvp;
}

// data definition statements
// augment statements
// rpc statements
// notification statements

<CODE ENDS>

<CODE BEGINS> file mpls-sr.yang
module mpls-sr {
  yang-version "1";
  // namespace
  namespace "http://openconfig.net/yang/sr";
  prefix "sr";

  // import some basic types

import ietf-inet-types { prefix inet; }
import mpls-types { prefix mplst; }

// meta
organization "OpenConfig working group";

contact
  "OpenConfig working group
  netopenconfig@googlegroups.com"

description
  "Configuration for MPLS with segment routing-based LSPs,
   including global parameters, and LSP-specific configuration for
   both constrained-path and IGP-congruent LSPs";

revision "2014-07-07" {
  description
    "Initial revision";
  reference "TBD";
}

// extension statements

// feature statements

// identity statements

// typedef statements

// grouping statements

grouping sr-global {
  description "global segment routing signaling configuration";

  container segment-routing {
    description "SR global signaling config";
  }
}

grouping te-tunnel-sr {
  description "definitions for SR-signaled LSP tunnel types,
   .e.g., applicable to point-to-point LSPs";

  container tunnel {
    description "contains configuration stanzas for different LSP
     tunnel types (P2P, P2MP, etc.)";
  }
}
leaf tunnel-type {
  type mplst:tunnel-type;
  description "specifies the type of LSP, e.g., P2P or P2MP";
}

container p2p-lsp {
  when "tunnel-type = 'P2P'" {
    description "container active when LSP tunnel type is point to point";
  }
  description "Config for point-to-point tunnels";
  // fill out the configuration details per segment
  // routing requirements
}
}

grouping te-lsp-sr-setup {
  description "data definitions for SR signaling";

container segment-routing {
  presence "Presence of this container sets the LSP to use SR signaling";
  description "Configuration for signaling SR-based TE LSPs";
  uses te-tunnel-sr;
}
}

grouping igp-tunnel-sr {
  description "definitions for SR-signaled, IGP-based LSP tunnel types";

container tunnel {
  description "contains configuration stanzas for different LSP tunnel types (P2P, P2MP, etc.)";

  leaf tunnel-type {
    type mplst:tunnel-type;
    description "specifies the type of LSP, e.g., P2P or P2MP";
  }

  container p2p-lsp {

when "tunnel-type = 'P2P'" {
    description "container active when LSP tunnel type is point to point";
}
description "properties of point-to-point tunnels";

leaf-list fec-address {
    type inet:ip-prefix;
    description "Address prefix for packets sharing the same forwarding equivalence class for the IGP-based LSP";
}
}
}
grouping igp-lsp-sr-setup {
    description "grouping for SR-IGP path setup for IGP-congruent LSPs"
    container segment-routing {
        presence "Presence of this container sets the LSP to use SR signaling";
        description "segment routing signaling extensions for IGP-congruent LSPs";
        uses igp-tunnel-sr;
    }
}

// data definition statements
// augment statements
// rpc statements
// notification statements
}

<CODE ENDS>

<CODE BEGINS> file mpls-ldp.yang
module mpls-ldp {
    yang-version "1";

// namespace
namespace "http://openconfig.net/yang/ldp";

prefix "ldp";

// import some basic types
import ietf-inet-types { prefix inet; }
import mpls-types { prefix mplst; }

// meta
organization "OpenConfig working group";

contact
  "OpenConfig working group
   netopenconfig@googlegroups.com";

description
  "Configuration of Label Distribution Protocol global and LSP-
   specific parameters for IGP-congruent LSPs";

revision "2014-07-07" { description
  "Initial revision";
  reference "TBD";
}

// extension statements
// feature statements
// identity statements
// typedef statements
// grouping statements

grouping ldp-global {
  description "global LDP signaling configuration";

  container ldp {
    description "LDP global signaling configuration";

    container timers {
      description "LDP timers";
    }
  }
}
grouping igp-tunnel-ldp {
  description "common definitions for LDP-signaled LSP tunnel types";
}

container tunnel {
  description "contains configuration stanzas for different LSP tunnel types (P2P, P2MP, etc.)";

  leaf tunnel-type {
    type mplst:tunnel-type;
    description "specifies the type of LSP, e.g., P2P or P2MP";
  }

  leaf ldp-type {
    type enumeration {
      enum BASIC {
        description "basic hop-by-hop LSP";
      }
      enum TARGETED {
        description "tLDP LSP";
      }
    }
    description "specify basic or targeted LDP LSP";
  }

  container p2p-lsp {
    when "tunnel-type = 'P2P'" {
      description "container active when LSP tunnel type is point to point";
    }

    description "properties of point-to-point tunnels";

    leaf-list fec-address {
      type inet:ip-prefix;
      description "Address prefix for packets sharing the same forwarding equivalence class for the IGP-based LSP";
    }
  }

  container p2mp-lsp {
    when "tunnel-type = 'P2MP'" {
      description "container is active when LSP tunnel type is point to multipoint";
    }

    description "properties of point-to-multipoint tunnels";
  }
}
// TODO: specify group/source, etc.
}

container mp2mp-lsp {
    when "tunnel-type = 'MP2MP'" {
        description "container is active when LSP tunnel type is
multipoint to multipoint";
    }
    description "properties of multipoint-to-multipoint tunnels";
    // TODO: specify group/source, etc.
}

grouping igp-lsp-ldp-setup {
    description "grouping for LDP setup attributes";
    container ldp {
        presence "Presence of this container sets the LSP to use
LDP signaling";
        description "LDP signaling setup for IGP-congruent LSPs";
        // include tunnel (p2p, p2mp, ...)
        uses igp-tunnel-ldp;
    }
}

// data definition statements
// augment statements
// rpc statements
// notification statements

<CODE ENDS>
7. Contributing Authors

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YANG Data Model for MPLS LDP and mLDP
draft-raza-mpls-ldp-mldp-yang-00

Abstract

This document describes a YANG data model for Multi-Protocol Label Switching (MPLS) Label Distribution Protocol (LDP) and Multipoint LDP (mLDP).

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 September 10, 2015.
1. Introduction

The Network Configuration Protocol (NETCONF) [RFC6241] is a network
management protocol that defines mechanisms to manage network
devices. YANG [RFC6020] is a modular language that represents data
structures in an XML tree format, and is used as a data modeling
language for the NETCONF.

This document introduces a YANG data model for MPLS Label
Distribution Protocol (LDP) [RFC5036] and Multipoint LDP (mLDP)
[RFC6388]. For LDP, it also covers LDP IPv6 [I-D.ietf-mpls-ldp-ipv6]
and LDP capabilities [RFC5561].
The data model is defined for following constructs that are used for
managing the protocol:

- Configuration
- Operational State
- Executables (Actions)
- Notifications

Given mLDP tight coupling with LDP, mLDP model is defined under LDP
tree. The document is organized to first define the data model for
the configuration, operational state, actions and notifications of
LDP, followed by mLDP.

2. Specification of 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 [RFC2119].

In this document, the word "IP" is used to refer to both IPv4 and
IPv6, unless otherwise explicitly stated. For example, "IP address
family" means and be read as "IPv4 and/or IPv6 address family"

3. LDP YANG Model

3.1. Overview

The LDP/mLDP Yang model is defined under "ietf-mpls-ldp" module and
augments "routing-protocol" list in ietf-routing module
[I-D.ietf-netmod-routing-cfg] with LDP and mLDP specific parameters.
[Ed note: This model will be aligned with MPLS as and when a base
tree for MPLS is defined and available].

There are four containers in LDP module as follows:

- Read-Write parameters (for configuration)
- Read-only parameters (for operational state)
- Notifications (for events)
- RPCs (for executing commands to perform some action)

Before going into data model details, it is important to take note of
the following points:
This module aims to address only the core LDP/mLDP parameters as per RFC specification, as well as some widely used and deployed non-RFC features. Any vendor specific feature should be defined in a vendor-specific augmentation of this model.

Multi-topology LDP [RFC7307] and Multi-topology mLDP [I-D.iwijnand-mpls-mldp-multi-topology] are beyond the scope of this document.

This module does not cover any applications running on top of LDP and mLDP, nor does it cover any OAM procedures for LDP and mLDP.

Current revision defines protocol-centric model as compared to vrf-centric model. The vrf-centric model will be specified in a later revision. [Ed note: This specification will be aligned as and when a decision to use protocol vs vrf centric model is made at RTG group level]

This model assumes platform-wide label space (i.e. label space Id of zero).

In this model, an "instance" under LDP tree refers to a VRF instance.

This model currently supports two address-families, namely "ipv4" and "ipv6".

The label and neighbor policies and filters are defined using a prefix-list. The prefix-list is referenced from routing-policy model as defined in [I-D.shaikh-rtgwg-policy-model].

The use of grouping (templates) for bundling and grouping the configuration items is not employed in current model, and is a subject for consideration in future.

A graphical representation of LDP YANG data model is presented in Figure 2, Figure 4, Figure 5, and Figure 6. Whereas, the actual model definition in YANG is captured in Section 5.

3.2. Configuration

This specification defines the configuration parameters for base LDP as defined in [RFC5036] and LDP IPv6 [I-D.ietf-mpls-ldp-ipv6]. Moreover, it incorporates provisions to enable LDP capabilities [RFC5561], and defines some of the most significant and commonly used capabilities such as Typed Wildcard FEC [RFC5918], End-of-LIB [RFC5919], and LDP Upstream Label Assignment [RFC6389].
This specification currently supports only protocol-centric configuration. We plan to specify VRF-centric configuration in a later next revision. In this protocol-centric model, the LDP configuration is applied within the standard routing-instance, with instance list helping to reference the routing instance (VRF) where LDP is enabled and activated.

![Figure 1](image-url)

Given the configuration hierarchy, the model allows inheritance such that an item in a child tree is able to derive value from a similar or related item in one of the parent. For instance, hello holdtime can be configured either globally or per-VRF or per-VRF-interface, thus allowing inheritance as well flexibility to override with a different value on any child level.

Following is a simplified graphical representation of the data model for LDP configuration.
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|  +--rw interfaces
|    |  +--rw hello-holdtime?   uint16
|    |  +--rw hello-interval?   uint16
|  +--rw targeted
|    |  +--rw hello-holdtime?   uint16
|    |  +--rw hello-interval?   uint16
|    |  +--rw hello-accept {policy-extended-discovery-config}?
|    |    +--rw enable?   boolean
|  +--rw neighbors
|    |  +--rw md5-password?          string
|    |  +--rw session-ka-holdtime?   uint16
|    |  +--rw session-ka-interval?   uint16
|  +--rw instance* [name]
|    |  +--rw name                         union
|    |  +--rw admin-down?                  boolean {admin-down-config}?
|    |  +--rw lsr-id?                      union
|  +--rw capability
|    |  +--rw end-of-lib {capability-end-of-lib-config}?
|    |    +--rw enable?   boolean
|    |    +--rw typed-wildcard-fec
|    |    |  +--rw enable?   boolean
|    |    |  +--rw upstream-label-assignment
|    |    |    |  +--rw enable?   boolean
|  +--rw graceful-restart
|    |  +--rw enable?   boolean
|    |  +--rw helper-enable?   boolean {graceful-restart-helper-mode}?
|    |  +--rw reconnect-time?   uint16
|    |  +--rw recovery-time?   uint16
|    |  +--rw forwarding-holdtime?   uint16
|  +--rw address-family
|    |  +--rw ipv4
|    |    |  +--rw enable?   boolean
|    |    |  +--rw label-policy
|    |    |    |  +--rw independent-mode
|    |    |    |    |  +--rw assign {policy-label-assignment-config}?
|    |    |    |    |    |  +--rw (prefix-option)?
|    |    |    |    |    |    |  +--:(prefix-list)
|    |    |    |    |    |    |    +--rw prefix-list?   prefix-list-ref
|    |    |    |    |    |    |    |  +--:(host-routes-only)
|    |    |    |    |    |    |    |  +--rw host-routes-only?   boolean
|    |    |    |    |  +--rw advertise
|    |    |    |    |    |  +--rw explicit-null!
|    |    |    |    |    |    |  +--rw prefix-list?   prefix-list-ref
|    |    |    |    |    |    |    |  +--rw prefix-list?   prefix-list-ref
---rw transport-address? union
  ---rw enable? boolean

---rw targeted
  ---rw hello-holdtime? uint16
  ---rw hello-interval? uint16
  ---rw hello-accept {policy-extended-discovery-config}?
    ---rw enable? boolean
    ---rw peer-list? peer-list-ref
  ---rw address-family
    ---rw ipv4
      ---rw target* [address]
        ---rw address inet:ipv4-address
        ---rw enable? boolean
    ---rw ipv6
      ---rw target* [address]
        ---rw address inet:ipv6-address
        ---rw enable? boolean

---rw neighbors
  ---rw md5-password? string
  ---rw session-ka-holdtime? uint16
  ---rw session-ka-interval? uint16
  ---rw session-downstream-on-demand
    {session-downstream-on-demand-config}?
      ---rw enable? boolean
      ---rw peer-list? peer-list-ref
  ---rw session-protection {session-protection}?
    ---rw enable? boolean
    ---rw peer-list? peer-list-ref
  ---rw neighbor* [lsr-id]
    ---rw lsr-id union
    ---rw admin-down? boolean
    ---rw md5-password? string
    ---rw graceful-restart
      ---rw enable? boolean
      ---rw reconnect-time? uint16
      ---rw recovery-time? uint16
    ---rw session-ka-holdtime? uint16
    ---rw session-ka-interval? uint16
    ---rw session-protection {session-protection}?
      ---rw enable? boolean
      ---rw duration? union
    ---rw address-family
      ---rw ipv4
        ---rw label-policy
          ---rw advertise
            ---rw prefix-list? prefix-list-ref
3.2.1. Configuration Hierarchy

The LDP configuration container is logically divided into following high level config areas:

1. Global parameters
2. Per-VRF parameters
   - Global parameters
   - Per-address-family parameters
   - Hello Discovery parameters
     - interfaces
     - Per-interface:
       - Per-interface Global
       - Per-interface per-address-family
     - targeted
     - Per-target
   - Neighbor parameters
     - Global
     - Per-neighbor
       Per-neighbor per-address-family

Following subsections briefly explain these configuration areas.

3.2.1.1. Global parameters

These are the parameters whose scope apply globally or apply to all VRF instances. The example of a global configuration is LDP non-stop-routing feature. Typically, most of the parameters configurable at global level can be configured at per-VRF level or under other subtree under per-VRF.
3.2.1.2. Per-VRF parameters

These are the parameters whose scope apply within the context of a given VRF instance and are configured under "instance [name]". The majority of the LDP configuration falls under this category and is divided further into sub categories as follows.

3.2.1.2.1. Per-VRF global parameters

There are configuration items that are available directly under a VRF instance and do not fall under any other sub tree. Example of such a parameter is LDP lsr-id which is typically configured per VRF.

3.2.1.2.2. Per-VRF Per-Address-Family parameters

Any LDP configuration parameter related to IP address family (AF) whose scope is VRF wide is configured under this tree. The examples of per-AF parameters include enabling the AF, prefix-list based label policies, and LDP transport address.

3.2.1.2.3. Per-VRF Hello Discovery parameters

This container is used to hold LDP configuration related to Hello and discovery process for both basic (link) and extended (targeted) discovery.

The "interfaces" is a container to configure parameters related to VRF interfaces. There are parameters that apply to all interfaces (such as hello timers), as well as parameters that can be configured per-interface. Hence, an interface list is defined under "interfaces" container. The model defines parameters to configure per-interface non address-family related items, as well as per-interface per-AF items. The example of former is interface hello timers, and example of later is enabling hellos for a given AF under an interface.

The "targeted" container under a VRF instance allows to configure LDP targeted discovery related parameters. Within this container, the "target" list provides a mean to configure multiple target addresses to perform extended discovery to a specific destination target, as well as to fine tune parameters per-target.

3.2.1.2.4. Per-VRF Neighbor parameters

This container is used to hold LDP configuration related to LDP neighbors (i.e. peers) under a VRF instance. This container allows to configure parameters that either apply on all VRF neighbors or a subset (peer-list) of VRF neighbors. The example of such parameters
include authentication password, session KA timers etc. Moreover, the model also allows per-neighbor parameter tuning by specifying a "neighbor" list under the "neighbors" container. A neighbor is uniquely identified using its LSR Id and hence lsr-id is the key for neighbor list.

Like per-interface parameters, some per-neighbor parameters are AF-agnostic (i.e. either non AF related or apply to both IP address families), and some are that belong to an AF. The example of former is per-neighbor password configuration, whereas the example of later is prefix-list based label policies (inbound and outbound) that apply to a given neighbor.

3.3. Operational State

Operational state of LDP can be queried and obtained from this read-only container "mpls-ldp" which is augmented from "routing-state" of a routing-protocol (/rt:routing-state/rt:routing-instance/rt:routing-protocols/rt:routing-protocol).

Following is a simplified graphical representation of the data model for LDP operational state.

```
module: ietf-mpls-ldp
augment /rt:routing-state/rt:routing-instance/rt:routing-protocols/rt:routing-protocol:
    +--ro mpls-ldp
      +--

[Ed note: TODO (later revision)]
```

Figure 4

3.4. Notifications

This model defines a list of notifications to inform client of important events detected during the protocol operation. These events include events related to changes in the operational state of an LDP neighbor, hello adjacency, etc.

Following is a simplified graphical representation of the data model for LDP notifications.
module: ietf-mpls-ldp

notifications:
  +---- n mpls-ldp-neighbor-event
  |      +-- ro event-type?              oper-status-event-type
  |      +-- ro routing-instance-ref?    rt:routing-instance-ref
  |      +-- ro ldp-protocol-name?       leafref
  |      +-- ro ldp-vrf-instance?        leafref
  |      +-- ro neighbor-ref?            leafref
  +---- n mpls-ldp-adjacency-event
  +-- ro event-type?                    oper-status-event-type
  +-- ro routing-instance-ref?          rt:routing-instance-ref
  +-- ro ldp-protocol-name?             leafref
  +-- ro ldp-vrf-instance?              leafref
  +-- ro (adjacency-type)?
      +-- ro targeted
      |      +-- ro target-address?        inet:ip-address
      +-- ro link
      |      +-- ro next-hop-interface?    if:interface-ref
      |      +-- ro next-hop-address?      inet:ip-address

Figure 5

3.5. Actions

This model defines a list of rpcs that allow performing an action or executing a command on the protocol. For example, it allows to clear (reset) LDP neighbors, hello-adjacencies, and statistics. The model makes an effort to provide different level of control so that a user is able to either clear all, or clear all of a given type, or clear a specific entity.

Following is a simplified graphical representation of the data model for LDP actions.
module: ietf-mpls-ldp
rpcs:
  +---x mpls-ldp-clear-neighbor
    +---ro input
      +---ro routing-instance-ref?  rt:routing-instance-ref
      +---ro ldp-protocol-name?    leafref
      +---ro ldp-vrf-instance?      leafref
      +---ro lsr-id?                union
  +---x mpls-ldp-clear-adjacency
    +---ro input
      +---ro routing-instance-ref?  rt:routing-instance-ref
      +---ro ldp-protocol-name?    leafref
      +---ro ldp-vrf-instance?      leafref
      +---ro adjacency
        +---ro (adjacency-type)?
          +---: (targeted)
            +---ro targeted!
              +---ro target-address?  inet:ip-address
          +---: (link)
            +---ro link!
              +---ro next-hop-interface?  if:interface-ref
              +---ro next-hop-address?    inet:ip-address
  +---x mpls-ldp-clear-neighbor-statistics
    +---ro input
      +---ro routing-instance-ref?  rt:routing-instance-ref
      +---ro ldp-protocol-name?    leafref
      +---ro ldp-vrf-instance?      leafref
      +---ro lsr-id?                union

Figure 6

4. mLDP YANG Model

[Ed note: TODO (later revision)]

5. YANG Specification

Following are actual YANG definition for LDP and mLDP constructs defined earlier in the document.

module ietf-mpls-ldp {
  namespace "urn:ietf:params:xml:ns:yang:ietf-mpls-ldp";
  // replace with IANA namespace when assigned
  prefix ldp;
  import ietf-inet-types {
prefix "inet";

import ietf-yang-types {
    prefix "yang";
}

import ietf-interfaces {
    prefix "if";
}

import ietf-ip {
    prefix "ip";
}

import ietf-routing {
    prefix "rt";
}

import routing-policy {
    prefix "rpl";
}

organization "TBD";
contact "TBD";
description "";

revision 2015-03-08 {
    description "Initial revision.";
    reference "";
}

/*
 * Features
 */

feature admin-down-config {
    description "This feature indicates that the system allows to configure administrative down on a VRF instance and a neighbor.";
}

feature capability-end-of-lib-config {
    description "This feature indicates that the system allows to configure LDP end-of-lib capability.";
}
feature capability-typed-wildcard-fec-config {
  description
    "This feature indicates that the system allows to configure
    LDP typed-wildcard-fec capability.";
}

feature capability-upstream-label-assignment-config {
  description
    "This feature indicates that the system allows to configure
    LDP upstream label assignment capability.";
}

feature global-session-authentication {
  description
    "This feature indicates that the system allows to configure
    authentication at global level.";
}

feature graceful-restart-helper-mode {
  description
    "This feature indicates that the system supports graceful
    restart helper mode.";
}

feature per-interface-timer-config {
  description
    "This feature indicates that the system allows to configure
    interface hello timers at the per-interface level.";
}

feature per-neighbor-graceful-restart-config {
  description
    "This feature indicates that the system allows to configure
    graceful restart at the per-neighbor level.";
}

feature per-neighbor-session-attributes-config {
  description
    "This feature indicates that the system allows to configure
    session attributes at the per-neighbor level.";
}

feature policy-extended-discovery-config {
  description
    "This feature indicates that the system allows to configure
    policies to control the acceptance of extended neighbor
discovery hello messages.

feature policy-label-assignment-config {
    description
        "This feature indicates that the system allows to configure policies to assign labels according to certain prefixes.";
}

feature policy-ordered-label-config {
    description
        "This feature indicates that the system allows to configure ordered label policies.";
}

feature session-downstream-on-demand-config {
    description
        "This feature indicates that the system allows to configure session downstream-on-demand";
}

feature session-protection {
    description
        "This feature indicates that the system supports session protection";
}

/*
 * Typedefs
 */
typedef peer-list-ref {
    type leafref {
        path "/rpl:routing-policy/rpl:defined-sets/rpl:neighbor-set/
            +"rpl:neighbor-set-name";
    }
    description
        "A type for a reference to a prefix list.";
}

typedef prefix-list-ref {
    type leafref {
        path "/rpl:routing-policy/rpl:defined-sets/rpl:prefix-set/
            +"rpl:prefix-set-name";
    }
    description
        "A type for a reference to a prefix list.";
}
typedef oper-status-event-type {
    type enumeration {
        enum up {
            value 1;
            description "Operational status changed to up.";
        }
        enum down {
            value 2;
            description "Operational status changed to down.";
        }
    }
    description "Operational status event type for notifications.";
}

/* Identities */

identity mpls-ldp {
    base "rt:routing-protocol";
    description "LDP";
}

/* Groupings */
grouping ldp-instance-ref {
    description "An absolute reference to an LDP instance.";
    leaf routing-instance-ref {
        type rt:routing-instance-ref;
        description "Reference to the routing instance.";
    }
}

leaf ldp-protocol-name {
    type leafref {
        path "/rt:routing/rt:routing-instance"
        + "[rt:name = current()//routing-instance-ref]/"
        + "rt:routing-protocols/rt:routing-protocol/rt:name";
    }
    description "Reference to an LDP protocol name.";
}

leaf ldp-vrf-instance {
    type leafref {

grouping ldp-instance-ref {
  path "/rt:routing/rt:routing-instance"
  + "[rt:name = current()/.../routing-instance-ref]/" + "rt:routing-protocols/rt:routing-protocol"
  + "[rt:name = current()/.../ldp-protocol-name]/mpls-ldp/
  + "instance/name";
  }
  description
  "Reference to an LDP instance.";
}
} // ldp-instance-ref

grouping ldp-neighbor-ref {
  description
  "An absolute reference to an LDP neighbor.";
  uses ldp-instance-ref;
  leaf neighbor-ref {
    type leafref {
      path "/rt:routing/rt:routing-instance"
      + "[rt:name = current()/.../routing-instance-ref]/" + "rt:routing-protocols/rt:routing-protocol"
      + "[rt:name = current()/.../ldp-protocol-name]/mpls-ldp/
      + "instance"
      + "[name = current()/.../ldp-vrf-instance]/neighbors/"
      + "neighbor/lsr-id";

      }
      description
      "Reference to an LDP neighbor.";
    }
  } // ldp-neighbor-ref

grouping ldp-adjacency-ref {
  description
  "An absolute reference to an LDP adjacency.";
  uses ldp-instance-ref;
  choice adjacency-type {
    description
      "Interface or targeted adjacency.";
    case targeted {
      container targeted {
        description "Targeted adjacency.";
        leaf target-address {
          type inet:ip-address;
          description "The target address.";
        }
      } // targeted
    }
    case link {
      }
  } // ldp-adjacency-ref
container link {
  description "Link adjacency.";
  leaf next-hop-interface {
    type if:interface-ref;
    description "Interface connecting to next-hop.";
  }
  leaf next-hop-address {
    type inet:ip-address;
    must ".../interface" {
      description "Applicable when interface is specified.";
    }
    description "IP address of next-hop.";
  }
} // link
} // ldp-adjacency-ref

grouping basic-discovery-timers {
  description "Basic discovery timer attributes.";
  leaf hello-holdtime {
    type uint16 {
      range 15..3600;
    }
    units seconds;
    default 15;
    description "The time interval for which a LDP link Hello adjacency
      is maintained in the absence of link Hello messages from
      the LDP neighbor";
  }
  leaf hello-interval {
    type uint16 {
      range 5..1200;
    }
    units seconds;
    default 5;
    description "The interval between consecutive LDP link Hello messages
      used in basic LDP discovery";
  }
} // basic-discovery-timers

grouping extended-discovery-timers {

description "Extended discovery timer attributes.";
leaf hello-holdtime {
    type uint16 {
        range 15..3600;
    }
    units seconds;
    default 45;
    description "The time interval for which LDP targeted Hello adjacency is maintained in the absence of targeted Hello messages from an LDP neighbor.";
}
leaf hello-interval {
    type uint16 {
        range 5..3600;
    }
    units seconds;
    default 15;
    description "The interval between consecutive LDP targeted Hello messages used in extended LDP discovery.";
}
} // extended-discovery-timers
grouping discovery-attributes-container {
    description "Discovery configuration attributes.";
    container discovery {
        description "Neighbor discovery attributes.";
        container interfaces {
            description "Basic discovery attributes.";
            uses basic-discovery-timers;
        }
    }
    container targeted {
        description "Extended discovery attributes.";
        uses extended-discovery-timers;
        container hello-accept {
            if-feature policy-extended-discovery-config;
            description "Extended discovery acceptance policies.";
            leaf enable {
type boolean;
    description
        "true’ to accept; ‘false’ to deny.”;
  }
  // hello-accept
} // targeted
} // discovery
} // discovery-attributes

grouping graceful-restart-attributes {
    description
        "Graceful restart configuration attributes.”;
    container graceful-restart {
        description
            "Attributes for graceful restart.”;
        leaf enable {
            type boolean;
            description
                "Enable or disable graceful restart.”;
        }
        leaf helper-enable {
            if-feature graceful-restart-helper-mode;
            type boolean;
            description
                "Enable or disable graceful restart helper mode.”;
        }
        leaf reconnect-time {
            type uint16 {
                range 10..1800;
            }
            units seconds;
            description
                "Specifies the time interval that the remote LDP peer
                must wait for the local LDP peer to reconnect after the
                remote peer detects the LDP communication failure.”;
        }
        leaf recovery-time {
            type uint16 {
                range 30..3600;
            }
            units seconds;
            description
                "";
        }
        leaf forwarding-holdtime {
            type uint16 {
                range 30..3600;
            }
        }
    } // graceful-restart
} // graceful-restart-attributes
grouping graceful-restart-attributes-per-neighbor {
  description "Per neighbor graceful restart configuration attributes.";
  container graceful-restart {
    description "Attributes for graceful restart.";
    leaf enable {
      type boolean;
      description "Enable or disable graceful restart.";
    }
    leaf reconnect-time {
      type uint16 {
        range 10..1800;
      }
      units seconds;
      description "Specifies the time interval that the remote LDP peer must wait for the local LDP peer to reconnect after the remote peer detects the LDP communication failure.";
    }
    leaf recovery-time {
      type uint16 {
        range 30..3600;
      }
      units seconds;
      description "";
    }
  }
} // graceful-restart-attributes-per-neighbor

grouping neighbor-attributes {
  description "Neighbor configuration attributes.";

  leaf session-ka-holdtime {
    type uint16 {
      range 45..3600;
    }
    units seconds;
    description "";
  }
} // graceful-restart-attributes-per-neighbor
"The time interval after which an inactive LDP session terminates and the corresponding TCP session closes. Inactivity is defined as not receiving LDP packets from the neighbor."

leaf session-ka-interval {
  type uint16 {
    range 15..1200;
  }
  units seconds;
  description
    "The interval between successive transmissions of keepalive packets. Keepalive packets are only sent in the absence of other LDP packets transmitted over the LDP session."
}

// neighbor-attributes

grouping session-protection-per-vrf {
  description "Session protection attributes.";
  container session-protection {
    if-feature session-protection;
    description
      "Session protection attributes.";
    leaf enable {
      type boolean;
      description
        "'true' if session protection is enabled.";
    }
    leaf duration {
      type union {
        type uint32;
        type enumeration {
          enum "infinite" {
            description "The duration is infinite.";
          }
        }
      }
    }
    units seconds;
    description
      "Session protection duration.";
  }
  leaf peer-list {
    type peer-list-ref;
    description
      "The name of a peer ACL.";
  }
}

// session-protection

// session-protection-per-vrf
grouping session-protection-per-neighbor {
  description "Session protection attributes.";
  container session-protection {
    if-feature session-protection;
    description "Session protection attributes.";
    leaf enable {
      type boolean;
      description "'true' if session protection is enabled.";
    }
    leaf duration {
      type union {
        type uint32;
        type enumeration {
          enum "infinite" {
            description "The duration is infinite.";
          }
        }
      }
      units seconds;
      description "Session protection duration.";
    }
  }
}
// session-protection
} // session-protection-per-neighbor

grouping neighbor-authentication {
  description "Neighbor authentication attributes.";
  leaf md5-password {
    type string {
      length "1..80";
    }
    description "Assigns an encrypted MD5 password to an LDP neighbor";
  }
}
// md5-password
} // neighbor-authentication

grouping neighbor-attributes-container {
  description "Container of neighbor configuration attributes.";
  container neighbors {
    description "Container of neighbor configuration attributes.";
    uses neighbor-authentication {
      if-feature global-session-authentication;
    }
  }
}
uses neighbor-attributes;
}
} // neighbor-attributes-container

grouping instance-attributes {
  description "Configuration attributes at instance level.";
  uses graceful-restart-attributes;

  leaf igp-synchronization-delay {
    type uint16 {
      range 3..60;
    }
    units seconds;
    description
    "Sets the interval that the LDP waits before notifying the Interior Gateway Protocol (IGP) that label exchange is completed so that IGP can start advertising the normal metric for the link.";
  }
} // instance-attributes

grouping global-attributes {
  description "Configuration attributes at global level.";
  uses instance-attributes;

  leaf nonstop-routing {
    type boolean;
    default false;
    description
    "Enables Nonstop Routing (NSR)";
  }
} // global-attributes

grouping policy-attributes {
  description
  "LDP policy attributes.";
  container label-policy {
    description
    "Label policy attributes.";
    container independent-mode {
      description
      "Independent label policy attributes.";
      container assign {
        if-feature policy-label-assignment-config;
        description
        "Label assignment policies";
      }
    }
  }
} // policy-attributes
choice prefix-option {
  description "Use either prefix-list or host-routes-only.";
  case prefix-list {
    leaf prefix-list {
      type prefix-list-ref;
      description "Assign labels according to certain prefixes.";
    }
  }
  case host-routes-only {
    leaf host-routes-only {
      type boolean;
      description "'true' to apply host routes only.";
    }
  }
} // prefix-option

container advertise {
  description "Label advertising policies.";
  container explicit-null {
    presence "Present to enable explicit null.";
    description "Enables an egress router to advertise an explicit null label (value 0) in place of an implicit null label (value 3) to the penultimate hop router.";
    leaf prefix-list {
      type prefix-list-ref;
      description "Prefix list name. Applies the filters in the specified prefix list to label advertisements. If the prefix list is not specified, explicit null label advertisement is enabled for all directly connected prefixes.";
    }
  }
  leaf prefix-list {
    type prefix-list-ref;
    description "Applies the prefix list to outgoing label advertisements.";
  }
} // advertise

container accept {

}
description
"Label advertisement acceptance policies."
leaf prefix-list {
  type prefix-list-ref;
  description
  "Applies the prefix list to incoming label advertisements.";
}

} // independent-mode
container ordered-mode {
  if-feature policy-ordered-label-config;
  description
  "Ordered label policy attributes.";
  container egress-lsr {
    description
    "Egress LSR label assignment policies";
    leaf prefix-list {
      type prefix-list-ref;
      description
      "Assign labels according to certain prefixes.";
    }
  }
  container advertise {
    description
    "Label advertising policies.";
    leaf prefix-list {
      type prefix-list-ref;
      description
      "Applies the prefix list to outgoing label advertisements.";
    }
  }
  container accept {
    description
    "Label advertisement acceptance policies.";
    leaf prefix-list {
      type prefix-list-ref;
      description
      "Applies the prefix list to incoming label advertisements.";
    }
  }
} // ordered-mode
} // label-policy
} // policy-attributes
description
"LDP policy attributes under neighbor address-family.";
container label-policy {
    description
    "Label policy attributes.";
    container advertise {
        description
        "Label advertising policies.";
        leaf prefix-list {
            type prefix-list-ref;
            description
            "Applies the prefix list to outgoing label
            advertisements.";
        }
    }
}
container accept {
    description
    "Label advertisement acceptance policies.";
    leaf prefix-list {
        type prefix-list-ref;
        description
        "Applies the prefix list to incoming label
        advertisements.";
    }
} // accept
} // label-policy
} // neighbor-af-policy-attributes

grouping extended-discovery-policy-attributes {
    description
    "LDP policy to control the acceptance of extended neighbor
discovery hello messages.";
    container hello-accept {
        if-feature policy-extended-discovery-config;
        description
        "Extended discovery acceptance policies.";
        leaf enable {
            type boolean;
            description
            "'true' to accept; 'false' to deny.";
        }
        leaf peer-list {
            type peer-list-ref;
            description
            "The name of a peer ACL.";
        }
    } // hello-accept
augment "/rt:routing/rt:routing-instance/rt:routing-protocols/"
+ "rt:routing-protocol" {
  when "rt:type = 'ldp:mpls-ldp'" {
    description
    "This augment is only valid for a protocol instance
    of LDP.";
  }
  description "LDP augmentation.";
}

container mpls-ldp {
  description
  "LDP.";

  uses global-attributes;
  uses discovery-attributes-container;
  uses neighbor-attributes-container;

  list instance {
    key "name";
    description
    "Per-vrf global params.";

    leaf name {
      type union {
        type enumeration {
          enum default {
            description "Special 'default' VRF instance.";
          }
        }
        type string;
      }
      description
      "VRF instance name.";
    }

    leaf admin-down {
      if-feature admin-down-config;
      type boolean;
      default false;
      description
      "'true' to disable the instance.";
    }
  }
}
leaf lsr-id {
    type union {
        type yang:dotted-quad;
        type uint32;
    }
    description "Router ID."
}

container capability {
    description "Configure capability.";
    container end-of-lib {
        if-feature capability-end-of-lib-config;
        description "Configure upstream label assignment capability.";
        leaf enable {
            type boolean;
            description "Enable end-of-lib capability.";
        }
    }
    container typed-wildcard-fec {
        if-feature capability-typed-wildcard-fec-config;
        description "Configure typed-wildcard-fec capability.";
        leaf enable {
            type boolean;
            description "Enable typed-wildcard-fec capability.";
        }
    }
    container upstream-label-assignment {
        if-feature capability-upstream-label-assignment-config;
        description "Configure upstream label assignment capability.";
        leaf enable {
            type boolean;
            description "Enable upstream label assignment.";
        }
    }
} // capability

uses instance-attributes;

container address-family {
    description "Per-vrf per-af params."
    container ipv4 {
        
description "IPv4 address family.";
leaf enable {
    type boolean;
    description "'true' to enable IPv4 address family.";
}
uses policy-attributes;
leaf transport-address {
    type inet:ipv4-address;
    description "The transport address advertised in LDP Hello messages.";
}
} // ipv4

container ipv6 {
    description "IPv6 address family.";
    leaf enable {
        type boolean;
        description "'true' to enable IPv6 address family.";
    }
    uses policy-attributes;
    leaf transport-address {
        type inet:ipv6-address;
        description "The transport address advertised in LDP Hello messages.";
    }
} // ipv6

container discovery {
    description "Neighbor discovery configuration.";

ccontainer interfaces {
    description "A list of interfaces for basic discovery.";
    uses basic-discovery-timers;

    list interface {
        key "interface";
        description "List of LDP interfaces.";
        leaf interface {
            type if:interface-ref;
        }
    }
} // interfaces
uses basic-discovery-timers {
    if-feature per-interface-timer-config;
}
leaf igp-synchronization-delay {
    if-feature per-interface-timer-config;
    type uint16 {
        range 3..60;
    }
    units seconds;
    description
        "Sets the interval that the LDP waits before
        notifying the Interior Gateway Protocol (IGP) that
        label exchange is completed so that IGP can start
        advertising the normal metric for the link.";
}

container address-family {
    description
        "Per-vrf per-af params.";
    container ipv4 {
        must "/if:interfaces/if:interface"
        + "[name = current()//../interface]/ip:ipv4" {
            description
                "Only if IPv4 is enabled on the interface.";
        }
        description
            "IPv4 address family.";
        leaf transport-address {
            type union {
                type enumeration {
                    enum "use-interface-address" {
                        description
                            "Use interface address as the transport
                            address.";
                    }
                }
                type inet:ipv4-address;
            }
            description
                "IP address to be advertised as the LDP
                transport address.";
        }
        leaf enable {
            type boolean;
            description
                "Enable IPv4 transport address.";
        }
    }
}
"Enable IPv4 address family on the interface.";
}
}
container ipv6 {
must "/if:interfaces/if:interface"
+ "[name = current()//..//interface]/ip:ipv6" {
description
 "Only if IPv6 is enabled on the interface.";
}
description
 "IPv6 address family.";
leaf transport-address {
type union {
type enumeration {
enum "use-interface-address" {
description
 "Use interface address as the transport address.";
}
}
type inet:ipv4-address;
}
description
 "IP address to be advertised as the LDP transport address.";
}
leaf enable {
type boolean;
description
 "Enable IPv6 address family on the interface.";
}
} // ipv6
} // address-family
} // list interface
} // interfaces

container targeted {
description
 "A list of targeted neighbors for extended discovery.";
uses extended-discovery-timers;
uses extended-discovery-policy-attributes;

container address-family {
description
 "Per-vrf per-af params.";
container ipv4 {
description

"IPv4 address family."
list target {
  key "address";
  description
    "Targeted discovery params."

  leaf address {
    type inet:ipv4-address;
    description
      "Configures a remote LDP neighbor and enables extended LDP discovery of the specified neighbor."
  }

  leaf enable {
    type boolean;
    description
      "Enable the target."
  }
}

// ipv4
container ipv6 {
  description
    "IPv6 address family."
  list target {
    key "address";
    description
      "Targeted discovery params."

    leaf address {
      type inet:ipv6-address;
      description
        "Configures a remote LDP neighbor and enables extended LDP discovery of the specified neighbor."
    }

    leaf enable {
      type boolean;
      description
        "Enable the target."
    }
  }
}

// ipv6
} // address-family
} // targeted
} // discovery

container neighbors {
  description

"Neighbors configuration attributes."

uses neighbor-authentication { 
  if-feature global-session-authentication; 
}
uses neighbor-attributes;

container session-downstream-on-demand { 
  if-feature session-downstream-on-demand-config; 
  description 
  "Session downstream-on-demand attributes."; 
  leaf enable { 
    type boolean; 
    description 
    "'true' if session downstream-on-demand is enabled."; 
  } 
  leaf peer-list { 
    type peer-list-ref; 
    description 
    "The name of a peer ACL."; 
  } 
}
uses session-protection-per-vrf;

list neighbor { 
  key "lsr-id"; 
  description 
  "List of neighbors."; 
  leaf lsr-id { 
    type union { 
      type yang:dotted-quad; 
      type uint32; 
    } 
    description "LSR ID."; 
  } 
  leaf admin-down { 
    type boolean; 
    default false; 
    description 
    "'true' to disable the neighbor."; 
  } 
}
uses neighbor-authentication;
uses graceful-restart-attributes-per-neighbor {
if-feature per-neighbor-graceful-restart-config;
}

uses neighbor-attributes {
    if-feature per-neighbor-session-attributes-config;
}

uses session-protection-per-neighbor;

container address-family {
    description "Per-vrf per-af params.";
    container ipv4 {
        description "IPv4 address family.";
        uses neighbor-af-policy-attributes;
    }
    container ipv6 {
        description "IPv6 address family.";
        uses neighbor-af-policy-attributes;
    } // ipv6
} // address-family
} // list neighbor
} // instance
} // container mpls-ldp

/*
 * Operational state data nodes
 */

augment "/rt:routing-state/rt:routing-instance/
+ rt:routing-protocols/rt:routing-protocol" { 
    when "rt:type = 'ldp:mpls-ldp'" {
        description "This augment is only valid for a protocol instance
of type 'ldp'.";
    }
    description "LDP state.";
    container mpls-ldp {
        description "LDP";
    }
}

/*
* RPCs
*/
rpc mpls-ldp-clear-neighbor {
  description "Clears the session to the neighbor.";
  input {
    uses ldp-instance-ref {
      description "VRF instance name. If this is not provided then all instances are cleared.";
    }
    leaf lsr-id {
      type union {
        type yang:dotted-quad;
        type uint32;
      }
      description "LSR ID of neighbor to be cleared. If this is not provided then all neighbors are cleared";
    }
  }
}

case targeted {
  container targeted {
    presence "Present to clear targeted adjacencies.";
    description "Clear targeted adjacencies.";
    leaf target-address {
      type inet:ip-address;
      description "The target address. If this is not provided then all targeted adjacencies are cleared";
    }
  }
}

rpc mpls-ldp-clear-adjacency {
  description "Clears the hello adjacency";
  input {
    uses ldp-instance-ref {
      description "VRF instance name. If this is not provided then all instances are cleared.";
    }
  }
  container adjacency {
    description "Link adjacency or targetted adjacency. If this is not provided then all hello adjacencies are cleared";
    choice adjacency-type {
      description "Adjacency type.";
      case targeted {
        container targeted {
          presence "Present to clear targeted adjacencies.";
          description "Clear targeted adjacencies.";
          leaf target-address {
            type inet:ip-address;
            description "The target address. If this is not provided then all targeted adjacencies are cleared";
          }
        }
      }
    }
  }
}
case link {
  container link {
    presence "Present to clear link adjacencies.";
    description "Clear link adjacencies.";
    leaf next-hop-interface {
      type if:interface-ref;
      description "Interface connecting to next-hop. If this is not provided then all link adjacencies are cleared.";
    }
    leaf next-hop-address {
      type inet:ip-address;
      must ".../interface" {
        description "Applicable when interface is specified.";
      }
      description "IP address of next-hop. If this is not provided then adjacencies to all next-hops on the given interface are cleared.";
    }
    // next-hop-address
    // link
    }
  } // link
}

case targeted
}

rpc mpls-ldp-clear-neighbor-statistics {
  description "Clears protocol statistics (e.g. sent and received counters).";
  input {
    uses ldp-instance-ref {
      description "VRF instance name. If this is not provided then all instances are cleared.";
    }
    leaf lsr-id {
      type union {
        type yang:dotted-quad;
        type uint32;
      }
"LSR ID of neighbor whose statistic are to be cleared. If this is not provided then all neighbors statistics are cleared";

/* Notifications */

notification mpls-ldp-neighbor-event {
    description
    "Notification event for a change of LDP neighbor operational status.";
    leaf event-type {
        type oper-status-event-type;
        description "Event type.";
    }
    uses ldp-neighbor-ref;
}

notification mpls-ldp-adjacency-event {
    description
    "Notification event for a change of LDP adjacency operational status.";
    leaf event-type {
        type oper-status-event-type;
        description "Event type.";
    }
    uses ldp-adjacency-ref;
}

6. Security Considerations

The configuration, state, action and notification data defined in this document are designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operations and content.
LDP is a MPLS protocol that is used to establish MPLS transport LSPs. So it is critical to ensure security of the protocol to avoid disruption of the services that depend on these transport LSPs.

There are a number of data nodes defined in the LDP and mLDP YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations.

The security concerns listed above are, however, no different than faced by other routing protocols. Hence, this draft does not change any underlying security issues inherent in [I-D.ietf-netmod-routing-cfg]

7. IANA Considerations

None.

8. Acknowledgments

The authors would like to acknowledge Eddie Chami, Mannan Venkatesan, and Jeff Tantsura for their useful comments.

9. References

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[I-D.ietf-netmod-routing-cfg]

[I-D.shaikh-rtgwg-policy-model]

9.2. Informative References

[I-D.iwijnand-mpls-mldp-multi-topology]


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Definitions of Managed Objects for the LDP Point-to-Multipoint and
  Multipoint-to-Multipoint Label Switched Paths
  draft-tiruveedhula-mpls-mldp-mib-03

Abstract

This memo defines a portion of the Management Information Base (MIB) for use with network management protocols. In particular it defines objects for managing multicast LDP point-to-multipoint (P2MP) and multipoint-to-multipoint (MP2MP) Label Switched Paths. The MIB module defined in this document is extension of LDP MIB defined in RFC3815 which supports only for LDP point-to-point LSPs.

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1. Introduction

This memo defines a portion of the Management Information Base (MIB) for use with network management protocols. In particular it defines objects for managing multicast LDP point-to-multipoint (P2MP) and multipoint-to-multipoint (MP2MP) Label Switched Paths. The MIB module defined in this document is an extension of LDP MIB defined in RFC3815 which supports only for LDP point-to-point LSPs.

The RFC3815 describes only unicast Managed objects for the Label distribution protocol. The RFC6388 describes LDP protocol extensions for the point to multipoint and multipoint to multipoint LSPs. The RFC 6826 describes multicast LDP inband signalling for P2MP and MP2MP LSPs.

This document defines a MIB module for managing and controlling mLDP P2MP and MP2MP LSPs. It builds on the objects and tables defined in [RFC3815] for mLDP MIB.

2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

Managed objects are accessed via a virtual information store, termed the Management Information Base or MIB. MIB objects are generally accessed through the Simple Network Management Protocol (SNMP). Objects in the MIB are defined using the mechanisms defined in the Structure of Management Information (SMI). This memo specifies a MIB module that is compliant to the SMIV2, which is described in STD 58, RFC 2578 [RFC2578], STD 58, RFC 2579 [RFC2579] and STD 58, RFC 2580 [RFC2580].
3. Conventions

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].

4. Overview

This document focuses on the management of following multicast LDP (mLDP) features, which were defined after unicast LDP [RFC5036].

- RFC6826: Multipoint LDP In-Band Signaling for Point-to-Multipoint and Multipoint-to-Multipoint Label Switched Paths.
- RFC7060: Using LDP Multipoint Extensions on Targeted LDP Sessions.
- [MoFRR] Multicast only Fast Re-Route draft-ietf-rtgwg-mofrr-03.
- [MLDP_NODE_PROT] mLDP Node Protection.

For all the above features, the mLDP MIB needs to include the following information:

- Session Capability (P2MP, MP2MP) information: configured capability, negotiated capability.
- mLDP FECs: include opaque information (Generic LSP Identifier, source and group address) and MoFRR enable.
- Primary and backup upstream session when mLDP MoFRR enabled.
- Active and inactive upstream session for make before break.
- mLDP Traffic stats per mLDP Fec: The traffic stats for mLDP fec.
- mLDP Traffic stats per per Interface: The mLDP traffic stats per Interface.
- Traps when mLDP Fec LSP up, down.
5. Future Considerations

Any new opaque TLVs added for any other mLDP features, the opaque value object in the mplsMldpFecTable need to be enhanced accordingly.

6. Structure of the MIB Module

This section describes the structure of the mLDP MIB. In this MIB MPLS-MLDP-STD-MIB, scalar objects, table objects and notifications are defined. Following section describes in details about each object.

6.1. Summary of mLDP Scalar Objects

New scalar objects mplsMldpP2mpCapable and mplsMldpMp2mpCapable are defined to provide the mLDP capabilities of P2MP, MP2MP support.

New scalar objects mplsMldpMbbCapable and mplsMldpMbbTime are defined to provide MBB capability information.

New scalar object mplsMldpNumFecs which will give the total number of mLDP FECs setup on the LSR.

Another New scalar object mplsMldpNumFecsActive, which will give the total number of active mLDP FECs.

New scalar objects mplsMldpPlrCapable, mplsMldpMptCapable, mplsMldpProtLsrCapable and mplsMldpNodeProtCapable are defined to provide mLDP node protection capabilities.

6.2. Summary of mLDP Table Objects

mplsLdpPeerCapabilityTable to include peer capability information.

mplsMldpSessionStatsTable: This table contains the number of mLDP FECs received and advertised to particular LDP session.

mplsMldpFecTable: This table is similar to point to point mplsLdpFecTable and will have mLDP specific Fec information.

mplsMldpFecBranchStatsTable: This table contains the traffic statistics for the given mLDP FECs on particular interface.

mplsMldpFecUpstreamSessTable: Includes the upstream session info for the particular mLDP Fec and also includes the primary or backup upstream session, that may be used for mLDP MoFRR.
mplsMldpInterfaceStatsTable : This table contains the traffic statistics for all mLDP related FECs.

7. mLDP Scalar Objects

There are ten scalars, listed below are defined for this MIB module.

7.1. mplsMldpP2mpCapable

The mplsMldpP2mpCapable scalar object denotes whether the LSR is capable of supporting multicast LDP with Point-to-Multipoint capability.

7.2. mplsMldpMp2mpCapable

The mplsMldpMp2mpCapable scalar object denotes whether the LSR is capable of supporting multicast LDP with Multipoint-to-Multipoint LSPs.

7.3. mplsMldpMbbCapable

The mplsMldpMbbCapable scalar object denotes whether the LSR is capable of supporting multicast LDP with MBB (make before break) feature mentioned in the section 8 of RFC 6388.

7.4. mplsMldpMbbTime

The mplsMldpMbbTime scalar object denotes MBB time for which LSR is waiting for MBB Ack from upstream node. This timer helps LSR to prevent waiting indefinitely for the MBB Notification from upstream node.

7.5. mplsMldpNumFecs

The mplsMldpNumFecs provides a read-only counter of the number of mLDP FECs setup on this LSR.

7.6. mplsMldpNumFecsActive

The mplsMldpNumFecsActive provides a read-only counter of the number of mLDP FECs Active on this LSR.

7.7. mplsMldpPlrCapable

The mplsMldpPlrCapable scalar object denotes whether the LSR is capable of supporting PLR capability as specified in the section 5.1 of [MLDP_NODE_PROT]
7.8.  mplsMldpMptCapable

The mplsMldpMptCapable scalar object denotes whether the LSR is capable of supporting MPT capability as specified in the section 5.2 of [MLDP_NODE_PROT]

7.9.  mplsMldpProtLsrCapable

The mplsMldpProtLsrCapable scalar object denotes whether the LSR is capable of supporting the "Protected LSR" capability as specified in the section 5.3 of [MLDP_NODE_PROT]

7.10. mplsMldpNodeProtCapable

The mplsMldpNodeProtCapable scalar object denotes whether the LSR is capable of supporting the "Node Protection" capability as specified in the section 5.4 of [MLDP_NODE_PROT]

8.  mLDP Table Objects

8.1.  LDP Peer Capability Table mplsLdpPeerCapabilityTable

The new table mplsLdpPeerCapabilityTable is read-only table, which contains learned capability information from LDP peer. This table augments the mplsLdpPeerTable, which is defined in RFC 3815.

8.2.  mLDP Session Stats Table: mplsMldpSessionStatsTable

The mplsMldpSessionStatsTable is a read-only table which contains mLDP statistical information on sessions. This table augments the mplsLdpSessionStatsTable, which is defined in the RFC 3815.

8.3.  mLDP Fec Table: mplsMldpFecTable

The mplsMldpFecTable is a table which contains FEC (Forwarding Equivalence Class) information relating to point to multi-point and multipoint to multipoint LDP LSP. Each entry/row represents a single FEC Element. This table is similar LDP LSP FEC Table, mplsLdpLspFecTable, which is defined in the RFC 3815, which associates FECs with the LSPs.

8.4.  mLDP Fec Branch Traffic statistics Table: mplsMldpFecBranchStatsTable

This table mplsMldpFecBranchStatsTable gives the information about number of packets and number of bytes sent out on particular downstream session or on outgoing interface.
8.5. mLDP Fec Upstream Session Table: mplsMldpFecUpstreamSessTable

The mplsMldpFecUpstreamSessTable is a read-only table which contains mLDP upstream session information for mLDP Fec. This table is similar to mplsInSegmentLdpLspTable. This table will also have information about primary, backup upstream session, and also indicates whether the label is in MBB request or MBB Ack received state.

8.6. mLDP Interface Traffic statistics Table: mplsMldpInterfaceStatsTable

This table mplsMldpInterfaceStatsTable gives the information about number of mLDP packets and number of mLDP bytes sent and received on particular interface for all mLDP FECs.

9. The mLDP Notifications

The RFC 3815 defined some of the notifications related to session and P2P Fec. In this MIB, the following notification added to support mLDP features.

The mplsMldpFecUp and mplsMldpFecDown notifications are generated when mLDP FEC changes the state to UP and Down.

The mplsMldpMoFrrStatusChange notification is generated when mLDP MoFRR status switches from primary to backup path and vice versa.

10. Relationship to Other MIB Modules

This section describes relationships between MIB tables defined in this document as part of MPLS-MLDP-STD-MIB, and the tables defined in MPLS-LDP-STD-MIB [RFC3815] and MPLS-LSR-STD-MIB [RFC3813].

The Figure 1 shows the diagrammatic representation of the relationship between MPLS-MLDP-STD-MIB, MPLS-LDP-STD-MIB and MPLS-LSR-STD-MIB. An arrow in the Figure shows that the MIB table pointed from contains a reference to the MIB table pointed to.

10.1. Diagrammatic Representation
10.2. Relationship to the LSR MIB

The LSR MIB [RFC3813] have below tables, which cross connects the incoming label to outgoing label. Below Tables will be used for mLDP also in the similar way as in the point to point LDP LSPs.

- mplsXCTable
- mplsInSegmentTable
- mplsOutSegmentTable

10.3. Relationship to the LDP MIB

The MIB module defined in this document is extension of MPLS-LDP-STD-MIB to support multicast LDP features.

Below optional tables in MPLS-LDP-STD-MIB, will also be used in mLDP for associating the mLDP LSPs to LSR-MIB tables.
mplsLdpLspFecTable
mplsInSegmentLdpLspTable
mplsOutSegmentLdpLspTable

11. Multicast MPLS Label Distribution Protocol MIB Definitions

MPLS-MLDP-STD-MIB DEFINITIONS ::= BEGIN
IMPORTS
    MODULE-IDENTITY, OBJECT-TYPE, NOTIFICATION-TYPE,
    Unsigned32, Counter32, Counter64, TimeTicks
    FROM SNMPv2-SMI                                    -- RFC 2578
    MODULE-COMPLIANCE, OBJECT-GROUP, NOTIFICATION-GROUP
    FROM SNMPv2-CONF                                   -- RFC 2580
    TruthValue, RowStatus, StorageType, TimeStamp
    FROM SNMPv2-TC                                     -- RFC 2579

    InterfaceIndex
    FROM IF-MIB                                       -- [RFC2020]

    mplsStdMIB, MplsLdpIdentifier
    FROM MPLS-TC-STD-MIB                               -- RFC 3811

    MplsIndexType
    FROM MPLS-LSR-STD-MIB                              -- RFC 3813

    IndexInteger, IndexIntegerNextFree
    FROM DIFFSERV-MIB                                  -- RFC 3289

    InetAddress, InetAddressType
    FROM INET-ADDRESS-MIB                              -- RFC 4001

    mplsLdpStdMIB
    FROM MPLS-LDP-STD-MIB                              -- RFC 3815
;

mplsMldpStdMIB MODULE-IDENTITY
LAST-UPDATED "201410100000Z"  -- Oct 10, 2014
ORGANIZATION "Multiprotocol Label Switching (mpls)
Working Group"

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Comments about this document should be emailed directly to the MPLS working group mailing list at mpls@lists.ietf.org

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The initial version of this MIB module was published in RFC XXXX. For full legal notices see the RFC itself or see: http://www.ietf.org/copyrights/ianamib.html

-- RFC Editor. Please replace XXXX with the RFC number for this document and remove this note.

This MIB module contains managed object definitions for mLDP LSPS defined in Label Distribution Protocol Extensions Point-to-Multipoint and Multipoint-to-Multipoint Label Switched Paths, RFC 6388, November 2011."

REVISION "201410100000Z" -- Oct 10, 2014
DESCRIPTION
"Initial version issued as part of RFC XXXX."

-- RFC Editor. Please replace XXXX with the RFC number for this document and remove this note.

 ::= { mplsStdMIB 99 }
-- RFC Editor. Please replace 99 with the codepoint issued by IANA and remove this note.

-- Top level components of this MIB module.

-- notifications
mplsMldpNotifications OBJECT IDENTIFIER ::= { mplsMldpStdMIB 0 }
-- tables, scalars
mplsMldpScalars     OBJECT IDENTIFIER ::= { mplsMldpStdMIB 1 }
mplsMldpObjects     OBJECT IDENTIFIER ::= { mplsMldpStdMIB 2 }

-- MPLS mLDP LSP scalars.

mplsMldpP2mpCapable OBJECT-TYPE
SYNTAX      INTEGER {
        enable(1),
        disable(2)
    }
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"This object provides the P2MP capability of the LSR."
REFERENCE
"Section 2.1 of [RFC6388]."
::= { mplsMldpScalars 1 }

mplsMldpMp2mpCapable OBJECT-TYPE
SYNTAX      INTEGER {
        enable(1),
        disable(2)
    }
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"This object provides MP2MP capability of the LSR."
REFERENCE
"Section 3.1 of [RFC6388]."
::= { mplsMldpScalars 2 }

mplsMldpMbbCapable OBJECT-TYPE
SYNTAX      INTEGER {
        enable(1),
        disable(2)
    }
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"This object provides MBB (make before break) capability of the LSR."
REFERENCE
"Section 8.3 of [RFC6388]."

::= { mplsMldpScalars 3 }

mplsMldpMbbTime OBJECT-TYPE
SYNTAX      Unsigned32 (1..300)
UNITS       "seconds"
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION  "The 32-bit unsigned integer value provides the time for waiting MBB Ack from upstream node."
DEFVAL { 30 }
::= { mplsMldpScalars 4 }

mplsMldpNumFecs OBJECT-TYPE
SYNTAX        Unsigned32
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION  "The number of active and passive mLdp Fecs on this device."
::= { mplsMldpScalars 5 }

mplsMldpNumFecsActive OBJECT-TYPE
SYNTAX        Unsigned32
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION  "The number of mLdp FECs Active on this device. The mLDP FEC is considered active if the mplsMldpFecOperStatus is up(1)."
::= { mplsMldpScalars 6 }

mplsMldpPlrCapable OBJECT-TYPE
SYNTAX      INTEGER {
    enable(1),
    disable(2)
}
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION  "This object provides Point of Local Repair (PLR) capability of the LSR."
REFERENCE
"Section 5.1 of [MLDP_NODE_PROT]."
::= { mplsMldpScalars 7 }

mplsMldpMptCapable OBJECT-TYPE
SYNTAX INTEGER {
    enable(1),
    disable(2)
}
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This object provides Merge Point (MPT) capability of the LSR."
REFERENCE
"Section 5.2 of [MLDP_NODE_PROT]."
::= { mplsMldpScalars 8 }

mplsMldProtLsrCapable OBJECT-TYPE
SYNTAX INTEGER {
    enable(1),
    disable(2)
}
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This object provides Protected LSR capability."
REFERENCE
"Section 5.3 of [MLDP_NODE_PROT]."
::= { mplsMldpScalars 9 }

mplsMldProtNodeProtCapable OBJECT-TYPE
SYNTAX INTEGER {
    enable(1),
    disable(2)
}
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This object provides Node Protection capability of the LSR."
REFERENCE
"Section 5.3 of [MLDP_NODE_PROT]."
::= { mplsMldpScalars 10 }

-- End of MPLS mLDP scalars.

-- MPLS mLDP tables.

-- The MPLS LDP Peer Capability Table

mplsLdpPeerCapabilityTable OBJECT-TYPE
SYNTAX      SEQUENCE OF MplsLdpPeerCapabilityEntry
MAX-ACCESS  not-accessible
STATUS      current
DESCRIPTION
"This table will have learned information relating to Mldp.
::= { mplsMldpObjects 1 }

mplsLdpPeerCapabilityEntry OBJECT-TYPE
SYNTAX      MplsLdpPeerCapabilityEntry
MAX-ACCESS  not-accessible
STATUS      current
DESCRIPTION
"Information about a single Peer which is related
to a Session.  This table is augmented by
the mplsLdpSessionTable."
INDEX       { mplsLdpEntityLdpId,
mplsLdpEntityIndex,
mplsLdpPeerLdpId }

::= { mplsLdpPeerCapabilityTable 1 }

mplsLdpPeerCapabilityEntry ::= SEQUENCE {
  mplsLdpPeerLdpId                MplsLdpIdentifier,
  mplsLdpPeerCapability           Integer32,
}

mplsLdpPeerCapability OBJECT-TYPE
SYNTAX      BITS {
  none (0),
p2mp (1),
mp2mp (2),
mbb (3),
upstream-label-assignment (4),
dynamic (5),
plr (6),
mpt (7),
prot-lsr (8),
}

Kishore Tiruveedhula, et Expires April 13, 2015 [Page 15]
node-prot (9)
}
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
" This will indicate the LDP capability information about peer. 
The p2mp indicates peer supports P2MP Capability. 
The mp2mp indicates peer supports MP2MP Capability. 
The mbb indicates peer supports MBB Capability. 
The upstream-label-assignment indicates peer supports Upstream label assignment Capability. 
The dynamic indicates peer supports dynamic Capability. 
The plr indicates Point of Local Repair Capability. 
The mpt indicates Point of Merge Point Capability. 
The prot-lsr indicates Protected LSR Capability. 
The node-prot indicates Node Protection LSR Capability. 
"

REFERENCE
"RFC6388, Section 2.1 for P2MP Capability TLV.
and the section 3.1 for MP2MP Capability TLV.
The RFC6388 for MBB Capability TLV.
RFC5561 Section 9 for Dynamic Capability Announcement TLV.
RFC6389 Section 3 for Upstream Label Assignment Capability TLV.
Section 5 of MLDP_NODE_PROT describes for Point of Local Repair (plr) capability, Merge Point (mpt) capability,
The Protected LSR (prot-lsr) and Node Protection (node-prot) Capability.
"

::= { mplsLdpPeerCapability 2 }

-- The MPLS mLDP Session Statistics Table
--

mplsMldpSessionStatsTable OBJECT-TYPE
SYNTAX      SEQUENCE OF MplsMldpSessionStatsEntry
MAX-ACCESS  not-accessible
STATUS      current
DESCRIPTION
"A table of statistics related to mLDP on Sessions.
This table AUGMENTS the mplsLdpSessionStatsTable."::= { mplsLdpObjects 2 }

mplsMldpSessionStatsEntry OBJECT-TYPE
SYNTAX      MplsMldpSessionStatsEntry
MAX-ACCESS  not-accessible
STATUS      current
DESCRIPTION
"An entry in this table represents mLDP statistical information on a single session between an LDP Entity and LDP Peer."

AUGMENTS { mplsLdpSessionStatsEntry }
 ::= { mplsmMldpSessionStatsTable 1 }

MplsMldpSessionStatsEntry ::= SEQUENCE {
    mplsMldpSessionStatsNumFecsSent          Counter32,
    mplsMldpSessionStatsNumMbbReqSentState   Counter32,
    mplsMldpSessionStatsNumFecsRcvd          Counter32,
    mplsMldpSessionStatsNumMbbReqRcvdState   Counter32,
    mplsMldpSessionStatsNumMbbResetAckByTimer Counter32
}

mplsMldpSessionStatsNumFecsSent OBJECT-TYPE
SYNTAX      Counter32
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
 "This object counts the number of mLDP FECs sent on this session. If the FEC is withdrawn, then this number is decremented. Discontinuities in the value of this counter can occur at re-initialization of the management system, and at other times as indicated by the value of mplsLdpSessionDiscontinuityTime."
 ::= { mplsMldpSessionStatsEntry 1 }

mplsMldpSessionStatsNumMbbReqSentState OBJECT-TYPE
SYNTAX      Counter32
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
 "This object counts the number of mLDP FECs sent on this session and waiting for MBB Ack. This counter will get incremented when MBB req sent for a label on this session and will get decremented when the MBB Ack received."
 ::= { mplsMldpSessionStatsEntry 2 }

mplsMldpSessionStatsNumFecsRcvd OBJECT-TYPE
SYNTAX      Counter32
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"This object counts the number of mLDP FECs received on this session. If the FEC is withdrawn from the downstream session, then this is decremented.

Discontinuities in the value of this counter can occur at re-initialization of the management system, and at other times as indicated by the value of mplsLdpSessionDiscontinuityTime."

::= { mplsMldpSessionStatsEntry 3 }

mplsMldpSessionStatsNumMbbReqRcvdState OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This object counts the number of mLDP FECs received on this session and waiting for sending MBB Ack. This counter will get incremented when MBB req is received for a label on this session and will get decremented when the MBB Ack sent."

::= { mplsMldpSessionStatsEntry 4 }

mplsMldpSessionStatsNumMbbResetAckByTimer OBJECT-TYPE
SYNTAX Counter32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This object counts the number mLDP FECs for which the MBB Ack is reset by MBB timer, in which the LSR is waiting for MBB ack.

::= { mplsMldpSessionStatsEntry 5 }

--
-- Mpls mLDP FEC Table
--

mplsMldpFecTable OBJECT-TYPE
SYNTAX SEQUENCE OF MplsFecEntry
MAX-ACCESS not-accessible
STATUS current
DESCRIPTION
"This table represents the FEC (Forwarding Equivalence Class) Information associated with an mLDP LSP."
::= { mplsMldpObjects 3 }

mplsMldpFecEntry OBJECT-TYPE
SYNTAX MplsMldpFecEntry
MAX-ACCESS not-accessible
STATUS current
DESCRIPTION "Each row represents a single mLDP FEC Element."
INDEX { mplsMldpFecIndex }
::= { mplsMldpFecTable 1 }

MplsMldpFecEntry ::= SEQUENCE {
  mplsMldpFecIndex               IndexInteger,
  mplsMldpFecType                INTEGER,
  mplsMldpFecRootAddrType        InetAddressType,
  mplsMldpFecRootAddr            InetAddress,
  mplsMldpFecOpaqueType          INTEGER,
  mplsMldpFecOpaqueGenLspId      Unsigned32,
  mplsMldpFecOpaqueTransitSourceOrBidirAddrType   InetAddressType,
  mplsMldpFecOpaqueTransitSourceOrBidirAddr       InetAddress,
  mplsMldpFecOpaqueTransitGroupAddrType           InetAddressType,
  mplsMldpFecOpaqueTransitGroupAddr               InetAddress,
  mplsMldpFecAdminStatus         INTEGER,
  mplsMldpFecOperStatus          INTEGER,
  mplsMldpFecMoFrr               INTEGER,
  mplsMldpFecLsrState            INTEGER,
  mplsMldpFecUpTime              TimeStamp
}

mplsMldpFecIndex OBJECT-TYPE
SYNTAX IndexInteger
MAX-ACCESS not-accessible
STATUS current
DESCRIPTION "The index which uniquely identifies this entry."
::= { mplsMldpFecEntry 1 }

mplsMldpFecType OBJECT-TYPE
SYNTAX INTEGER {
    p2mp(6),
    mp2mpUpstream(7),
    mp2mpDownstream(8)
}
MAX-ACCESS read-only
 STATUS current
MAX-ACCESS read-only
DESCRIPTION
"The type of the FEC. If the value of this object is 6, then it is P2MP Fec Type, and 7, 8 are correspond to MP2MP upstream and downstream type."
REFERENCE
"RFC6388, Section 2.2. The P2MP FEC Element and the section 3.3 for the MP2MP Fec elements."

::= { mplsMldpFecEntry 2 }

mplsMldpFecRootAddrType OBJECT-TYPE
SYNTAX InetAddressType
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The value of this object is the type of the Internet address. The value of this object, decides how the value of the mplsMldpFecRootAddr object is interpreted."
REFERENCE
"RFC6388, Section 2.2. The P2MP FEC Element and the section 3.3 for the MP2MP Fec elements."

::= { mplsMldpFecEntry 3 }

mplsMldpFecRootAddr OBJECT-TYPE
SYNTAX InetAddress
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The value of this object is interpreted based on the value of the mplsMldpFecRootAddrType object. This is ingress node address for the mLDP LSP."
REFERENCE
"RFC6388, Section 2.2. The P2MP FEC Element and the section 3.3 for the MP2MP Fec elements."

::= { mplsMldpFecEntry 4 }

mplsMldpFecOpaqueType OBJECT-TYPE
SYNTAX INTEGER {
  genericLspId(1),
}
transitIpv4Source(3),
transitIpv6Source(4),
transitIpv4Bidir(5),
transitIpv6Bidir(6)
)
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This is opaque type of the mLDP FEC. The value of this object is
shown below.

1 - The Generic LSP Identifier
3 - Transit IPv4 Source TLV
4 - Transit IPv6 Source TLV
5 - Transit IPv4 Bidir TLV
6 - Transit IPv6 Bidir TLV.
"
::= { mplsMldpFecEntry 5 }

mplsMldpFecOpaqueGenLspId OBJECT-TYPE
SYNTAX Unsigned32
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The 32-bit unsigned integer value which is to represent Generic
LSP ID. This value is only valid if the mplsMldpFecOpaqueType is
genericLspId(1), otherwise 0 must be returned."

REFERENCE
"RFC6388, Section 2.3.1."
::= { mplsMldpFecEntry 6 }

mplsMldpFecOpaqueTransitSourceOrBidirAddrType OBJECT-TYPE
SYNTAX InetAddressType
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"The value of this object is the type of the
Internet address. The value of this object,
decides how the value of the mplsMldpFecOpaqueTransitSourceOrBidir
Addr
object is interpreted."
REFERENCE
"RFC6826, Section 3.1."
::= { mplsMldpFecEntry 7 }

mplsMldpFecOpaqueTransitSourceOrBidirAddr OBJECT-TYPE
SYNTAX      InetAddress
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"The value of this object is interpreted based on the value of the mplsMldpFecOpaqueTransitSourceOrBidirAddrType object. This is source node address for the mLDP inband LSP."

REFERENCE
"RFC6826, Section 3.1."

::= { mplsMldpFecEntry 8 }

mplsMldpFecOpaqueTransitGroupAddrType OBJECT-TYPE
SYNTAX      InetAddressType
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"The value of this object is the type of the Internet address. The value of this object, decides how the value of the mplsMldpFecOpaqueTransitGroupAddr object is interpreted."

REFERENCE
"RFC6826, Section 3.2."

::= { mplsMldpFecEntry 9 }

mplsMldpFecOpaqueTransitGroupAddr OBJECT-TYPE
SYNTAX      InetAddress
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
"The value of this object is interpreted based on the value of the mplsMldpFecOpaqueTransitGroupAddrType object. This is group node address for the mLDP inband LSP."

REFERENCE
"RFC6826, Section 3.2."

::= { mplsMldpFecEntry 10 }

mplsMldpFecAdminStatus OBJECT-TYPE
SYNTAX       INTEGER {
               up(1), -- ready to pass data
               down(2) -- out of service
             }

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MAX-ACCESS    read-only
STATUS        current
DESCRIPTION  "Indicates the admin status of this mLDP FEC."
DEFVAL { up }
::= { mplsMldpFecEntry 11 }

mplsMldpFecOperStatus OBJECT-TYPE
SYNTAX        INTEGER {
    up(1),             -- ready to pass data
    down(2)            -- out of service
}
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION  "Indicates the actual operational status of this mLDP Fec."
::= { mplsMldpFecEntry 12 }

mplsMldpFecMoFrr OBJECT-TYPE
SYNTAX      INTEGER {
    enable(1),
    disable(2)
}
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION "This object provides whether MoFRR enabled for this mLDP FEC.
on this mLDP FEC. As mentioned in the section 3.2 of [MoFRR],
When this is enabled, then mLDP may select two upstream sessions,
one is primary and other one is backup. The backup traffic is
discarded when the primary upstream session is UP. When the
primary upstream session goes down, the traffic from the backup
upstream session will be forwarded to downstream.
"
::= { mplsMldpFecEntry 13 }

mplsMldpFecLsrState OBJECT-TYPE
SYNTAX        INTEGER {
    egress(1),
    bud(2),
    transit(3),
    ingress(4)
}
MAX-ACCESS    read-only
mldsMldpFecEntry 14

mplsMldpFecUpTime  OBJECT-TYPE
SYNTAX        TimeStamp
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION    "This values shows Fec UP time. This is time since mplsMldpFecOperStatus is UP."

mplsMldpFecBranchStatsTable  OBJECT-TYPE
SYNTAX        SEQUENCE OF MplsMldpFecBranchStatsEntry
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION    "This table provides mLDP Fec branch MPLS Traffic Stats information."

mplsMldpFecBranchStatsEntry OBJECT-TYPE
SYNTAX        MplsMldpFecBranchStatsEntry
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION    "An entry in this table is created by the LSR for each downstream branch (out-segment) from this LSR for this mLDP LSP. Each downstream session may represent a single out-segment. Each entry in the table is indexed by the four identifiers of the mLDP LSP, and the out-segment that identifies the outgoing branch."

INDEX       { mplsLdpEntityLdpId, mplsLdpEntityIndex, mplsLdpPeerLdpId, mplsMldpFecBranchFecIndex, mplsMldpFecBranchOutSegIndex }

::= { mplsMldpFecBranchStatsTable 1 }
MplsMldpFecBranchStatsEntry ::= SEQUENCE {
    mplsMldpFecBranchFecIndex           MplsIndexType,
    mplsMldpFecBranchOutSegIndex        MplsIndexType,
    mplsMldpFecBranchStatsPackets       Counter64,
    mplsMldpFecBranchStatsBytes         Counter64,
    mplsMldpFecBranchStatsDiscontinuityTime TimeStamp
}

mplsMldpFecBranchFecIndex          OBJECT-TYPE
SYNTAX        MplsIndexType
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION
    "This index identifies the mLDP FEC entry in the
    mplsMldpFecTable. This is same as mplsMldpFecIndex."
 ::= { mplsMldpFecBranchStatsEntry 1 }

mplsMldpFecBranchOutSegIndex          OBJECT-TYPE
SYNTAX        MplsIndexType
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION
    "This object identifies an outgoing branch from this mLDP LSP
    Its value is unique within the context of the mLDP LSP.
    This contains the same value as the mplsOutSegmentIndex in the
    MPLS-LSR-STD-MIBs mplsOutSegmentTable."
 ::= { mplsMldpFecBranchStatsEntry 2 }

mplsMldpFecBranchStatsPackets OBJECT-TYPE
SYNTAX        Counter64
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION
    "This object represent the 64-bit value, which gives the number
    of packets forwarded by the mLDP LSP onto this branch.
    This object should be read in conjunction with
    mplsMldpFecBranchStatsDiscontinuityTime."
 ::= { mplsMldpFecBranchStatsEntry 3 }

mplsMldpFecBranchStatsBytes OBJECT-TYPE
SYNTAX        Counter64
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION
"This object represent the 64-bit value, which gives the number
of bytes forwarded by the mLDP LSP onto this branch.
This object should be read in conjunction with
mplsMldpFecBranchStatsDiscontinuityTime."

::= { mplsMldpFecBranchStatsEntry 4 }

mplsMldpFecBranchStatsDiscontinuityTime OBJECT-TYPE
SYNTAX     TimeStamp
MAX-ACCESS read-only
STATUS      current
DESCRIPTION
"The value of sysUpTime on the most recent occasion at which
any one or more of this rows Counter32 or Counter64 objects
experienced a discontinuity. If no such discontinuity has
occurred since the last re-initialization of the local
management subsystem, then this object contains a zero
value."
::= { mplsMldpFecBranchStatsEntry 5 }

-- End of mplsMldpFecBranchStatsTable

-- MPLS mLDP LSP Upstream Session Table.

mplsMldpFecUpstreamSessTable OBJECT-TYPE
SYNTAX        SEQUENCE OF MplsMldpFecUpstreamSessEntry
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION
"This table provides mLDP Fec upstream Session information."
::= { mplsMldpObjects 5 }

mplsMldpFecUpstreamSessEntry OBJECT-TYPE
SYNTAX        MplsMldpFecUpstreamSessEntry
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION
"An entry in this table is created by the LSR for each
upstream session (in-segment) from this LSR for this mLDP
LSP. Each upstream session may represent a single in-segment.

Each entry in the table is indexed by the four identifiers
of the mLDP LSP, and the in-segment that identifies the
incoming traffic."
INDEX { mplsLdpEntityLdpId,
mplsLdpEntityIndex,
mplsLdpPeerLdpId,
mplsMldpFecUpstreamSessFecIndex,
mplsMldpFecUpstreamSessInSegIndex }

 ::= { mplsMldpFecUpstreamSessTable 1 }

MplsmLdpFecUpstreamSessEntry ::= SEQUENCE {
mplsMldpFecUpstreamSessFecIndex     MplsIndexType,
mplsMldpFecUpstreamSessInSegIndex   MplsIndexType,
mplsMldpFecUpstreamSessPrimary      INTEGER,
mplsMldpFecUpstreamSessActive       INTEGER,
mplsMldpFecUpstreamSessPackets      Counter64,
mplsMldpFecUpstreamSessBytes        Counter64,
mplsMldpFecUpstreamSessDiscontinuityTime TimeStamp }

mplsMldpFecUpstreamSessFecIndex OBJECT-TYPE
SYNTAX         MplsIndexType
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION  "This index identifies the mLDP FEC entry in the
mplsMldpFecTable."

 ::= { mplsMldpFecUpstreamSessEntry 1 }

mplsMldpFecUpstreamSessInSegIndex OBJECT-TYPE
SYNTAX         MplsIndexType
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION  "This object identifies an upstream session from this mLDP LSP
Its value is unique within the context of the mLDP LSP.
This contains the same value as the mplsInSegmentIndex in the
MPLS-LSR-STD-MIBs mplsInSegmentTable."

 ::= { mplsMldpFecUpstreamSessEntry 2 }

mplsMldpFecUpstreamSessPrimary OBJECT-TYPE
SYNTAX      INTEGER {
    primary(1),
    backup(2)
}

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MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
 "This indicated whether the received traffic from upstream is
 primary or backup. This is valid only if the MoFRR
 (mplsMldpFecMoFrr) is enabled on this FEC."

::= { mplsMldpFecUpstreamSessEntry 3 }

mplsMldpFecUpstreamSessActive  OBJECT-TYPE
SYNTAX      INTEGER { 
    active(1),
    inactive(2) 
} 
MAX-ACCESS  read-only
STATUS      current
DESCRIPTION
 "This indicates whether the upstream session is active, means the
 LSR programmed the forwarding engine to receive the traffic from
 this upstream session. This will be Inactive if the LSR is waiting
 for MBB Ack."

::= { mplsMldpFecUpstreamSessEntry 4 }

mplsMldpFecUpstreamSessPackets  OBJECT-TYPE
SYNTAX        Counter64
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION
 "This object represent the 64-bit value, which gives the number
 of packets received by the mLDP LSP from this upstream
 session. This object should be read in conjunction with
 mplsMldpFecUpstreamSessDiscontinuityTime."

::= { mplsMldpFecUpstreamSessEntry 5 }

mplsMldpFecUpstreamSessBytes   OBJECT-TYPE
SYNTAX        Counter64
MAX-ACCESS    read-only
STATUS        current
DESCRIPTION
 "This object represent the 64-bit value, which gives the number
 of bytes received by the mLDP LSP from this upstream
 session. This object should be read in conjunction with
 mplsMldpFecUpstreamSessDiscontinuityTime."

::= { mplsMldpFecUpstreamSessEntry 6 }
mplsMldpFecUpstreamSessDiscontinuityTime OBJECT-TYPE
SYNTAX     TimeStamp
MAX-ACCESS read-only
STATUS      current
DESCRIPTION
"The value of sysUpTime on the most recent occasion at which
any one or more of this rows Counter32 or Counter64 objects
experienced a discontinuity. If no such discontinuity has
occurred since the last re-initialization of the local
management subsystem, then this object contains a zero
value."
 ::= { mplsMldpFecUpstreamSessEntry 7 }

-- End of mplsMldpFecBranchStatsTable

-- MPLS mLDP Interface Traffic Stats Table.

mplsMldpInterfaceStatsTable OBJECT-TYPE
SYNTAX        SEQUENCE OF MplsMldpInterfaceStatsEntry
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION
"This table provides mLDP Traffic Stats on specified interface."
 ::= { mplsMldpObjects 6 }

MplsMldpInterfaceStatsEntry OBJECT-TYPE
SYNTAX        MplsMldpInterfaceStatsEntry
MAX-ACCESS    not-accessible
STATUS        current
DESCRIPTION
"An entry in this table is created by the LSR for each
downstream branch (out-segment) from this LSR for this mLDP
LSP. Each downstream session may represent a single out-segment.

Each entry in the table is indexed by the four identifiers
of the mLDP LSP, and the out-segment that identifies the
outgoing branch."

INDEX       { mplsMldpInterfaceIndex

 ::= { mplsMldpInterfaceStatsTable 1 }

MplsMldpInterfaceStatsEntry ::= SEQUENCE {
            mplsMldpInterfaceIndex            InterfaceIndex,
            mplsMldpInterfaceStatsSentPackets  Counter64,
mplsMldpInterfaceIndex OBJECT-TYPE
SYNTAX InterfaceIndex
MAX-ACCESS not-accessible
STATUS current
DESCRIPTION "This index identifies the specific interface."
::= { mplsMldpInterfaceStatsEntry 1 }

mplsMldpInterfaceStatsSentPackets OBJECT-TYPE
SYNTAX Counter64
MAX-ACCESS read-only
STATUS current
DESCRIPTION "This is 64 bit value, which gives the number of packets forwarded by all mLDP LSPs onto this interface."
::= { mplsMldpInterfaceStatsEntry 2 }

mplsMldpInterfaceStatsSentBytes OBJECT-TYPE
SYNTAX Counter64
MAX-ACCESS read-only
STATUS current
DESCRIPTION "This is 64 bit value, which gives the number of bytes forwarded by all mLDP LSPs onto this interface."
::= { mplsMldpInterfaceStatsEntry 3 }

mplsMldpInterfaceRecvPackets OBJECT-TYPE
SYNTAX Counter64
MAX-ACCESS read-only
STATUS current
DESCRIPTION "This is 64 bit value, which gives the number of packets received by all mLDP LSPs from this interface."
::= { mplsMldpInterfaceStatsEntry 4 }

mplsMldpInterfaceStatsRecvBytes OBJECT-TYPE
SYNTAX Counter64
MAX-ACCESS read-only
STATUS  current
DESCRIPTION
"This is 64 bit value, which gives the number of bytes
received by all mLDP LSPs from this interface."

::= { mplsMldpInterfaceStatsEntry 5 }

-- End of mplsMldpInterfaceStatsTable

-- Notifications.

mplsMldpFecUp NOTIFICATION-TYPE
OBJECTS  {
    mplsMldpFecAdminStatus,
    mplsMldpFecOperStatus
}
STATUS  current
DESCRIPTION
"This notification is generated when a mplsMldpFecOperStatus
object changes from down to up."

::= { mplsMldpNotifications 1 }

mplsMldpFecDown NOTIFICATION-TYPE
OBJECTS  {
    mplsMldpFecAdminStatus,
    mplsMldpFecOperStatus
}
STATUS  current
DESCRIPTION
"This notification is generated when a mplsMldpFecOperStatus
object changes from up to down."

::= { mplsMldpNotifications 2 }

mplsMldpMoFrrStatusChange NOTIFICATION-TYPE
OBJECTS  {
    mplsMldpFecUpstreamSessPrimary,
}
STATUS  current
DESCRIPTION
"This notification is generated when a mplsMldpFecUpstreamSessPrimary
object changes from primary to backup and vice versa."

::= { mplsMldpNotifications 3 }

-- End of notifications.
12. Security Considerations

This MIB module is useful for the configuration of certain objects and monitoring of mLDP LSPs.

There are no management objects defined in this MIB module that have a MAX-ACCESS clause of read-write and/or read-create. So, if this MIB module is implemented correctly, then there is no risk that an intruder can alter or create any management objects of this MIB module via direct SNMP SET operations.

Some of the readable objects in this MIB module (i.e., objects with a MAX-ACCESS other than not-accessible) may be considered sensitive or vulnerable in some network environments. It is thus important to control even GET and/or NOTIFY access to these objects and possibly to even encrypt the values of these objects when sending them over the network via SNMP. These are the tables and objects and their sensitivity/vulnerability:

- mplsMldpFecTable
- mplsLdpPeerCapabilityTable
- mplsMldpSessionStatsTable
- mplsMldpFecBranchStatsTable
- mplsMldpFecUpstreamSessTable
- mplsMldpInterfaceStatsTable
- mplsMldpNumFecs
- mplsMldpNumFecsActive
- mplsMldpMbbTime

Above listed tables and objects show information about the mLDP LSPs, its route through the network, and its traffic statistics. Knowledge of this information could be used to compromise the network, or simply to breach confidentiality. If an Administrator does not want to reveal this information, these tables and objects should be considered sensitive/vulnerable.

SNMP versions prior to SNMPv3 did not include adequate security. Even if the network itself is secure (for example by using IPsec), there is no control as to who on the secure network is allowed to
access and GET/SET (read/change/create/delete) the objects in this
MIB module.

Implementations SHOULD provide the security features described by the
SNMPv3 framework (see [RFC3410]), and implementations claiming
compliance to the SNMPv3 standard MUST include full support for
authentication and privacy via the User-based Security Model (USM)
[RFC3414] with the AES cipher algorithm [RFC3826]. Implementations
MAY also provide support for the Transport Security Model (TSM)
[RFC5591] in combination with a secure transport such as SSH
[RFC5592] or TLS/DTLS [RFC6353].

Further, deployment of SNMP versions prior to SNMPv3 is NOT
RECOMMENDED. Instead, it is RECOMMENDED to deploy SNMPv3 and to
enable cryptographic security. It is then a customer/operator
responsibility to ensure that the SNMP entity giving access to an
instance of this MIB module is properly configured to give access to
the objects only to those principals (users) that have legitimate
rights to indeed GET or SET (change/create/delete) them.

13. IANA Considerations

This is new MPLS MIB module, contained in this document and IANA is
requested to assign an oid under the mplsStdMIB subtree to the MPLS-
MDLP-STD-MIB module specified in this document.

14. Acknowledgments

The authors wish to thank Santosh Esale, Alia Atlas and Martin Ehlers
for doing the detailed review. Thanks to Adrian Farrel and Raveendra
Torvi for their input to this work and for many helpful suggestions.

15. References

15.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate

Schoenwaelder, Ed., "Structure of Management Information
Version 2 (SMIv2)", STD 58, RFC 2578, April 1999.

Schoenwaelder, Ed., "Textual Conventions for SMIv2", STD
58, RFC 2579, April 1999.


15.2. Informative References


Appendix A.  Change Log

Appendix B.  Open Issues

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Yang Data Model for LSP-PING
draft-zheng-mpls-lsp-ping-yang-cfg-00.txt

Abstract

This document defines a YANG data model that can be used to configure and manage LSP-Ping.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

When an LSP fails to deliver user traffic, the failure cannot always be detected by the MPLS control plane. [RFC4379] defines a mechanism that would enable users to detect such failure and to isolate faults. YANG [RFC6020] is a data definition language that was introduced to define the contents of a conceptual data store that allows networked devices to be managed using NETCONF [RFC6241]. This document defines a YANG data model that can be used to configure and manage LSP-Ping [RFC4379].

The rest of this document is organized as follows. Section 2 presents the scope of this document. Section 3 provides the design of the LSP-Ping configuration data model in details by containers. Section 4 presents the complete data hierarchy of LSP-Ping YANG model. Section 5 discusses the interaction between LSP-Ping data model and other MPLS tools data models. Section 6 specifies the YANG module and section 7 lists examples which conform to the YANG module.
specified in this document. Finally, security considerations are discussed in Section 8.

1.1. Support of Long Running Command with NETCONF

LSP Ping is one of examples of what can described as "long-running operation". Unlike most of configuration operations that result in single response execution of an LSP Ping triggers multiple responses from a node under control. The question of implementing long-running operation in NETCONF is still open and possible solutions being discussed:

1. Consecutive Remote Processing Calls (RPC) to poll for results;
2. Model presented in [RFC4560];
3. The one outlined in [I-D.mahesh-netconf-persistent].

The problem of long-running operation as well can be considered as a case of controlling and obtaining results from a Measurement Agent (MA) as defined in [I-D.ietf-lmap-framework].

1.2. Contributors

The following made vital contributions to this document:

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2. Scope

The fundamental mechanism of LSP-Ping is defined in [RFC4379]. Extentions of LSP-Ping has been developed over the years. Examples are performing LSP ping over P2MP MPLS LSPs [RFC6425] and traceroute over MPLS tunnels [RFC6424] etc. These extentions will be considered in update of this document.

3. Design of the Data Model

The LSP-Ping Yang model defined in this document provides the following features:

1. Configuration of control information of a LSP-Ping test;
2. Configuration of schedule parameters of a LSP-Ping test;
3. Display of result information of a LSP-Ping test.
3.1. Configuration of Control Information

Container lspPings:lspPing:ctrlInfo defines the configuration parameters control a LSP-Ping test. Examples are the Target FEC address type/address and the reply mode of the echo reply packet. Some node may be auto-assigned by the system, but there may be requirement of configuration. Examples are source address and interface.

The data hierarchy for control information configuration is presented below:

module: mpls-lsp-ping
    +--rw lspPings
        +--rw lspPing* [lsp-ping-name]
            +--rw lsp-ping-name    string
            +--rw ctrlInfo
                +--rw TargetAddType?       enumeration
                +--rw (TargetAdd)?
                    |  +--rw ipv4add?             inet:ip-address
                    |  +--rw ipv6add?             inet:ip-address
                    |  +--rw bgp?                 inet:ip-address
                    |  +--rw l3vpnid?             uint32
                    |  +--rw l3vpn-ipadd?         inet:ip-address
                    +--rw (tunnel-if)
                    |  +--rw tunnel-if?           uint32
                    +--rw (vc)
                    |  +--rw vc?                  uint32
                    +--rw (vpls)
                    |  +--rw vpls?                string
                +--rw ReplyMode?           enumeration
                +--rw TimeOut?             uint32
                +--rw Frequency?           uint32
                +--rw AdminStatus?         enumeration
                +--rw ProbeCount?          uint32
                +--rw DataSize?            uint32
                +--rw DataFill?            string
                +--rw Descr?               string
                +--rw SourceAddressType?   enumeration
                +--rw SourceAddress?       inet:ip-address
                +--rw IfIndex?             uint32
3.2. Configuration of Schedule Parameters

Container lspPings:lspPing:schedulePara defines the test schedule parameters of a LSP-Ping test, which basically describes when to start and when to end the test. Four start modes and three end modes are defined respectively.

The data hierarchy for schedule information configuration is presented below:

module: mpls-lsp-ping
  +--rw lspPings
        +--rw lspPing* [lsp-ping-name]
              +--rw lsp-ping-name    string
              +--rw ctrlInfo
              ... 
              +--rw schedulePara
                    +--rw (startTest)?
                    |   +--:(now)
                    |   |   +--rw startTestNow?      empty
                    |   +--:(at)
                    |   |   +--rw startTestAt?       yang:date-and-time
                    |   +--:(delay)
                    |   |   +--rw startTestDelay?    uint32
                    |   +--:(daily)
                    |       +--rw startTestDaily?   yang:date-and-time
                    +--rw (endTest)?
                    |   +--:(at)
                    |       +--rw endTestAt?       yang:date-and-time
                    |   +--:(delay)
                    |       +--rw endTestDelay?    uint32
                    |   +--:(daily)
                    |       +--rw endTestLifetime?  uint32

3.3. Display of Result Information

Container lspPings:lspPing:resultInfo shows the result of the current LSP-Ping test. The data hierarchy for display of result information is presented below:
module: mpls-lsp-ping
  +--rw lspPings
  +--rw lspPing* [lsp-ping-name]
     +--rw lsp-ping-name    string
     +--rw ctrlInfo
     ...  
     +--rw schedulePara  
     ...  
     +--ro resultInfo
        +--ro OperStatus?       enumeration
        +--ro TargetAddType?       enumeration
        +--ro (TargetAdd)?
           |  +--:(ipv4)
           |     |  +--ro ipv4add?           inet:ip-address
           |  +--:(ipv6)
           |     |  +--ro ipv6add?           inet:ip-address
           |  +--:(bgp)
           |     |  +--ro bgp?               inet:ip-address
           |  +--:(l3vpn)
           |     |  +--ro l3vpnid?           uint32
           |     |  +--ro l3vpn-ipadd?        inet:ip-address
           |     +--:(tunnel-if)
           |        |  +--ro tunnel-if?         uint32
           |     +--:(vc)
           |        |  +--ro vc?               uint32
           |     +--:(vplsl)
           |        |  +--ro vpls?              string
           |  +--ro MinRtt?             uint32
           +--ro MaxRtt?             uint32
           +--ro AverageRtt?         uint32
           +--ro ProbeResponses?      uint32
           +--ro SentProbes?          uint32
           +--ro SumOfSquares?        uint32
           +--ro LastGoodProbe?       yang:date-and-time

4. Data Hierarchy

The complete data hierarchy of LSP-Ping YANG model is presented below.

module: mpls-lsp-ping
  +--rw lspPings
     +--rw lspPing* [lsp-ping-name]
        +--rw lsp-ping-name    string
        +--rw ctrlInfo
           +--rw TargetAddType?       enumeration
           |  +--:(ipv4)
| +--rw ipv4add?           inet:ip-address
|   +--:(ipv6)
|   | +--rw ipv6add?           inet:ip-address
|   +--:(bgp)
|   | +--rw bgp?               inet:ip-address
|   +--:(l3vpn)
|   | +--rw l3vpnid?           uint32
|   | +--rw l3vpn-ipadd?        inet:ip-address
|   +--:(tunnel-if)
|   | +--rw tunnel-if?         uint32
|   +--:(vc)
|   | +--rw vc?                uint32
|   +--:(vpls)
|   | +--rw vpls?              string
|   | +--rw ReplyMode?         enumeration
|   | +--rw Timeout?           uint32
|   | +--rw Frequency?         uint32
|   | +--rw AdminStatus?       enumeration
|   | +--rw ProbeCount?        uint32
|   | +--rw DataSize?          uint32
|   | +--rw DataFill?          string
|   | +--rw Descr?             string
|   | +--rw SourceAddressType? enumeration
|   | +--rw SourceAddress?     inet:ip-address
|   | +--rw IfIndex?           uint32
|   +--rw schedulePara
|   | +--rw (startTest)?
|   |   +--:(now)
|   |   | +--rw startTestNow?     empty
|   |   +--:(at)
|   |   | +--rw startTestAt?      yang:date-and-time
|   |   +--:(delay)
|   |   | +--rw startTestDelay?   uint32
|   |   +--:(daily)
|   |   | +--rw startTestDaily?   yang:date-and-time
|   |   +--rw (endTest)?
|   |   +--:(at)
|   |   | +--rw endTestAt?        yang:date-and-time
|   |   +--:(delay)
|   |   | +--rw endTestDelay?     uint32
|   |   +--:(daily)
|   |   | +--rw endTestLifetime?  uint32
|   +--ro resultInfo
|   | +--ro OperStatus?        enumeration
|   | +--ro TargetAddType?     enumeration
|   | +--ro (TargetAdd)?
|   |   +--:(ipv4)
|   |   | +--ro ipv4add?          inet:ip-address
module mpls-lsp-ping {
    namespace "urn:ietf:params:xml:ns:yang:mpls-lsp-ping";
    //namespace need to be assigned by IANA
    prefix "lspping";

    import ietf-inet-types {
        prefix inet;
    }
    import ietf-yang-types{
        prefix yang;
    }

    organization "IETF MPLS (Multiprotocol Label Switching) Working Group";
    contact "vero.zheng@huawei.com
              zhangyanfeng@huawei.com"

    description "MPLS LSP-PING Yang Module";
    revision "2015-01-21" {
        description
                 "Initial version";
    }
}
container lspPings {
  list lspPing {
    key "lsp-ping-name";
    leaf lsp-ping-name {
      description "lsp ping name";
      mandatory "true";
      type string {
        length "1..31";
      }
    }
  }
}

container ctrlInfo {
  leaf TargetAddType {
    description "Specifies the address type of Target FEC.";
    type enumeration {
      enum ipv4 {
        value "0";
        description "IPv4 LSP’s destination";
      }
      enum ipv6 {
        value "1";
        description "IPv6 LSP’s destination";
      }
      enum bgp {
        value "2";
        description "BGP LSP’s destination";
      }
      enum tunnel-if {
        value "3";
        description "tunnel interface";
      }
      enum l3vpn {
        value "4";
        description "l3vpn-instance and remote address";
      }
      enum pwid {
        value "5";
        description "pwid";
      }
      enum vsi-name {
        value "6";
        description "name of VSI";
      }
    }
  }
}
choice TargetAdd{
    description
    "Specifies the address of Target FEC";
    case ipv4 {
        leaf ipv4add{
            type inet:ip-address;
        }
    }
    case ipv6 {
        leaf ipv6add{
            type inet:ip-address;
        }
    }
    case bgp {
        leaf bgp{
            type inet:ip-address;
        }
    }
    case l3vpn {
        leaf l3vpnid{
            type uint32;
        }
        leaf l3vpn-ipadd{
            type inet:ip-address;
        }
    }
    case tunnel-if {
        leaf tunnel-if{
            type uint32;
        }
    }
    case vc {
        leaf vc{
            type uint32;
        }
    }
    case vpls {
        leaf vpls{
            type string;
        }
    }
}

leaf ReplyMode {
    description
    "Specifies the reply mode.";
    type enumeration {
        enum 1 {

        }
    }
}
value "1";
    description "Do not reply";
  }
}

enum 2 {
  value "2";
  description "Reply via an IPv4/IPv6 UDP packet";
}

enum 3 {
  value "3";
  description "Reply via an IPv4/IPv6 UDP packet with Router Alert";
}

enum 4 {
  value "4";
  description "Reply via application level control channel";
}

leaf TimeOut {
  description "Specifies the time-out value, in seconds, for a lsp ping operation.";
  type uint32;
}

leaf Frequency {
  description "Specifies the frequency to perform a lsp ping operation as part of one ping test.";
  type uint32;
}

leaf AdminStatus {
  description "Specifies the desired state is enabled(1) or disabled(2)";
  type enumeration {
    enum enabled {
      value "1";
      description "The desired state is enabled";
    }
    enum disabled {
      value "2";
      description "The desired state is disabled";
    }
  }
}

leaf ProbeCount {
  description "Specifies the number of probe sent of one lsp ping test.";
}
type uint32;
}

leaf DataSize {
  description
  "Specifies the size of the data portion to be transmitted in a lsp ping operation, in octets.";
  type uint32;
}

leaf DataFill {
  description
  "The content of this object is used together with the corresponding DataSize value to determine how to fill the data portion of a probe packet."
  type string{
    length "0..1564";
  }
}

leaf Descr {
  description
  "a descriptive name of the lsp ping test.";
  type string{
    length "1..31";
  }
}

leaf SourceAddressType {
  description
  "Specifies the type of the source address.";
  type enumeration {
    enum ipv4 {
      value "0";
      description "IPv4 address";
    }
    enum ipv6 {
      value "1";
      description "IPv6 address";
    }
  }
}

leaf SourceAddress {
  description
  "Specifies the source address.";
  type inet:ip-address;
}

leaf IfIndex {
  description
  "Specifies
"Setting this object to an interface’s ifIndex prior to starting a remote ping operation directs the ping probes to be transmitted over the specified interface."

```yml
container schedulePara {
    description "LSP ping schedule parameter";
    choice startTest {
        description "Specifies when the test begins to start, include 4 schedule method: start now(1), start at(2), start delay(3) start daily(4).";
        case now {
            leaf startTestNow {
                description "Start test now.";
                type empty;
            }
        }
        case at {
            leaf startTestAt {
                description "Start test at a time."
                type yang:date-and-time;
            }
        }
        case delay {
            leaf startTestDelay {
                description "Start delay time."
                type uint32;
            }
        }
        case daily {
            leaf startTestDaily {
                description "Start test daily."
                type yang:date-and-time;
            }
        }
    }
    choice endTest {
        description "Specifies when the test ends, include 3 schedule method: end at(1), end delay(2), end lifetime(3).";
        case at {
            leaf endTestAt {
                description "End test at a time."
                type yang:date-and-time;
            }
        }
        case delay {
        }
    }
}
```
leaf endTestDelay{
    description "End delay some time.";
    type uint32;
}

case daily {
    leaf endTestLifetime{
        description "Set the test lifetime.";
        type uint32;
    }
}
}

container resultInfo {
    config "false";
    leaf OperStatus {
        description "Reflects the operational state of a lsp Ping test";
        type enumeration {
            enum enabled {
                value "1";
                description "The Test is active";
            }
            enum disabled {
                value "2";
                description "The test has stopped";
            }
            enum completed {
                value "3";
                description "The test is completed";
            }
        }
    }
}

leaf TargetAddType {
    description "Specifies the address type of Target FEC.";
    type enumeration {
        enum ipv4 {
            value "0";
            description "IPv4 LSP’s destination";
        }
        enum ipv6 {
            value "1";
            description "IPv6 LSP’s destination";
        }
        enum bgp {
            description "The test has stopped";
        }
    }
}
value "2";
  description "BGP LSP’s destination";
}
enum tunnel-if {
  value "3";
  description "tunnel interface";
}
enum l3vpn {
  value "4";
  description "l3vpn-instance and remote address";
}
enum pwid {
  value "5";
  description "pwid";
}
enum vsi-name {
  value "6";
  description "name of VSI";
}

choice TargetAdd{
  case ipv4 {
    leaf ipv4add{
      type inet:ip-address;
    }
  }
  case ipv6 {
    leaf ipv6add{
      type inet:ip-address;
    }
  }
  case bgp {
    leaf bgp{
      type inet:ip-address;
    }
  }
  case l3vpn {
    leaf l3vpnid{
      type uint32;
    }
    leaf l3vpn-ipadd{
      type inet:ip-address;
    }
  }
  case tunnel-if {
    leaf tunnel-if{
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    type uint32;
 }
}
}
}
}

leaf MinRtt {
    description
        "The minimum lsp ping round-trip-time (RTT) received.";
    type uint32;
}

leaf MaxRtt {
    description
        "The maximum lsp ping round-trip-time (RTT) received.";
    type uint32;
}

leaf AverageRtt {
    description
        "The current average lsp ping round-trip-time (RTT).";
    type uint32;
}

leaf ProbeResponses {
    description
        "Number of responses received for the corresponding lsp ping test.";
    type uint32;
}

leaf SentProbes {
    description
        "Number of probes sent for the corresponding lsp ping test.";
    type uint32;
}

leaf SumOfSquares {
    description
        "This object contains the sum of the squares for all replies received.";
type uint32;
}

leaf LastGoodProbe {
  description
    "Date and time when the last response was received for a probe.";
  type yang:date-and-time;
}

7. Examples

Examples of using Yang module to configure and manage LSP-Ping will be given here in the update when the Yang module is stable.

8. Security Considerations

The configuration and state data defined in this document is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The authors recommend to implement the NETCONF access control model [RFC6536] to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operations and content.

There are a number of config true nodes defined in the YANG module which are writable/creatable/deletable. These data nodes may be considered sensitive or vulnerable in some network environments. Write operations to these data nodes without proper protection can have a negative effect on network operations.

9. IANA Considerations

The IANA is requested to assign a new namespace URI from the IETF XML registry.

URI:TBD

10. Acknowledgements

We would also like to thank XXX.
11. References

11.1. Normative References


11.2. Informative References


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