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RFC6374 Synonymous Flow Labels
draft-bryant-mpls-rfc6374-sfl-04

Abstract

This document describes a method of making RFC6374 performance measurements on flows carried over an MPLS Label Switched path. This allows loss and delay measurements to be made on multi-point to point LSPs and allows the measurement of flows within an MPLS construct using RFC6374.

Status of This Memo

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1. Introduction

[RFC6374] was originally designed for use as an OAM protocol for use with MPLS Transport Profile (MPLS-TP) [RFC5921] LSPs. MPLS-TP only supports point-to-point and point-to-multi-point LSPs. This document describes how to use RFC6374 in the general MPLS case, and also introduces a number of more sophisticated measurements of applicability to both cases.

[I-D.ietf-mpls-flow-ident] describes the requirement for introducing flow identities when using RFC6374 [RFC6374] packet Loss Measurements (LM). In summary RFC6374 uses the loss-measurement (LM) packet as the packet accounting demarcation point. Unfortunately this gives rise to a number of problems that may lead to significant packet accounting errors in certain situations. For example:

1. Where a flow is subjected to Equal Cost Multi-Path (ECMP) treatment packets can arrive out of order with respect to the LM packet.

2. Where a flow is subjected to ECMP treatment, packets can arrive at different hardware interfaces, thus requiring reception of an LM packet on one interface to trigger a packet accounting action on a different interface which may not be co-located with it. This is a difficult technical problem to address with the required degree of accuracy.

3. Even where there is no ECMP (for example on RSVP-TE, MPLS-TP LSPs and PWs) local processing may be distributed over a number of processor cores, leading to synchronization problems.

4. Link aggregation techniques may also lead to synchronization issues.

5. Some forwarder implementations have a long pipeline between processing a packet and incrementing the associated counter again leading to synchronization difficulties.

An approach to mitigating these synchronization issue is described in [I-D.tempia-ippm-p3m] and [I-D.chen-ippm-coloring-based-ipfpm-framework] in which packets are batched by the sender and each batch is marked in some way such that adjacent batches can be easily recognized by the receiver.

An additional problem arises where the LSP is a multi-point to point LSP, since MPLS does not include a source address in the packet. Network management operations require the measurement of packet loss between a source and destination. It is thus necessary to introduce some source specific information into the packet to identify packet batches from a specific source.

[I-D.bryant-mpls-sfl-framework] describes a method of encoding per flow instructions in an MPLS label stack using a technique called Synonymous Flow Labels (SFL) in which labels which mimic the behaviour of other labels provide the packet batch identifiers and enable the per batch packet accounting. This memo specifies how SFLs

are used to perform RFC6374 packet loss and RFC6374 delay measurements.

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. RFC6374 Packet Loss Measurement with SFL

The data service packets of the flow being instrumented are grouped into batches, and all the packets within a batch are marked with the SFL [I-D.ietf-mpls-flow-ident] corresponding to that batch. The sender counts the number of packets in the batch. When the batch has completed and the sender is confident that all of the packets in that batch will have been received, the sender issues an RFC6374 Query message to determine the number actually received and hence the number of packets lost. The RFC6374 Query message is sent using the same SFL as the co-responding batch of data service packets. The format of the Query and Response packet is described in Section 9.

4. RFC6374 Single Packet Delay Measurement

RFC6374 describes how to measure the packet delay by measuring the transit time of an RFC6374 packet over an LSP. Such a packet may not need to be carried over an SFL since the delay over a particular LSP should be a function of the TC bits.

However where SFLs are being used to monitor packet loss or where label inferred scheduling is used [RFC3270] then the SFL would be REQUIRED to ensure that the RFC6374 packet which was being used as a proxy for a data service packet experienced a representative delay. The format of an RFC6374 packet carried over the LSP using an SFL is shown in Section 9.

5. Data Service Packet Delay Measurement

Where it is desired to more thoroughly instrument a packet flow and to determine the delay of a number of packets it is undesirable to send a large number of RFC6374 packets acting as proxy data service packets Section 4. A method of directly measuring the delay characteristics of a batch of packets is therefore needed.

Given the long intervals over which it is necessary to measure packet loss, it is not necessarily the case that the batch times for the two measurement types would be identical. This it is proposed that the

two measurements are relatively independent. The notion that they are relatively independent arises for the potential for the two batches to overlap in time, in which case either the delay batch time will need to be cut short or the loss time will need to be extended to allow correct reconciliation of the various counters.

The problem is illustrated in Figure 1 below:

(1) AAAAAAAAAABBBBBBBBBBAAAAAAAAAABBBBBBBBBB

SFL Marking of a packet batch for loss measurement

(2) AADDDDAAAABBBBBBBBBBAAAAAAAAAABBBBBBBBBB

SFL Marking of a subset if the packets for delay

(3) AAAAAAAADDDDBBBBBBBBAAAAAAAAAABBBBBBBBBB

SFL Marking of a subset of the packets across a packet loss measurement boundary

(4) AACDCDCDAABBBBBBBBBBAAAAAAAAAABBBBBBBBBB

The case of multiple delay measurements within a packet loss measurement

Figure 1: RFC6734 Query Packet with SFL

In case 1 of Figure 1 we show the case were loss measurement alone is being carried out on the flow under analysis. For illustrative purposes consider that in the time interval being analyzed, 10 packets always flow.

Now consider case 2 of Figure 1 where a small batch of packets need to analyzed for delay. These are marked with a different SFL type indicating that they are to be monitored for both loss and delay. The SFL=A indicates loss batch A, SFL=D indicates a batch of packets that are to be instrumented for delay, but SFL D is synonymous with SFL A, which in turn is synonymous with the underlying FEC. Thus a packet marked D will be accumulated into the A loss batch, into the delay statistics and will be forwarded as normal. Whether the packet is actually counted twice (for loss and delay) or whether the two counters are reconciled during reporting is a local matter.

Now consider case 3 of Figure 1 where a small batch of packets are marked for delay across a loss batch boundary. These packets need to considered as part of batch A or a part of batch B, and any RFC6374

Query needs to take place after all the packets A or D (which ever option is chosen) have arrived at the receiving LSR.

Now consider case 4 of Figure 1. Here we have a case where it is required to take a number of delay measurements within a batch of packets that we are measuring for loss. To do this we need two SFLs for delay (C and D) and alternate between them (on a delay batch by delay batch basis) for the purposes of measuring the delay characteristics of the different batches of packets.

6. Some Simplifying Rules

It is possible to construct a large set of overlapping measurement type, in terms of loss, delay, loss and delay and batch overlap. If we allow all combination of cases, this leads to configuration, testing and implementation complexity and hence increased operation and capital cost. The following simplifying rules represent the default case:

1. Any system that needs to measure delay MUST be able to measure loss.

2. Any system that is to measure delay MUST be configured to measure loss. Whether the loss statistics are collected or not is a local matter.

3. A delay measurement MAY start at any point during a loss measurement batch, subject to rule 4.

4. A delay measurement interval MUST be short enough that it will complete before the enclosing loss batch completes.

5. The duration of a second delay (D in Figure 1 batch must be such that all packets from the packets belonging to a first delay batch (C in Figure 1)will have been received before the second delay batch completes.

Given that the sender controls both the start and duration of a loss and a delay packet batch, these rules are readily implemented in the control plane.

7. Multiple Packet Delay Characteristics

A number of methods are described. The expectation is that the MPLS WG possibly with the assistance of the IPPM WG will select one or maybe more than one of these methods for standardization.

Three Methods are discussed:

1. Time Buckets

2. Classic Standard Deviation

3. Average Delay

7.1. Method 1: Time Buckets

In this method the receiving LSR measures the inter-packet gap, classifies the delay into a number of delay buckets and records the number of packets in each bucket. As an example, if the operator were concerned about packets with a delay of up to 1us, 2us, 4us, 8us, and over 8us then there would be five buckets and packets that arrived up to 1us would cause the 1us bucket counter to increase, between 1us and 2us the 2us bucket counter would increase etc. In practice it might be better in terms of processing and potential parallelism if, when a packet had a delay relative to its predecessor of 2us both the up to 1us and the 2us counter were incremented and any more detailed information was calculated in the analytics system.

This method allows the operator to see more structure in the jitter characteristics than simply measuring the average jitter, and avoids the complication of needing to perform a per packet multiply, but will probably need to time intervals between buckets to be programmable by the operator.

The packet format of an RFC6374 Bucket Jitter Measurement Message is shown below:

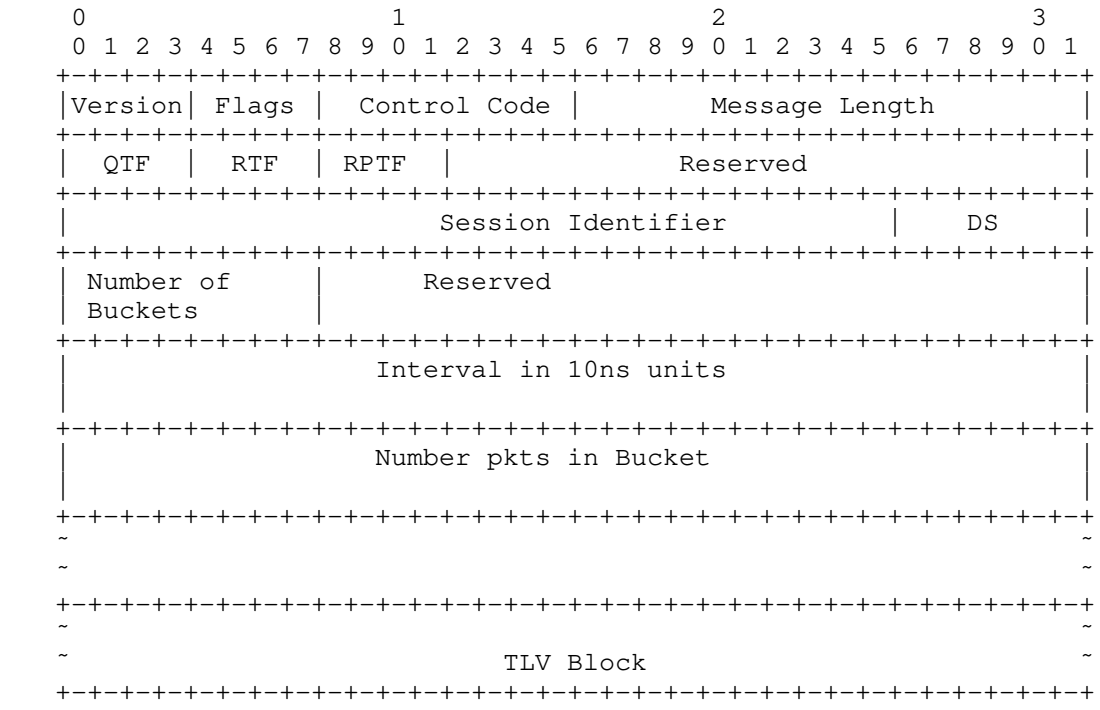

Figure 2: Bucket Jitter Measurement Message Format

The Version, Flags, Control Code, Message Length, QTF, RTF, RPTF, Session Identifier, and DS Fields are as defined in section 3.7 of RFC6374. The remaining fields are as follows:

- Number of Buckets in the measurement
- Reserved must be sent as zero and ignored on receipt
- Interval in 10ns units is the inter-packet interval for this bucket
- Number Pkts in Bucket is the number of packets found in this bucket.

There will be a number of Interval/Number pairs depending on the number of buckets being specified by the Querier. If an RFC6374 message is being used to configure the buckets, (i.e. the responder is creating or modifying the buckets according to the intervals in the Query message), then the Responder MUST respond with 0 packets in each bucket until it has been configured for a full measurement period. This indicates that it was configured at the time of the

last response message, and thus the response is valid for the whole interval. As per the [RFC6374] convention the Number of pkts in Bucket fields are included in the Query message and set to zero.

Out of band configuration is permitted by this mode of operation.

Note this is a departure from the normal fixed format used in RFC6374. We need to establish if this is problematic or not.

This RFC6374 message is carried over an LSP in the way described in [RFC6374] and over an LSP with an SFL as described in Section 9.

7.2. Method 2 Classic Standard Deviation

In this method, provision is made for reporting the following delay characteristics:

1. Number of packets in the batch (n).

2. Sum of delays in a batch (S)

3. Maximum Delay.

4. Minimum Delay.

5. Sum of squares of Inter-packet delay (SS).

Characteristic's 1 and 2 give the mean delay. Measuring the delay of each pair in the batch is discussed in Section 7.3.

Characteristics 3 and 4 give the outliers.

Characteristics 1, 2 and 5 can be used to calculate the variance of the inter-packet gap and hence the standard deviation giving a view of the distribution of packet delays and hence the jitter. The equation for the variance (var) is given by:

var = (SS - S*S/n)/(n-1)

There is some concern over the use of this algorithm for measuring variance, because SS and S*S/n can be similar numbers, particularly where variance is low. However the method commends it self by not requiring a division in the hardware. A future version of this document will look at using improved statistical methods such as the assumed mean.

7.2.1. RFC6374 Multi-Packet Delay Measurement Message Format

The packet format of an RFC6374 Multi-Packet Delay Measurement Message is shown below:

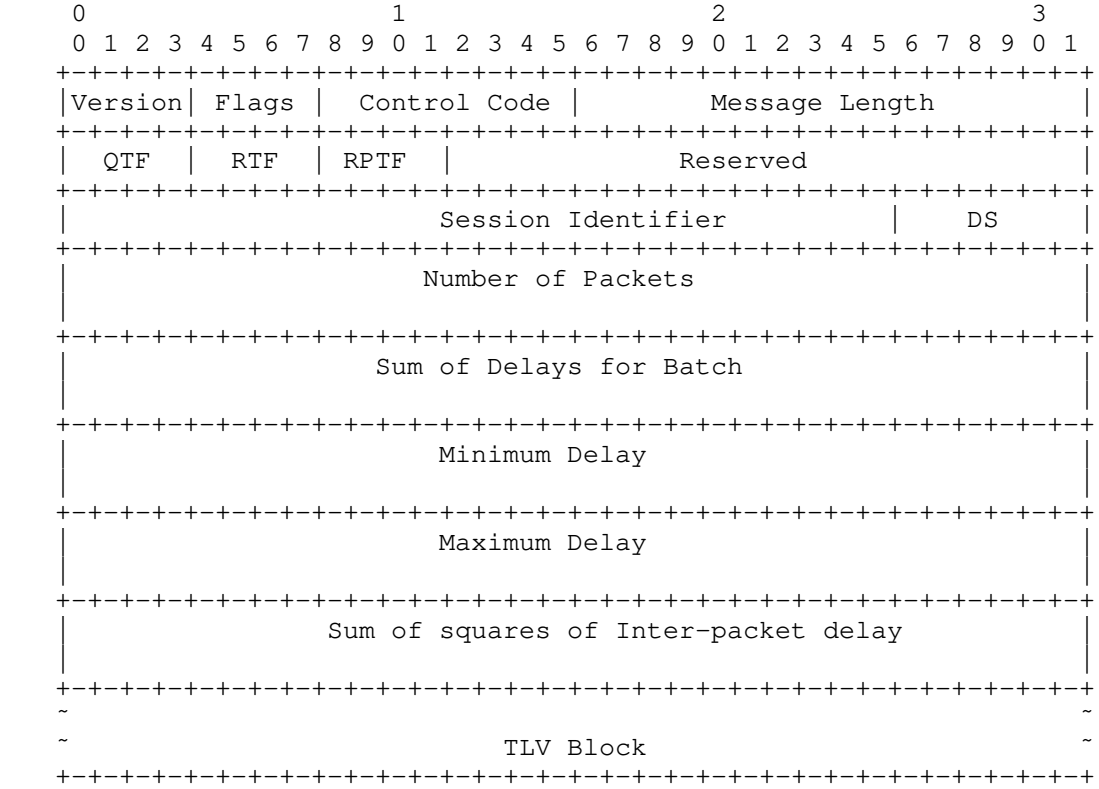

Figure 3: Multi-packet Delay Measurement Message Format

The Version, Flags, Control Code, Message Length, QTF, RTF, RPTF, Session Identifier, and DS Fields are as defined in section 3.7 of RFC6374. The remaining fields are as follows:

- Number of Packets is the number of packets in this batch
- Sum of Delays for Batch is the duration of the batch in the time measurement format specified in the RTF field.
- Minimum Delay is the minimum inter-packet gap observed during the batch in the time format specified in the RTF field.
- Maximum Delay is the maximum inter-packet gap observed during the batch in the time format specified in the RTF field.

This RFC6374 message is carried over an LSP in the way described in [RFC6374] and over an LSP with an SFL as described in Section 9.

7.3. Per Packet Delay Measurement

If detailed packet delay measurement is required then it might be possible to record the inter-packet gap for each packet pair. In other that exception cases of slow flows or small batch sizes, this would create a large demand on storage in the instrumentation system, bandwidth to such a storage system and bandwidth to the analytics system. Such a measurement technique is outside the scope of this document.

7.4. Average Delay

Introduced in [I-D.ietf-ippm-alt-mark] is the concept of a one way delay measurement in which the average time of arrival of a set of packets is measured. In this approach the packet is time-stamped at arrival and the Responder returns the sum of the time-stamps and the number of times-tamps. From this the analytics engine can determine the mean delay. An alternative model is that the Responder returns the time stamp of the first and last packet and the number of packets. This method has the advantage of allowing the average delay to be determined at a number of points along the packet path and allowing the components of the delay to be characterized.

The packet format of an RFC6374 Average Delay Measurement Message is shown below:

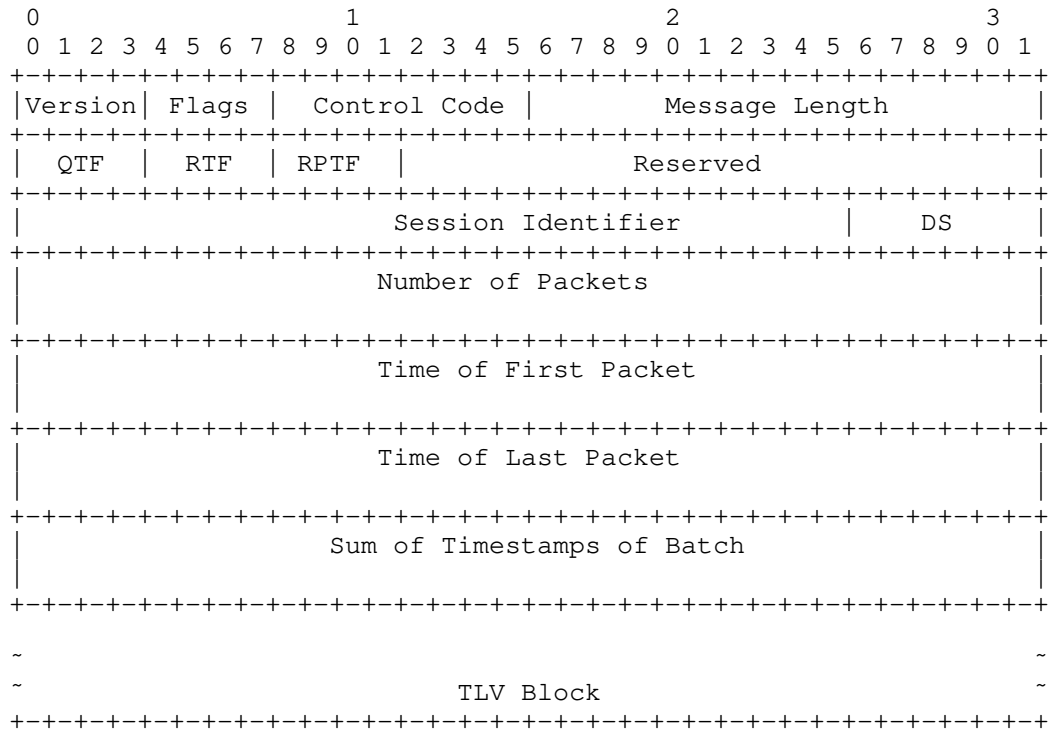

Figure 4: Average Delay Measurement Message Format

The Version, Flags, Control Code, Message Length, QTF, RTF, RPTF, Session Identifier, and DS Fields are as defined in section 3.7 of RFC6374. The remaining fields are as follows:

- Number of Packets is the number of packets in this batch.
- Time of First Packet is the time of arrival of the first packet in the batch.
- Time of Last Packet is the time of arrival of the last packet in the batch.
- Sum of Timestamps of Batch.

This RFC6374 message is carried over an LSP in the way described in [RFC6374] and over an LSP with an SFL as described in Section 9. As is the convention with RFC6374, the Query message contains placeholders for the Response message. The placeholders are sent as zero.

8. Sampled Measurement

In the discussion so far it has been assumed that we would measure the delay characteristics of every packet in a delay measurement interval defined by an SL of constant colour. In [I-D.ietf-ippm-alt-mark] the concept of a sampled measurement is considered. That is the Responder only measures a packet at the start of a group of packets being marked for delay measurement by a particular colour, rather than every packet in the marked batch. A measurement interval is not defined by the duration of a marked batch of packets but the interval between a pair of RFC6374 packets taking a readout of the delay characteristic. This approach has the advantage that the measurement is not impacted by ECMP effects.

9. Carrying RFC6374 Packets over an LSP using an SFL

The packet format of an RFC6374 Query message using SFLs is shown in Figure 5.

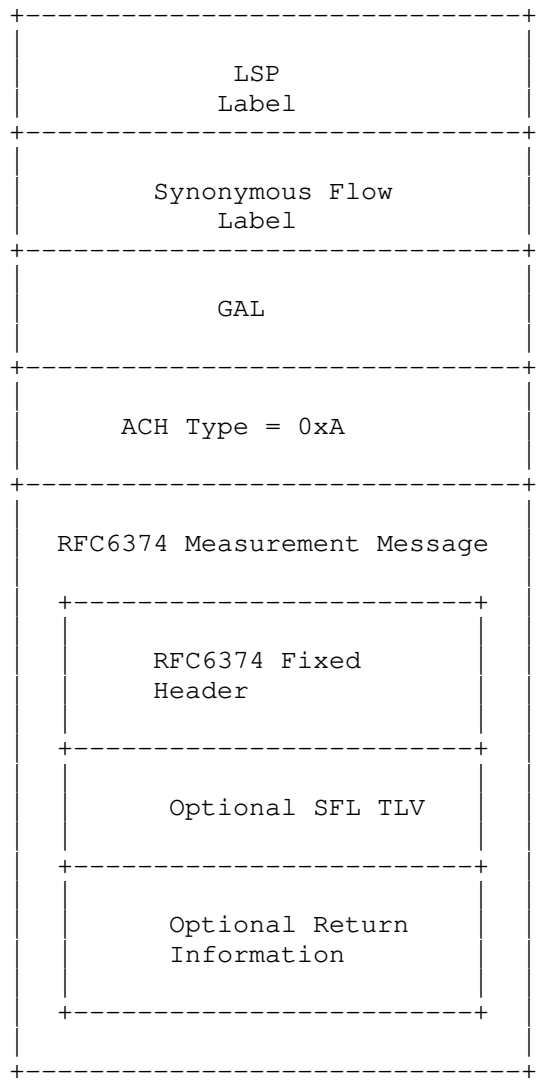

Figure 5: RFC6734 Query Packet with SFL

The MPLS label stack is exactly the same as that used for the user data service packets being instrumented except for the inclusion of the GAL [RFC5586] to allow the receiver to distinguish between normal data packets and OAM packets. Since the packet loss measurements are being made on the data service packets, an RFC6374 direct loss measurement is being made, and which is indicated by the type field in the ACH (Type = 0x000A).

The RFC6374 measurement message consists of the three components, the RFC6374 fixed header as specified in [RFC6374] carried over the ACH channel type specified the type of measurement being made (currently: loss, delay or loss and delay) as specified in RFC6374.

Two optional TLVs MAY also be carried if needed. The first is the SFL TLV specified in Section 9.1. This is used to provide the implementation with a reminder of the SFL that was used to carry the RFC6374 message. This is needed because a number of MPLS implementations do not provide the MPLS label stack to the MPLS OAM handler. This TLV is required if RFC6374 messages are sent over UDP [RFC7876]. This TLV MUST be included unless, by some method outside the scope of this document, it is known that this information is not needed by the RFC6374 Responder.

The second set of information that may be needed is the return information that allows the responder send the RFC6374 response to the Querier. This is not needed if the response is requested in-band and the MPLS construct being measured is a point to point LSP, but otherwise MUST be carried. The return address TLV is defined in RFC6378 and the optional UDP Return Object is defined in [RFC7876].

9.1. RFC6374 SFL TLV

Editor's Note we need to review the following in the light of further thoughts on the associated signaling protocol(s). I am fairly confident that we need all the fields other than SFL Batch and SFL Index. The Index is useful in order to map between the label and information associated with the FEC. The batch is part of the lifetime management process.

The required RFC6374 SFL TLV is shown in Figure 6. This contains the SFL that was carried in the label stack, the FEC that was used to allocate the SFL and the index into the batch of SLs that were allocated for the FEC that corresponds to this SFL.

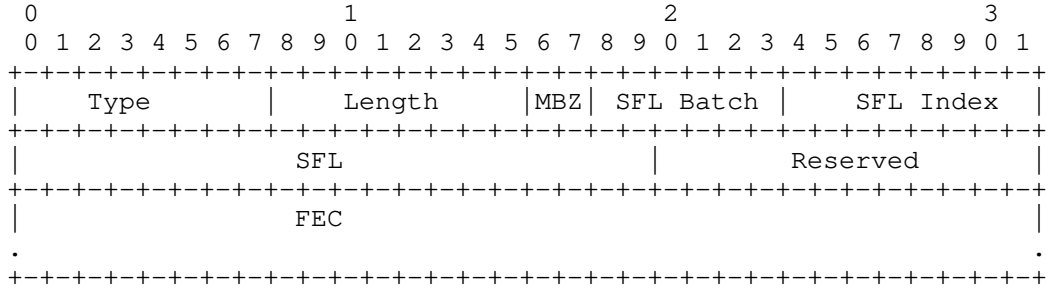

Figure 6: SFL TLV

Where:

Type Type is set to Synonymous Flow Label (SFL-TLV).

Length The length of the TLV as specified in RFC6374.

MBZ MUST be sent as zero and ignored on receive.

SFL Batch The SFL batch that this SFL was allocated as part of see [I-D.bryant-mpls-sfl-control]

SPL Index The index into the list of SFLs that were assigned against the FEC that corresponds to the SFL.

SFL The SFL used to deliver this packet. This is an MPLS label which is a component of a label stack entry as defined in Section 2.1 of [RFC3032].

Reserved MUST be sent as zero and ignored on receive.

FEC The Forwarding Equivalence Class that was used to request this SFL. This is encoded as per Section 3.4.1 of TBD

This information is needed to allow for operation with hardware that discards the MPLS label stack before passing the remainder of the stack to the OAM handler. By providing both the SFL and the FEC plus index into the array of allocated SFLs a number of implementation types are supported.

10. Applicability to Pro-active and On-demand Measurement

A future version of the this document will discuss the applicability of the various methods to pro-active and on-demand Measurement.

11. RFC6374 Combined Loss-Delay Measurement

This mode of operation is not currently supported by this specification.

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. 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.

13. Security Considerations

The issue noted in Section 5 is a security consideration. There are no other new security issues associated with the MPLS dataplane. Any control protocol used to request SFLs will need to ensure the legitimacy of the request.

14. IANA Considerations

14.1. Allocation of PW Associated Channel Type

As per the IANA considerations in [RFC5586], IANA is requested to allocate the following Channel Type in the "PW Associated Channel Type" registry:

Value	Description	TLV Follows	Reference
TBD	RFC6374 Bucket Jitter Measurement	No	This
TBD	RFC6374 Multi-Packet Delay Measurement	No	This
TBD	RFC6374 Average Delay Measurement	No	This

14.2. MPLS Loss/Delay TLV Object

IANA is request to allocate a new TLV from the 0-127 range on the MPLS Loss/Delay Measurement TLV Object Registry:

Type	Description	Reference
TBD	Synonymous Flow Label	This

A value of 4 is recommended.

15. References

15.1. Normative References

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15.2. Informative References

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July 7, 2016

Path Computation API
draft-busibel-ccamp-path-computation-api-00.txt

Status of this Memo

The list of Internet-Draft Shadow Directories can be accessed at http://www.ietf.org/shadow.html

This Internet-Draft will expire on January 7, 2016.

Abstract

There are scenarios, typically in a hierarchical SDN context, in which an orchestrator may not have detailed information to be able to perform an end-to-end path computation and would need to request lower layer/domain controllers to calculate some (partial) feasible paths.

Multiple protocol solutions can be used for communication between different controller hierarchical levels. This document assumes that the controllers are communicating using YANG-based Application Programming Interface (APIs).

This document describes some use cases for an Application Programming Interface for path computation. A related yang model will be proposed in a next version or in another document.

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1. Introduction

There are scenarios, typically in a hierarchical SDN context, in which an orchestrator may not have detailed information to be able to perform an end-to-end path computation and would need to request lower layer/domain controllers to calculate some (partial) feasible paths.

Multiple protocol solutions can be used for communication between different controller hierarchical levels. This document assumes that the controllers are communicating using YANG-based Application Programming Interface (APIs).

Path Computation Elements, Controllers and Orchestrators perform their operations based on Traffic Engineering Databases (TED). Such TEDs can be described, in a technology agnostic way, with the YANG Data Model for TE Topologies [TE-TOPO]. Furthermore, the technology specific details of the TED are modeled in the augmented TE topology models (e.g. [L1-TOPO] for Layer-1 ODU technologies).

The availability of such topology models allows providing the TED via Netconf or Restconf API. Furthermore, it enables that a PCE/Controller performs the necessary abstractions or modifications and offer this customized topology to another PCE/Controller or high level orchestrator.

The tunnels that can be provided over the networks described with the topology models can be also set-up, deleted and modified via Netconf or Restconf API using the TE-Tunnel Yang model [TE-TUNNEL].

This document describes some use cases where a path computation function, also using Netconf or Restconf API, can be needed. A related yang model will be proposed in a next version or in another document.

2. Use Cases

This document presents different use cases, where an API for path computation is required. The presented uses cases have been grouped, depending on the different underlying topologies: a) IP-Optical integration; b) Multi-domain Optical Networks; and c) Data center interconnections.

2.1. IP-Optical integration

In these use cases, there is an Optical domain which is used to provide connectivity between IP routers which are connected with the Optical domains using access links (see Figure 1).

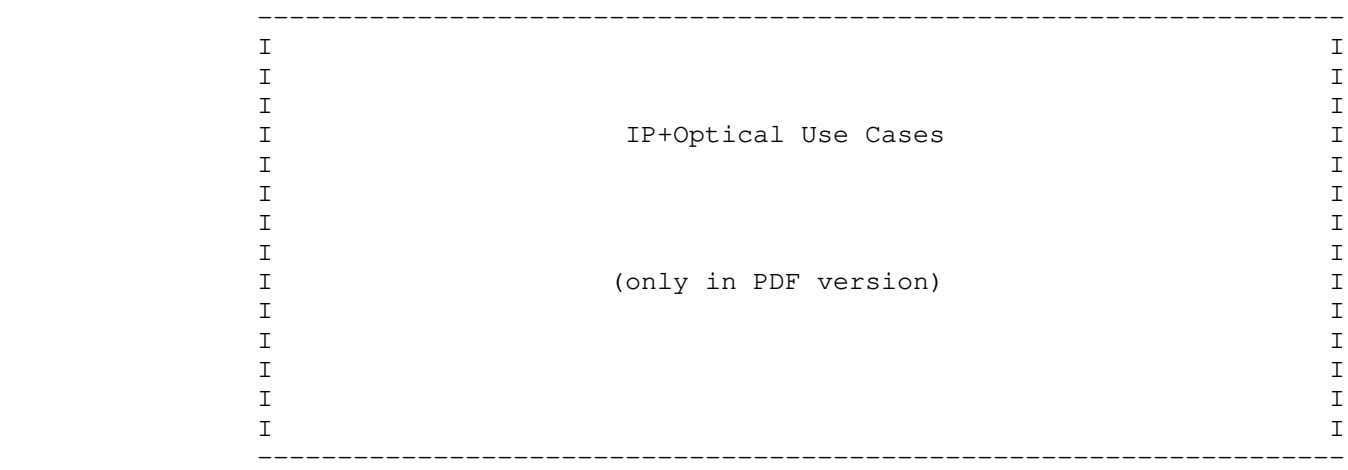

Figure 1 - IP+Optical Use Cases

It is assumed that the Optical domain controller provides to the orchestrator an abstracted view of the Optical network. A possible abstraction shall be representing the optical domain as one "virtual node" with "virtual ports" connected to the access links.

The path computation request helps the orchestrator to know which are the real connections that can be provided at the optical domain.

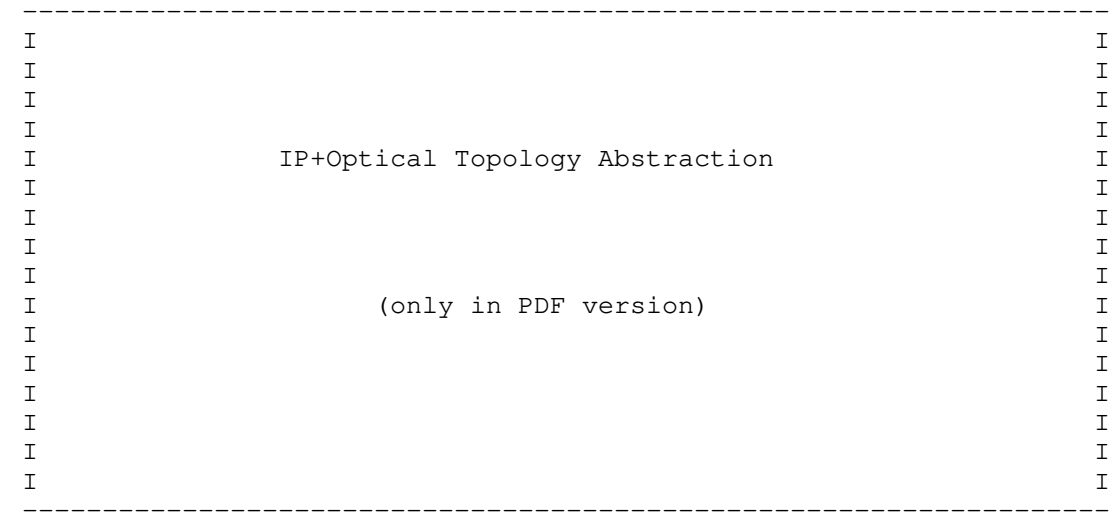

Figure 2 - IP+Optical Topology Abstraction

2.1.1. Inter-layer path computation

In this use case the orchestrator needs to setup an optimal path between two IP routers R1 and R2.

As depicted in Figure 2, the Orchestrator has only an "abstracted view" of the physical network, and it does not know the feasibility or the cost of the possible optical paths (e.g., VP1-VP4 and VP2-VP5), which depend from the current status of the physical resources within the optical network and on vendor-specific optical attributes.

However, the orchestrator can ask the underlying Optical domain controller to compute a set of potential optimal paths, taking into account optical constraints Then, based on its own constraints, policy and knowledge (e.g. cost of the access links), it can choose

which one of these potential paths to use to setup the optimal e2e path crossing optical network.

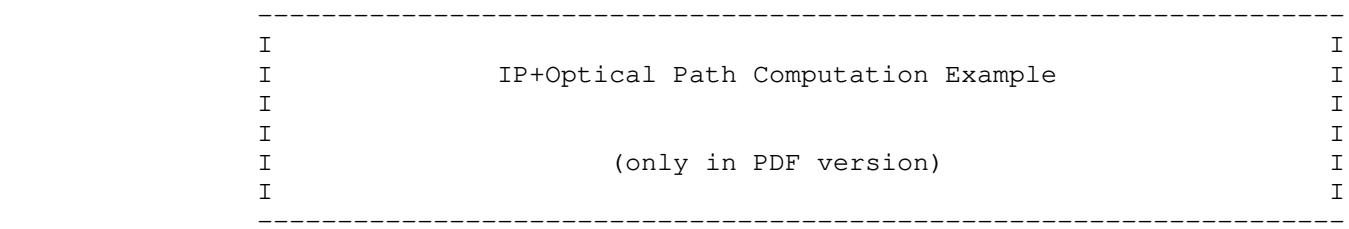

Figure 3 - IP+Optical Path Computation Example

For example, in Figure 3, the Orchestrator can request the Optical domain controller to compute the paths between VP1-VP4 and VP2-VP5 and then decide to setup the optimal end-to-end path which passes through the VP2-VP5 Optical path even this is not the optimal path from the Optical domain perspective.

An alternative approach could be to have the Optical domain controller making the information shown in Figure 3 available to the Orchestrator.

One possibility, under discussion within the TEAS WG, is to provide a "detailed connectivity matrix" which extends the "connectivity matrix" defined in [RFC7446] and describes not only the valid inbound-outbound TE link switching combinations, but also specifies a vector of various costs (in terms of delay, OSNR, intra-node SRLGs and summary TE metrics) a potential TE path associated with the connectivity matrix entry.

The information provided by the "detailed abstract connectivity matrix" would be equivalent to the information that should be provided by "virtual link model" as defined in [TE-INTERCONNECT].

In this case, the Path Computation Element (PCE) within the Orchestrator could use this information to calculate by its own the optimal path between routers R1 and R2, without requesting any additional information to the Optical Domain Controller.

However, there is a tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the Orchestrator's PCE) and scalability to be considered when designing the amount of information to provide within the "detailed abstract connectivity matrix".

Figure 4 below shows another example, similar to the one in Figure 3, but where there are two possible Optical paths between VP1 and VP4 with different properties (e.g., available bandwidth and cost).

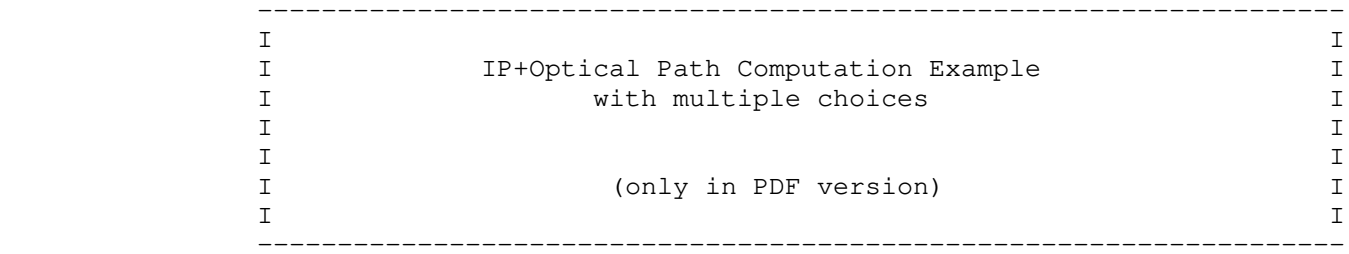

Figure 4 - IP+Optical Path Computation Example with multiple choices

Reporting all the information, as in Figure 4, using the "detailed abstract connectivity matrix" is quite challenging from a scalability perspective since the amount of this information is not just based on number of end points (which would scale as N-square), but also on many other parameters, including client rate, user constraints / policies for the service, e.g. max latency < N ms, max cost, etc., exclusion policies to route around busy links, min OSNR margin, max preFEC BER etc. All these constraints could be different based on connectivity requirements.

It is also worth noting that the "connectivity matrix" has been originally defined in WSON, [RFC7446] to report the connectivity constrains of a physical node within the WDM network: the information it contains is pretty "static" and therefore, once taken and stored in the TE data base, it can be always being considered valid and up-to-date in path computation request.

Using the "connectivity matrix" with an abstract node to abstract the information regarding the connectivity constraints of an Optical domain, would make this information more "dynamic" since the

connectivity constraints of an Optical domain can change over time because some optical paths that are feasible at a given time may become unfeasible at a later time when e.g., another optical path is established. The information in the "detailed abstract connectivity matrix" is even more dynamic since the establishment of another optical path may change some of the parameters (e.g., delay or available bandwidth) in the "detailed abstract connectivity matrix" while not changing the feasibility of the path.

"Connectivity matrix" is sometimes confused with optical reach table that contain multiple (e.g. k-shortest) regen-free reachable paths for every A-Z node combination in the network. Optical reach tables can be calculated offline, utilizing vendor optical design and planning tools,and periodically uploaded to the Controller: these optical path reach tables are fairly static. However, to get the connectivity matrix, between any two sites, either a regen free path can be used, if one is available, or multiple regen free paths are concatenated to get from src to dest, which can be a very large combination. Additionally, when the optical path within optical domain needs to be computed, it can result in different paths based on input objective, constraints, and network conditions. In summary, even though "optical reachability table" is fairly static, which regen free paths to build the connectivity matrix between any source and destination is very dynamic, and is done using very sophisticated routing algorithms.

There is therefore the need to keep the information in the "connectivity matrix" updated which means that there another tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the Orchestrator's PCE) and having up-to-date information. The more the information is provided and the longer it takes to keep it up-to-date which increases the likelihood that the Orchestrator's PCE computes paths using not updated information.

It seems therefore quite challenging to have a "detailed abstract connectivity matrix" that provides accurate, scalable and updated information to allow the Orchestrator's PCE to take optimal decisions by its own.

If the information in the "detailed abstract connectivity matrix" is not complete/accurate, we can have the following drawbacks considering for example the case in Figure 4:

- If only the VP1-VP4 path with available bandwidth of 2 Gb/s and cost 50 is reported, the Orchestrator's PCE will fail to compute a 5 Gb/s path between routers R1 and R2, although this would be feasible;

- If only the VP1-VP4 path with available bandwidth of 10 Gb/s and cost 60 is reported, the Orchestrator's PCE will compute, as optimal, the 1 Gb/s path between R1 and R2 going through the VP2-VP5 path within the Optical domain while the optimal path would actually be the one going thought the VP1-VP4 sub-path (with cost 50) within the Optical domain.

Instead, using the approach proposed in this document, the Orchestrator, when it needs to setup an end-to-end path, it can request the Optical domain controller to compute a set of optimal paths (e.g., for VP1-VP4 and VP2-VP5) and take decisions based on the information received:

- When setting up a 5 Gb/s path between routers R1 and R2, the Optical domain controller may report only the VP1-VP4 path as the only feasible path: the Orchestrator can successfully setup the end-to-end path passing though this Optical path;

- When setting up a 1 Gb/s path between routers R1 and R2, the Optical domain controller (knowing that the path requires only 1 Gb/s) can report both the VP1-VP4 path, with cost 50, and the VP2-VP5 path, with cost 65. The Orchestrator can then compute the optimal path which is passing thought the VP1-VP4 sub-path (with cost 50) within the Optical domain.

Considering the dynamicity of the connectivity constraints of an Optical domain, it is possible that a path computed by the Optical domain controller when requested by the Orchestrator is no longer valid when the Orchestrator requests it to be setup up.

It is worth noting that with the approach proposed in this document, the likelihood for this issue to happen can be quite small since the time window between the path computation request and the path setup request should be quite short (especially if compared with the time that would be needed to update the information of a very detailed abstract connectivity matrix).

If this risk is still not acceptable, the Orchestrator may also optionally request the Optical domain controller not only to compute the path but also to keep track of its resources (e.g., these

resources can be reserved to avoid being used by any other connection). In this case, some mechanism (e.g., a timeout) needs to be defined to avoid having stranded resources within the Optical domain.

These issues and solutions can be fine-tuned during the design of the Path Computation API.

2.1.2. Route Diverse IP Services

This is for further study.

2.2. Multi-domain Optical Networks

In this use case there are two optical domains which are interconnected together by multiple inter-domains links.

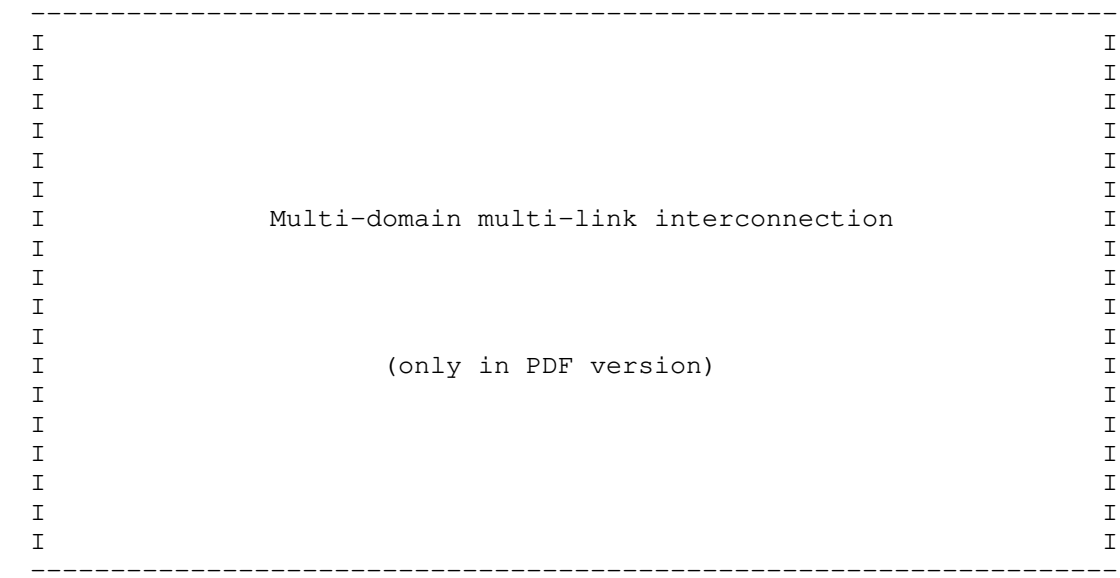

Figure 5 - Multi-domain multi-link interconnection

In order to setup an end-to-end multi-domain Optical path (e.g., between nodes A and H), the orchestrator needs to know the feasibility or the cost of the possible optical paths within the two

optical domains, which depend from the current status of the physical resources within each optical network and on vendor-specific optical attributes (which may be different in the two domains if they are provided by different vendors).

There is a trade-off between having the Orchestrator's PCE being able to take path computation decisions by its own versus having the Orchestrator being able to ask the Domain Controllers to provide a set of feasible optimal optical paths.

Orchestrator could want to select/optimize end-to-end path based on abstract topology information provided by the domain controllers. For example:

- Need to compute a path between A and H
- That path can go through inter-domain link C-E or through inter-domain link D-F
- Orchestrator's PCE, based on its own information, can compute the optimal multi-domain path being A-B-C-E-G-H
- But, during path setup, the domain controller may find out that A-B-C is not optically feasible, while only the path A-B-D is feasible
- So what the hierarchical controller computed is not good and need to re-start the path computation from scratch

As discussed in section 3.1, providing more extensive abstract information from the Optical domain controllers to the multi-domain Orchestator may lead to scalability problems.

Alternatively the Orchestrator can request the Optical domain controllers to compute a set of optimal paths and take decisions based on the information received. For example:

- Need to compute a path between A and H
- The Orchestrator asks Optical domain controllers to provide set of paths between A-C, A-D, E-H and F-H
- Optical domain controllers return a set of feasible paths with the associated costs: the path A-C would not be part of this set

- The Orchestrator will select the path A-B-D-F-G-H since it is the only feasible path and then request the Optical domain controllers to setup the A-B-D and F-G-H paths

- If there are multiple feasible paths, the Orchestrator can select the optimal path knowing the cost of the intra-domain paths (provided by the Optical domain controllers) and the cost of the inter-domain links (known by the Orchestrator)

In a sense this is similar to the problem of routing and wavelength assignment within an Optical domain. It is possible to do first routing (step 1) and then wavelength assignment (step 2), but the chances of ending up with a good path is low. Alternatively, it is possible to do combined routing and wavelength assignment, which is known to be a more optimal and effective way for Optical path setup. Similarly, it is possible to first compute an abstract end-to-end path within the multi-domain Orchestrator (step 1) and then compute an intra-domain path within each Optical domain (step 2), but there are more chances not to find a path or to get a suboptimal path that performing per-domain path computation and then stitch them.

The approach to request each Optical domain controllers to compute a set of optimal paths and take decisions based on the information received may still have some scalability issues when the number of Optical domains is quite big (e.g. 20).

In this case, it would be worthwhile combining the two approaches and use the abstract topology information provided by the domain controllers to limit the number of potential optimal end-to-end paths and then the Path Computation to decide what is the optimal path within this limited set.

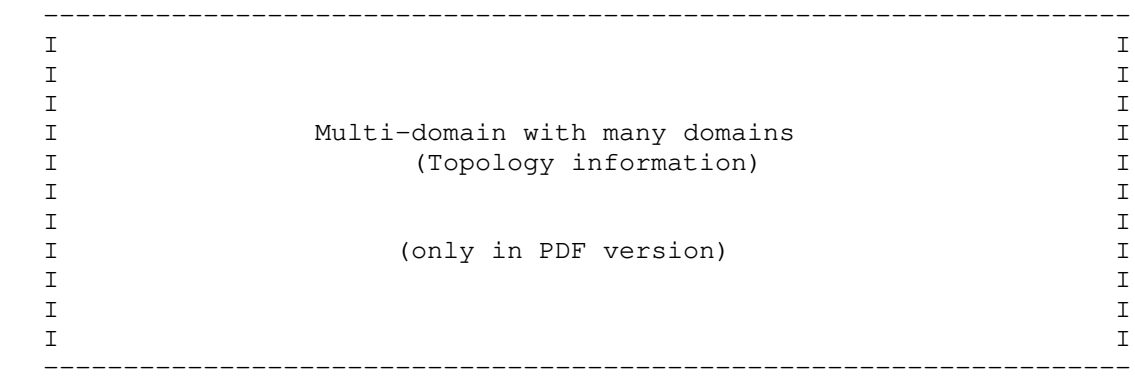

Figure 6 - Multi-domain with many domains (Topology information)

An example can be described considering multi-domain abstract topology shown in Figure 6. In this example an end-to-end Optical path between domains A and F needs to be setup. The transit domain should be selected between domains B, C, D and E.

The actual cost of each intra-domain path is not known a priori from the abstract topology information. The Orchestrator only knows the feasibility of some intra-domain paths and some upper-bound and/or lower-bound cost information. With this information, together with the cost of inter-domain links, the Orchestrator can decide that:

- Domain B cannot be selected as the path connecting domains A and E is not feasible;

- Domain E cannot be selected as a transit domain since it is know from the abstract topology information provided by domain controllers that the cost of the multi-domain path A-E-F (which is 100, in the best case) will be always be higher than the cost of the multi-domain paths A-D-F (which is 90, in the worst case) and A-E-F (which is 80, in the worst case)

Therefore, the Orchestrator can decide by its own that the optimal multi-domain path could be either A-D-F or A-E-F.

The Orchestrator can therefore request only the Optical domain controllers A, D, E and F to provide a set of optimal paths.

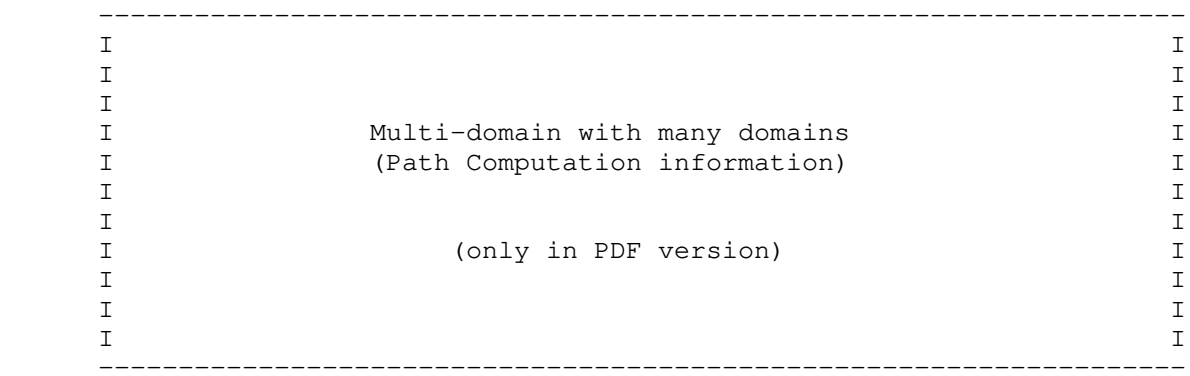

Figure 7 - Multi-domain with many domains (Path Computation information)

Based on these requests, the Orchestrator can know the actual cost of each intra-domain paths which belongs to potential optimal end-to-end paths, as shown in Figure 7, and then compute the optimal end-to-end path (e.g., A-D-F, having total cost of 50, instead of A-C-F having a total cost of 70).

2.3. Data center interconnections

In these use case, there is an Optical domain which is used to provide connectivity between data centers which are connected with the Optical domains using access links.

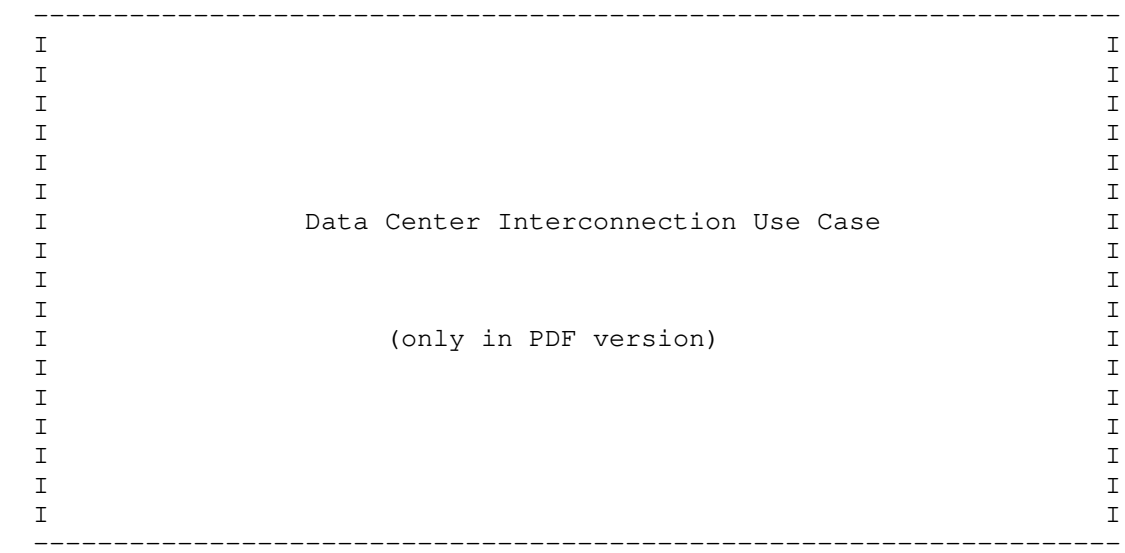

Figure 8 - Data Center Interconnection Use Case

In this use case, a virtual machine within Data Center 1 (DC1) needs to transfer data to another virtual machine that can reside either in DC2 or in DC3.

The optimal decision depends both on the cost of the optical path (DC1-DC2 or DC1-DC3) and of the computing power (data center resources) within DC2 or DC3.

The Cloud Orchestrator may not be able to make this decision because it has only an abstract view of the optical network (as in use case in 3.1).

The cloud orchestrator can request to the Optical domain controller to compute the cost of the possible optical paths (e.g., DC1-DC2 and DC1-DC3) and to the DC controller to compute the cost of the computing power (DC resources) within DC2 and DC3 and then it can take the decision about the optimal solution based on this information and its policy.

3. Security Considerations

This is for further study

4. IANA Considerations

This document requires no IANA actions.

5. References

5.1. Normative References

[RFC7446] Lee, Y. et al., "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, February 2015.

5.2. Informative References

[TE-TOPO] Liu, X. et al., "YANG Data Model for TE Topologies", draft-ietf-teas-yang-te-topo, work in progress.

[L1-TOPO] Zhang, X. et al., "A YANG Data Model for Layer 1 (ODU) Network Topology", draft-zhang-ccamp-l1-topo-yang, work in progress.

[TE-TUNNEL] Xhang, X. et al., "A YANG Data Model for Traffic Engineering Tunnels and Interfaces", draft-ietf-teas-yang-te, work in progress.

[TE-INTERCONNECT] Farrel, A. et al., "Problem Statement and Architecture for Information Exchange Between Interconnected Traffic Engineered Networks", draft-ietf-teas-interconnected-te-info-exchange, work in progress.

6. Acknowledgments

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NEC

October 28, 2016

Yang model for requesting Path Computation
draft-busibel-teas-yang-path-computation-00.txt

Status of this Memo

The list of Internet-Draft Shadow Directories can be accessed at http://www.ietf.org/shadow.html

This Internet-Draft will expire on April 28, 2016.

Abstract

There are scenarios, typically in a hierarchical SDN context, in which an orchestrator may not have detailed information to be able to perform an end-to-end path computation and would need to request lower layer/domain controllers to calculate some (partial) feasible paths.

Multiple protocol solutions can be used for communication between different controller hierarchical levels. This document assumes that the controllers are communicating using YANG-based protocols (e.g., NETCONF or RESTCONF).

This document describes some use cases for a YANG model to request path computation.

Table of Contents

1. Introduction

There are scenarios, typically in a hierarchical SDN context, in which an orchestrator may not have detailed information to be able to perform an end-to-end path computation and would need to request lower layer/domain controllers to calculate some (partial) feasible paths.

When we are thinking to this type of scenarios we have in mind specific level of interfaces on which this request can be applied.

We can reference ABNO Control Interface [RFC7491] in which an Application Service Coordinator can request ABNO controller to take in charge path calculation (see Figure 1 in the RFC) and/or ACTN [ACTN-frame],where controller hierarchy is defined, the need for path computation arises on both interfaces CMI (interface between Customer Network Controller(CNC) and Multi Domain Service Coordinator (MDSC)) and/or MPI (interface between MSDC-PNC).[ACTN-Info] describes an information model for the Path Computation request.

Multiple protocol solutions can be used for communication between different controller hierarchical levels. This document assumes that the controllers are communicating using YANG-based protocols (e.g., NETCONF or RESTCONF).

Path Computation Elements, Controllers and Orchestrators perform their operations based on Traffic Engineering Databases (TED). Such TEDs can be described, in a technology agnostic way, with the YANG Data Model for TE Topologies [TE-TOPO]. Furthermore, the technology specific details of the TED are modeled in the augmented TE topology models (e.g. [L1-TOPO] for Layer-1 ODU technologies).

The availability of such topology models allows providing the TED using YANG-based protocols (e.g., NETCONF or RESTCONF). Furthermore, it enables a PCE/Controller performing the necessary abstractions or modifications and offering this customized topology to another PCE/Controller or high level orchestrator.

The tunnels that can be provided over the networks described with the topology models can be also set-up, deleted and modified via YANG-based protocols (e.g., NETCONF or RESTCONF)using the TE-Tunnel Yang model [TE-TUNNEL].

This document describes some use cases where a path computation request, via YANG-based protocols (e.g., NETCONF or RESTCONF), can be needed.

2. Use Cases

This section presents different use cases, where an orchestrator needs to request underlying SDN controllers for path computation.

The presented uses cases have been grouped, depending on the different underlying topologies: a) IP-Optical integration; b) Multi-domain Traffic Engineered (TE) Networks; and c) Data center interconnections.

2.1. IP-Optical integration

In these use cases, an Optical domain is used to provide connectivity between IP routers which are connected with the Optical domains using access links (see Figure 1).

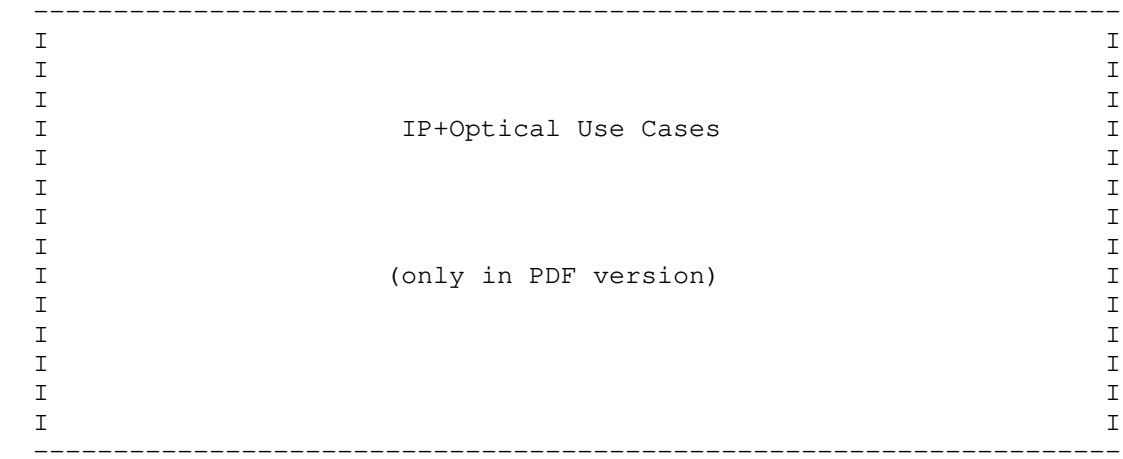

Figure 1 - IP+Optical Use Cases

It is assumed that the Optical domain controller provides to the orchestrator an abstracted view of the Optical network. A possible abstraction shall be representing the optical domain as one "virtual node" with "virtual ports" connected to the access links.

The path computation request helps the orchestrator to know which are the real connections that can be provided at the optical domain.

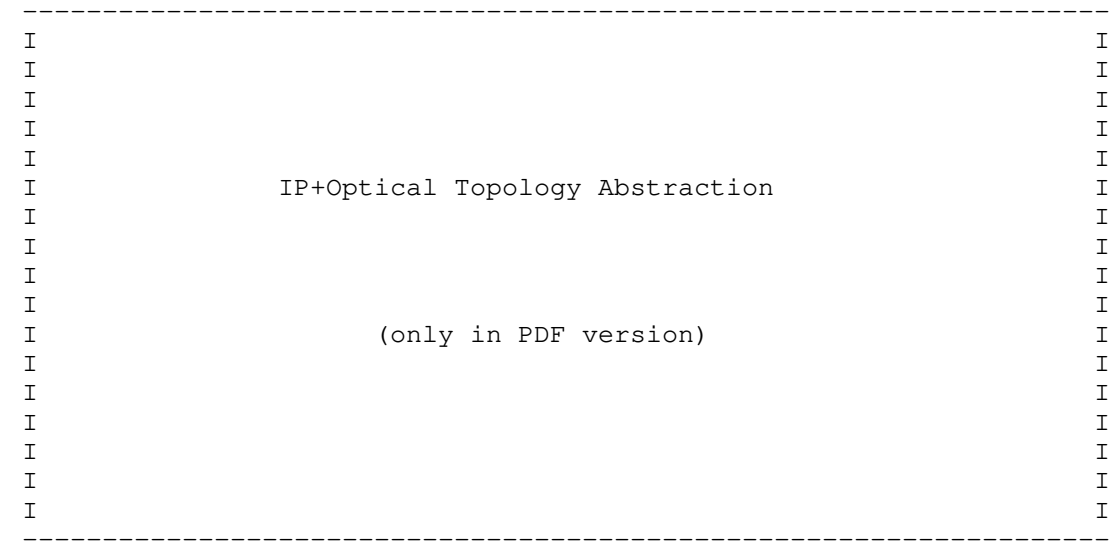

Figure 2 - IP+Optical Topology Abstraction

2.1.1. Inter-layer path computation

In this use case, the orchestrator needs to setup an optimal path between two IP routers R1 and R2.

As depicted in Figure 2, the Orchestrator has only an "abstracted view" of the physical network, and it does not know the feasibility or the cost of the possible optical paths (e.g., VP1-VP4 and VP2-VP5), which depend from the current status of the physical resources within the optical network and on vendor-specific optical attributes.

The orchestrator can request the underlying Optical domain controller to compute a set of potential optimal paths, taking into account optical constraints. Then, based on its own constraints, policy and knowledge (e.g. cost of the access links), it can choose

which one of these potential paths to use to setup the optimal e2e path crossing optical network.

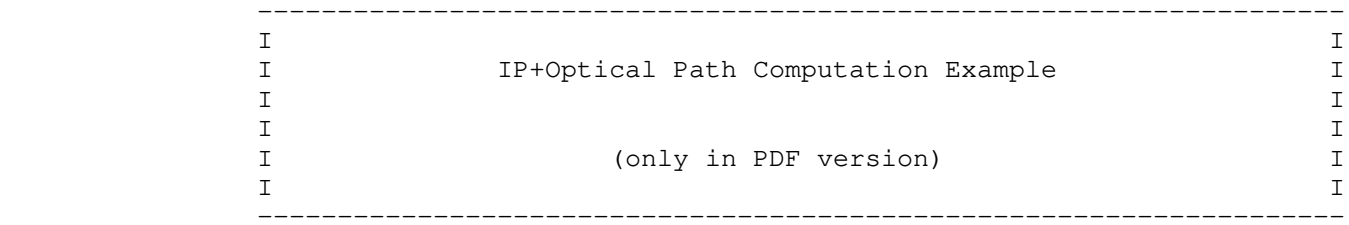

Figure 3 - IP+Optical Path Computation Example

For example, in Figure 3, the Orchestrator can request the Optical domain controller to compute the paths between VP1-VP4 and VP2-VP5 and then decide to setup the optimal end-to-end path using the VP2-VP5 Optical path even this is not the optimal path from the Optical domain perspective.

Considering the dynamicity of the connectivity constraints of an Optical domain, it is possible that a path computed by the Optical domain controller when requested by the Orchestrator is no longer valid when the Orchestrator requests it to be setup up.

It is worth noting that with the approach proposed in this document, the likelihood for this issue to happen can be quite small since the time window between the path computation request and the path setup request should be quite short (especially if compared with the time that would be needed to update the information of a very detailed abstract connectivity matrix).

If this risk is still not acceptable, the Orchestrator may also optionally request the Optical domain controller not only to compute the path but also to keep track of its resources (e.g., these resources can be reserved to avoid being used by any other connection). In this case, some mechanism (e.g., a timeout) needs to be defined to avoid having stranded resources within the Optical domain.

These issues and solutions can be fine-tuned during the design of the YANG model for requesting Path Computation.

2.1.2. Route Diverse IP Services

This is for further study.

2.2. Multi-domain TE Networks

In this use case there are two TE domains which are interconnected together by multiple inter-domains links.

A possible example could be a multi-domain optical network.

Figure 4 - Multi-domain multi-link interconnection

In order to setup an end-to-end multi-domain TEpath (e.g., between nodes A and H), the orchestrator needs to know the feasibility or the cost of the possible TE paths within the two TE domains, which depend from the current status of the physical resources within each TE network. This is more challenging in case of optical networks because the optimal paths depend also on vendor-specific optical attributes (which may be different in the two domains if they are provided by different vendors).

In order to setup a multi-domain TE path (e.g., between nodes A and H), Orchestrator can request the TE domain controllers to compute a set of intra-domain optimal paths and take decisions based on the information received. For example:

- The Orchestrator asks TE domain controllers to provide set of paths between A-C, A-D, E-H and F-H
- TE domain controllers return a set of feasible paths with the associated costs: the path A-C is not part of this set(in optical networks, it is typical to have some paths not being feasible due to optical constraints that are known only by the optical domain controller)
- The Orchestrator will select the path A- D-F- H since it is the only feasible multi-domain path and then request the TE domain controllers to setup the A-D and F-H intra-domain paths
- If there are multiple feasible paths, the Orchestrator can select the optimal path knowing the cost of the intra-domain paths (provided by the TE domain controllers) and the cost of the inter-domain links (known by the Orchestrator)

This approach may have some scalability issues when the number of TE domains is quite big (e.g. 20).

In this case, it would be worthwhile using the abstract TE topology information provided by the domain controllers to limit the number of potential optimal end-to-end paths and then request path computation to fewer domain controllers in order to decide what the optimal path within this limited set is.

For more details, see section 3.3.

2.3. Data center interconnections

In these use case, there is an TE domain which is used to provide connectivity between data centers which are connected with the TE domain using access links.

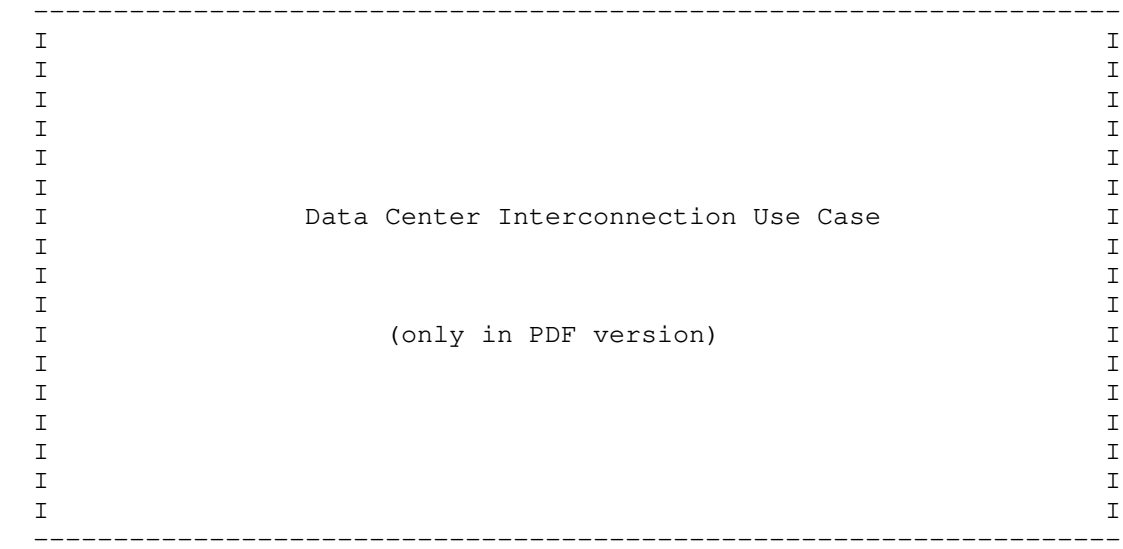

Figure 5 - Data Center Interconnection Use Case

In this use case, a virtual machine within Data Center 1 (DC1) needs to transfer data to another virtual machine that can reside either in DC2 or in DC3.

The optimal decision depends both on the cost of the TE path (DC1-DC2 or DC1-DC3) and of the computing power (data center resources) within DC2 or DC3.

The Cloud Orchestrator may not be able to make this decision because it has only an abstract view of the TE network (as in use case in 2.1).

The cloud orchestrator can request to the TE domain controller to compute the cost of the possible TE paths (e.g., DC1-DC2 and DC1-DC3) and to the DC controller to compute the cost of the computing power (DC resources) within DC2 and DC3 and then it can take the decision about the optimal solution based on this information and its policy.

3. Interactions with TE Topology

The use cases described in section 2 have been described assuming that the topology view exported by each underlying SDN controller to the orchestrator is aggregated using the "virtual node model", defined in [RFC7926].

TE Topology information, e.g., as provided by [TE-TOPO], could in theory be used by an underlying SDN controllers to provide TE information to the orchestrator thus allowing the Path Computation Element (PCE) within the Orchestrator to perform multi-domain path computation by its own, without requesting path computations to the underlying SDN controllers.

This section analyzes the need for an orchestrator to request underlying SDN controllers for path computation even in these scenarios as well as how the TE Topology information and the path computation can be complementary.

In nutshell, there is a scalability trade-off between providing all the TE information needed by the Orchestrator's PCE to take optimal path computation decisions by its own versus requesting the Orchestrator to ask to too many underlying SDN Domain Controllers a set of feasible optimal intra-domain TE paths.

3.1. TE Topology Aggregation using the "virtual link model"

Using the TE Topology model, as defined in [TE-TOPO], the underlying SDN controller can export the whole TE domain as a single abstract TE node with a "detailed connectivity matrix", which extends the "connectivity matrix", defined in [RFC7446], with specific TE attributes (e.g., delay, SRLGs and summary TE metrics).

The information provided by the "detailed abstract connectivity matrix" would be equivalent to the information that should be provided by "virtual link model" as defined in [RFC 7926].

For example, in the IP-Optical integration use case, described in section 2.1, the Optical domain controller can make the information shown in Figure 3 available to the Orchestrator as part of the TE Topology information and the Orchestrator could use this information to calculate by its own the optimal path between routers R1 and R2, without requesting any additional information to the Optical Domain Controller.

However, there is a tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the Orchestrator's PCE) and scalability to be considered when designing the amount of information to provide within the "detailed abstract connectivity matrix".

Figure 6 below shows another example, similar to Figure 3, where there are two possible Optical paths between VP1 and VP4 with different properties (e.g., available bandwidth and cost).

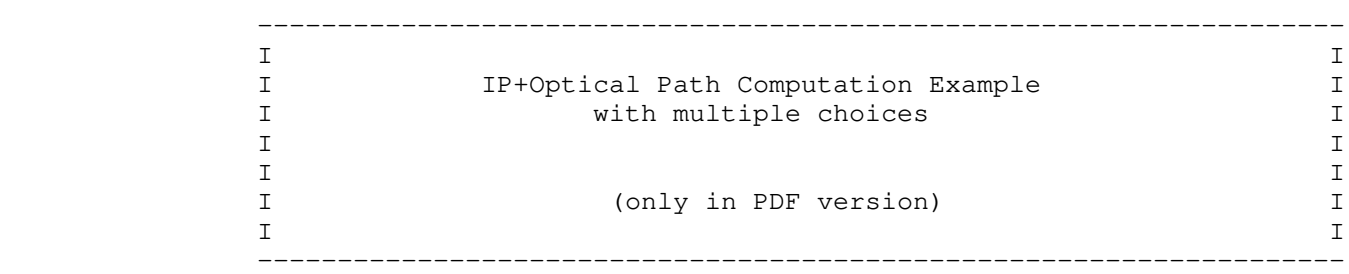

Figure 6 - IP+Optical Path Computation Example with multiple choices

Reporting all the information, as in Figure 6, using the "detailed abstract connectivity matrix", is quite challenging from a scalability perspective. The amount of this information is not just based on number of end points (which would scale as N-square), but also on many other parameters, including client rate, user constraints / policies for the service, e.g. max latency < N ms, max cost, etc., exclusion policies to route around busy links, min OSNR margin, max preFEC BER etc. All these constraints could be different based on connectivity requirements.

It is also worth noting that the "connectivity matrix" has been originally defined in WSON, [RFC7446] to report the connectivity constrains of a physical node within the WDM network: the information it contains is pretty "static" and therefore, once taken and stored in the TE data base, it can be always being considered valid and up-to-date in path computation request.

Using the "connectivity matrix" with an abstract node to abstract the information regarding the connectivity constraints of an Optical domain, would make this information more "dynamic" since the

connectivity constraints of an Optical domain can change over time because some optical paths that are feasible at a given time may become unfeasible at a later time when e.g., another optical path is established. The information in the "detailed abstract connectivity matrix" is even more dynamic since the establishment of another optical path may change some of the parameters (e.g., delay or available bandwidth) in the "detailed abstract connectivity matrix" while not changing the feasibility of the path.

"Connectivity matrix" is sometimes confused with optical reach table that contain multiple (e.g. k-shortest) regen-free reachable paths for every A-Z node combination in the network. Optical reach tables can be calculated offline, utilizing vendor optical design and planning tools,and periodically uploaded to the Controller: these optical path reach tables are fairly static. However, to get the connectivity matrix, between any two sites, either a regen free path can be used, if one is available, or multiple regen free paths are concatenated to get from src to dest, which can be a very large combination. Additionally, when the optical path within optical domain needs to be computed, it can result in different paths based on input objective, constraints, and network conditions. In summary, even though "optical reachability table" is fairly static, which regen free paths to build the connectivity matrix between any source and destination is very dynamic, and is done using very sophisticated routing algorithms.

There is therefore the need to keep the information in the "connectivity matrix" updated which means that there another tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the Orchestrator's PCE) and having up-to-date information. The more the information is provided and the longer it takes to keep it up-to-date which increases the likelihood that the Orchestrator's PCE computes paths using not updated information.

It seems therefore quite challenging to have a "detailed abstract connectivity matrix" that provides accurate, scalable and updated information to allow the Orchestrator's PCE to take optimal decisions by its own.

If the information in the "detailed abstract connectivity matrix" is not complete/accurate, we can have the following drawbacks considering for example the case in Figure 6:

- If only the VP1-VP4 path with available bandwidth of 2 Gb/s and cost 50 is reported, the Orchestrator's PCE will fail to compute a 5 Gb/s path between routers R1 and R2, although this would be feasible;

- If only the VP1-VP4 path with available bandwidth of 10 Gb/s and cost 60 is reported, the Orchestrator's PCE will compute, as optimal, the 1 Gb/s path between R1 and R2 going through the VP2-VP5 path within the Optical domain while the optimal path would actually be the one going thought the VP1-VP4 sub-path (with cost 50) within the Optical domain.

Instead, using the approach proposed in this document, the Orchestrator, when it needs to setup an end-to-end path, it can request the Optical domain controller to compute a set of optimal paths (e.g., for VP1-VP4 and VP2-VP5) and take decisions based on the information received:

- When setting up a 5 Gb/s path between routers R1 and R2, the Optical domain controller may report only the VP1-VP4 path as the only feasible path: the Orchestrator can successfully setup the end-to-end path passing though this Optical path;

- When setting up a 1 Gb/s path between routers R1 and R2, the Optical domain controller (knowing that the path requires only 1 Gb/s) can report both the VP1-VP4 path, with cost 50, and the VP2-VP5 path, with cost 65. The Orchestrator can then compute the optimal path which is passing thought the VP1-VP4 sub-path (with cost 50) within the Optical domain.

3.2. TE Topology Abstraction

Using the TE Topology model, as defined in [TE-TOPO], the underlying SDN controller can export an abstract TE Topology, composed by a set of TE nodes and TE links, which are abstracting the topology controlled by each domain controller.

Considering the example in Figure 4, the TE domain controller 1 can export a TE Topology encompassing the TE nodes A, B, C and D and the TE Link interconnecting them. In a similar way, TE domain controller 2 can export a TE Topology encompassing the TE nodes E, F, G and H and the TE Link interconnecting them.

In this example, for simplicity reasons, each abstract TE node maps with each physical node, but this is not necessary.

In order to setup a multi-domain TE path (e.g., between nodes A and H), the Orchestrator can compute by its own an optimal end-to-end path based on the abstract TE topology information provided by the domain controllers. For example:

- Orchestrator's PCE, based on its own information, can compute the optimal multi-domain path being A-B-C-E-G-H, and then request the TE domain controllers to setup the A-B-C and E-G-H intra-domain paths

- But, during path setup, the domain controller may find out that A-B-C intra-domain path is not feasible (as discussed in section 2.2, in optical networks it is typical to have some paths not being feasible due to optical constraints that are known only by the optical domain controller), while only the path A-B-D is feasible

- So what the hierarchical controller computed is not good and need to re-start the path computation from scratch

As discussed in section 3.1, providing more extensive abstract information from the TE domain controllers to the multi-domain Orchestator may lead to scalability problems.

In a sense this is similar to the problem of routing and wavelength assignment within an Optical domain. It is possible to do first routing (step 1) and then wavelength assignment (step 2), but the chances of ending up with a good path is low. Alternatively, it is possible to do combined routing and wavelength assignment, which is known to be a more optimal and effective way for Optical path setup. Similarly, it is possible to first compute an abstract end-to-end path within the multi-domain Orchestrator (step 1) and then compute an intra-domain path within each Optical domain (step 2), but there are more chances not to find a path or to get a suboptimal path that performing per-domain path computation and then stitch them.

3.3. Complementary use of TE topology and path computation

As discussed in section 2.2, there are some scalability issues with path computation requests in a multi-domain TE network with many TE domains, in terms of the number of requests to send to the TE domain controllers. It would therefore be worthwhile using the TE topology information provided by the domain controllers to limit the number of requests.

An example can be described considering the multi-domain abstract topology shown in Figure 7. In this example, an end-to-end TE path between domains A and F needs to be setup. The transit domain should be selected between domains B, C, D and E.

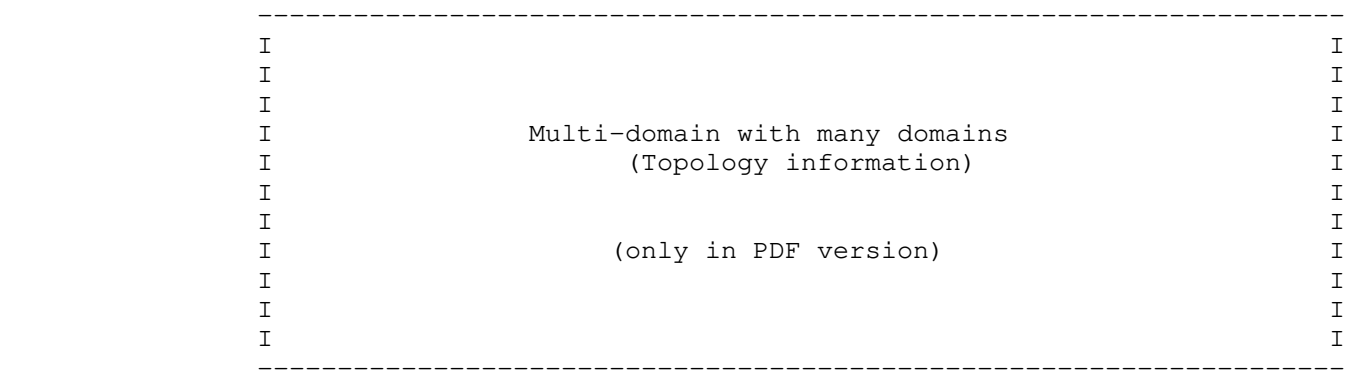

Figure 7 - Multi-domain with many domains (Topology information)

The actual cost of each intra-domain path is not known a priori from the abstract topology information. The Orchestrator only knows, from the TE topology provided by the underlying domain controllers, the feasibility of some intra-domain paths and some upper-bound and/or lower-bound cost information. With this information, together with the cost of inter-domain links, the Orchestrator can understand by its own that:

- Domain B cannot be selected as the path connecting domains A and E is not feasible;

- Domain E cannot be selected as a transit domain since it is know from the abstract topology information provided by domain controllers that the cost of the multi-domain path A-E-F (which is 100, in the best case) will be always be higher than the cost of the multi-domain paths A-D-F (which is 90, in the worst case) and A-E-F (which is 80, in the worst case)

Therefore, the Orchestrator can understand by its own that the optimal multi-domain path could be either A-D-F or A-E-F but it

cannot known which one of the two possible option actually provides the optimal end-to-end path.

The Orchestrator can therefore request path computation only to the TE domain controllers A, D, E and F (and not to all the possible TE domain controllers).

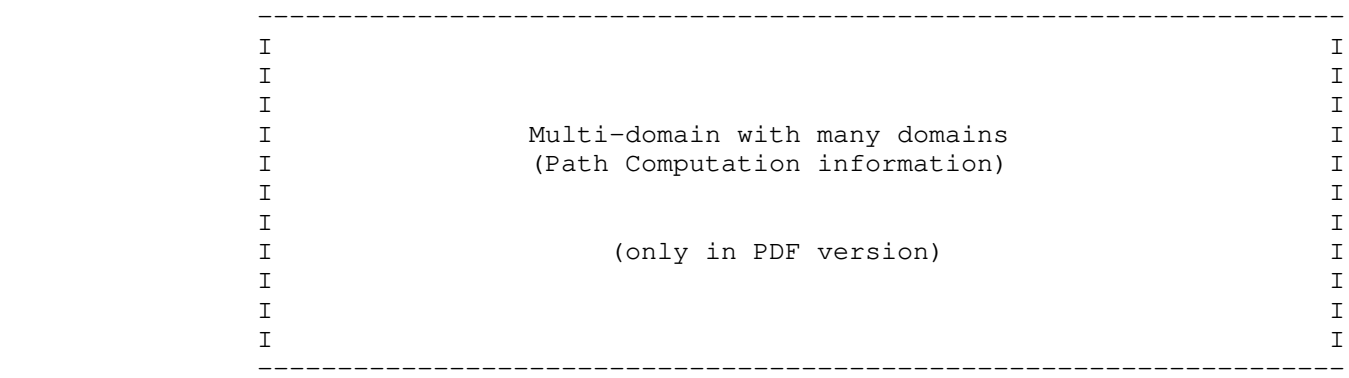

Figure 8 - Multi-domain with many domains (Path Computation information)

Based on these requests, the Orchestrator can know the actual cost of each intra-domain paths which belongs to potential optimal end-to-end paths, as shown in Figure 8, and then compute the optimal end-to-end path (e.g., A-D-F, having total cost of 50, instead of A-C-F having a total cost of 70).

4. Motivation for a YANG Model

4.1. Benefits of common data models

Path computation requests should be closely aligned with the YANG data models that provide (abstract) TE topology information, i.e., [TE-TOPO] as well as that are used to configure and manage TE Tunnels, i.e., [TE-TUNNEL]. Otherwise, an error-prone mapping or correlation of information would be required. For instance, there is benefit in using the same endpoint identifiers in path computation requests and in the topology modeling. Also, the attributes used in path computation constraints could use the same or similar data

models. As a result, there are many benefits in aligning path computation requests with YANG models for TE topology information and TE Tunnels configuration and management.

4.2. Benefits of a single interface

A typical use case for path computation requests is the interface between an orchestrator and a domain controller. The system integration effort is typically lower if a single, consistent interface is used between such systems, i.e., one data modeling language (i.e., YANG) and a common protocol (e.g., NETCONF or RESTCONF).

Practical benefits of using a single, consistent interface include:

1. Simple authentication and authorization: The interface between different components has to be secured. If different protocols have different security mechanisms, ensuring a common access control model may result in overhead. For instance, there may be a need to deal with different security mechanisms, e.g., different credentials or keys. This can result in increased integration effort.
2. Consistency: Keeping data consistent over multiple different interfaces or protocols is not trivial. For instance, the sequence of actions can matter in certain use cases, or transaction semantics could be desired. While ensuring consistency within one protocol can already be challenging, it is typically cumbersome to achieve that across different protocols.
3. Testing: System integration requires comprehensive testing, including corner cases. The more different technologies are involved, the more difficult it is to run comprehensive test cases and ensure proper integration.
4. Middle-box friendliness: Provider and consumer of path computation requests may be located in different networks, and middle-boxes such as firewalls, NATs, or load balancers may be deployed. In such environments it is simpler to deploy a single protocol. Also, it may be easier to debug connectivity problems.
5. Tooling reuse: Implementers may want to implement path computation requests with tools and libraries that already exist in controllers and/or orchestrators, e.g., leveraging the rapidly growing eco-system for YANG tooling.

4.3. Extensibility

Path computation is only a subset of the typical functionality of a controller. In many use cases, issuing path computation requests comes along with the need to access other functionality on the same system. In addition to obtaining TE topology, for instance also configuration of services (setup/modification/deletion) may be required, as well as:

1. Receiving notifications for topology changes as well as integration with fault management
2. Performance management such as retrieving monitoring and telemetry data
3. Service assurance, e.g., by triggering OAM functionality
4. Other fulfilment and provisioning actions beyond tunnels and services, such as changing QoS configurations

YANG is a very extensible and flexible data modeling language that can be used for all these use cases.

Adding support for path computation requests to YANG models would seamlessly complement with [TE-TOPO] and [TE-TUNNEL] in the use cases where YANG-based protocols (e.g., NETCONF or RESTCONF) are used.

5. Path Optimization Request

This is for further study

6. YANG Model for requesting Path Computation

Work on extending the TE Tunnel YANG model to support the need to request path computation has recently started also in the context of the [TE-TUNNEL] draft.

It is possible to request path computation by configuring a "compute-only" TE tunnel and retrieving the computed path(s) in the LSP(s) Record-Route Object (RRO) list as described in [TE-TUNNEL].

This is a stateful solution since the state of each created "compute-only" TE tunnel needs to be maintained and updated, when underlying network conditions change.

The need also for a stateless solution, based on an RPC, has been recognized.

The YANG model to support stateless RPC is for further study.

7. Security Considerations

This is for further study

8. IANA Considerations

This document requires no IANA actions.

9. References

9.1. Normative References

[RFC7926] Farrel, A. et al., "Problem Statement and Architecture for Information Exchange Between Interconnected Traffic Engineered Networks", RFC 7926, July 2016.

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9.2. Informative References

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July 8, 2016

RSVP Extensions for RMR
draft-deshmukh-rsvp-rmr-extension-00

Abstract

Rings are the most common topology in access and aggregation networks. However, the use of MPLS as the transport protocol for rings is very limited today. draft-ietf-mpls-rmr-02 describes a mechanism to handle rings efficiently using MPLS. This document describes the extensions to the RSVP protocol for signaling MPLS label switched paths in rings.

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].

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 January 9, 2017.

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Table of Contents

1. Introduction

This document extends RSVP-TE [RFC3209] to establish label-switched path (LSP) tunnels in the ring topology. Rings are auto-discovered using the mechanisms mentioned in the [draft-ietf-mpls-rmr-02]. Either IS-IS [RFC5305] or OSPF[RFC3630] can be used as the IGP for auto-discovering the rings.

After the rings are auto-discovered, each ring node knows its clockwise (CW) and anticlockwise (AC) ring neighbors and its ring links. All of the express links in the ring also get identified as part of the auto-discovery process. At this point, every node in the ring informs the RSVP protocol to begin the signaling of the ring LSPs.

Section 2 covers the terminology used in this document. Section 3 presents the RSVP protocol extensions needed to support MPLS rings. Section 4 describes the procedures of RSVP LSP signaling in detail.

2. Terminology

A ring consists of a subset of n nodes {R_i, 0 <= i < n}. We define the direction from node R_i to R_i+1 as "clockwise" (CW) and the reverse direction as "anti-clockwise" (AC). As there may be several rings in a graph, we number each ring with a distinct ring ID RID.

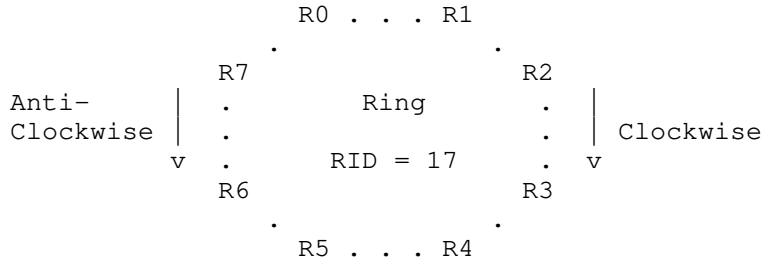


Figure 1: Ring with 8 nodes

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. A node may belong to multiple rings.

Ring node: A member of a ring. Note that a device may belong to several rings.

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 neighbors: Nodes whose indices differ by one (modulo ring size).

Ring links: Links that connect ring neighbors.

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

MP2P LSP: Each LSP in the ring is a multipoint to point LSP such that LSP can have multiple ingress nodes and one egress node.

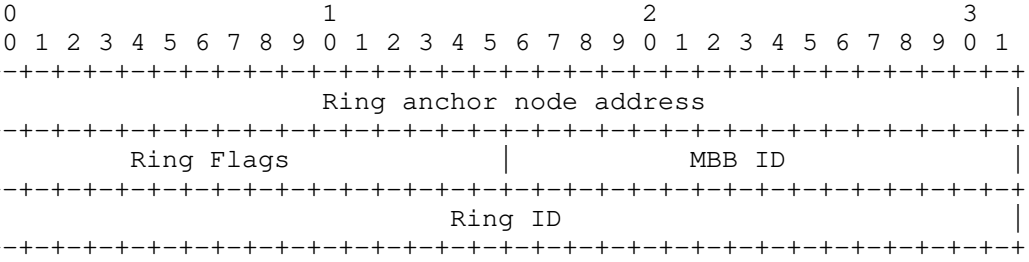
3. RSVP Extensions

Since the procedures of signaling ring LSPs will be different from the signaling of regular RSVP LSPs, a new C-Type is defined here for the SESSION object. This new C-Type will help to clearly

differentiate ring LSPs from regular LSPs. In addition, new flags are introduced in the SESSION object to represent the ring direction of the corresponding Path message.

3.1. Session Object

Class = SESSION, LSP_TUNNEL_IPv4 C-Type = TBD



SESSION Object

Ring anchor node address: IPv4 address of the anchor node. Each anchor node creates a LSP addressed to itself.

MBB ID: A 16-bit identifier used in the SESSION. This "Make-before-break" (MBB) ID is useful for graceful ring changes. If a new node is being added to the ring or some existing node goes down and we have to signal a smaller ring, in those cases, anchor node creates a new tunnel with a different "MBB ID".

Ring ID: A 32-bit number that identifies a ring; this is unique in some scope of a Service Provider's network. This number remains constant throughout the existence of ring.

Ring Flags: For each ring, the anchor node starts signaling of a ring LSP. Ring LSP RL_i, anchored on node R_i, consists of two counter-rotating unicast LSPs that start and end at R_i. One LSP will be in the clockwise direction and other LSP will be in the anti-clockwise direction. 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). Two new flags are defined in the SESSION object which define the ring direction of the corresponding Path message.

ClockWise(CW) Direction 0x01: This flag indicates that the corresponding Path message is traveling in the ClockWise(CW) direction along the ring.

Anti-ClockWise(AC) Direction 0x02: This flag indicates that the corresponding Path message is traveling in the Anti-ClockWise(AC) direction along the ring.

3.2. SENDER_TEMPLATE,FILTER_SPEC Objects

There will be no changes to the SENDER_TEMPLATE and FILTER_SPEC objects. The format of the above 2 objects will be similar to the definitions in RFC 3209. [RFC3209] Only the semantics of these objects will slightly change. This will be explained in section Section 4.5 below.

4. Ring Signaling Procedures

A ring node indicates in its IGP updates the ring LSP signaling protocols that it supports. This can be LDP and/or RSVP-TE. Ideally, each node should support both. If the ring is configured with RSVP as the signaling protocol, then once a ring node R_i knows the RID, its ring links and directions, it kicks off ring RSVP LSP signaling automatically.

4.1. Differences from regular RSVP-TE LSPs

Ring LSPs differ from regular RSVP-TE LSPs in several ways:

1. Ring LSPs (by construction) form a loop.

2. Ring LSPs are multipoint-to-point. Any ring node can inject traffic into a ring LSP.

3. The bandwidth of a ring LSP can change hop-to-hop.

4. Ring LSPs are protected without the use of bypass or detour LSPs. Ring LSP protection is akin to SONET/SDH ring protection.

4.2. LSP signaling

After the ring auto-discovery process, each anchor node creates a LSP addressed to itself. This ring LSP contains of a pair of counter-rotating unicast LSPs. So, for a ring containing N nodes, there will be 2N total LSPs signaled.

There is no need for ERO object in the Path message. The Path message for ring LSPs has the following format:

```
        <Path Message> ::=  <Common Header> [ <INTEGRITY> ]
                                <SESSION> <RSVP_HOP>
                                <TIME_VALUES>
                                <LABEL_REQUEST>
                                [ <SESSION_ATTRIBUTE> ]
                                <sender descriptor list>

        <sender descriptor list> ::= <sender descriptor>|
                                          <sender descriptor list> <sender descri
ptor>
        <sender descriptor> ::= <SENDER_TEMPLATE> <SENDER_TSPEC>
```

The anchor node creates 2 Path messages traveling in opposite directions. The SESSION format MUST be as per the description in Section 3.1. The anchor node which creates the LSP will insert it's own address in the "Ring node anchor address" field of the SESSION object. So effectively, the Path messages are addressed to the originating node itself.

The SESSION flags of these 2 Path messages are different. The Path message sent to the CW neighbor MUST have the CW flag set in the SESSION object to signal the LSP going in the clockwise direction. The Path message sent to the AC neighbor MUST have the AC flag set to signal the LSP in the anti-clockwise direction. The details for signaling over express links will be given in a future version.

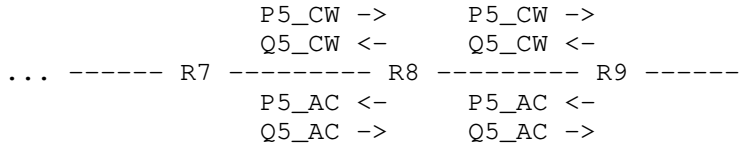
When an incoming Path message is received at the ring node R_i, it consults the results of auto-discovery to find the appropriate ring neighbor. If the incoming Path message has CW direction flag set, then R_i sends a Path message to its CW ring neighbor (and vice versa). Thus, there is no need of ERO in the Path message. The Path message is routed locally at each ring based on the ring auto-discovery calculations.

The RESV message for ring LSPs also uses the new RING_IPv4 SESSION object. When the Path message originated from the anchor node R_i reaches back to R_i, R_i generates a Resv message. Note that this means that anchor node is both Ingress and Egress for the Path message. The Resv message copies the same ring flags as received in the corresponding Path message. So, a Resv message for a CW LSP goes in the AC direction (unlike the Path message, which goes CW). This is done to correctly match Path and corresponding Resv messages at transit ring nodes. Upon receiving Resv message with CW flag set, the ring node will forward the Resv message to its AC neighbor.

Each ring node R_i allocates CW and AC labels for each ring LSP RL_k. 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.

Consider the following three nodes of the ring, and their signaling interactions for LSP RL_5 originating from anchor node R5:



P corresponds to the Path message and Q corresponds to the Resv message.

Also, since ring LSPs are MP2P in nature, each ring node SHOULD also signal a Path message towards anchor node. The procedure for that is as follows:

When a ring node R5 receives a Path message initiated by anchor node R1(for anchor lsp "lsp1"), R5 SHOULD make a copy of the received Path message for "lsp1". R5 then modifies the sender-template object from the copied Path message for "lsp1". In the sender-template object, R5 uses the sender address as the loopback address of node R5 and lsp-id = X. R5 then forwards this new Path message to it's ring neighbor. The original anchor Path message has sender address as loopback address of R1 and lsp-id = X.

So at this point, there will be 2 different path messages existing for lsp1 First Path message will be for the anchor LSP with sender address = node R1. Second Path message will be for the ring LSP with sender address = node R5.

When node R1 receives this modified Path message, it replies with the Resv message containing the same label it advertised for the original anchor lsp "lsp1". The SESSION object of the Resv message will also exactly match with the received Path message. Only the FILTER_SPEC object in the Resv message will have the sender address as loopback of node R5. As this Resv message propagates back towards R5, all the transit nodes also send the same label that they have allocated for the original anchor lsp "lsp1". So no new label routes get installed as part of signaling for this ring lsp. The anchor LSP and all of their associated ring LSPs share label routes. The label actions are described below in Section 4.3.

4.3. Protection

In the rings, there are no protection LSPs -- no node or link bypass LSPs, no standby LSPs and no detours. 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.

Since each ring LSP is a MP2P LSP, any ring node can inject traffic onto a LSP whose anchor might be a different ring node. To achieve the above, an ingress route will be installed as follows at every ring node J, for a given ring-LSP with anchor Rk (say 1.2.3.4).

```
1.2.3.4  ->  (Push CL_J+1,K, NH: R_J+1)       # CW
         ->  (Push AL_J-1,K, NH: R_J-1)       # AC

          CL = Clockwise label
          AL = Anti-Clockwise label
```

Traffic will either be load balanced in the CW and AC directions or the traffic will be sent on just CW or AC lsp based on parameters such as hop-count, policy etc.

Also, 2 transit routes will be installed for the anchor LSP transiting from node Rj as follows:

```
CL_J,K ->  SWAP(CL_J+1,K,  NH: R_J+1)              #CW
       ->  SWAP(AL_J-1,K , NH: R_J-1)              #AC

           CL = Clockwise label
           AL = Anti-Clockwise label
           CW NH has weight 1, AC NH has higher-weight.


AL_J,K -> SWAP(AL_J-1,K , NH: R_J-1)  #AC
       -> SWAP(CL_J+1,K,  NH: R_J+1)  #CW

           CL = Clockwise label
           AL = Anti-Clockwise label
           AC NH has weight 1, CW NH has higher weight.
```

Suppose a packet headed in anti-clockwise direction towards R5 and it arrives at node R8. Lets say that now R8 learns there is a link

failure in the AC direction. R8 reroutes this packet back onto the clockwise direction. This reroute action is pre-programmed in the LFIB, to minimize the time between detection of a fault and the corresponding recovery action.

At this time, R8 also sends a notification to R7 that the AC direction is not working, so that R7 can similarly switch traffic to the CW direction. These notification SHOULD propagate CW until each traffic source on the ring CW of the failure uses the CW direction.For RSVP-TE, this notification is sent in the form of PathErr message.

To provide this notification, the ring node detecting failure SHOULD send a Path Error message with error code of "Notify" and an error value field of ("Tunnel locally repaired"). This Path Error code and value is same as defined in RFC 4090[RFC4090] for the notification of local repair.

Note that the failure of a node or a link will not necessarily affect all ring LSPs. Thus, it is important to identify the affected LSPs and only switch the affected LSPs.

4.4. Ring changes

A ring node can go down resulting in a smaller ring or a new node can be added to the ring which will increase the ring size. In both of the above cases, the ring auto-discovery process SHOULD kick in and it SHOULD calculate a new ring with the changed ring nodes.

When the ring auto-discovery process is complete, IGP will signal RSVP to begin the MBB process for the existing ring LSPs. For this MBB process, the anchor node will create a new Path message with a different "MBB ID" in the SESSION object. All other fields in the SESSION Object will remain same as the existing Path message(before the ring change).

This new Path message will then propagate along the ring neighbors in the same way as the original Path message. Each ring neighbor SHOULD forward the Path message to it’s appropriate neighbor based on the new auto-discovery calculations.

For the ring links which are common between the old and new LSPs, the LSPs will share resources(SE style reservation) on those ring links. Note that here we are using MBB_ID in the SESSION object to share resources instead of the LSP_ID in the SENDER_TEMPLATE Object(which is used in RSVP-TE for sharing resources as described in RFC 3209 [RFC4090]). The LSP_ID use is reserved for a different functionality as described in section Section 4.5.

4.5. Bandwidth management

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.

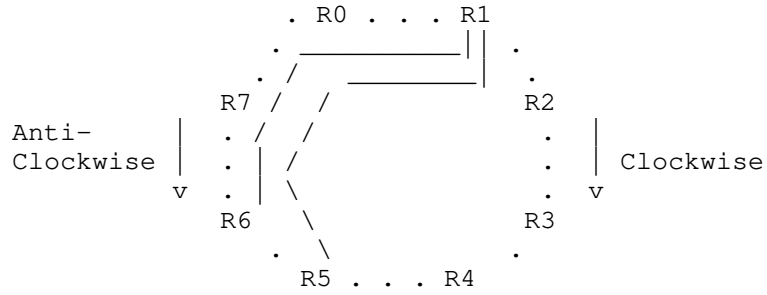


Figure 2: BW Management in Ring with 8 nodes

Let's say that Ring node R5 wants to increase the BW for the LSP whose egress is at node R1. To achieve this BW increase, Ring node R5 has to increase BW along the LSP anchored at node R1(say lsp1).

R5 makes a copy of the existing ring Path message for lsp1. R5 then modifies the sender-template object from the copied Path message for "lsp1". In the sender-template object, R5 uses the sender address as the loopback address of node R5 and lsp-id = X+1. R5 also modifies the TSPEC object which represents the BW increase/decrease in this new Path message. R5 then forwards this new Path message to it's ring neighbor. Note that R5 MUST also continue signaling the original anchor Path message received from ring node R1 for lsp1. The original anchor Path message has sender address as loopback address of R1.

Now, let's say, node 5 wants to increase BW again for lsp1, then R5 adds a new SENDER_TEMPLATE object in the existing Path message for "lsp1" with sender address as loopback of node 5 and lsp-id = X+2. So at this point, there will be 2 different path messages existing for lsp1 First Path message will be for the anchor LSP with sender address = node 1. Second Path message will contain 2 SENDER_TEMPLATE objects as [node5, lsp-id = X+1] and [node5, lsp-id =X+2].

Similarly, if node R6 wants to increase the BW for "lsp1", it SHOULD create a new Path message containing SENDER_TEMPLATE object with

sender address = loopback of node 6 and lsp-id = Y+1. Thus, the LSP-ID field is local to each sender node along the ring.

If sufficient BW is available all the way towards ring node R1, then this new Path message reaches node R1. R1 generates a Resv message with the correct FILTER_SPEC object corresponding to the received SENDER_TEMPLATE object. This Resv message will also have the correct FLOWSPEC object as per the requested bandwidth.

If sufficient BW is not available at some downstream (say node R9), then ring node R9 SHOULD generate a PathErr message with the corresponding Sender Template Object. When node R5 receives this PathErr message, R5 understands that the BW increase was not successful. Note that the existing established bandwidths for lsp1 are not affected by this new PathErr message.

When ring node R5 no longer needs the BW reservation, then ring node R5 SHOULD originate a PathTear message with the appropriate Sender Template Object as described above. Every downstream node SHOULD then remove bandwidth allocated on the corresponding link on receipt of this PathTear message.

Also, note that as part of this BW increase or decrease process, any ring node does not actually change any label associated with the LSP. So, the label remains same as it was signaled initially when the anchor LSP came up.

5. 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.

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7. IANA Considerations

Requests to IANA will be made in a future version of this document.

8. References

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A YANG model to manage the optical interface parameters for an external transponder in a WDM network
draft-dharini-ccamp-dwdm-if-param-yang-00

Abstract

This memo defines a Yang model related to the Optical Transceiver optical parameters characterising the 100G and above interfaces. 100G and above Transceivers support coherent transmission, different modulation format, multiple FEC algorithms not yet specified by ITU-T G.698.2 [ITU.G698.2] or any other ITU-T recommendation. The use cases and the state of the Coherent transceivers is well describe in draft-many-coherent-DWDM-if-control.

The Yang model defined in this memo can be used for Optical Parameters monitoring and/or configuration of the endpoints of the multi-vendor IaDI optical link.

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 May 4, 2017.

Table of Contents

1. Introduction

This memo defines a Yang model that translates and obsolete the SNMP mib module defined in draft-galikunze-ccamp-dwdm-if-snmp-mib for managing single channel optical interface parameters of DWDM applications, using the approach specified in G.698.2. This model is to support the optical parameters specified in ITU-T G.698.2 [ITU.G698.2], plus some parameters related to full coherent transmission and not yet specified by ITU-T like modulation format, finer Grid provisioning, multiple carrier, etc. The application identifiers specified in ITU-T G.874.1 [ITU.G874.1] and the Optical Power at Transmitter and Receiver side. Note that G.874.1 encompasses vendor-specific codes, which if used would make the interface a single vendor IaDI and could still be managed.

[Editor's note: In G.698.2 this corresponds to the optical path from point S to R; network media channel is also used and explained in draft-ietf-ccamp-flexi-grid-fwk-02]

Management will be performed at the edges of the network media channel (i.e., at the transmitters and receivers attached to the S and R reference points respectively) for the relevant parameters specified in G.698.2 [ITU.G698.2], G.798 [ITU.G798], G.874 [ITU.G874], and the performance parameters specified in G.7710/Y.1701 [ITU-T G.7710] and G.874.1 [ITU.G874.1].

G.698.2 [ITU.G698.2] is primarily intended for metro applications that include optical amplifiers. Applications are defined in G.698.2 [ITU.G698.2] using optical interface parameters at the single-channel connection points between optical transmitters and the optical multiplexer, as well as between optical receivers and the optical demultiplexer in the DWDM system. This Recommendation uses a methodology which does not explicitly specify the details of the optical network between reference point Ss and Rs, e.g., the passive and active elements or details of the design. The Recommendation currently includes unidirectional DWDM applications at 2.5 and 10 Gbit/s (with 100 GHz and 50 GHz channel frequency spacing). Work is still under way for 40, 100 and Higher Gbit/s interfaces. There is possibility for extensions to a lower channel frequency spacing. This document specifically refers also to the "application code" defined in the G.698.2 [ITU.G698.2] and included in the Application Identifier defined in G.874.1 [ITU.G874.1] and G.872 [ITU.G872], plus a few optical parameters not included in the G.698.2 application code specification.

This draft refers and supports the draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk and draft-many-coherent-DWDM-if-control.

The building of a yang model describing and extending the optical parameters defined in G.698.2 [ITU.G698.2], and reflected in G.874.1 [ITU.G874.1], allows the different vendors and operator to retrieve, provision and exchange information across the G.698.2 multi-vendor IaDI in a standardised way. In addition to the parameters specified in ITU recommendations the Yang models support also the "vendor specific application identifier", the Tx and Rx power at the Ss and Rs points and the channel frequency and the detailed parameters described in G.698.2 extending them to the new 100G and higher coherent interfaces..

The Yang Model, reporting the Optical parameters and their values, characterizes the features and the performances of the optical components and allow a reliable link design in case of multi vendor optical networks.

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].

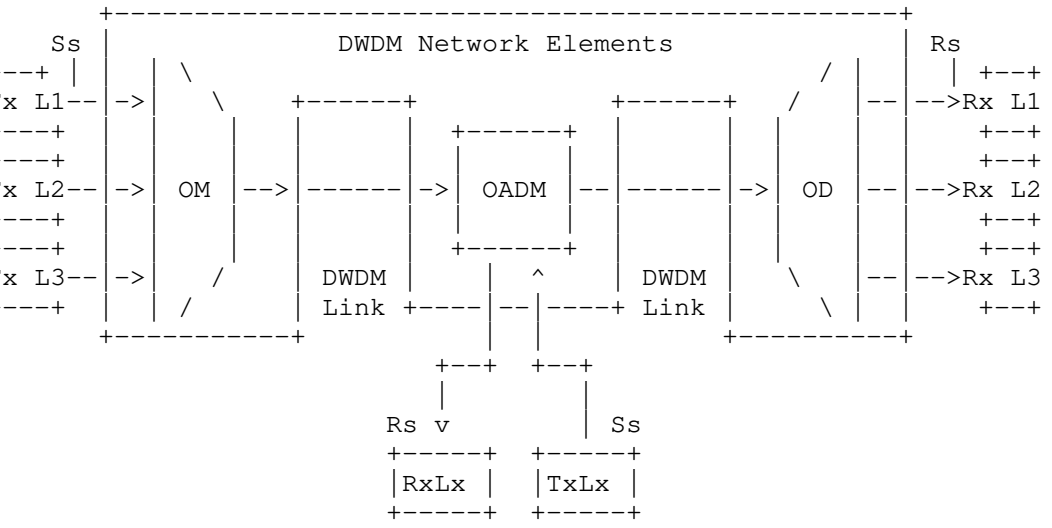
This memo specifies a Yang model for optical interfaces.

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 RFC 2119 [RFC2119] In the description of OIDs the convention: Set (S) Get (G) and Trap (T) conventions will describe the action allowed by the parameter.

4. Overview

Figure 1 shows a set of reference points, for single-channel connection between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an OM and an OD (which are used as a pair with the opposing element), one or more optical amplifiers and may also include one or more OADMs.



Ss = reference point at the DWDM network element tributary output
Rs = reference point at the DWDM network element tributary input
Lx = Lambda x
OM = Optical Mux
OD = Optical Demux
OADM = Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: External transponder in WDM netwoks

4.1. Optical Parameters Description

The link between the external transponders through a WDM network media channels are managed at the edges, i.e. at the transmitters (Tx) and receivers (Rx) attached to the S and R reference points respectively. The set of parameters that could be managed are defined by the "application code" notation

The definitions of the optical parameters are provided below to increase the readability of the document, where the definition is

ended by (R) the parameter can be retrieve with a read, when (W) it can be provisioned by a write, (R,W) can be either read or written.

4.1.1. Table of Application Codes

This table has a list of Application codes supported by this interface at point R are defined in G.698.2.

Application code Identifier:
The Identifier for the Application code.

Application code Type:
This parameter indicates the transceiver type of application code at Ss and Rs as defined in [ITU.G874.1], that is used by this interface Standard = 0, PROPRIETARY = 1
If Proprietary the first 6 octets of the printable string will be the OUI (organizationally unique identifier) assigned to the vendor whose implementation generated the Application Identifier Code.

Application code:
This is the application code that is defined in G.698.2 or the vendor generated code which has the OUI.

Number of Single-channel application codes Supported:
This parameter indicates the number of Single-channel application codes supported by this interface

Application code Length:
The number of octets in the Application Code.

4.1.2. Rs-Ss Configuration and operating parameters

The Rs-Ss configuration table allows configuration of Central Frequency, Power and Application codes as described in [ITU.G698.2] and G.694.1 [ITU.G694.1] and other parameters related to new high speed coherent interfaces.

Number of subcarriers:
This parameter indicates the number of subcarriers available for the super-channel in case the Transceiver can support multipla carrier Circuits.

Current Laser Output power:
This parameter report the current Transceiver Output power, it can be either a setting and measured value (R/W).

Central frequency (see G.694.1 Table 1):
This parameter indicates the Central frequency value that Ss and Rs will be set to work (in THz). See the details in Section 6/ G.694.1 or based on "n" and "k" values in case of multicarrier transceivers (R/W).

Central frequency franularity:
This parameter indicates the Central frequency granularity supported by the transceiver, this value is combined with K and n value to calculate the central frequency on the carrier or sub-carriers (R).

Current Laser Input power:
This parameter report the current Transceiver Input power (G).

Minimum channel spacing:
This is the minimum nominal difference in frequency (in GHz) between two adjacent channels (or carriers) depending on the Transceiver characteristics (R).

Bit rate / Baud rate of optical tributary signals:
Optical tributary signal bit (for NRZ signals) rate or Symbol (for Multiple bit per symbol) rate .

FEC Coding:
This parameter indicate what Forward Error Correction (FEC) code is used at Ss and Rs (R/W) (not mentioned in G.698). .

Maximum bit error ratio (BER):
This parameter indicate the maximum Bit error rate can be supported by the application at the Receiver. In case of FEC applications it is intended after the FEC correction (R) .

Wavelength Range (see G.694.1): [ITU.G694.1]
This parameter indicate minimum and maximum wavelength spectrum (R) in a definite wavelength Band (L, C and S).

Modulatoin format:
This parameter indicates the list of supported Modulation Formats and the provisioned Modulation Format. (R/W).

Inter carrier skew:
This parameter indicates, in case of multi-carrier transceivers the maximum skew between the sub-carriers supported by the transceiver (R).

4.2. Parameters at Ss

The following parameters for the interface at point S are defined in G.698.2 [ITU.G698.2].

Maximum and minimum mean channel output power:
The mean launched power at Ss is the average power (in dBm) of a pseudo-random data sequence coupled into the DWDM link. It is defined as the rhange (Max and Min) of the parameter (R/W)

Minimum and maximum central frequency:
The central frequency is the nominal single-channel frequency (in THz) on which the digital coded information of the particular optical channel is modulated by use of the NRZ line code. The central frequencies of all channels within an application lie on the frequency grid for the minimum channel spacing of the application given in ITU-T Rec. G.694.1. This parameter give the Maximum and minimum frequency interval the channel must be modulated (R)

Maximum spectral excursion:
This is the maximum acceptable difference between the nominal central frequency (in GHz) of the channel and the minus 15 dB points of the transmitter spectrum furthest from the nominal central frequency measured at point Ss. (R)

Maximum transmitter (residual) dispersion OSNR penalty (B.3/G.959.1) [ITU.G959.1]
Defines a reference receiver that this penalty is measured with. Lowest OSNR at Ss with worst case (residual) dispersion minus the Lowest OSNR at Ss with no dispersion. Lowest OSNR at Ss with no dispersion (R)

Minimum side mode suppression ratio, Minimum channel extinction ratio, Eye mask:
Although are defined in G.698.2 are not supported by this draft (R).

Current Laser Output power:
This parameter report the current Transceiver Output power, it can be either a setting and measured value (R/W) NEED TO DISCUSS ON THIS.

4.3. Interface at point Rs

The following parameters for the interface at point R are defined in G.698.2.

4.3.1. Mandatory parameters

Maximum and minimum mean input power:
The maximum and minimum values of the average received power (in dBm) at point Rs. (R)

Minimum optical signal-to-noise ratio (OSNR):
The minimum optical signal-to-noise ratio (OSNR) is the minimum value of the ratio of the signal power in the wanted channel to the highest noise power density in the range of the central frequency plus and minus the maximum spectral excursion (R)

Receiver OSNR tolerance:
The receiver OSNR tolerance is defined as the minimum value of OSNR at point Rs that can be tolerated while maintaining the maximum BER of the application. (R)

Maximum reflectance at receiver:
Although is defined in G.698.2, this parameter is not supported by this draft (R).

4.3.2. Optional parameters

Current Chromatic Dispersion (CD):
Residual Chromatic Dispersion measuread at Rx Transceiver port (R).

Current Optical Signal to Noise Ratio (OSNR):
Current Optical Signal to Noise Ratio (OSNR) estimated at Rx Transceiver port (R).

Current Quality factor (Q):
"Q" factor estimated at Rx Transceiver port (R).

4.3.3. Optical path from point Ss to Rs

The following parameters for the optical path from point S and R are defined in G.698.2 and are covered by draft-ggalimbe-ccamp-iv-yang [ITU.G698.2].

4.4. Use Cases

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

4.5. Optical Interface for external transponder in a WDM network

The ietf-ext-xponder-wdm-if is an augment to the ietf-interface. It allows the user to set the application code/vendor transceiver class/ Central frequency and the output power. The module can also be used to get the list of supported application codes/transceiver class and also the Central frequency/output power/input power of the interface.

```
     module: ietf-ext-xponder-wdm-if
     augment /if:interfaces/if:interface:
         +--rw optIfOChRsSs
               +--rw if-current-application-code
               |  +--rw application-code-id    uint8
               |  +--rw application-code-type  uint8
               |  +--rw application-code-length uint8
               |  +--rw application-code?     string
               +--ro if-supported-application-codes
               |  +--ro number-application-codes-supported?   uint32
               |  +--ro application-codes-list* [application-code-id]
               |     +--ro application-code-id   uint8
               |     +--rw application-code-type  uint8
               |     +--rw application-code-length uint8
               |     +--ro application-code?    string
               +--rw output-power?                      int32
               +--ro input-power?                       int32
               +--rw central-frequency?                 uint32


      notifications:
     +---n opt-if-och-central-frequency-change
     |  +--ro if-name?      leafref
     |  +--ro new-central-frequency
     |     +--ro central-frequency?   uint32
     +---n opt-if-och-application-code-change
     |  +--ro if-name?              leafref
     |  +--ro new-application-code
     |     +--ro application-code-id?   uint8
     |     +--rw application-code-type  uint8
     |     +--rw application-code-length uint8
     |     +--ro application-code?     string
```

5. Structure of the Yang Module

ietf-ext-xponder-wdm-if is a top level model for the support of this feature.

6. Yang Module

The ietf-ext-xponder-wdm-if is defined as an extension to ietf interfaces.

```
   <CODE BEGINS> file "ietf-ext-xponder-wdm-if.yang"

   module ietf-ext-xponder-wdm-if {
        namespace "urn:ietf:params:xml:ns:yang:ietf-ext-xponder-wdm-if";
        prefix ietf-ext-xponder-wdm-if;

        import ietf-interfaces {
          prefix if;
        }

        organization
          "IETF CCAMP
          Working Group";

        contact
          "WG Web:   <http://tools.ietf.org/wg/ccamp/>
           WG List:  <mailto:ccamp@ietf.org>


           Editor:   Dharini Hiremagalur
                     <mailto:dharinih@juniper.net>";

        description
          "This module contains a collection of YANG definitions for
           configuring Optical interfaces.

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           Legal Provisions Relating to IETF Documents
           (http://trustee.ietf.org/license-info).";

       revision "2016-03-17" {
              description
                  "Initial revision.";
              reference
                  "";
       }




         grouping opt-if-och-application-code  {
```

```
                description "Application code entity.";
                leaf application-code-id {
                   type uint8 {
                         range "1..255";
                   }
                   description
                         "Id for the Application code";
                }
                leaf application-code-type {
                   type uint8 {
                         range "0..1";
                }
                  description
                         "Type for the Application code
                           0 - Standard, 1 - Proprietory
                           When the Type is Proprietory, then the
                           first 6 octets of the application-code
                           will be the OUI (organizationally unique
                           identifier)";

                }
                leaf application-code-length {
                   type uint8 {
                         range "1..255";
                   }
                   description
                         "Number of octets in the Application code";

                }
                leaf application-code {
                   type string {
                         length "1..255";
                   }
                   description "This parameter indicates the
                        transceiver application code at Ss and Rs as
                        defined in [ITU.G698.2] Chapter 5.3, that
                        is/should be used by this interface.
                        The optIfOChApplicationsCodeList has all the
                        application codes supported by this
                        interface.";

                }
         }

        typedef dbm-t {
          type decimal64 {
            fraction-digits 2;
            range "-50..-30 | -10..5 | 10000000";
```

```
          }
          description "
            Amplifier Power in dBm ";
        }
         grouping opt-if-och-application-code-list {
           description "List of Application codes group.";
           leaf number-application-codes-supported {
               type uint32;
               description "Number of Application codes
                            supported by this interface";
            }
           list application-code-list {
               key "application-code-id";
               description "List of the application codes";
               uses opt-if-och-application-code;
           }
         }


        grouping opt-if-och-power {
           description "Interface optical Power";
           leaf output-power {
               type int32;
               units ".01dbm";
               description "The output power for this interface in
                            .01 dBm.
                            The setting of the output power is
                             optional";
           }

           leaf input-power {
                type int32;
                units ".01dbm";
                config false;
                description "The current input power of this
                      interface";
           }
        }

     grouping channel-ITU {
     description "channel-ITU";
     container channel-t {
           description "wavelength notation according to RFC-6205";
            leaf grid {
              type uint32;
              description "grid type e.g.: 0=reserved, 1=DWDM, 2=CWDM";
            }
            leaf channel-spacing {
```

```
            type uint32;
            description "DWDM grid e.g.: 1=100GHz, 2=50GHz, 3=25GHz";
          }
          leaf identifier {
            type uint32;
            description "Channel identifier";
          }
          leaf n {
            type uint32;
            description "N Value (Channel n-m notation)";
          }
        }
      }

    grouping channel-flex {
      description "channel-flex";
      container channel-n-m {
        description "Channel N / M Notation to describe the
                     MEdiachannel";
         leaf grid {
           type uint32;
            description "grid type e.g.: 0=reserved, 1=DWDM, 2=CWDM";
           }
         leaf channel-spacing {
           type uint32;
            description "DWDM grid e.g.: 1=100GHz, 2=50GHz, 3=25GHz";
      }
         leaf n {
            type uint32;
             description "N Value (Channel n-m notation)";
      }
         leaf m {
           type uint32;
              description "M Value (Channel n-m notation)";
        }
      }
    }


    grouping feasibility-limit-list {
      list feasibility-limit {
        key "id";
        description "Feasibility limit power / osnr pair";
        leaf id {
          type uint32;
          description "Unique Identifier";
        }
        leaf power {
```

```
          type decimal64 {
            fraction-digits 2;
          }
          units "dB";
          description "Feasibility power";
        }
        leaf osnr {
          type decimal64 {
            fraction-digits 2;
          }
          description "Feasibility Signal / Noise";
        }
      }
      description "
        Ordered list of feasibility limits
        (should match order of supported FEC types
        given in fec-type-list).
      ";

    }

    grouping power-failure-low-alarm-grp {
      description "
        Optical Power failure alarm ";
        leaf power-failure-low {
        type dbm-t;
        units "dBm";
        default -1;
        description "Power Failure Low Value";
      }
    }

        grouping opt-if-och-central-frequency {
          description "Interface Central Frequency";
            leaf  central-frequency {
              type uint32;
              description "This parameter indicate This parameter
                      indicates the frequency of this interface ";

             }
       }


        notification opt-if-och-central-frequency-change {
           description "A change of Central Frequency has been
                        detected.";
           leaf "if-name" {
               type leafref {
```

```
                path "/if:interfaces/if:interface/if:name";
            }
            description "Interface name";
         }
         container new-opt-if-och-central-frequency {
         description "The new Central Frequency of the
                      interface";
         uses opt-if-och-central-frequency;
         }
      }

      notification opt-if-och-application-code-change {
         description "A change of Application code has been
                      detected.";
         leaf "if-name" {
             type leafref {
                 path "/if:interfaces/if:interface/if:name";
             }
             description "Interface name";
         }
         container new-application-code {
            description "The new application code for the
                interface";
            uses opt-if-och-application-code;
         }
      }



      augment "/if:interfaces/if:interface" {
        description "Parameters for an optical interface";
        container optIfOChRsSs {
           description "RsSs path configuration for an interface";
           container if-current-application-code {
                description "Current Application code of the
                             interface";
                uses opt-if-och-application-code;
            }

            container if-supported-application-codes {
                config false;
                description "Supported Application codes of
                             the interface";
                uses opt-if-och-application-code-list;
            }

            uses opt-if-och-power;
```

```
                uses opt-if-och-central-frequency;

            }
          }
        }
```

<CODE ENDS>

7. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. he 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 the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operation and content.

8. IANA Considerations

This document registers a URI in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made:

URI: urn:ietf:params:xml:ns:yang:ietf-interfaces:ietf-ext-xponder-wdm-if

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [RFC6020].

This document registers a YANG module in the YANG Module Names registry [RFC6020].

prefix: ietf-ext-xponder-wdm-if reference: RFC XXXX

9. Acknowledgements

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Appendix A. Change Log

This optional section should be removed before the internet draft is submitted to the IESG for publication as an RFC.

Note to RFC Editor: please remove this appendix before publication as an RFC.

Appendix B. Open Issues

Note to RFC Editor: please remove this appendix before publication as an RFC.

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LDP Extensions for RMR
draft-esale-ldp-rmr-extensions-00

Abstract

This document describes LDP extensions to signal Resilient MPLS Ring (RMR) Label Switched Paths (LSPs). An RMR LSP is a multipoint to point LSP signaled using LDP (Label Distribution Protocol). RMR Architecture document - draft-ietf-mpls-rmr-02 - describes why and how MPLS should be used in ring topologies.

Table of Contents

1 Introduction

This document describes LDP extensions to signal resilient MPLS ring (RMR) label switched paths (LSPs). An RMR LSP is a multipoint to point LSP signaled using LDP (Label Distribution Protocol). Architecture document of RMR - draft-ietf-mpls-rmr-02 - describes why and how MPLS should be used in ring topologies.

The ring is either auto-discovered or configured using IGP protocol such as OSPF or ISIS. IGP extensions for RMR will be described in a companion documents. After the ring discovery, each ring node acting as egress constructs and signals a clockwise (CW) and anti-clockwise (AC) ring FEC towards AC and CW direction respectively. Each transit node that receives the RMR FEC signals this LSP further in same direction using RMR link state database. In addition, it also adds a transit and ingress route for this LSP. Once the signaling is complete, every node in a ring should have two counter rotating LSPs in CW and AC direction to reach every other node on the ring.

2. Terminology

A ring consists of a subset of n nodes {R_i, 0 <= i < n}. The direction from node R_i to R_i+1 is defined as as "clockwise" (CW) and the reverse direction is defined as "anti-clockwise" (AC). As there may be several rings in a graph, each ring is numbered with a distinct ring ID (RID).

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. A node may belong to multiple rings.

Ring node: A member of a ring. Note that a device may belong to several rings.

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 neighbors: Nodes whose indices differ by one (modulo ring size).

Ring links: Links that connect ring neighbors.

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

MP2P LSP: Each LSP in the ring is a multipoint to point LSP such that LSP can have multiple ingress nodes and one egress node.

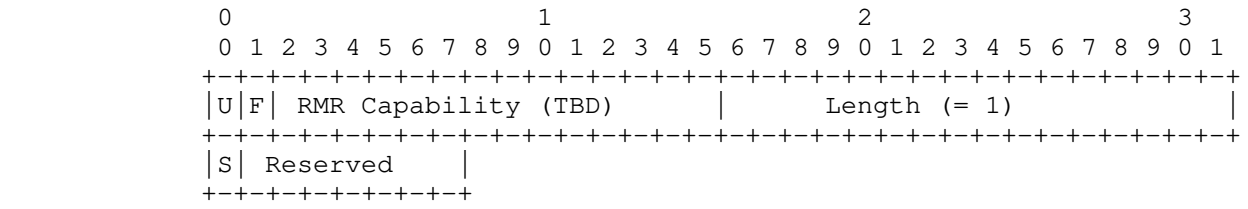
3. Protocol extensions

This section describes LDP extensions to signal RMR LSP in a ring.

3.1. Ring LSP Capability

RMR LSPs support for a LSR is advertised using LDP capabilities as defined in [RFC5561]. An implementation that supports the RMR procedures specified in this document MUST add the procedures pertaining to Capability Parameters for Initialization messages.

A new optional capability parameter TLV, RMR Capability, is defined. Following is the format of the RMR Capability Parameter:



As described in [RFC5561]
U: set to 1. Ignore, if not known.
F: Set to 0. Do not forward.
S: MUST be set to 1 to advertise the RMR Capability TLV.

The RMR Capability TLV MUST be advertised in the LDP Initialization message. If the peer has not advertised the RMR capability, then label messages pertaining to RMR FEC Element MUST not be sent to the peer.

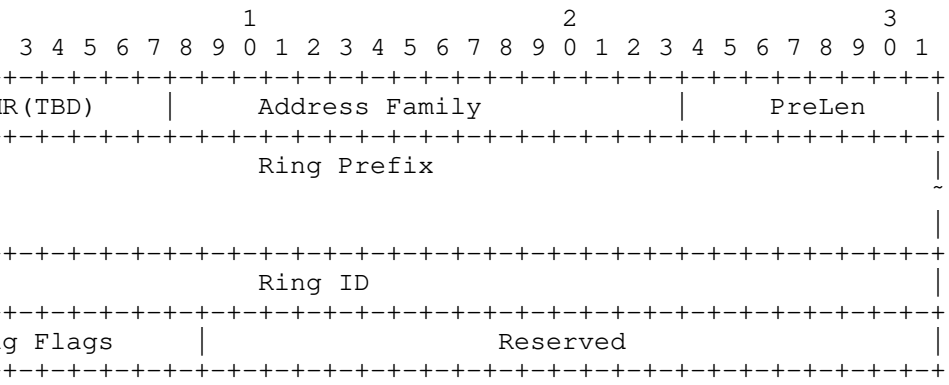
3.2. Ring FEC Element

In order to setup RMR LSP in clockwise and anti-clockwise direction for every ring node, this document defines new protocol entity, the RMR FEC Element, to be used as a FEC Element in the FEC TLV.

The RMR FEC Element consists of the ring address, ring identifier and ring flags which depicts ring direction. The combination of ring address, ring identifier and ring flags uniquely identifies a ring

LSP within the MPLS network.

The RMR FEC Element value encoding is as follows:



FEC Type
One octet quantity containing a value from FEC Type Name Space that encodes the fec type for a RMR LDP LSP.

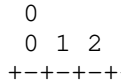
Address Family
Two octet quantity containing a value from ADDRESS FAMILY NUMBERS in [ASSIGNED_AF] that encodes the address family for the address prefix in the Prefix field.

PreLen
One octet unsigned integer containing the length in bits of the address prefix that follows. A length of zero indicates a prefix that matches all addresses (the default destination); in this case, the Prefix itself is zero octets).

Prefix
An address prefix encoded according to the Address Family field, whose length, in bits, was specified in the PreLen field, padded to a byte boundary.

Ring ID (RID)
A four-octet non-zero number that identifies a ring; this is unique in some scope of a Service Provider's network.

Ring Flags



```
|RF | Reserved  |
+-+-+-+-+-+-+-+-+
The value of ring flags (RF) is defined as follows:
1: Clockwise (CW) FEC
2: Anti-clockwise (AC) FEC
```

4. Ring Procedures

Resilient MPLS ring architecture needs interaction between MPLS protocols such as LDP and RSVP and IGP to signal a RMR LSP.

4.1 Upstream LSR

This section describes how to select a upstream LSR for RMR LSP. Consider MPLS rings as follows:

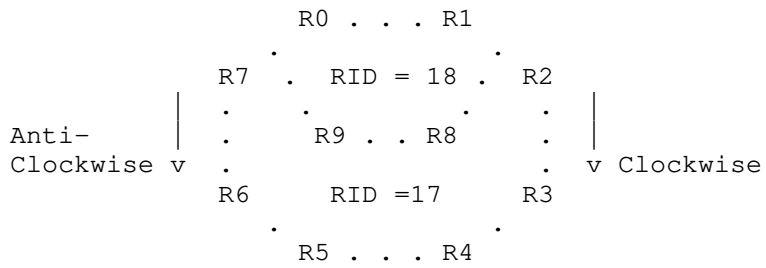


Figure 1: Two Rings with 10 nodes

During the discovery of a MPLS ring, IGP populates its link state database with ring information. After the discovery, there are just two paths - one in clockwise direction and other in anti-clockwise direction - for every ring neighbor on a specific ring. For instance, the following table shows router R0's path for ring 17 and 18 depicted in figure 1.

RID	CW neighbor	AC neighbor
17	R1	R7
18	R1	R9

Figure 2: R0's RMR upstream signaling table

IGP informs LDP that a new MPLS ring, RID 17, is discovered. A LDP transit LSR uses this information to establish RMR LSPs. For

instance, suppose R5 receives a FEC with prefix R0, RID 17 and ring flags AC. R5 knows that its clockwise path is R6 and anti-clockwise path is R4 to reach R0 and that the label map arrived from router R4 for a anti-clockwise LSP. Therefore, R5 selects the upstream session for this LSP as R6.

4.2 Ring Label Mapping Procedures

The procedures in the subsequent sections are organized by the role that a node plays to establish a ring LSP. Each node is egress for its own prefixes and transit for every prefix received with a Label Mapping message. Every transit node is also a ingress for that LSP.

4.2.1 Definitions

This section defines the notations for initiation, decoding, processing and propagation of RMR FEC Element.

1. RMR FEC Element <P, R, C> or <P, R, A>: a FEC Element with egress prefix P, RID R and clockwise direction C or anti-clockwise direction A.
2. RMR Label Mapping <P, R, C, L> or <P, R, A, L>: a Label Mapping message with a FEC TLV with a single RMR FEC Element <P, R, C> or <P, R, A> and Label TLV with label L. Label L MUST be allocated from the per-platform label space of the LSR sending the Label Mapping message. The use of the interface label space is outside the scope of this document.
3. RMR Label Withdraw <P, R, C, L> or <P, R, A, L>: a Label Withdraw message with a FEC TLV with a single RMR FEC Element <P, R, C> or <P, R, A> and Label TLV with label L.
4. RMR LSP <P, R, C> or <P, R, A>: A RMR LSP with egress prefix P, Ring ID R and clockwise direction C or anti-clockwise direction A.

4.2.2 Preliminary

A node X wishing to participate in LDP RMR signaling SHOULD negotiate the RMR capability with all its neighbors. When the IGP informs X of its RMR neighbors A and C for RID R, it MUST check that A and C have also negotiated the RMR capability with X. If these conditions are not satisfied, X cannot participate in signaling for ring R. This applies for all roles that X may play: ingress, transit and egress.

4.2.3 Egress LSR

Every ring node initiates two counter-rotating LSPs that egress on that node. After the IGP discovers the ring, LDP constructs the clockwise RMR FEC <P, R, C> and sends it in a Label Mapping message

to anti-clockwise neighbor. Similarly, LDP constructs a anti-clockwise RMR FEC <P, R, A> and sends it in a Label Mapping message to clockwise neighbor. This SHOULD establish a clockwise and anti-clockwise LSP - in terms of data traffic - in the clockwise and anti-clockwise direction respectively.

Furthermore, if a label other than implicit or explicit null is advertised for a LSP, LDP SHOULD add a pop route for this label in the Incoming Label Map (ILM) MPLS table.

When the node is no longer part of the ring, it SHOULD tear down its egress LSPs - CW and AC - by sending a label withdraw message.

4.2.4 Ingress and Transit LSR

When a transit LSR R5 depicted in figure 1 receives a label map message with RMR FEC Element <R0, 17, A, L1> from a downstream LDP session to R4, it SHOULD verify that R4 is indeed its anticlockwise neighbor for ring 17. If not, it SHOULD stop decoding the FEC TLV, abort processing the message containing the TLV, send an "Unknown FEC" Notification message to its LDP peer R4 signaling an error and close the session.

If the LSR encounters no other error while parsing the RMR FEC element, it allocates a Label L2 and determines a upstream LDP session as R6 using the algorithm described in section 'Upstream LSR'. It also programs a MPLS ILM table with label route L2 swapped to L1 and Ingress tunnel table with prefix R0 with label push L1 on all the LDP interfaces to R4, and sends the RMR FEC Element <R0, 17, A, L2> to R6.

If a session to the anti-clockwise neighbor for RID 17 depicted in Figure 2, namely R6, does not exist, the RMR FEC Element <R0, 17, A, L2> SHOULD not be propagated further. Similarly, when the upstream session changes because of ring topology change, transit LSR should send a label withdraw for RMR FEC Element <R0, 17, A, L2> to older upstream session R6 before sending Label Mapping message with RMR FEC Element <R0, 17, A, L2> to a new upstream session.

4.3 Equal Cost Multipath (ECMP)

A transit and ingress LSR of RMR LSP uses all the links between itself and downstream LSR to program transit and ingress route. Thus, ECMP works automatically for a LDP RMR LSP. A vendor could provide exception when necessary to this behavior by disabling certain ring links for RMR LSPs.

4.4 Protection

RMR uses the two counter-rotating LSPs to protect the other. Say that R5 wants to protect the LSP to R0 for RID 17. R5 receives RMR FEC Element <R0, 17, A, L1> from R4 and sends RMR FEC Element <R0, 17, A, L2> to R6. Then the primary path for the AC LSP is to swap L1 with L2 with next hop R4. Also, R5 receives RMR FEC Element <R0, 17, C, L3> from R6 and sends RMR FEC Element <R0, 17, C, L4> to R4. The primary path for the CW LSP is to swap L3 with L4. The protection path for the AC LSP is to swap L1 with L4 with next hop R6, thus sending the traffic back where it came from, but with a different label. The protection path for the CW LSP is to swap L3 with L2 with next hop R4.

5. LSP Hierarchy

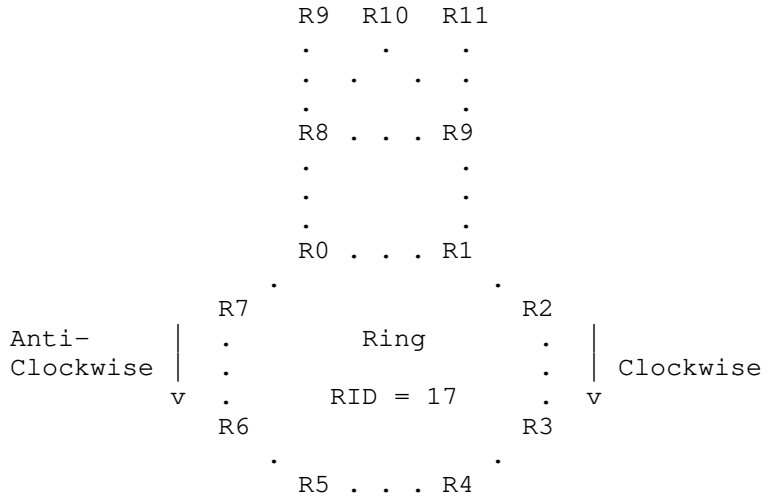


Figure 3: Ring 17 with rest of the Network

Suppose R5 needs to reach R10. Only RMR LSPs are setup inside the ring 17. Additionally, whenever services on R5 need to reach R10, R5 dynamically establishes a tLDP session to ring 17 master node R0 and R1. Further, suppose it only learns IPv4 and IPv6 FECs only over this session using [draft-ietf-mpls-app-aware-tldp-05]. Thus, in order to reach R10, R5 uses top label as RMR LSP label to R0 or R1 and bottom label as R10's FEC label received over tLDP session of R0 or R1 respectively.

6. Ring LSPs

An RMR LSP consists of two counter-rotating ring LSPs that start and end at the same node, say R1. As such, this appears to cause a loop, something that is normally to be avoided by LDP [RSVP-TE]. There are some benefits to this. Having a ring LSP allows the anchor node R1 to ping itself and thus verify the end-to-end operation of the LSP. This, in conjunction with link-level OAM, offers a good indication of the operational state of the LSP. [Also, having R1 be the ingress means that R1 can initiate the Path messages for the two ring LSPs. This avoids R1 having to coordinate with its neighbors to signal the LSPs, and simplifies the case where a ring update changes R1's ring neighbors.] The cost of this is a little more signaling and a couple more label entries in the LFIB. However, we will let implementation guide us to the wisdom of this approach.

7. Security Considerations

The Capability and RMR FEC procedures described in this document will not introduce any change to LDP Security Considerations section described in [RFC5036].

8. IANA Considerations

This document requires the assignment of a new code point for a Capability Parameter TLVs from the IANA managed LDP registry "TLV Type Name Space", corresponding to the advertisement of the RMR capability. IANA is requested to assign the lowest available value.

Value	Description	Reference
TBD1	RMR capability	[this document]

This document requires the assignment of a new code point for a FEC type from the IANA managed LDP registry "Forwarding Equivalence Class (FEC) Type Name Space". IANA is requested to assign the lowest available value.

Value	Description	Reference
TBD1	RMR FEC type	[this document]

9. Acknowledgments

TODO.

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October 25, 2016

Fast Reroute for Node Protection in LDP-based LSPs
draft-esale-mpls-ldp-node-frr-04

Abstract

This document describes procedures to support node protection for unicast Label Switched Paths (LSPs) established by Label Distribution Protocol (LDP). In order to protect a node N, the Point of Local Repair (PLR) of N must discover the Merge Points (MPs) of node N such that traffic can be redirected to them in case of node N failure. Redirecting the traffic around the failed node N depends on existing point-to-point LSPs originated from the PLR to the MPs while bypassing the protected node N. The procedures described in this document are topology independent in a sense that they provide node protection in any topology so long as there is a alternate path in the network that avoids the protected node.

Status of this Memo

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

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Table of Contents

1. Introduction

This document describes procedures to support node protection for unicast Label Switched Paths (LSPs) established by Label Distribution Protocol (LDP) [RFC5036]. In order to protect a node N, the Point of Local Repair (PLR) of N must discover the Merge Points (MPs) of node N such that traffic can be redirected to them in case of node N

failure. Redirecting the traffic around the failed node N depends on existing explicit path Point-to-Point (P2P) LSPs originated from the PLR LSR to the MPs while bypassing node N. The procedures to setup these P2P LSPs are outside the scope of this document, but one option is to use RSVP-TE based techniques [RFC3209] to accomplish it. Finally, sending traffic from the PLR to the MPs requires the PLR to obtain FEC-label bindings from the MPs. The procedures described in this document relies on Targeted LDP (tLDP) session [RFC5036] for the PLR to obtain such FEC-Label bindings.

The procedure described in this document assumes the use of platform-wide label space. The procedures for node protection described in this document fall into the category of local protection. The procedures described in this document apply to LDP LSPs bound to either an IPv4 or IPv6 Prefix FEC element. The procedures described in this document are topology independent in a sense that they provide node protection in any topology so long as there is a alternate path in the network that avoids the protected node. Thus these procedures provide topology independent fast reroute.

1.1 Abbreviations

PLR: Point of Local Repair - the LSR that redirects the traffic to one or more Merge Point LSRs.

MP: Merge Point. Any LSR on the LDP-signaled (multi-point to point) LSP, provided that the path from that LSR to the egress of that LSP is not affected by the failure of the protected node.

tLDP: A targeted LDP session is an LDP session between non-directly connected LSRs, established using the LDP extended discovery mechanism.

FEC: Forwarding equivalence class.

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3. Merge Point (MP) Discovery

For a given LSP that traverses the PLR, the protected node N, and a particular neighbor of the protected node, we'll refer to this neighbor as the "next next-hop". Note that from the PLR's perspective the protected node N is the next hop for the FEC associated with that LSP. Likewise, from the protected node's perspective the next next-hop is the next hop for that FEC. If for a given <LSP, PLR, N> triplet the next next-hop is in the same routing subdomain (area) as the PLR, then that next next-hop acts as the MP for that triplet. For a given LSP traversing a PLR and the node protected by the PLR, the PLR discovers its next next-hops (MPs) that are in the same routing subdomain (IGP area) as the PLR from IGP shortest path first (SPF) calculations. The discovery of next next-hop, depending on an implementation, may not involve any additional SPF, above and beyond what will be needed by either ISIS or OSPF anyway, as the next next-hop, just like the next-hop, is a by-product of SPF computation.

Also, the PLR may discover all possible MPs from either its traffic engineering database or link state database. Some implementations MAY need appropriate configuration to populate the traffic engineering database. The traffic engineering database is populated by routing protocols such as ISIS and OSPF or configured statically.

If for a given <LSP, PLR, N> triplet the node protected by the PLR is an Border Router (BR), then the PLR and the next next-hop may end up in different routing subdomain. This could happen when an LSP

traversing the PLR and the protected node does not terminate in the same routing subdomain as the PLR. In this situation the PLR may not be able to determine the next next-hop from shortest path first (SPF) calculations, and thus may not be able to use the next next-hop as the MP. In this scenario the PLR uses an "alternative" BR as the MP, where an alternative BR is defined as follows. For a given LSP that traverses the PLR and the (protected) BR, an alternative BR is defined as any BR that advertises into PLR's own routing subdomain reachability to the FEC associated with the LSP.

Note that even if a PLR protects an BR, for some of the LSPs traversing the PLR and the BR, the next next-hops may be in the same routing subdomain as the PLR, in which case these next next-hops act as MPs for these LSPs. Note that even if the protected node is not an BR, if an LSP traversing the PLR and the protected node does not terminate in the same routing subdomain as the PLR, then for this LSP the PLR MAY use an alternative BR (as defined earlier), rather than the next next-hop as the MP. When there are several candidate BRs for alternative BR, the LSR MUST select one BR. The algorithm used for the alternative BR selection is a local matter but one option is to select the BR per FEC based on shortest path from PLR to the BR.

4. Constructing Bypass LSPs

As mentioned before, redirecting traffic around the failed node N depends on existing explicit path Point-to-Point (P2P) LSPs originated from the PLR to the MPs while bypassing node N. Let's refer to these LSPs as "bypass LSPs". While the procedures to signal these bypass LSPs are outside the scope of this document, this document assumes use of RSVP-TE LSPs [RFC3209] to accomplish it. Once a PLR that protects a given node N discovers the set of MPs associated with itself and the protected node, at the minimum the PLR MUST (automatically) establish bypass LSPs to all these MPs. The bypass LSPs MUST be established prior to the failure of the protected node.

One could observe that if the protected node is not an BR and the PLR does not use alternative BR(s) as MP(s), then the set of all the IGP neighbors of the protected node forms a superset of the MPs. Thus it would be sufficient for the PLR to establish bypass LSPs with all the IGP neighbors of the protected node, even though some of these neighbors may not be MPs for any of the LSPs traversing the PLR and the protected node.

The bypass LSPs MUST avoid traversing the protected node, which means that the bypass LSPs are explicitly routed LSPs. Of course, using

RSVP-TE to establish bypass LSPs allows these LSPs to be explicitly routed. As a given router may act as an MP for more than one LSP traversing the PLR, the protected node, and the MP, the same bypass LSP will be used to protect all those LSPs.

5. Obtaining Label Mapping from MP

As mentioned before, sending traffic from the PLR to the MPs requires the PLR to obtain FEC-label bindings from the MPs. The solution described in this document relies on Targeted LDP (tLDP) session [RFC5036] for the PLR to obtain such mappings. Specifically, for a given PLR and the node protected by this PLR, at the minimum the PLR MUST (automatically) establish tLDP with all the MPs associated with this PLR and the protected node. These tLDP sessions MUST be established prior to the failure of the protected node. One could observe that if the protected node is not an BR and the PLR does not use alternative BR(s) as MP(s), then the set of all the IGP neighbors of the protected node forms a superset of the MPs. Thus it will be sufficient for the PLR to (automatically) establish tLDP session with all the IGP neighbors of the protected node – except the PLR – that are in the same area as the PLR, even though some of these neighbors may not be MPs for any of the LSPs traversing the PLR and the protected node.

At the minimum for a given tLDP peer the PLR MUST obtain FEC-label mapping for the FEC(s) for which the peer acts as an MP. The PLR MUST obtain this mapping before the failure of the protected node. To obtain this mapping for only these FECs and no other FECs that the peer may maintain, the PLR SHOULD rely on the LDP Downstream on Demand (DoD) procedures [RFC5036]. Otherwise, without relying on the DoD procedures, the PLR may end up receiving from a given tLDP peer FEC-label mappings for all the FECs maintained by the peer, even if the peer does not act as an MP for some of these FECs. If the LDP DoD procedures are not used, then for the purpose of the procedures specified in this draft the only label mappings that SHOULD be exchanged are for the Prefix FEC elements whose PreLen value is either 32 (IPv4), or 128 (IPv6); label mappings for the Prefix FEC elements with any other PreLen value SHOULD NOT be exchanged.

When a PLR has one or more BRs acting as MPs, the PLR MAY use the procedures specified in [draft-ietf-mpls-app-aware-tldp] to limit the set of FEC-label mappings received from non-BR MPs to only the mappings for the FECs associated with the LSPs that terminate in the PLR's own routing subdomain (area).

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When a PLR detects failure of the protected node then rather than

swapping an incoming label with a label that the PLR received from the protected node, the PLR swaps the incoming label with the label that the PLR receives from the MP, and then pushes the label associated with the bypass LSP to that MP.

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7. Synergy with node protection in mLDP

Both the bypass LSPs and tLDP sessions described in this document could also be used for the purpose of mLDP node protection, as described in [draft-ietf-mpls-mldp-node-protection].

8. Security Considerations

The same security considerations apply as those for the base LDP specification, as described in [RFC5036].

9. IANA Considerations

This document introduces no new IANA Considerations.

10. Acknowledgements

We are indebted to Yakov Rekhter for many discussions on this topic. We like to thank Hannes Gredler, Aman Kapoor, Minto Jeyananth, Eric Rosen, Vladimir Blazhkun and Loa Andersson for through review of this document.

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Fast Reroute for Node Protection in LDP-based LSPs
draft-esale-mpls-ldp-node-frr-05

Abstract

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YANG Data Model for MPLS LDP and mLDP
draft-ietf-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).

Table of Contents

1. Introduction

The Network Configuration Protocol (NETCONF) [RFC6241] is one of the network management protocols 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 modelling 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 [RFC7552] 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

This document is organized to define the data model for each of the above constructs (configuration, state, action, and notifications) in the sequence as listed earlier. Given that mLDP is tightly coupled with LDP, mLDP data model is defined under LDP tree and in the same sequence as listed above.

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

This document defines a new module named "ietf-mpls-ldp" for LDP/mLDP data model where this module augments /rt:routing/rt:control-plane-protocols that is defined in [I-D.ietf-netmod-routing-cfg].

There are four main containers in "ietf-mpls-ldp" module as follows:

- Read-Write parameters for configuration (Discussed in Section 3.2)
- Read-only parameters for operational state (Discussed in Section 3.3)
- Notifications for events (Discussed in Section 3.4)
- RPCs for executing commands to perform some action (Discussed in Section 3.5)

For the configuration and state data, this model follows the similar approach described in [I-D.openconfig-netmod-opstate] to represent the configuration (intended state) and operational (applied and derived) state. This means that for every configuration (rw) item, there is an associated (ro) item under "state" container to represent the applied state. Furthermore, protocol derived state is also kept under "state" tree corresponding to the protocol area (discovery, peer etc.). [Ed note: This document will be (re-)aligned with [I-D.openconfig-netmod-opstate] once that specification is adopted as a WG document]

Following diagram depicts high level LDP yang tree organization and hierarchy:

```
module: ietf-mpls-ldp
     +-- rw routing
       +-- rw control-plane-protocols
          +-- rw mpls-ldp
              +-- rw global
              |   +-- rw config
              |       +-- rw ...
              |   +-- ro state
              |       +-- ro ...
              |       .
              +-- rw ...
              |
              |
              +-- rw ...
              ...

rpcs:
   +-- x mpls-ldp-rpc
   +-- x . . . . .

notifications:
   +--- n mpls-ldp-notif
   +--- n ...
```

Figure 1

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 (such as label policies, session authentication etc). 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.

- This model is a VPN Forwarding and Routing (VRF)-centric model. It is important to note that [RFC4364] defines VRF tables and default forwarding tables as different, however from a yang modelling perspective this introduces unnecessary complications,

hence we are treating the default forwarding table as just another VRF.

- A "network-instance" as defined in [I-D.rtgyangdt-rtgwg-ni-model] refers to a VRF instance (both default and non-default) within the scope of this model.

- This model supports two address-families, namely "ipv4" and "ipv6".

- This model assumes platform-wide label space (i.e. label space Id of zero). However, when Upstream Label assignment [RFC6389] is in use, an upstream assigned label is looked up in a Context-Specific label space as defined in [RFC5331].

- The label and peer policies (including filters) are defined using a prefix-list. When used for a peer policy, the prefix refers to the LSR Id of the peer. The prefix-list is referenced from routing-policy model as defined in [I-D.ietf-rtgwg-policy-model].

- The use of grouping (templates) for bundling and grouping the configuration items is not employed in current revision, and is a subject for consideration in future.

- This model uses the terms LDP "neighbor"/"adjacency", "session", and "peer" with the following semantics:

  * Neighbor/Adjacency: An LDP enabled LSR that is discovered through LDP discovery mechanisms.

  * Session: An LDP neighbor with whom a TCP connection has been established.

  * Peer: An LDP session which has successfully progressed beyond its initialization phase and is either already exchanging the bindings or is ready to do so.

  It is to be noted that LDP Graceful Restart mechanisms defined in [RFC3478] allow keeping the exchanged bindings for some time after a session goes down with a peer. We call such a state -- i.e. keeping peer bindings without established or recovered peering -- a "stale" peer. When used in this document, the above terms will refer strictly to the semantics and definitions defined for them.

A graphical representation of LDP YANG data model is presented in Figure 3, Figure 5, Figure 11, and Figure 12. Whereas, the actual model definition in YANG is captured in Section 6.

While presenting the YANG tree view and actual .yang specification, this document assumes the reader is familiar with the concepts of YANG modeling, its presentation and its compilation.

3.2. Configuration

This specification defines the configuration parameters for base LDP as specified in [RFC5036] and LDP IPv6 [RFC7552]. 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 supports VRF-centric configuration. For implementations that support protocol-centric configuration, with provision for inheritance and items that apply to all vrfs, we recommend an augmentation of this model such that any protocol-centric or all-vrf configuration is defined under their designated containers within the standard network-instance (please see Section 3.2.2)

This model augments /rt:routing/rt:control-plane-protocols that is defined in [I-D.ietf-netmod-routing-cfg]. For LDP interfaces, this model refers the MPLS interface as defined under MPLS base specification [I-D.saad-mpls-base-yang]. Furthermore, as mentioned earlier, the configuration tree presents read-write intended configuration leave/items as well as read-only state of the applied configuration. The former is listed under "config" container and latter under "state" container.

Following is high-level configuration organization for LDP/mLDP:

```
module: ietf-mpls-ldp
   +-- routing
    +-- control-plane-protocols
          +-- mpls-ldp
              +-- global
              |    +-- ...
              |    +-- ...
              |    +-- address-family* [afi]
              |        +-- . . .
              |        +-- . . .
              |    +-- discovery
              |        +-- . . .
              +-- peers
                   +-- ...
                   +-- ...
```

Figure 2

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 per-VRF or per-VRF-interface, thus allowing inheritance as well flexibility to override with a different value at any child level.

Following is a simplified graphical representation of the data model for LDP configuration

```
+--rw mpls-ldp!
   +--rw global
      |  +--rw config
      |  |  +--rw capability
      |  |  |  +--rw end-of-lib {capability-end-of-lib}?
      |  |  |  |  +--rw enable?   boolean
      |  |  |  +--rw typed-wildcard-fec {capability-typed-wildcard-fec}?
      |  |  |  |  +--rw enable?   boolean
      |  |  |  +--rw upstream-label-assignment {capability-upstream-label-assign
ment}?
      |  |  |     +--rw enable?   boolean
      |  |  +--rw graceful-restart
      |  |  |  +--rw enable?                boolean
      |  |  |  +--rw helper-enable?         boolean {graceful-restart-helper-mod
e}?
      |  |  |  +--rw reconnect-time?        uint16
      |  |  |  +--rw recovery-time?         uint16
      |  |  |  +--rw forwarding-holdtime?   uint16
      |  |  +--rw igp-synchronization-delay?   uint16
      |  |  +--rw lsr-id?                      yang:dotted-quad
```

```
       |  +--rw address-family* [afi]
       |  |  +--rw afi       ldp-address-family
       |  |  +--rw config
       |  |     +--rw enable?         boolean
       |  |     +--rw label-policy
       |  |     |  +--rw independent-mode
       |  |     |  |  +--rw assign {policy-label-assignment-config}?
       |  |     |  |  |  +--rw (prefix-option)?
       |  |     |  |  |     |  +--rw prefix-list?        prefix-list-ref
       |  |     |  |  |     +--rw host-routes-only?   boolean
       |  |     |  |  +--rw advertise
       |  |     |  |  |  +--rw explicit-null
       |  |     |  |  |  |  +--rw enable?        boolean
       |  |     |  |  |  |  +--rw prefix-list?   prefix-list-ref
       |  |     |  |  |  +--rw prefix-list?     prefix-list-ref
       |  |     |  |  +--rw accept
       |  |     |  |     +--rw prefix-list?   prefix-list-ref
       |  |     |  +--rw ordered-mode {policy-ordered-label-config}?
       |  |     |     +--rw egress-lsr
       |  |     |     |  +--rw prefix-list?   prefix-list-ref
       |  |     |     +--rw advertise
       |  |     |     |  +--rw prefix-list?   prefix-list-ref
       |  |     |     +--rw accept
       |  |     |        +--rw prefix-list?   prefix-list-ref
       |  |     +--rw ipv4
       |  |     |  +--rw transport-address?   inet:ipv4-address
       |  |     +--rw ipv6
       |  |        +--rw transport-address?   inet:ipv6-address
       |  +--rw discovery
       |  |  +--rw interfaces
       |  |  |  +--rw config
       |  |  |  |  +--rw hello-holdtime?   uint16
       |  |  |  |  +--rw hello-interval?   uint16
       |  |  |  +--rw interface* [interface]
       |  |  |     +--rw interface         mpls-interface-ref
       |  |  |     +--rw config
       |  |  |     |  +--rw hello-holdtime?              uint16
       |  |  |     |  +--rw hello-interval?              uint16
       |  |  |     |  +--rw igp-synchronization-delay?   uint16 {per-interface-ti
mer-config}?
       |  |  |     +--rw address-family* [afi]
       |  |  |        +--rw afi       ldp-address-family
       |  |  |        +--rw config
       |  |  |           +--rw enable?   boolean
       |  |  |           +--rw ipv4
       |  |  |           |  +--rw transport-address?   union
       |  |  |           +--rw ipv6
       |  |  |              +--rw transport-address?   union
       |  |  +--rw targeted
```

```
|  |  |     +--rw config
|  |  |     |  +--rw hello-holdtime?   uint16
|  |  |     |  +--rw hello-interval?   uint16
|  |  |     |  +--rw hello-accept {policy-extended-discovery-config}?
|  |  |     |     +--rw enable?          boolean
|  |  |     |     +--rw neighbor-list?   neighbor-list-ref
|  |  |     +--rw address-family* [afi]
|  |  |        +--rw afi      ldp-address-family
|  |  |        +--rw ipv4
|  |  |        |  +--rw target* [adjacent-address]
|  |  |        |     +--rw adjacent-address    inet:ipv4-address
|  |  |        |     +--rw config
|  |  |        |        +--rw enable?          boolean
|  |  |        |        +--rw local-address?   inet:ipv4-address
|  |  |        +--rw ipv6
|  |  |           +--rw target* [adjacent-address]
|  |  |              +--rw adjacent-address    inet:ipv6-address
|  |  |              +--rw config
|  |  |                 +--rw enable?          boolean
|  |  |                 +--rw local-address?   inet:ipv6-address
|  |  +--rw forwarding-nexthop {forwarding-nexthop-config}?
|  |  |  +--rw interfaces
|  |  |     +--rw interface* [interface]
|  |  |        +--rw interface         mpls-interface-ref
|  |  |        +--rw address-family* [afi]
|  |  |           +--rw afi       ldp-address-family
|  |  |           +--rw config
|  |  |              +--rw ldp-disable?    boolean
|  |  +--rw label-policy
|  |     +--rw independent-mode
|  |     |  +--rw assign {policy-label-assignment-config}?
|  |     |  |  +--rw (prefix-option)?
|  |     |  |        +--rw prefix-list?        prefix-list-ref
|  |     |  |        +--rw host-routes-only?   boolean
|  |     |  +--rw advertise
|  |     |  |  +--rw explicit-null
|  |     |  |  |  +--rw enable?        boolean
|  |     |  |  |  +--rw prefix-list?   prefix-list-ref
|  |     |  |  +--rw prefix-list?     prefix-list-ref
|  |     |  +--rw accept
|  |     |     +--rw prefix-list?   prefix-list-ref
|  |     +--rw ordered-mode {policy-ordered-label-config}?
|  |        +--rw egress-lsr
|  |        |  +--rw prefix-list?   prefix-list-ref
|  |        +--rw advertise
|  |        |  +--rw prefix-list?   prefix-list-ref
|  |        +--rw accept
|  |           +--rw prefix-list?   prefix-list-ref
```

```
      +--rw peers
         +--rw config
         |  +--rw session-authentication-md5-password?   string
         |  +--rw session-ka-holdtime?                   uint16
         |  +--rw session-ka-interval?                   uint16
         |  +--rw session-downstream-on-demand {session-downstream-on-demand-con
fig}?
         |     +--rw enable?      boolean
         |     +--rw peer-list?   peer-list-ref
         +--rw peer* [lsr-id]
            +--rw lsr-id    yang:dotted-quad
            +--rw config
               +--rw admin-down?                              boolean
               +--rw capability
               +--rw label-policy
               |  +--rw advertise
               |  |  +--rw prefix-list?   prefix-list-ref
               |  +--rw accept
               |     +--rw prefix-list?   prefix-list-ref
               +--rw session-authentication-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 address-family
                  +--rw ipv4
                  |  +--rw label-policy
                  |     +--rw advertise
                  |     |  +--rw prefix-list?   prefix-list-ref
                  |     +--rw accept
                  |        +--rw prefix-list?   prefix-list-ref
                  +--rw ipv6
                     +--rw label-policy
                        +--rw advertise
                        |  +--rw prefix-list?   prefix-list-ref
                        +--rw accept
                           +--rw prefix-list?   prefix-list-ref
```

Figure 3

3.2.1. Configuration Hierarchy

The LDP configuration container is logically divided into following high-level config areas:

```
Per-VRF parameters
    o Global parameters
    o Per-address-family parameters
    o LDP Capabilities parameters
    o Hello Discovery parameters
        - interfaces
           - Per-interface:
              Global
              Per-address-family
        - targeted
           - Per-target
  o Peer parameters
        - Global
        - Per-peer
           Per-address-family
           Capabilities parameters
  o Forwarding parameters
```

Figure 4

Following subsections briefly explain these configuration areas.

3.2.1.1. Per-VRF parameters

LDP module resides under an network-instance and the scope of any LDP configuration defined under this tree is per network-instance (per-VRF). This configuration is further divided into sub categories as follows.

3.2.1.1.1. 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 that is typically configured per VRF. To keep legacy LDP features and applications working in an LDP IPv4 networks with this model, this document recommends an operator to pick a routable IPv4 unicast address as an LSR Id.

3.2.1.1.2. Per-VRF Capabilities parameters

This container falls under global tree and holds the LDP capabilities that are to be enabled for certain features. By default, an LDP capability is disabled unless explicitly enabled. These capabilities are typically used to negotiate with LDP peer(s) the support/non-support related to a feature and its parameters. The scope of a capability enabled under this container applies to all LDP peers in the given VRF instance. There is also a peer level capability

container that is provided to override a capability that is enabled/ specified at VRF level.

3.2.1.1.3. 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 LDP for an address family, prefix-list based label policies, and LDP transport address.

3.2.1.1.4. 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 AF related items, as well as per-interface per-AF items. The example of former is interface hello timers, and example of latter 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 the per-target parameters.

3.2.1.1.5. Per-VRF Peer parameters

This container is used to hold LDP configuration related to LDP sessions and peers under a VRF instance. This container allows to configure parameters that either apply on VRF’s all peers or a subset (peer-list) of VRF peers. The example of such parameters include authentication password, session KA timers etc. Moreover, the model also allows per-peer parameter tuning by specifying a "peer" list under the "peers" container. A peer is uniquely identified using its LSR Id and hence LSR Id is the key for peer list

Like per-interface parameters, some per-peer parameters are AF-agnostic (i.e. either non AF related or apply to both IP address families), and some that belong to an AF. The example of former is per-peer session password configuration, whereas the example of latter is prefix-list based label policies (inbound and outbound) that apply to a given peer.

3.2.1.1.6. Per-VRF Forwarding parameters

This container is used to hold configuration used to control LDP forwarding behavior under a VRF instance. One example of a configuration under this container is when a user wishes to enable neighbor discovery on an interface but wishes to disable use of the same interface as forwarding nexthop. This example configuration makes sense only when there are more than one LDP enabled interfaces towards the neighbor.

3.2.2. All-VRFs Configuration

[Ed note: TODO]

3.3. Operational State

Operational state of LDP can be queried and obtained from read-only state containers that fall under the same tree (/rt:routing/ rt:control-plane-protocols/) as the configuration.

Please note this state tree refers both the configuration "applied" state as well as the "derived" state related to the protocol. [Ed note: This is where this model differs presently from [I-D.openconfig-netmod-opstate] and subject to alignment in later revisions]

Following is a simplified graphical representation of the data model for LDP operational state.

```
module: ietf-mpls-ldp
augment /rt:routing/rt:control-plane-protocols:
   +--rw mpls-ldp!
      +--rw global
      |  +--ro state
      |  |  +--ro capability
      |  |  |  +--ro end-of-lib {capability-end-of-lib}?
      |  |  |  |  +--ro enable?   boolean
      |  |  |  +--ro typed-wildcard-fec {capability-typed-wildcard-fec}?
      |  |  |  |  +--ro enable?   boolean
      |  |  |  +--ro upstream-label-assignment {capability-upstream-label-assign
ment}?
      |  |  |  |  +--ro enable?   boolean
      |  |  +--ro graceful-restart
      |  |  |  +--ro enable?                boolean
      |  |  |  +--ro helper-enable?         boolean {graceful-restart-helper-mod
e}?
      |  |  |  +--ro reconnect-time?        uint16
      |  |  |  +--ro recovery-time?         uint16
      |  |  |  +--ro forwarding-holdtime?   uint16
```

```
      |  |  +--ro igp-synchronization-delay?   uint16
      |  |  +--ro lsr-id?                      yang:dotted-quad
      |  +--rw address-family* [afi]
      |  |  +--rw afi       ldp-address-family
      |  |  +--ro state
      |  |     +--ro enable?         boolean
      |  |     +--ro label-policy
      |  |     |  +--ro independent-mode
      |  |     |  |  +--ro assign {policy-label-assignment-config}?
      |  |     |  |  |  +--ro (prefix-option)?
      |  |     |  |  |     +--:(prefix-list)
      |  |     |  |  |     |  +--ro prefix-list?        prefix-list-ref
      |  |     |  |  |     +--:(host-routes-only)
      |  |     |  |  |        +--ro host-routes-only?   boolean
      |  |     |  |  +--ro advertise
      |  |     |  |  |  +--ro explicit-null
      |  |     |  |  |  |  +--ro enable?        boolean
      |  |     |  |  |  |  +--ro prefix-list?   prefix-list-ref
      |  |     |  |  |  +--ro prefix-list?     prefix-list-ref
      |  |     |  |  +--ro accept
      |  |     |  |     +--ro prefix-list?   prefix-list-ref
      |  |     |  +--ro ordered-mode {policy-ordered-label-config}?
      |  |     |     +--ro egress-lsr
      |  |     |     |  +--ro prefix-list?   prefix-list-ref
      |  |     |     +--ro advertise
      |  |     |     |  +--ro prefix-list?   prefix-list-ref
      |  |     |     +--ro accept
      |  |     |        +--ro prefix-list?   prefix-list-ref
      |  |     +--ro ipv4
      |  |     |  +--ro transport-address?   inet:ipv4-address
      |  |     |  +--ro bindings
      |  |     |     +--ro address* [address]
      |  |     |     |  +--ro address      inet:ipv4-address
      |  |     |     |  +--ro advertisement-type?   advertised-received
      |  |     |     |  +--ro peer?        leafref
      |  |     |     +--ro fec-label* [fec]
      |  |     |        +--ro fec     inet:ipv4-prefix
      |  |     |        +--ro peer* [peer advertisement-type]
      |  |     |           +--ro peer                   leafref
      |  |     |           +--ro advertisement-type     advertised-received
      |  |     |           +--ro label?                 mpls:mpls-label
      |  |     |           +--ro used-in-forwarding?    boolean
      |  |     +--ro ipv6
      |  |        +--ro transport-address?   inet:ipv6-address
      |  |        +--ro binding
      |  |           +--ro address* [address]
      |  |           |  +--ro address      inet:ipv6-address
      |  |           |  +--ro advertisement-type?   advertised-received
```

```
      |  |           |  +--ro peer?        leafref
      |  |           +--ro fec-label* [fec]
      |  |              +--ro fec     inet:ipv6-prefix
      |  |              +--ro peer* [peer advertisement-type]
      |  |                 +--ro peer                  leafref
      |  |                 +--ro advertisement-type    advertised-received
      |  |                 +--ro label?                mpls:mpls-label
      |  |                 +--ro used-in-forwarding?   boolean
      |  +--rw discovery
      |     +--rw interfaces
      |     |  +--ro state
      |     |  |  +--ro hello-holdtime?   uint16
      |     |  |  +--ro hello-interval?   uint16
      |     |  +--rw interface* [interface]
      |     |     +--ro state
      |     |     |  +--ro hello-holdtime?              uint16
      |     |     |  +--ro hello-interval?              uint16
      |     |     |  +--ro igp-synchronization-delay?   uint16 {per-interface-ti
mer-config}?
      |     |     |  +--ro next-hello?                  uint16
      |     |     +--rw address-family* [afi]
      |     |        +--rw afi       ldp-address-family
      |     |        +--ro state
      |     |           +--ro enable?   boolean
      |     |           +--ro ipv4
      |     |           |  +--ro transport-address?   union
      |     |           |  +--ro hello-adjacencies* [adjacent-address]
      |     |           |     +--ro adjacent-address    inet:ipv4-address
      |     |           |     +--ro flag*               identityref
      |     |           |     +--ro hello-holdtime
      |     |           |     |  +--ro adjacent?     uint16
      |     |           |     |  +--ro negotiated?   uint16
      |     |           |     |  +--ro remaining?    uint16
      |     |           |     +--ro next-hello?         uint16
      |     |           |     +--ro statistics
      |     |           |     |  +--ro discontinuity-time    yang:date-and-time
      |     |           |     |  +--ro hello-received?       yang:counter64
      |     |           |     |  +--ro hello-dropped?        yang:counter64
      |     |           |     +--ro peer?               leafref
      |     |           +--ro ipv6
      |     |              +--ro transport-address?   union
      |     |              +--ro hello-adjacencies* [adjacent-address]
      |     |                 +--ro adjacent-address    inet:ipv6-address
      |     |                 +--ro flag*               identityref
      |     |                 +--ro hello-holdtime
      |     |                 |  +--ro adjacent?     uint16
      |     |                 |  +--ro negotiated?   uint16
      |     |                 |  +--ro remaining?    uint16
      |     |                 +--ro next-hello?         uint16
```

```
      |  |  |                +--ro statistics
      |  |  |                |  +--ro discontinuity-time    yang:date-and-time
      |  |  |                |  +--ro hello-received?       yang:counter64
      |  |  |                |  +--ro hello-dropped?        yang:counter64
      |  |  |                +--ro peer?               leafref
      |  |  +--rw targeted
      |  |     +--ro state
      |  |     |  +--ro hello-holdtime?   uint16
      |  |     |  +--ro hello-interval?   uint16
      |  |     |  +--ro hello-accept {policy-extended-discovery-config}?
      |  |     |     +--ro enable?          boolean
      |  |     |     +--ro neighbor-list?   neighbor-list-ref
      |  |     +--rw address-family* [afi]
      |  |        +--rw afi      ldp-address-family
      |  |        +--ro state
      |  |        |  +--ro ipv4
      |  |        |  |  +--ro hello-adjacencies* [local-address adjacent-address
]
      |  |        |  |     +--ro local-address       inet:ipv4-address
      |  |        |  |     +--ro adjacent-address    inet:ipv4-address
      |  |        |  |     +--ro flag*               identityref
      |  |        |  |     +--ro hello-holdtime
      |  |        |  |     |  +--ro adjacent?     uint16
      |  |        |  |     |  +--ro negotiated?   uint16
      |  |        |  |     |  +--ro remaining?    uint16
      |  |        |  |     +--ro next-hello?         uint16
      |  |        |  |     +--ro statistics
      |  |        |  |     |  +--ro discontinuity-time    yang:date-and-time
      |  |        |  |     |  +--ro hello-received?       yang:counter64
      |  |        |  |     |  +--ro hello-dropped?        yang:counter64
      |  |        |  |     +--ro peer?               leafref
      |  |        |  +--ro ipv6
      |  |        |     +--ro hello-adjacencies* [local-address adjacent-address
]
      |  |        |        +--ro local-address       inet:ipv6-address
      |  |        |        +--ro adjacent-address    inet:ipv6-address
      |  |        |        +--ro flag*               identityref
      |  |        |        +--ro hello-holdtime
      |  |        |        |  +--ro adjacent?     uint16
      |  |        |        |  +--ro negotiated?   uint16
      |  |        |        |  +--ro remaining?    uint16
      |  |        |        +--ro next-hello?         uint16
      |  |        |        +--ro statistics
      |  |        |        |  +--ro discontinuity-time    yang:date-and-time
      |  |        |        |  +--ro hello-received?       yang:counter64
      |  |        |        |  +--ro hello-dropped?        yang:counter64
      |  |        |        +--ro peer?               leafref
      |  |        +--rw ipv4
      |  |        |  +--rw target* [adjacent-address]
      |  |        |     +--rw adjacent-address    inet:ipv4-address
```

```
      |  |  |     +--ro state
      |  |  |        +--ro enable?          boolean
      |  |  |        +--ro local-address?   inet:ipv4-address
      |  |  +--rw ipv6
      |  |     +--rw target* [adjacent-address]
      |  |        +--rw adjacent-address    inet:ipv6-address
      |  |        +--ro state
      |  |           +--ro enable?          boolean
      |  |           +--ro local-address?   inet:ipv6-address
      |  +--rw forwarding-nexthop {forwarding-nexthop-config}?
      |  |  +--rw interfaces
      |  |     +--rw interface* [interface]
      |  |        +--rw interface         mpls-interface-ref
      |  |        +--rw address-family* [afi]
      |  |           +--rw afi       ldp-address-family
      |  |           +--ro state
      |  |              +--ro ldp-disable?    boolean
      +--rw peers
         +--ro state
         |  +--ro session-authentication-md5-password?   string
         |  +--ro session-ka-holdtime?                   uint16
         |  +--ro session-ka-interval?                   uint16
         |  +--ro session-downstream-on-demand {session-downstream-on-demand-con
fig}?
         |     +--ro enable?      boolean
         |     +--ro peer-list?   peer-list-ref
         +--rw peer* [lsr-id]
            +--rw lsr-id    yang:dotted-quad
            +--ro state
               +--ro admin-down?                              boolean
               +--ro capability
               +--ro label-policy
               |  +--ro advertise
               |  |  +--ro prefix-list?   prefix-list-ref
               |  +--ro accept
               |     +--ro prefix-list?   prefix-list-ref
               +--ro session-authentication-md5-password?   string
               +--ro graceful-restart
               |  +--ro enable?           boolean
               |  +--ro reconnect-time?   uint16
               |  +--ro recovery-time?    uint16
               +--ro session-ka-holdtime?                   uint16
               +--ro session-ka-interval?                   uint16
               +--ro address-family
               |  +--ro ipv4
               |  |  +--ro label-policy
               |  |  |  +--ro advertise
               |  |  |  |  +--ro prefix-list?   prefix-list-ref
               |  |  |  +--ro accept
```

```
|  |  |     +--ro prefix-list?   prefix-list-ref
|  |  +--ro hello-adjacencies* [local-address adjacent-address]
|  |     +--ro local-address       inet:ipv4-address
|  |     +--ro adjacent-address    inet:ipv4-address
|  |     +--ro flag*               identityref
|  |     +--ro hello-holdtime
|  |     |  +--ro adjacent?     uint16
|  |     |  +--ro negotiated?   uint16
|  |     |  +--ro remaining?    uint16
|  |     +--ro next-hello?         uint16
|  |     +--ro statistics
|  |     |  +--ro discontinuity-time    yang:date-and-time
|  |     |  +--ro hello-received?       yang:counter64
|  |     |  +--ro hello-dropped?        yang:counter64
|  |     +--ro interface?          mpls-interface-ref
|  +--ro ipv6
|     +--ro label-policy
|     |  +--ro advertise
|     |  |  +--ro prefix-list?   prefix-list-ref
|     |  +--ro accept
|     |     +--ro prefix-list?   prefix-list-ref
|     +--ro hello-adjacencies* [local-address adjacent-address]
|        +--ro local-address       inet:ipv6-address
|        +--ro adjacent-address    inet:ipv6-address
|        +--ro flag*               identityref
|        +--ro hello-holdtime
|        |  +--ro adjacent?     uint16
|        |  +--ro negotiated?   uint16
|        |  +--ro remaining?    uint16
|        +--ro next-hello?         uint16
|        +--ro statistics
|        |  +--ro discontinuity-time    yang:date-and-time
|        |  +--ro hello-received?       yang:counter64
|        |  +--ro hello-dropped?        yang:counter64
|        +--ro interface?          mpls-interface-ref
+--ro label-advertisement-mode
|  +--ro local?        label-adv-mode
|  +--ro peer?         label-adv-mode
|  +--ro negotiated?   label-adv-mode
+--ro next-keep-alive?                        uint16
+--ro peer-ldp-id?                            yang:dotted-quad
+--ro received-peer-state
|  +--ro graceful-restart
|  |  +--ro enable?           boolean
|  |  +--ro reconnect-time?   uint16
|  |  +--ro recovery-time?    uint16
|  +--ro capability
|     +--ro end-of-lib
```

```
|     |  +--ro enable?   boolean
|     +--ro typed-wildcard-fec
|     |  +--ro enable?   boolean
|     +--ro upstream-label-assignment
|        +--ro enable?   boolean
+--ro session-holdtime
|  +--ro peer?         uint16
|  +--ro negotiated?   uint16
|  +--ro remaining?    uint16
+--ro session-state?                          enumeration
+--ro tcp-connection
|  +--ro local-address?    inet:ip-address
|  +--ro local-port?       inet:port-number
|  +--ro remote-address?   inet:ip-address
|  +--ro remote-port?      inet:port-number
+--ro up-time?                                string
+--ro statistics
   +--ro discontinuity-time          yang:date-and-time
   +--ro received
   |  +--ro total-octets?          yang:counter64
   |  +--ro total-messages?        yang:counter64
   |  +--ro address?               yang:counter64
   |  +--ro address-withdraw?      yang:counter64
   |  +--ro initialization?        yang:counter64
   |  +--ro keepalive?             yang:counter64
   |  +--ro label-abort-request?   yang:counter64
   |  +--ro label-mapping?         yang:counter64
   |  +--ro label-release?         yang:counter64
   |  +--ro label-request?         yang:counter64
   |  +--ro label-withdraw?        yang:counter64
   |  +--ro notification?          yang:counter64
   +--ro sent
   |  +--ro total-octets?          yang:counter64
   |  +--ro total-messages?        yang:counter64
   |  +--ro address?               yang:counter64
   |  +--ro address-withdraw?      yang:counter64
   |  +--ro initialization?        yang:counter64
   |  +--ro keepalive?             yang:counter64
   |  +--ro label-abort-request?   yang:counter64
   |  +--ro label-mapping?         yang:counter64
   |  +--ro label-release?         yang:counter64
   |  +--ro label-request?         yang:counter64
   |  +--ro label-withdraw?        yang:counter64
   |  +--ro notification?          yang:counter64
   +--ro total-addresses?            uint32
   +--ro total-labels?               uint32
   +--ro total-fec-label-bindings?   uint32
```

Figure 5

3.3.1. Derived States

Following are main areas for which LDP operational "derived" state is defined:

Neighbor Adjacencies

Peer

Bindings (FEC-label and address)

Capabilities

3.3.1.1. Adjacency state

Neighbor adjacencies are per address-family hello adjacencies that are formed with neighbors as result of LDP basic or extended discovery. In terms of organization, there is a source of discovery (e.g. interface or target address) along with its associated parameters and one or more discovered neighbors along with neighbor discovery related parameters. For the basic discovery, there could be more than one discovered neighbor for a given source (interface), whereas there is at most one discovered neighbor for an extended discovery source (local-address and target-address). This is also to be noted that the reason for a targeted neighbor adjacency could be either an active source (locally configured targeted) or passive source (to allow any incoming extended/targeted hellos). A neighbor/adjacency record also contains session-state that helps highlight whether a given adjacency has progressed to subsequent session level or to eventual peer level.

Following captures high level tree hierarchy for neighbor adjacency state.

```
   +--rw mpls-ldp!
      +--rw discovery
         +--rw interfaces
         |  +--rw interface* [interface]
         |     +--rw address-family* [af]
         |        +--ro state
         |           +--ro ipv4 (or ipv6)
         |              +--ro hello-adjacencies* [adjacent-address]
         |                 +--ro adjacent-address
         |                    . . . .
         |                    . . . .
         +--rw targeted
            +--rw address-family* [afi]
                +--rw afi      address-family
                   +--ro state
                      +--ro ipv4 (or ipv6)
                         +--ro hello-adjacencies* [local-address adjacent-addres
s]
                            +--ro local-address
                            +--ro adjacent-address
                               . . . .
                               . . . .
```

Figure 6

3.3.1.2. Peer state

Peer related derived state is presented under peers tree. This is one of the core state that provides info on the session related parameters (mode, authentication, KA timeout etc.), TCP connection info, hello adjacencies for the peer, statistics related to messages and bindings, and capabilities exchange info.

Following captures high level tree hierarchy for peer state.

```
  +--rw mpls-ldp!
      +--rw peers
         +--rw peer* [lsr-id]
            +--rw lsr-id
            +--ro state
               +--ro session-ka-holdtime?
               +-- . . . .
               +-- . . . .
               +--ro capability
               +  +ro -- . . .
               +--ro address-family
               |  +--ro ipv4 (or ipv6)
               |     +--ro hello-adjacencies* [local-address adjacent-address]
               |        . . . .
               |        . . . .
               +--ro received-peer-state
               |  +--ro . . . .
               |  +--ro capability
               |     +--ro . . . .
               +--ro statistics
                  +-- . . . .
                  +-- . . . .
```

Figure 7

3.3.1.3. Bindings state

Binding state provides information on LDP FEC-label bindings as well as address binding for both inbound (received) as well as outbound (advertised) direction. FEC-label bindings are presented as a FEC-centric view, and address bindings are presented as an address-centric view:

```
        FEC-Label bindings:
            FEC 200.1.1.1/32:
              advertised: local-label 16000
                peer 192.168.0.2:0
                peer 192.168.0.3:0
                peer 192.168.0.4:0
              received:
                peer 192.168.0.2:0, label 16002, used-in-forwarding=Yes
                peer 192.168.0.3:0, label 17002, used-in-forwarding=No
            FEC 200.1.1.2/32:
               . . . .
            FEC 201.1.0.0/16:
               . . . .


        Address bindings:
            Addr 1.1.1.1:
              advertised
            Addr 1.1.1.2:
              advertised
            Addr 2.2.2.2:
              received, peer 192.168.0.2
            Addr 2.2.2.22:
              received, peer 192.168.0.2
            Addr 3.3.3.3:
              received, peer 192.168.0.3
            Addr 3.3.3.33:
              received, peer 192.168.0.3
```

Figure 8

Note that all local addresses are advertised to all peers and hence no need to provide per-peer information for local address advertisement. Furthermore, note that it is easy to derive a peer-centric view for the bindings from the information already provided in this model.

Following captures high level tree hierarchy for bindings state.

```
   +--rw mpls-ldp!
      +--rw global
         +--rw address-family* [afi]
            +--rw afi       address-family
            +--ro state
               +--ro ipv4 (or ipv6)
                  +--ro bindings
                     +--ro address* [address]
                     |  +--ro address
                     |  +--ro direction?   advertised-received
                     |  +--ro peer?        leafref
                     +--ro fec-label* [fec]
                        +--ro fec     inet:ipv4-prefix
                        +--ro peer* [peer advertisement-type]
                           +--ro peer                   leafref
                           +--ro advertisement-type     advertised-received
                           +--ro label?                 mpls:mpls-label
                           +--ro used-in-forwarding?    boolean
```

Figure 9

3.3.1.4. Capabilities state

LDP capabilities state comprise two types of information - global information (such as timer etc.), and per-peer information.

Following captures high level tree hierarchy for LDP capabilities state.

```
   +--rw mpls-ldp!
      +--rw global
      |  +--ro state
      |     +--ro capability
      |        +--ro . . . .
      |        +--ro . . . .
      +--rw peers
         +--rw peer* [lsr-id]
            +--rw lsr-id    yang:dotted-quad
            +--ro state
               +--ro received-peer-state
                  +--ro capability
                     +--ro . . . .
                     +--ro . . . .
```

Figure 10

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 peer, hello adjacency, and FEC etc. It is to be noted that an LDP FEC is treated as operational (up) as long as it has at least 1 NHLFE with outgoing label.

Following is a simplified graphical representation of the data model for LDP notifications.

```
module: ietf-mpls-ldp
notifications:
   +---n mpls-ldp-peer-event
   |  +--ro event-type?   oper-status-event-type
   |  +--ro peer-ref?     leafref
   +---n mpls-ldp-hello-adjacency-event
   |  +--ro event-type?   oper-status-event-type
   |  +--ro (hello-adjacency-type)?
   |     +--:(targeted)
   |     |  +--ro targeted
   |     |     +--ro target-address?   inet:ip-address
   |     +--:(link)
   |        +--ro link
   |           +--ro next-hop-interface?   mpls-interface-ref
   |           +--ro next-hop-address?     inet:ip-address
   +---n mpls-ldp-fec-event
      +--ro event-type?   oper-status-event-type
      +--ro prefix?       inet:ip-prefix
```

Figure 11

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 peers, 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 for 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-peer
   |  +---w input
   |     +---w lsr-id?   union
   +---x mpls-ldp-clear-hello-adjacency
   |  +---w input
   |     +---w hello-adjacency
   |        +---w (hello-adjacency-type)?
   |           +--:(targeted)
   |           |  +---w targeted!
   |           |     +---w target-address?   inet:ip-address
   |           +--:(link)
   |              +---w link!
   |                 +---w next-hop-interface?   mpls-interface-ref
   |                 +---w next-hop-address?     inet:ip-address
   +---x mpls-ldp-clear-peer-statistics
      +---w input
         +---w lsr-id?   union
```

Figure 12

4. mLDP YANG Model

4.1. Overview

Due to tight dependency of mLDP on LDP, mLDP model builds on top of LDP model defined earlier in the document. Following are the main mLDP areas and documents that are within the scope of this model:

- mLDP Base Specification [RFC6388]
- mLDP Recursive FEC [RFC6512]
- Targeted mLDP [RFC7060]
- mLDP Fast-Reroute (FRR)
  - Node Protection [RFC7715]
  - Multicast-only
- Hub-and-Spoke Multipoint LSPs [RFC7140]
- mLDP In-band Signaling [RFC6826] (future revision)
- mLDP In-band signaling in a VRF [RFC7246]

- mLDP In-band Signaling with Wildcards [RFC7438] (future revision)
- Configured Leaf LSPs (manually provisioned)

[Ed Note: Some of the topics in the above list are to be addressed/ added in later revision of this document].

4.2. Configuration

4.2.1. Configuration Hierarchy

In terms of overall configuration layout, following figure highlights extensions to LDP configuration model to incorporate mLDP:

```
      +-- mpls-ldp
         +-- ...
         +-- ...
         +-- mldp
         |  +-- ...
         |  +-- ...
         |  +-- address-family* [af]
         |     +-- af
         |        +-- ...
         |        +-- ...
         +-- global
         |  +-- ...
         |  +-- capability
         |     +-- ...
         |     +-- ...
         |     +-- mldp
         |        +-- ...
         |        +-- ...
         +-- discovery
         |  +-- ...
         |  +-- ...
         +-- forwarding-nexthop
         |  +-- interfaces
         |     +-- interface* [interface]
         |        +-- interface
         |        +-- address-family* [af]
         |           +-- af
         |           +-- ...
         |           +-- mldp-disable
         +-- peers
            +-- ...
            +-- ...
            +-- peer* [lsr-id]
                +-- ...
                +-- ...
                +-- capability
                    +-- ...
                    +-- ...
                    +-- mldp
                        +-- ...
                        +-- ...
```

Figure 13

From above hierarchy, we can categorize mLDP configuration parameters into two types:

- Parameters that leverage/extend LDP containers and parameters
- Parameters that are mLDP specific

Following subsections first describe mLDP specific configuration parameters, followed by those leveraging LDP.

4.2.2. mldp container

mldp container resides directly under "mpls-ldp" and holds the configuration related to items that are mLDP specific. The main items under this container are:

- mLDP enabling: To enable mLDP under a (VRF) routing instance, mldp container is enabled under LDP. Given that mLDP requires LDP signalling, it is not sensible to allow disabling LDP control plane under a (VRF) network-instance while requiring mLDP to be enabled for the same. However, if a user wishes only to allow signalling for multipoint FECs on an LDP/mLDP enabled VRF instance, he/she can use LDP label-policies to disable unicast FECs under the VRF.
- mLDP per-AF features: mLDP manages its own list of IP address-families and the features enabled underneath. The per-AF mLDP configuration items include:
  - Multicast-only FRR: This enables Multicast-only FRR functionality for a given AF under mLDP. The feature allows route-policy to be configured for finer control/applicability of the feature.
  - Recursive FEC: The recursive-fec feature [RFC6512] can be enabled per AF with a route-policy.
  - Configured Leaf LSPs: To provision multipoint leaf LSP manually, a container is provided per-AF under LDP. The configuration is flexible and allows a user to specify MP LSPs of type p2mp or mp2mp with IPv4 or IPv6 root address(es) by using either LSP-Id or (S,G).

Targeted mLDP feature specification [RFC7060] do not require any mLDP specific configuration. It, however, requires LDP upstream-label-assignment capability [RFC6389] to be enabled.

4.2.3. Leveraging LDP containers

mLDP configuration model leverages following configuration areas and containers that are already defined for LDP:

- Capabilities: A new container "mldp" is defined under Capabilities container. This new container specifies any mLDP specific capabilities and their parameters. Moreover, a new "mldp" container is also added under per-peer capability container to override/control mLDP specific capabilities on a peer level. In the scope of this document, the most important capabilities related to mLDP are p2mp, mp2mp, make-before-break, hub-and-spoke, and node-protection.

- Discovery and Peer: mLDP requires LDP discovery and peer procedures to form mLDP peering. A peer is treated as mLDP peer only when either P2MP or MP2MP capabilities have been successfully exchanged with the peer. If a user wish to selectively enable or disable mLDP with a LDP-enabled peer, he/she may use per-peer mLDP capabilities configuration. [Ed Note: The option to control mLDP enabling/disabling on a peer-list is being explored for future]. In most common deployments, it is desirable to disable mLDP (capabilities announcements) on a targeted-only LDP peering, where targeted-only peer is the one whose discovery sources are targeted only. In future revision, a configuration option for this support will also be provided.

- Forwarding: By default, mLDP is allowed to select any of the LDP enabled interface as a downstream interface towards a nexthop (LDP/mLDP peer) for MP LSP programming. However, a configuration option is provided to allow mLDP to exclude a given interface from such a selection. Note that such a configuration option will be useful only when there are more than one interfaces available for the downstream selection.

This goes without saying that mLDP configuration tree follows the same approach as LDP, where the tree comprise leafs for intended configuration.

4.2.4. YANG tree

The following figure captures the YANG tree for mLDP configuration. To keep the focus, the figure has been simplified to display only mLDP items without any LDP items.

```
module: ietf-mpls-ldp
augment /rt:routing/rt:control-plane-protocols:
   +--rw mpls-ldp!
```

```
      +--rw global
      |  +--rw config
      |  |  +--rw capability
      |  |     +--rw mldp {mldp}?
      |  |        +--rw p2mp
      |  |        |  +--rw enable?   boolean
      |  |        +--rw mp2mp
      |  |        |  +--rw enable?   boolean
      |  |        +--rw make-before-break
      |  |        |  +--rw enable?             boolean
      |  |        |  +--rw switchover-delay?   uint16
      |  |        |  +--rw timeout?            uint16
      |  |        +--rw hub-and-spoke {capability-mldp-hsmp}?
      |  |        |  +--rw enable?   boolean
      |  |        +--rw node-protection {capability-mldp-node-protection}?
      |  |           +--rw plr?           boolean
      |  |           +--rw merge-point
      |  |              +--rw enable?                                boolean
      |  |              +--rw targeted-session-teardown-delay?   uint16
      |  +--rw mldp {mldp}?
      |  |  +--rw config
      |  |  |  +--rw enable?   boolean
      |  |  +--rw address-family* [afi]
      |  |     +--rw afi                      ldp-address-family
      |  |     +--rw config
      |  |     |  +--rw multicast-only-frr {mldp-mofrr}?
      |  |     |  |  +--rw prefix-list?   prefix-list-ref
      |  |     |  +--rw recursive-fec
      |  |     |     +--rw prefix-list?   prefix-list-ref
      |  |     +--rw configured-leaf-lsps
      |  |        +--rw p2mp
      |  |        |  +--rw roots-ipv4
      |  |        |  |  +--rw root* [root-address]
      |  |        |  |     +--rw root-address    inet:ipv4-address
      |  |        |  |     +--rw lsp* [lsp-id source-address group-address]
      |  |        |  |        +--rw lsp-id            uint16
      |  |        |  |        +--rw source-address    inet:ipv4-address
      |  |        |  |        +--rw group-address     inet:ipv4-address-no-zone
      |  |        |  +--rw roots-ipv6
      |  |        |     +--rw root* [root-address]
      |  |        |        +--rw root-address    inet:ipv6-address
      |  |        |        +--rw lsp* [lsp-id source-address group-address]
      |  |        |           +--rw lsp-id            uint16
      |  |        |           +--rw source-address    inet:ipv6-address
      |  |        |           +--rw group-address     inet:ipv6-address-no-zone
      |  |        +--rw mp2mp
      |  |           +--rw roots-ipv4
      |  |           |  +--rw root* [root-address]
```

```
|  |  |           |     +--rw root-address    inet:ipv4-address
|  |  |           |     +--rw lsp* [lsp-id source-address group-address]
|  |  |           |        +--rw lsp-id            uint16
|  |  |           |        +--rw source-address    inet:ipv4-address
|  |  |           |        +--rw group-address     inet:ipv4-address-no-zone
|  |  |           +--rw roots-ipv6
|  |  |              +--rw root* [root-address]
|  |  |                 +--rw root-address    inet:ipv6-address
|  |  |                 +--rw lsp* [lsp-id source-address group-address]
|  |  |                    +--rw lsp-id            uint16
|  |  |                    +--rw source-address    inet:ipv6-address
|  |  |                    +--rw group-address     inet:ipv6-address-no-zone
|  |  +--rw forwarding-nexthop {forwarding-nexthop-config}?
|  |     +--rw interfaces
|  |        +--rw interface* [interface]
|  |           +--rw interface         if:interface-ref
|  |           +--rw address-family* [afi]
|  |              +--rw afi       address-family
|  |              +--rw config
|  |                 +--rw mldp-disable?   boolean {mldp}?
|  +--rw peers
|     +--rw peer* [lsr-id]
|           +--rw capability
|              +--rw mldp {mldp}?
|                 +--rw p2mp
|                 |  +--rw enable?   boolean
|                 +--rw mp2mp
|                 |  +--rw enable?   boolean
|                 +--rw make-before-break
|                 |  +--rw enable?             boolean
|                 |  +--rw switchover-delay?   uint16
|                 |  +--rw timeout?            uint16
|                 +--rw hub-and-spoke {capability-mldp-hsmp}?
|                 |  +--rw enable?   boolean
|                  +--rw node-protection {capability-mldp-node-protection}?
|                    +--rw plr?           boolean
|                    +--rw merge-point
|                       +--rw enable?                              boolean
|                       +--rw targeted-session-teardown-delay?   uint16
```

Figure 14

4.3. Operational State

Operational state of mLDP can be queried and obtained from this read-only container "mldp" which resides under mpls-ldp container.

Please note this state tree refers both the configuration "applied" state as well as the "derived" state related to the mLDP protocol.

Following is a simplified graphical representation of the data model for mLDP operational state:

```
module: ietf-mpls-ldp
augment /rt:routing/rt:control-plane-protocols:
   +--rw mpls-ldp!
      +--rw global
      |  +--ro state
      |  |  +--ro capability
      |  |     +--ro mldp {mldp}?
      |  |        +--ro p2mp
      |  |        |  +--ro enable?   boolean
      |  |        +--ro mp2mp
      |  |        |  +--ro enable?   boolean
      |  |        +--ro make-before-break
      |  |        |  +--ro enable?             boolean
      |  |        |  +--ro switchover-delay?   uint16
      |  |        |  +--ro timeout?            uint16
      |  |        +--ro hub-and-spoke {capability-mldp-hsmp}?
      |  |        |  +--ro enable?   boolean
      |  |        +--ro node-protection {capability-mldp-node-protection}?
      |  |           +--ro plr?           boolean
      |  |           +--ro merge-point
      |  |              +--ro enable?                                boolean
      |  |              +--ro targeted-session-teardown-delay?   uint16
      |  |
      |  +--rw mldp {mldp}?
      |  |  +--ro state
      |  |     +--ro enable?   boolean
      |  |  +--rw address-family* [afi]
      |  |     +--rw afi                     ldp-address-family
      |  |     +--ro state
      |  |        +--ro multicast-only-frr {mldp-mofrr}?
      |  |        |  +--ro prefix-list?   prefix-list-ref
      |  |        +--ro recursive-fec
      |  |        |  +--ro prefix-list?   prefix-list-ref
      |  |        +--ro ipv4
      |  |           |  +--ro roots
      |  |           |  |  +--ro root* [root-address]
      |  |           |  |     +--ro root-address    inet:ipv4-address
      |  |           |  |     +--ro is-self?        boolean
      |  |           |  |     +--ro reachability* [address interface]
      |  |           |  |        +--ro address      inet:ipv4-address
      |  |           |  |        +--ro interface    mpls-interface-ref
```

```
      |  |         |  |        +--ro peer?        leafref
      |  |         |  +--ro bindings
      |  |         |     +--ro opaque-type-lspid
      |  |         |     |  +--ro fec-label* [root-address lsp-id recur-root-addr
ess recur-rd]
      |  |         |     |     +--ro root-address          inet:ipv4-address
      |  |         |     |     +--ro lsp-id                uint32
      |  |         |     |     +--ro recur-root-address    inet:ip-address
      |  |         |     |     +--ro recur-rd              route-distinguisher
      |  |         |     |     +--ro multipoint-type?      multipoint-type
      |  |         |     |     +--ro peer* [direction peer advertisement-type]
      |  |         |     |        +--ro direction             downstream-upstream
      |  |         |     |        +--ro peer                  leafref
      |  |         |     |        +--ro advertisement-type    advertised-received
      |  |         |     |        +--ro label?                mpls:mpls-label
      |  |         |     |        +--ro mbb-role?             enumeration
      |  |         |     |        +--ro mofrr-role?           enumeration
      |  |         |     +--ro opaque-type-src
      |  |         |     |  +--ro fec-label* [root-address source-address group-a
ddress rd recur-root-address recur-rd]
      |  |         |     |     +--ro root-address          inet:ipv4-address
      |  |         |     |     +--ro source-address        inet:ip-address
      |  |         |     |     +--ro group-address         inet:ip-address-no-zon
e
      |  |         |     |     +--ro rd                    route-distinguisher
      |  |         |     |     +--ro recur-root-address    inet:ip-address
      |  |         |     |     +--ro recur-rd              route-distinguisher
      |  |         |     |     +--ro multipoint-type?      multipoint-type
      |  |         |     |     +--ro peer* [direction peer advertisement-type]
      |  |         |     |        +--ro direction             downstream-upstream
      |  |         |     |        +--ro peer                  leafref
      |  |         |     |        +--ro advertisement-type    advertised-received
      |  |         |     |        +--ro label?                mpls:mpls-label
      |  |         |     |        +--ro mbb-role?             enumeration
      |  |         |     |        +--ro mofrr-role?           enumeration
      |  |         |     +--ro opaque-type-bidir
      |  |         |        +--ro fec-label* [root-address rp group-address rd re
cur-root-address recur-rd]
      |  |         |           +--ro root-address          inet:ipv4-address
      |  |         |           +--ro rp                    inet:ip-address
      |  |         |           +--ro group-address         inet:ip-address-no-zon
e
      |  |         |           +--ro rd                    route-distinguisher
      |  |         |           +--ro recur-root-address    inet:ip-address
      |  |         |           +--ro recur-rd              route-distinguisher
      |  |         |           +--ro multipoint-type?      multipoint-type
      |  |         |           +--ro peer* [direction peer advertisement-type]
      |  |         |              +--ro direction             downstream-upstream
      |  |         |              +--ro peer                  leafref
      |  |         |              +--ro advertisement-type    advertised-received
      |  |         |              +--ro label?                mpls:mpls-label
      |  |         |              +--ro mbb-role?             enumeration
      |  |         |              +--ro mofrr-role?           enumeration
```

```
      |  |        +--ro ipv6
      |  |           +--ro roots
      |  |           |  +--ro root* [root-address]
      |  |           |     +--ro root-address    inet:ipv6-address
      |  |           |     +--ro is-self?        boolean
      |  |           |     +--ro reachability* [address interface]
      |  |           |        +--ro address      inet:ipv6-address
      |  |           |        +--ro interface    mpls-interface-ref
      |  |           |        +--ro peer?        leafref
      |  |           +--ro bindings
      |  |              +--ro opaque-type-lspid
      |  |              |  +--ro fec-label* [root-address lsp-id recur-root-addr
ess recur-rd]
      |  |              |     +--ro root-address          inet:ipv6-address
      |  |              |     +--ro lsp-id                uint32
      |  |              |     +--ro recur-root-address    inet:ip-address
      |  |              |     +--ro recur-rd              route-distinguisher
      |  |              |     +--ro multipoint-type?      multipoint-type
      |  |              |     +--ro peer* [direction peer advertisement-type]
      |  |              |        +--ro direction             downstream-upstream
      |  |              |        +--ro peer                  leafref
      |  |              |        +--ro advertisement-type    advertised-received
      |  |              |        +--ro label?                mpls:mpls-label
      |  |              |        +--ro mbb-role?             enumeration
      |  |              |        +--ro mofrr-role?           enumeration
      |  |              +--ro opaque-type-src
      |  |              |  +--ro fec-label* [root-address source-address group-a
ddress rd recur-root-address recur-rd]
      |  |              |     +--ro root-address          inet:ipv6-address
      |  |              |     +--ro source-address        inet:ip-address
      |  |              |     +--ro group-address         inet:ip-address-no-zon
e
      |  |              |     +--ro rd                    route-distinguisher
      |  |              |     +--ro recur-root-address    inet:ip-address
      |  |              |     +--ro recur-rd              route-distinguisher
      |  |              |     +--ro multipoint-type?      multipoint-type
      |  |              |     +--ro peer* [direction peer advertisement-type]
      |  |              |        +--ro direction             downstream-upstream
      |  |              |        +--ro peer                  leafref
      |  |              |        +--ro advertisement-type    advertised-received
      |  |              |        +--ro label?                mpls:mpls-label
      |  |              |        +--ro mbb-role?             enumeration
      |  |              |        +--ro mofrr-role?           enumeration
      |  |              +--ro opaque-type-bidir
      |  |                 +--ro fec-label* [root-address rp group-address rd re
cur-root-address recur-rd]
      |  |                    +--ro root-address          inet:ipv6-address
      |  |                    +--ro rp                    inet:ip-address
      |  |                    +--ro group-address         inet:ip-address-no-zon
e
      |  |                    +--ro rd                    route-distinguisher
      |  |                    +--ro recur-root-address    inet:ip-address
      |  |                    +--ro recur-rd              route-distinguisher
```

```
      |  |                    +--ro multipoint-type?      multipoint-type
      |  |                    +--ro peer* [direction peer advertisement-type]
      |  |                       +--ro direction             downstream-upstream
      |  |                       +--ro peer                  leafref
      |  |                       +--ro advertisement-type    advertised-received
      |  |                       +--ro label?                mpls:mpls-label
      |  |                       +--ro mbb-role?             enumeration
      |  |                       +--ro mofrr-role?           enumeration
      |  +--rw forwarding-nexthop {forwarding-nexthop-config}?
      |     +--rw interfaces
      |        +--rw interface* [interface]
      |           +--rw address-family* [afi]
      |              +--ro state
      |                 +--ro mldp-disable?   boolean {mldp}?
      +--rw peers
         +--rw peer* [lsr-id]
            +--ro state
               +--ro capability
               |   +--ro mldp {mldp}?
               |     +--ro p2mp
               |     |  +--ro enable?   boolean
               |     +--ro mp2mp
               |     |  +--ro enable?   boolean
               |     +--ro make-before-break
               |     |  +--ro enable?             boolean
               |     |  +--ro switchover-delay?   uint16
               |     |  +--ro timeout?            uint16
               |     +--ro hub-and-spoke {capability-mldp-hsmp}?
               |     |  +--ro enable?   boolean
               |     +--ro node-protection {capability-mldp-node-protection}?
               |        +--ro plr?           boolean
               |        +--ro merge-point
               |           +--ro enable?                               boolean
               |           +--ro targeted-session-teardown-delay?   uint16
               +--ro received-peer-state
                  +--ro capability
                     +--ro mldp {mldp}?
                        +--ro p2mp
                        |  +--ro enable?   boolean
                        +--ro mp2mp
                        |  +--ro enable?   boolean
                        +--ro make-before-break
                        |  +--ro enable?   boolean
                        +--ro hub-and-spoke
                        |  +--ro enable?   boolean
                        +--ro node-protection
                           +--ro plr?           boolean
                           +--ro merge-point?   boolean
```

Figure 15

4.3.1. Derived states

Following are main areas for which mLDP operational derived state is defined:

- Root
- Bindings (FEC-label)
- Capabilities

4.3.1.1. Root state

Root address is a fundamental construct for MP FEC bindings and LSPs. The root state provides information on all the known roots in a given address-familty, and their information on the root reachability (as learnt from RIB). In case of multi-path reachability to a root, the selection of upstream path is done on per-LSP basis at the time of LSP setup. Similarly, when protection mechanisms like MBB or MoFRR are in place, the path designation as active/standby or primary/ backup is also done on per LSP basis. It is to be noted that a given root can be shared amongst multiple P2MP and/or MP2MP LSPs. Moreover, an LSP can be signaled to more than one root for RNR purposes.

The following diagram illustrates a root database on a branch/transit LSR:

```
        root 1.1.1.1:
            path1:
                RIB: GigEthernet 1/0, 12.1.0.2;
                LDP: peer 192.168.0.1:0
            path2:
                RIB: GigEthernet 2/0, 12.2.0.2;
                LDP: peer 192.168.0.3:0

        root 2.2.2.2:
            path1:
                RIB: 3.3.3.3;              (NOTE: This is a recursive path)
                LDP: peer 192.168.0.3:0    (NOTE: T-mLDP peer)

         root 9.9.9.9:
            . . . .
```

Figure 16

A root entry on a root LSR itself will be presented as follows:

```
          root 9.9.9.9:
              is-self
```

Figure 17

4.3.1.2. Bindings state

Binding state provides information on mLDP FEC-label bindings for both P2MP and MP2MP FEC types. Like LDP, the FEC-label binding derived state is presented in a FEC-centric view per address-family, and provides information on both inbound (received) and outbound (advertised) bindings. The FEC is presented as (root-address, opaque-type-data) and the direction (upstream or downstream) is picked with respect to root reachability. In case of MBB or/and MoFRR, the role of a given peer binding is also provided with respect to MBB (active or standby) or/and MoFRR (primary or backup).

This document covers following type of opaque values with their keys in the operational model of mLDP bindings:

Opaque Type	Key	RFC
Generic LSP Identifier	LSP Id	[RFC6388]
Transit IPv4 Source	Source, Group	[RFC6826]
Transit IPv6 Source	Source, Group	[RFC6826]
Transit IPv4 Bidir	RP, Group	[RFC6826]
Transit IPv6 Bidir	RP, Group	[RFC6826]
Transit VPNv4 Source	Source, Group, RD	[RFC7246]
Transit VPNv6 Source	Source, Group, RD	[RFC7246]
Transit VPNv4 Bidir	RP, Group, RD	[RFC7246]
Transit VPNv6 Bidir	RP, Group, RD	[RFC7246]
Recursive Opaque	Root	[RFC6512]
VPN-Recursive Opaque	Root, RD	[RFC6512]

Table 1: MP Opaque Types and keys

It is to be noted that there are three basic types (LSP Id, Source, and Bidir) and then there are variants (VPN, recursive, VPN-recursive) on top of these basic types.

Following captures high level tree hierarchy for mLDP bindings state:

```
+--rw mpls-ldp!
    +--rw mldp
      +--rw address-family* [afi]
         +--rw afi       address-family
         +--ro state
            +--ro ipv4 (or ipv6)
               +--ro bindings
                  +--ro opaque-type-xxx [root-address, type-specific-key]
                     +--ro root-address
                     +--ro ...
                     +--ro recur-root-address    inet:ipv4-address
                     +--ro recur-rd              route-distinguisher
                     +--ro multipoint-type?      multipoint-type
                     +--ro peer* [direction peer advertisement-type]
                        +--ro direction             downstream-upstream
                        +--ro peer                  leafref
                        +--ro advertisement-type    advertised-received
                        +--ro label?                mpls:mpls-label
                        +--ro mbb-role?             enumeration
                        +--ro mofrr-role?           enumeration
```

Figure 18

In the above tree, the type-specific-key varies with the base type as listed in earlier Table 1. For example, if the opaque type is Generic LSP Identifier, then the type-specific-key will be a uint32 value corresponding to the LSP. Please see the complete model for all other types.

Moreover, the binding tree defines only three types of sub-trees (i.e. lspid, src, and bidir) which is able to map the respective variants (vpn, recursive, and vpn-recusrive) accordingly. For example, the key for opaque-type-src is [R, S, G, rd, recur-R, recur-RD], where basic type will specify (R, S,G,-, -, -), VPN type will specify (R, S,G, rd, -, -), recursive type will specify [R, S,G, -, recur-R, -] and VPN-recursive type will specify [R, S,G, -, recur-R, recur-rd].

It is important to take note of the following:

- The address-family ipv4/ipv4 applies to "root" address in the mLDP binding tree. The other addresses (source, group, RP etc) do not have to be of the same address family type as the root.

- The "recur-root-address" field applies to Recursive opaque type, and (recur-root-address, recur-rd) fields applies to VPN-Recursive opaque types as defined in [RFC6512]

- In case of a recursive FEC, the address-family of the recur-root-address could be different than the address-family of the root address of original encapsulated MP FEC

The following diagram illustrates the FEC-label binding information structure for a P2MP (Transit IPv4 Source type) LSP on a branch/ transit LSR:

```
FEC (root 2.2.2.2, S=192.168.1.1, G=224.1.1.1):
  type: p2mp
  upstream:
    advertised:
      peer 192.168.0.1:0, label 16000 (local)
  downstream:
    received:
      peer 192.168.0.2:0, label 17000 (remote)
      peer 192.168.0.3:0, label 18000  (remote)
```

Figure 19

The following diagram illustrates the FEC-label binding information structure for a similar MP2MP LSP on a branch/transit LSR:

```
      FEC (root 2.2.2.2, RP=192.168.9.9, G=224.1.1.1):
        type: mp2mp
        upstream:
          advertised:
            peer 192.168.0.1:0, label 16000 (local)
          received:
            peer 192.168.0.1:0, label 17000 (remote)
        downstream:
          advertised:
            peer 192.168.0.2:0, label 16001 (local), MBB role=active
            peer 192.168.0.3:0, label 16002 (local), MBB role=standby
          received:
            peer 192.168.0.2:0, label 17001 (remote)
            peer 192.168.0.3:0, label 18001 (remote)
```

Figure 20

4.3.1.3. Capabilities state

Like LDP, mLDP capabilities state comprise two types of information - global information and per-peer information.

4.4. Notifications

mLDP notification module consists of notification related to changes in the operational state of an mLDP FEC. Following is a simplified graphical representation of the data model for mLDP notifications:

```
notifications:
   +---n mpls-mldp-fec-event
      +--ro event-type?       oper-status-event-type
      +--ro tree-type?        multipoint-type
      +--ro root?             inet:ip-address
      +--ro (lsp-key-type)?
         +--:(lsp-id-based)
         |  +--ro lsp-id?           uint16
         +--:(source-group-based)
            +--ro source-address?   inet:ip-address
            +--ro group-address?    inet:ip-address
```

Figure 21

4.5. Actions

Currently, no RPCs/actions are defined for mLDP.

5. Open Items

Following is a list of open items that are to be discussed and addressed in future revisions of this document:

- Close on augmentation off "mpls" list in "ietf-mpls" defined in [I-D.saad-mpls-base-yang]
- Align operational state modeling with other routing procols and [I-D.openconfig-netmod-opstate]
- Complete the section on Protocol-centric implementations and all-vrfs
- Specify default values for configuration parameters
- Revisit and cut down on the scope of the document and number of features it is trying to cover
- Split the model into a base and extended items
- Add statistics for mLDP root LSPs and bindings
- Extend the "Configured Leaf LSPs" for various type of opaque-types
- Extend mLDP notifications for other types of opaque values as well
- Close on single vs separate document for mLDP Yang

6. YANG Specification

Following are actual YANG definition for LDP and mLDP constructs defined earlier in the document.

```
 <CODE BEGINS> file "ietf-mpls-ldp@2016-07-08.yang" -->

 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 ietf-mpls {
    prefix "mpls";
  }

  organization
    "IETF MPLS Working Group";
  contact
    "WG Web:   <http://tools.ietf.org/wg/teas/>
     WG List:  <mailto:teas@ietf.org>

     WG Chair: Loa Andersson
               <mailto:loa@pi.nu>

     WG Chair: Ross Callon
               <mailto:rcallon@juniper.net>

     WG Chair: George Swallow
               <mailto:swallow.ietf@gmail.com>

     Editor:   Kamran Raza
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     Editor:   Rajiv Asati
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     Editor:   Xufeng Liu
               <mailto:xliu@kuatrotech.com>

     Editor:   Santosh Esale
```

```
                <mailto:sesale@juniper.net>

       Editor:  Xia Chen
                <mailto:jescia.chenxia@huawei.com>

       Editor:  Himanshu Shah
                <mailto:hshah@ciena.com>";

   description
     "This YANG module defines the essential components for the
      management of Multi-Protocol Label Switching (MPLS) Label
      Distribution Protocol (LDP) and Multipoint LDP (mLDP).";

   revision 2016-07-08 {
     description
       "Initial revision.";
     reference
       "RFC XXXX: YANG Data Model for MPLS LDP and mLDP.";
   }

   /*
    * Features
    */

   feature admin-down-config {
     description
       "This feature indicates that the system allows to configure
        administrative down on a VRF instance and a peer.";
   }

   feature all-af-policy-config {
     description
       "This feature indicates that the system allows to configure
        policies that are applied to all address families.";
   }

   feature capability-end-of-lib {
     description
       "This feature indicates that the system allows to configure
        LDP end-of-lib capability.";
   }

   feature capability-mldp-hsmp {
     description
       "This feature indicates that the system allows to configure
        mLDP hub-and-spoke-multipoint capability.";
   }
```

```
   feature capability-mldp-node-protection {
     description
       "This feature indicates that the system allows to configure
        mLDP node-protection capability.";
   }

   feature capability-typed-wildcard-fec {
     description
       "This feature indicates that the system allows to configure
        LDP typed-wildcard-fec capability.";
   }

   feature capability-upstream-label-assignment {
     description
       "This feature indicates that the system allows to configure
        LDP upstream label assignment capability.";
   }

   feature forwarding-nexthop-config {
     description
       "This feature indicates that the system allows to configure
        forwarding nexthop on interfaces.";
   }

   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 mldp {
     description
       "This feature indicates that the system supports Multicast
        LDP (mLDP).";
   }

   feature mldp-mofrr {
     description
       "This feature indicates that the system supports mLDP
        Multicast only FRR (MoFRR).";
   }
```

```
   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-peer-graceful-restart-config {
     description
       "This feature indicates that the system allows to configure
        graceful restart at the per-peer level.";
   }

   feature per-peer-session-attributes-config {
     description
       "This feature indicates that the system allows to configure
        session attributes at the per-peer 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";
   }

   /*
    * Typedefs
    */
   typedef ldp-address-family {
     type identityref {
```

```
        base rt:address-family;
      }
      description
        "LDP address family type.";
    }

    typedef duration32-inf {
      type union {
        type uint32;
        type enumeration {
          enum "infinite" {
            description "The duration is infinite.";
          }
        }
      }
      units seconds;
      description
        "Duration represented as 32 bit seconds with infinite.";
    }

    typedef advertised-received {
      type enumeration {
        enum advertised {
          description "Advertised information.";
        }
        enum received {
          description "Received information.";
        }
      }
      description
        "Received or advertised.";
    }

    typedef downstream-upstream {
      type enumeration {
        enum downstream {
          description "Downstream information.";
        }
        enum upstream {
          description "Upstream information.";
        }
      }
      description
        "Received or advertised.";
    }

    typedef label-adv-mode {
      type enumeration {
```

```
        enum downstream-unsolicited {
          description "Downstream Unsolicited.";
        }
        enum downstream-on-demand {
          description "Downstream on Demand.";
        }
      }
      description
        "Label Advertisement Mode.";
    }

    typedef mpls-interface-ref {
      type leafref {
        path "/rt:routing/mpls:mpls/mpls:interface/mpls:name";
      }
      description
        "This type is used by data models that need to reference
         mpls interfaces.";
    }

    typedef multipoint-type {
      type enumeration {
        enum p2mp {
          description "Point to multipoint.";
        }
        enum mp2mp {
          description "Multipoint to multipoint.";
        }
      }
      description
        "p2mp or mp2mp.";
    }

    typedef neighbor-list-ref {
      type string;
      description
        "A type for a reference to a neighbor list.";
    }

    typedef peer-list-ref {
      type string;
      description
        "A type for a reference to a peer list.";
    }

    typedef prefix-list-ref {
      type string;
      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.";
  }

  typedef route-distinguisher {
    type string {
    }
    description
      "Type definition for route distinguisher.";
    reference
      "RFC4364: BGP/MPLS IP Virtual Private Networks (VPNs).";
  }

  /*
   * Identities
   */
  identity adjacency-flag-base {
    description "Base type for adjacency flags.";
  }

  identity adjacency-flag-active {
    base "adjacency-flag-base";
    description
      "This adjacency is configured and actively created.";
  }

  identity adjacency-flag-passive {
    base "adjacency-flag-base";
    description
      "This adjacency is not configured and passively accepted.";
  }

  /*
```

```
    * Groupings
    */

   grouping adjacency-state-attributes {
     description
       "Adjacency state attributes.";

     leaf-list flag {
       type identityref {
         base "adjacency-flag-base";
       }
       description "Adjacency flags.";
     }
     container hello-holdtime {
       description "Hello holdtime state.";
       leaf adjacent {
         type uint16;
         units seconds;
         description "Peer holdtime.";
       }
       leaf negotiated {
         type uint16;
         units seconds;
         description "Negotiated holdtime.";
       }
       leaf remaining {
         type uint16;
         units seconds;
         description "Remaining holdtime.";
       }
     }

     leaf next-hello {
       type uint16;
       units seconds;
       description "Time to send the next hello message.";
     }

     container statistics {
       description
         "Statistics objects.";

       leaf discontinuity-time {
         type yang:date-and-time;
         mandatory true;
         description
           "The time on the most recent occasion at which any one or
            more of this interface's counters suffered a
```

```
            discontinuity.  If no such discontinuities have occurred
            since the last re-initialization of the local management
            subsystem, then this node contains the time the local
            management subsystem re-initialized itself.";
        }

        leaf hello-received {
          type yang:counter64;
          description
            "The number of hello messages received.";
        }
        leaf hello-dropped {
          type yang:counter64;
          description
            "The number of hello messages received.";
        }
      } // statistics
    } // adjacency-state-attributes

    grouping basic-discovery-timers {
      description
        "Basic discovery timer attributes.";
      leaf hello-holdtime {
        type uint16 {
          range 15..3600;
        }
        units seconds;
        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;
        description
          "The interval between consecutive LDP link Hello messages
           used in basic LDP discovery";
      }
    } // basic-discovery-timers

    grouping binding-address-state-attributes {
      description
        "Address binding attributes";
      leaf advertisement-type {
        type advertised-received;
```

```
      description
        "Received or advertised.";
    }
    leaf peer {
      type leafref {
        path "../../../../../../../peers/peer/lsr-id";
      }
      must "../advertisement-type = 'received'" {
        description
          "Applicable for received address.";
      }
      description
        "LDP peer from which this address is received.";
    } // peer
  } // binding-address-state-attributes

  grouping binding-label-state-attributes {
    description
      "Label binding attributes";
    list peer {
      key "peer advertisement-type";
      description
        "List of advertised and received peers.";
      leaf peer {
        type leafref {
          path "../../../../../../../../peers/peer/lsr-id";
        }
        description
          "LDP peer from which this binding is received,
           or to which this binding is advertised.";
      }
      leaf advertisement-type {
        type advertised-received;
        description
          "Received or advertised.";
      }
      leaf label {
        type mpls:mpls-label;
        description
          "Advertised (outbound) or received (inbound)
           label.";
      }
      leaf used-in-forwarding {
        type boolean;
        description
          "'true' if the lable is used in forwarding.";
      }
    } // peer
```

```
   } // binding-label-state-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 neighbor-list {
         type neighbor-list-ref;
         description

           "The name of a peer ACL.";
       }
     } // hello-accept
   } // extended-discovery-policy-attributes

   grouping extended-discovery-timers {
     description
       "Extended discovery timer attributes.";
     leaf hello-holdtime {
       type uint16 {
         range 15..3600;
       }
       units seconds;
       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;
       description
         "The interval between consecutive LDP targeted Hello
          messages used in extended LDP discovery.";
     }
```

```
   } // extended-discovery-timers

   grouping global-attributes {
     description "Configuration attributes at global level.";

     uses instance-attributes;
   } // global-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
           "Specifies the time interval, in seconds, that the remote
            LDP peer preserves its MPLS forwarding state after
            receiving the Initialization message from the restarted
            local LDP peer.";
       }
       leaf forwarding-holdtime {
         type uint16 {
```

```
          range 30..3600;
        }
        units seconds;
        description
          "Specifies the time interval, in seconds, before the
           termination of the recovery phase.";
      }
    } // graceful-restart
  } // graceful-restart-attributes

  grouping graceful-restart-attributes-per-peer {
    description
      "Per peer 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
          "Specifies the time interval, in seconds, that the remote
           LDP peer preserves its MPLS forwarding state after
           receiving the Initialization message from the restarted
           local LDP peer.";
      }
    } // graceful-restart
  } // graceful-restart-attributes-per-peer

  grouping instance-attributes {
    description "Configuration attributes at instance level.";
```

```
    container capability {
      description "Configure capability.";
      container end-of-lib {
        if-feature capability-end-of-lib;
        description
          "Configure end-of-lib capability.";
        leaf enable {
          type boolean;
          description
            "Enable end-of-lib capability.";
        }
      }
      container typed-wildcard-fec {
        if-feature capability-typed-wildcard-fec;
        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;
        description
          "Configure upstream label assignment capability.";
        leaf enable {
          type boolean;
          description
            "Enable upstream label assignment.";
        }
      }
      container mldp {
        if-feature mldp;

        description
          "Multipoint capabilities.";
        uses mldp-capabilities;
      }
    } // capability

    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.";
    }
    leaf lsr-id {
      type yang:dotted-quad;
      description "Router ID.";
    }
  } // instance-attributes

  grouping ldp-adjacency-ref {
    description
      "An absolute reference to an LDP adjacency.";
    choice hello-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 {
        container link {
          description "Link adjacency.";
          leaf next-hop-interface {
            type mpls-interface-ref;
            description
              "Interface connecting to next-hop.";
          }
          leaf next-hop-address {
            type inet:ip-address;
            must "../next-hop-interface" {
              description
                "Applicable when interface is specified.";

            }
            description
              "IP address of next-hop.";
          }
        } // link
      }
```

```
    }
  } // ldp-adjacency-ref

  grouping ldp-fec-event {
    description
      "A LDP FEC event.";
    leaf prefix {
      type inet:ip-prefix;
      description
        "FEC.";
    }
  } // ldp-fec-event

  grouping ldp-peer-ref {
    description
      "An absolute reference to an LDP peer.";
    leaf peer-ref {
      type leafref {
        path "/rt:routing/rt:control-plane-protocols/mpls-ldp/"
          + "peers/peer/lsr-id";
      }
      description
        "Reference to an LDP peer.";
    }
  } // ldp-peer-ref

  grouping mldp-capabilities {
    description
      "mLDP capabilities.";
    container p2mp {
      description
        "Configure point-to-multipoint capability.";
      leaf enable {
        type boolean;
        description
          "Enable point-to-multipoint.";
      }
    }
    container mp2mp {
      description
        "Configure multipoint-to-multipoint capability.";
      leaf enable {
        type boolean;
        description
          "Enable multipoint-to-multipoint.";
      }
    }
    container make-before-break {
```

```
        description
          "Configure make-before-break capability.";
        leaf enable {
          type boolean;
          description
            "Enable make-before-break.";
        }
        leaf switchover-delay {
          type uint16;
          units seconds;
          description
            "Switchover delay in seconds.";
        }
        leaf timeout {
          type uint16;
          units seconds;
          description
            "Timeout in seconds.";
        }
      }
      container hub-and-spoke {
        if-feature capability-mldp-hsmp;
        description
          "Configure hub-and-spoke-multipoint capability.";
        reference
          "RFC7140: LDP Extensions for Hub and Spoke Multipoint
           Label Switched Path";
        leaf enable {
          type boolean;
          description
            "Enable hub-and-spoke-multipoint.";
        }
      }
      container node-protection {
        if-feature capability-mldp-node-protection;
        description
          "Configure node-protection capability.";
        reference
          "RFC7715: mLDP Node Protection.";
        leaf plr {
          type boolean;
          description
            "Point of Local Repair capable for MP LSP node
             protection.";
        }
        container merge-point {
          description
            "Merge Point capable for MP LSP node protection.";
```

```
        leaf enable {
          type boolean;
          description
            "Enable merge point capability.";
        }
        leaf targeted-session-teardown-delay {
          type uint16;
          units seconds;
          description
            "Targeted session teardown delay.";
        }
      } // merge-point
    }
  } // mldp-capabilities

  grouping  mldp-configured-lsp-roots {
    description
      "mLDP roots containers.";

    container roots-ipv4 {

      when "../../../af = 'ipv4'" {
        description
          "Only for IPv4.";
      }
      description
        "Configured IPv4 multicast LSPs.";
      list root {
        key "root-address";
        description
          "List of roots for configured multicast LSPs.";

        leaf root-address {
          type inet:ipv4-address;
          description
            "Root address.";
        }

        list lsp {
          must "(lsp-id = 0 and source-address != '0.0.0.0' and "
            + "group-address != '0.0.0.0') or "
            + "(lsp-id != 0 and source-address = '0.0.0.0' and "
            + "group-address = '0.0.0.0')" {
            description
              "A LSP can be identified by either <lsp-id> or
               <source-address, group-address>.";
          }
          key "lsp-id source-address group-address";
```

```
          description
            "List of LSPs.";
          leaf lsp-id {
            type uint16;
            description "ID to identify the LSP.";
          }
          leaf source-address {
            type inet:ipv4-address;
            description
              "Source address.";
          }
          leaf group-address {
            type inet:ipv4-address-no-zone;
            description
              "Group address.";
          }
        } // list lsp
      } // list root
    } // roots-ipv4

    container roots-ipv6 {

      when "../../../af = 'ipv6'" {
        description
          "Only for IPv6.";
      }
      description
        "Configured IPv6 multicast LSPs.";

      list root {
        key "root-address";
        description
          "List of roots for configured multicast LSPs.";

        leaf root-address {
          type inet:ipv6-address;
          description
            "Root address.";
        }

        list lsp {
          must "(lsp-id = 0 and source-address != '::' and "
            + "group-address != '::') or "
            + "(lsp-id != 0 and source-address = '::' and "
            + "group-address = '::')" {
            description
              "A LSP can be identified by either <lsp-id> or
               <source-address, group-address>.";
```

```
          }
          key "lsp-id source-address group-address";
          description
            "List of LSPs.";
          leaf lsp-id {
            type uint16;
            description "ID to identify the LSP.";
          }
          leaf source-address {
            type inet:ipv6-address;
            description
              "Source address.";
          }
          leaf group-address {
            type inet:ipv6-address-no-zone;
            description
              "Group address.";
          }
        } // list lsp
      } // list root
    } // roots-ipv6
  } // mldp-configured-lsp-roots

  grouping mldp-fec-event {
    description
      "A mLDP FEC event.";
    leaf tree-type {
      type multipoint-type;
      description
        "p2mp or mp2mp.";
    }
    leaf root {
      type inet:ip-address;
      description
        "Root address.";
    }
    choice lsp-key-type {
      description
        "LSP ID based or source-group based .";
      case lsp-id-based {
        leaf lsp-id {
          type uint16;
          description
            "ID to identify the LSP.";
        }
      }
      case source-group-based {
        leaf source-address {
```

```
          type inet:ip-address;
          description

            "LSP source address.";
        }
        leaf group-address {
          type inet:ip-address;
          description
            "Multicast group address.";
        }
      } // case source-group-based
    }
  } // mldp-fec-event

  grouping  mldp-binding-label-state-attributes {
    description
      "mLDP label binding attributes.";

    leaf multipoint-type {
      type multipoint-type;
      description
        "The type of mutipoint, p2mp or mp2mp.";
    }
    list peer {
      key "direction peer advertisement-type";
      description
        "List of advertised and received peers.";
      leaf direction {
        type downstream-upstream;
        description
          "Downstream or upstream.";
      }
      leaf peer {
        type leafref {
          path
            "../../../../../../../../../../peers/peer/lsr-id";
        }
        description
          "LDP peer from which this binding is received,
           or to which this binding is advertised.";
      }
      leaf advertisement-type {
        type advertised-received;
        description
          "Advertised or received.";
      }
      leaf label {
        type mpls:mpls-label;
```

```
        description
          "Advertised (outbound) or received (inbound) label.";
      }
      leaf mbb-role {
        when "../direction = 'upstream'" {
          description
            "For upstream.";
        }
        type enumeration {
          enum none {
            description "MBB is not enabled.";
          }
          enum active {
            description "This LSP is active.";
          }
          enum inactive {
            description "This LSP is inactive.";
          }
        }
        description
          "The MBB status of this LSP.";
      }
      leaf mofrr-role {
        when "../direction = 'upstream'" {
          description
            "For upstream.";
        }
        type enumeration {
          enum none {
            description "MOFRR is not enabled.";
          }
          enum primary {
            description "This LSP is primary.";
          }
          enum backup {
            description "This LSP is backup.";
          }
        }
        description
          "The MOFRR status of this LSP.";
      }
    } // peer
  } // mldp-binding-label-state-attributes

  grouping peer-af-policy-container {
    description
      "LDP policy attribute container under peer 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
  } // peer-af-policy-container

  grouping peer-attributes {
    description "Peer configuration attributes.";

    leaf session-ka-holdtime {
      type uint16 {
        range 45..3600;
      }
      units seconds;
      description
        "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
         peer.";
    }
    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.";
```

```
    }
  } // peer-attributes

  grouping peer-authentication {
    description
      "Peer authentication attributes.";
    leaf session-authentication-md5-password {
      type string {
        length "1..80";
      }
      description
        "Assigns an encrypted MD5 password to an LDP
         peer";
    } // md5-password
  } // peer-authentication

  grouping peer-state-derived {
    description "Peer derived state attributes.";

    container label-advertisement-mode {
      description "Label advertisement mode state.";
      leaf local {
        type label-adv-mode;
        description
          "Local Label Advertisement Mode.";
      }
      leaf peer {
        type label-adv-mode;
        description
          "Peer Label Advertisement Mode.";
      }
      leaf negotiated {
        type label-adv-mode;
        description
          "Negotiated Label Advertisement Mode.";
      }
    }
    leaf next-keep-alive {
      type uint16;
      units seconds;
      description "Time to send the next KeepAlive message.";
    }

    leaf peer-ldp-id {
      type yang:dotted-quad;
      description "Peer LDP ID.";
    }
```

```
    container received-peer-state {
      description "Peer features.";

      uses graceful-restart-attributes-per-peer;

      container capability {
        description "Configure capability.";
        container end-of-lib {
          description
            "Configure end-of-lib capability.";
          leaf enable {
            type boolean;
            description
              "Enable end-of-lib capability.";
          }
        }
        container typed-wildcard-fec {
          description
            "Configure typed-wildcard-fec capability.";
          leaf enable {
            type boolean;
            description
              "Enable typed-wildcard-fec capability.";
          }
        }
        container upstream-label-assignment {
          description
            "Configure upstream label assignment capability.";
          leaf enable {
            type boolean;
            description
              "Enable upstream label assignment.";
          }
        }
        container mldp {
          if-feature mldp;
          description
            "Multipoint capabilities.";

          container p2mp {
            description
              "Configure point-to-multipoint capability.";
            leaf enable {
              type boolean;
              description
                "Enable point-to-multipoint.";
            }
          }
```

```
          container mp2mp {
            description
              "Configure multipoint-to-multipoint capability.";
            leaf enable {
              type boolean;
              description
                "Enable multipoint-to-multipoint.";
            }
          }
          container make-before-break {
            description
              "Configure make-before-break capability.";
            leaf enable {
              type boolean;
              description
                "Enable make-before-break.";
            }
          }
          container hub-and-spoke {
            description
              "Configure hub-and-spoke-multipoint capability.";
            reference
              "RFC7140: LDP Extensions for Hub and Spoke Multipoint
               Label Switched Path";
            leaf enable {
              type boolean;
              description
                "Enable hub-and-spoke-multipoint.";
            }
          }
          container node-protection {
            description
              "Configure node-protection capability.";
            reference
              "RFC7715: mLDP Node Protection.";
            leaf plr {
              type boolean;
              description
                "Point of Local Repair capable for MP LSP node
                 protection.";
            }
            leaf merge-point {
              type boolean;
              description
                "Merge Point capable for MP LSP node protection.";
            } // merge-point
          } // node-protection
        } // mldp
```

```
        } // capability
      } // received-peer-state

      container session-holdtime {
        description "Session holdtime state.";
        leaf peer {
          type uint16;
          units seconds;
          description "Peer holdtime.";
        }
        leaf negotiated {
          type uint16;
          units seconds;
          description "Negotiated holdtime.";
        }
        leaf remaining {
          type uint16;
          units seconds;
          description "Remaining holdtime.";
        }
      } // session-holdtime

      leaf session-state {
        type enumeration {
          enum non-existent {
            description "NON EXISTENT state. Transport disconnected.";
          }
          enum initialized {
            description "INITIALIZED state.";
          }
          enum openrec {
            description "OPENREC state.";
          }
          enum opensent {
            description "OPENSENT state.";
          }
          enum operational {
            description "OPERATIONAL state.";
          }
        }
        description
          "Representing the operational status.";
      }

      container tcp-connection {
        description "TCP connection state.";
        leaf local-address {
          type inet:ip-address;
```

```
        description "Local address.";
      }
      leaf local-port {
        type inet:port-number;
        description "Local port.";
      }
      leaf remote-address {
        type inet:ip-address;
        description "Remote address.";
      }
      leaf remote-port {
        type inet:port-number;
        description "Remote port.";
      }
    } // tcp-connection

    leaf up-time {
      type string;
      description "Up time. The interval format in ISO 8601.";
    }

    container statistics {
      description
        "Statistics objects.";

      leaf discontinuity-time {
        type yang:date-and-time;
        mandatory true;
        description
          "The time on the most recent occasion at which any one or
           more of this interface's counters suffered a
           discontinuity.  If no such discontinuities have occurred
           since the last re-initialization of the local management
           subsystem, then this node contains the time the local
           management subsystem re-initialized itself.";
      }

      container received {
        description "Inbound statistics.";
        uses statistics-peer-received-sent;
      }
      container sent {
        description "Outbound statistics.";
        uses statistics-peer-received-sent;
      }

      leaf total-addresses {
        type uint32;
```

```
        description
          "The number of learned addresses.";
      }
      leaf total-labels {
        type uint32;
        description
          "The number of learned labels.";
      }
      leaf total-fec-label-bindings {
        type uint32;
        description
          "The number of learned label-address bindings.";
      }
    } // statistics
  } // peer-state-derived

  grouping policy-container {
    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";
          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 {
            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 enable {
              type boolean;
              description
                "'true' to enable explicit null.";
            }
            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.";

          }
        }
        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-container

  grouping statistics-peer-received-sent {
    description
      "Inbound and outbound statistic counters.";
    leaf total-octets {
      type yang:counter64;
      description
        "The total number of octets sent or received.";
    }
    leaf total-messages {
      type yang:counter64;
      description
        "The number of messages sent or received.";
    }
    leaf address {
```

```
        type yang:counter64;
        description
          "The number of address messages sent or received.";
      }
      leaf address-withdraw {
        type yang:counter64;
        description
          "The number of address-withdraw messages sent or received.";
      }
      leaf initialization {
        type yang:counter64;
        description
          "The number of initialization messages sent or received.";
      }
      leaf keepalive {
        type yang:counter64;
        description
          "The number of keepalive messages sent or received.";
      }
      leaf label-abort-request {
        type yang:counter64;
        description
          "The number of label-abort-request messages sent or
           received.";
      }
      leaf label-mapping {
        type yang:counter64;
        description
          "The number of label-mapping messages sent or received.";
      }
      leaf label-release {
        type yang:counter64;
        description
          "The number of label-release messages sent or received.";
      }
      leaf label-request {
        type yang:counter64;
        description
          "The number of label-request messages sent or received.";
      }
      leaf label-withdraw {
        type yang:counter64;
        description
          "The number of label-withdraw messages sent or received.";
      }
      leaf notification {
        type yang:counter64;
        description
```

```
          "The number of messages sent or received.";
      }
    } // statistics-peer-received-sent

    /*
     * Configuration data nodes
     */

    augment "/rt:routing/rt:control-plane-protocols" {
      description "LDP augmentation.";

      container mpls-ldp {
        presence "Container for LDP protocol.";
        description
          "Container for LDP protocol.";

        container global {
          description
            "Global attributes for LDP.";
          container config {
            description
              "Configuration data.";
            uses global-attributes;
          }
          container state {
            config false;
            description
              "Operational state data.";
            uses global-attributes;
          }

          container mldp {
            if-feature mldp;
            description
              "mLDP attributes at per instance level. Defining
               attributes here does not enable any MP capabilities.
               MP capabilities need to be explicitly enabled under
               container capability.";

            container config {
              description
                "Configuration data.";
              leaf enable {
                type boolean;
                description
                  "Enable mLDP.";
              }
            }
```

```
          container state {
            config false;
            description

              "Operational state data.";
            leaf enable {
              type boolean;
              description
                "Enable mLDP.";
            }
          }

          list address-family {
            key "afi";
            description
              "Per-af params.";
            leaf afi {
              type ldp-address-family;
              description
                "Address family type value.";
            }

            container config {
              description
                "Configuration data.";
              container multicast-only-frr {
                if-feature mldp-mofrr;
                description
                  "Multicast only FRR (MoFRR) policy.";
                leaf prefix-list {
                  type prefix-list-ref;
                  description
                    "Enables MoFRR for the specified access list.";
                }
              } // multicast-only-frr
              container recursive-fec {
                description
                  "Recursive FEC policy.";
                leaf prefix-list {
                  type prefix-list-ref;
                  description
                    "Enables recursive FEC for the specified access
                     list.";
                }
              } // recursive-for
            }
            container state {
              config false;
```

```
            description
              "Operational state data.";
            container multicast-only-frr {
              if-feature mldp-mofrr;

              description
                "Multicast only FRR (MoFRR) policy.";
              leaf prefix-list {
                type prefix-list-ref;
                description
                  "Enables MoFRR for the specified access list.";
              }
            } // multicast-only-frr
            container recursive-fec {
              description
                "Recursive FEC policy.";
              leaf prefix-list {
                type prefix-list-ref;
                description
                  "Enables recursive FEC for the specified access
                   list.";
              }
            } // recursive-fec

            container ipv4 {
              when "../../afi = 'ipv4'" {
                description
                  "Only for IPv4.";
              }
              description
                "IPv4 state information.";
              container roots {
                description
                  "IPv4 multicast LSP roots.";
                list root {
                  key "root-address";
                  description
                    "List of roots for configured multicast LSPs.";

                  leaf root-address {
                    type inet:ipv4-address;
                    description
                      "Root address.";
                  }

                  leaf is-self {
                    type boolean;
                    description
```

```
                    "This is the root.";
                  }

                  list reachability {
                    key "address interface";
                    description
                      "A next hop for reachability to root,
                       as a RIB view.";
                    leaf address {
                      type inet:ipv4-address;
                      description
                        "The next hop address to reach root.";
                    }
                    leaf interface {
                      type mpls-interface-ref;
                      description
                        "Interface connecting to next-hop.";
                    }
                    leaf peer {
                      type leafref {
                        path
                          "../../../../../../../../../peers/peer/"
                          + "lsr-id";
                      }
                      description
                        "LDP peer from which this next hop can be
                         reached.";
                    }
                  }
                } // list root
              } // roots
              container bindings {
                description
                  "mLDP FEC to label bindings.";
                container opaque-type-lspid {
                  description
                    "The type of opaque value element is
                     the generic LSP identifier";
                  reference
                    "RFC6388: Label Distribution Protocol
                     Extensions for Point-to-Multipoint and
                     Multipoint-to-Multipoint Label Switched
                     Paths.";
                  list fec-label {
                    key
                      "root-address lsp-id "
                      + "recur-root-address recur-rd";
                    description
```

```
            "List of FEC to label bindings.";
          leaf root-address {
            type inet:ipv4-address;
            description
              "Root address.";
          }
          leaf lsp-id {
            type uint32;
            description "ID to identify the LSP.";
          }
          leaf recur-root-address {
            type inet:ip-address;
            description
              "Recursive root address.";
            reference
              "RFC6512: Using Multipoint LDP When the
               Backbone Has No Route to the Root";
          }
          leaf recur-rd {
            type route-distinguisher;
            description
              "Route Distinguisher in the VPN-Recursive
               Opaque Value.";
            reference
              "RFC6512: Using Multipoint LDP When the
               Backbone Has No Route to the Root";
          }
          uses mldp-binding-label-state-attributes;
        } // fec-label
      } // opaque-type-lspid

      container opaque-type-src {
        description
          "The type of opaque value element is
           the transit source TLV";
        reference
          "RFC6826: Multipoint LDP In-Band Signaling for
           Point-to-Multipoint and
           Multipoint-to-Multipoint Label Switched
           Paths.";
        list fec-label {
          key
            "root-address source-address group-address "
            + "rd recur-root-address recur-rd";
          description
            "List of FEC to label bindings.";
          leaf root-address {
            type inet:ipv4-address;
```

```
            description
              "Root address.";
            }
            leaf source-address {
              type inet:ip-address;
              description
                "Source address.";
            }
            leaf group-address {
              type inet:ip-address-no-zone;
              description
                "Group address.";
            }
            leaf rd {
              type route-distinguisher;
              description
                "Route Distinguisher.";
              reference
                "RFC7246: Multipoint Label Distribution
                 Protocol In-Band Signaling in a Virtual
                 Routing and Forwarding (VRF) Table
                 Context.";
            }
            leaf recur-root-address {
              type inet:ip-address;
              description
                "Recursive root address.";
              reference
                "RFC6512: Using Multipoint LDP When the
                 Backbone Has No Route to the Root";
            }
            leaf recur-rd {
              type route-distinguisher;
              description
                "Route Distinguisher in the VPN-Recursive
                 Opaque Value.";
              reference
                "RFC6512: Using Multipoint LDP When the
                 Backbone Has No Route to the Root";
            }
            uses mldp-binding-label-state-attributes;
          } // fec-label
        } // opaque-type-src

        container opaque-type-bidir {
          description
            "The type of opaque value element is
             the generic LSP identifier";
```

```
                reference
                  "RFC6826: Multipoint LDP In-Band Signaling for
                   Point-to-Multipoint and
                   Multipoint-to-Multipoint Label Switched
                   Paths.";
                list fec-label {
                  key
                    "root-address rp group-address "
                    + "rd recur-root-address recur-rd";
                  description
                    "List of FEC to label bindings.";
                  leaf root-address {
                    type inet:ipv4-address;
                    description
                      "Root address.";
                  }
                  leaf rp {
                    type inet:ip-address;
                    description
                      "RP address.";
                  }
                  leaf group-address {
                    type inet:ip-address-no-zone;
                    description
                      "Group address.";
                  }
                  leaf rd {
                    type route-distinguisher;
                    description
                      "Route Distinguisher.";
                    reference
                      "RFC7246: Multipoint Label Distribution
                       Protocol In-Band Signaling in a Virtual
                       Routing and Forwarding (VRF) Table
                       Context.";
                  }
                  leaf recur-root-address {
                    type inet:ip-address;
                    description
                      "Recursive root address.";
                    reference
                      "RFC6512: Using Multipoint LDP When the
                       Backbone Has No Route to the Root";
                  }
                  leaf recur-rd {
                    type route-distinguisher;
                    description
                      "Route Distinguisher in the VPN-Recursive
```

```
                        Opaque Value.";
                      reference
                        "RFC6512: Using Multipoint LDP When the
                         Backbone Has No Route to the Root";
                    }
                    uses mldp-binding-label-state-attributes;
                  } // fec-label
                } // opaque-type-bidir
              } // bindings
            } // ipv4

            container ipv6 {
              when "../../afi = 'ipv6'" {
                description
                  "Only for IPv6.";
              }
              description
                "IPv6 state information.";
              container roots {
                description
                  "IPv6 multicast LSP roots.";
                list root {
                  key "root-address";
                  description
                    "List of roots for configured multicast LSPs.";

                  leaf root-address {
                    type inet:ipv6-address;
                    description
                      "Root address.";
                  }

                  leaf is-self {
                    type boolean;
                    description
                      "This is the root.";
                  }

                  list reachability {
                    key "address interface";
                    description
                      "A next hop for reachability to root,
                       as a RIB view.";
                    leaf address {
                      type inet:ipv6-address;
                      description
                        "The next hop address to reach root.";
                    }
```

```
            leaf interface {
              type mpls-interface-ref;
              description
                "Interface connecting to next-hop.";
            }
            leaf peer {
              type leafref {
                path
                  "../../../../../../../../../peers/peer/"
                  + "lsr-id";
              }
              description
                "LDP peer from which this next hop can be
                 reached.";
            }
          }
        } // list root
      } // roots
      container bindings {
        description
          "mLDP FEC to label bindings.";
        container opaque-type-lspid {
          description
            "The type of opaque value element is
             the generic LSP identifier";
          reference
            "RFC6388: Label Distribution Protocol
             Extensions for Point-to-Multipoint and
             Multipoint-to-Multipoint Label Switched
             Paths.";
          list fec-label {
            key
              "root-address lsp-id "
              + "recur-root-address recur-rd";
            description
              "List of FEC to label bindings.";
            leaf root-address {
              type inet:ipv6-address;
              description
                "Root address.";
            }
            leaf lsp-id {
              type uint32;
              description "ID to identify the LSP.";
            }
            leaf recur-root-address {
              type inet:ip-address;
              description
```

```
                    "Recursive root address.";
                  reference
                    "RFC6512: Using Multipoint LDP When the
                     Backbone Has No Route to the Root";
                }
                leaf recur-rd {
                  type route-distinguisher;
                  description
                    "Route Distinguisher in the VPN-Recursive
                     Opaque Value.";
                  reference
                    "RFC6512: Using Multipoint LDP When the
                     Backbone Has No Route to the Root";
                }
                uses mldp-binding-label-state-attributes;
              } // fec-label
            } // opaque-type-lspid

            container opaque-type-src {
              description
                "The type of opaque value element is
                 the transit Source TLV";
              reference
                "RFC6826: Multipoint LDP In-Band Signaling for
                 Point-to-Multipoint and
                 Multipoint-to-Multipoint Label Switched
                 Paths.";
              list fec-label {
                key
                  "root-address source-address group-address "
                  + "rd recur-root-address recur-rd";
                description
                  "List of FEC to label bindings.";
                leaf root-address {
                  type inet:ipv6-address;
                  description
                    "Root address.";
                }
                leaf source-address {
                  type inet:ip-address;
                  description
                    "Source address.";
                }
                leaf group-address {
                  type inet:ip-address-no-zone;
                  description
                    "Group address.";
                }
```

```
            leaf rd {
              type route-distinguisher;
              description
                "Route Distinguisher.";
              reference
                "RFC7246: Multipoint Label Distribution
                 Protocol In-Band Signaling in a Virtual
                 Routing and Forwarding (VRF) Table
                 Context.";
            }
            leaf recur-root-address {
              type inet:ip-address;
              description
                "Recursive root address.";
              reference
                "RFC6512: Using Multipoint LDP When the
                 Backbone Has No Route to the Root";
            }
            leaf recur-rd {
              type route-distinguisher;
              description
                "Route Distinguisher in the VPN-Recursive
                 Opaque Value.";
              reference
                "RFC6512: Using Multipoint LDP When the
                 Backbone Has No Route to the Root";
            }
            uses mldp-binding-label-state-attributes;
          } // fec-label
        } // opaque-type-src

        container opaque-type-bidir {
          description
            "The type of opaque value element is
             the generic LSP identifier";
          reference
            "RFC6826: Multipoint LDP In-Band Signaling for
             Point-to-Multipoint and
             Multipoint-to-Multipoint Label Switched
             Paths.";
          list fec-label {
            key
              "root-address rp group-address "
              + "rd recur-root-address recur-rd";
            description
              "List of FEC to label bindings.";
            leaf root-address {
              type inet:ipv6-address;
```

```
                    description
                      "Root address.";
                  }
                  leaf rp {
                    type inet:ip-address;
                    description
                      "RP address.";
                  }
                  leaf group-address {
                    type inet:ip-address-no-zone;
                    description
                      "Group address.";
                  }
                  leaf rd {
                    type route-distinguisher;
                    description
                      "Route Distinguisher.";
                    reference
                      "RFC7246: Multipoint Label Distribution
                       Protocol In-Band Signaling in a Virtual
                       Routing and Forwarding (VRF) Table
                       Context.";
                  }
                  leaf recur-root-address {
                    type inet:ip-address;
                    description
                      "Recursive root address.";
                    reference
                      "RFC6512: Using Multipoint LDP When the
                       Backbone Has No Route to the Root";
                  }
                  leaf recur-rd {
                    type route-distinguisher;
                    description
                      "Route Distinguisher in the VPN-Recursive
                       Opaque Value.";
                    reference
                      "RFC6512: Using Multipoint LDP When the
                       Backbone Has No Route to the Root";
                  }
                  uses mldp-binding-label-state-attributes;
                } // fec-label
              } // opaque-type-bidir
            } // bindings
          } // ipv6
        } // state

        container configured-leaf-lsps {
```

```
            description
              "Configured multicast LSPs.";

            container p2mp {
              description
                "Configured point-to-multipoint LSPs.";
              uses mldp-configured-lsp-roots;
            }
            container mp2mp {
              description
                "Configured multipoint-to-multipoint LSPs.";
              uses mldp-configured-lsp-roots;
            }
          } // configured-leaf-lsps
        } // list address-family
      } // mldp

      list address-family {
        key "afi";
        description
          "Per-vrf per-af params.";
        leaf afi {
          type ldp-address-family;
          description
            "Address family type value.";
        }

        container config {
          description
            "Configuration data.";
          leaf enable {
            type boolean;
            description
              "'true' to enable the address family.";
          }
          uses policy-container;

          container ipv4 {
            when "../../afi = 'ipv4'" {
              description
                "Only for IPv4.";
            }
            description
              "IPv4 address family.";
            leaf transport-address {
              type inet:ipv4-address;
              description
                "The transport address advertised in LDP Hello
```

```
                messages.";
            }
          } // ipv4
          container ipv6 {
            when "../../afi = 'ipv6'" {
              description
                "Only for IPv6.";
            }
            description
              "IPv6 address family.";
            leaf transport-address {
              type inet:ipv6-address;
              description
                "The transport address advertised in LDP Hello
                 messages.";
            }
          } // ipv6
        }
        container state {
          config false;
          description
            "Operational state data.";
          leaf enable {
            type boolean;
            description
              "'true' to enable the address family.";
          }

          uses policy-container;

          container ipv4 {
            when "../../afi = 'ipv4'" {
              description
                "Only for IPv4.";
            }
            description
              "IPv4 address family.";
            leaf transport-address {
              type inet:ipv4-address;
              description
                "The transport address advertised in LDP Hello
                 messages.";
            }

            container bindings {
              description
                "LDP address and label binding information.";
              list address {
```

```
                key "address";
                description
                  "List of address bindings.";
                leaf address {
                  type inet:ipv4-address;
                  description
                    "Binding address.";
                }
                uses binding-address-state-attributes;
              } // binding-address

              list fec-label {
                key "fec";
                description
                  "List of label bindings.";
                leaf fec {
                  type inet:ipv4-prefix;
                  description
                    "Prefix FEC.";
                }
                uses binding-label-state-attributes;
              } // fec-label
            } // binding
          } // ipv4
          container ipv6 {
            when "../../afi = 'ipv6'" {
              description
                "Only for IPv6.";
            }
            description
              "IPv6 address family.";
            leaf transport-address {
              type inet:ipv6-address;
              description
                "The transport address advertised in LDP Hello
                 messages.";
            }

            container binding {
              description
                "LDP address and label binding information.";
              list address {
                key "address";
                description
                  "List of address bindings.";
                leaf address {
                  type inet:ipv6-address;
                  description
```

```
                    "Binding address.";
                }
                uses binding-address-state-attributes;
              } // binding-address

              list fec-label {
                key "fec";
                description
                  "List of label bindings.";
                leaf fec {
                  type inet:ipv6-prefix;
                  description
                    "Prefix FEC.";
                }
                uses binding-label-state-attributes;
              } // fec-label
            } // binding
          } // ipv6
        } // state
      } // address-family

      container discovery {
        description
          "Neibgbor discovery configuration.";

        container interfaces {
          description
            "A list of interfaces for basic descovery.";
          container config {
            description
              "Configuration data.";
            uses basic-discovery-timers;
          }
          container state {
            config false;
            description

              "Operational state data.";
            uses basic-discovery-timers;
          }

          list interface {
            key "interface";
            description
              "List of LDP interfaces.";
            leaf interface {
              type mpls-interface-ref;
              description
```

```
            "Interface.";
          }
          container config {
            description
              "Configuration data.";
            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 state {
            config false;
            description
              "Operational state data.";
            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.";
            }
            leaf next-hello {
              type uint16;
              units seconds;
              description "Time to send the next hello message.";
            }
          } // state
```

```
              list address-family {
                key "afi";
                description
                  "Per-vrf per-af params.";
                leaf afi {
                  type ldp-address-family;
                  description
                    "Address family type value.";
                }
                container config {
                  description
                    "Configuration data.";
                  leaf enable {
                    type boolean;
                    description
                      "Enable the address family on the interface.";
                  }

                  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.";
                    }
                  }

                  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.";
                }
              } // ipv6
            }
            container state {
              config false;
              description
                "Operational state data.";
              leaf enable {
                type boolean;
                description
                  "Enable the address family on the interface.";
              }

              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.";
          }

          list hello-adjacencies {
            key "adjacent-address";
            description "List of hello adjacencies.";

            leaf adjacent-address {
              type inet:ipv4-address;
              description
                "Neighbor address of the hello adjacency.";
            }

            uses adjacency-state-attributes;

            leaf peer {
              type leafref {
                path "../../../../../../../../peers/peer/"
                  + "lsr-id";
              }
              description
                "LDP peer from this adjacency.";
            }
          } // hello-adjacencies
        }
        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.";
                  }

                  list hello-adjacencies {
                    key "adjacent-address";
                    description "List of hello adjacencies.";

                    leaf adjacent-address {
                      type inet:ipv6-address;
                      description
                        "Neighbor address of the hello adjacency.";
                    }

                    uses adjacency-state-attributes;

                    leaf peer {
                      type leafref {
                        path "../../../../../../../../../peers/peer/"
                          + "lsr-id";
                      }
                      description
                        "LDP peer from this adjacency.";
                    }
                  } // hello-adjacencies
                } // ipv6
              }
            } // address-family
          } // list interface
        } // interfaces

        container targeted
        {
          description
            "A list of targeted neighbors for extended discovery.";
          container config {

            description
              "Configuration data.";
            uses extended-discovery-timers;
            uses extended-discovery-policy-attributes;
          }
          container state {
```

```
            config false;
            description
              "Operational state data.";
            uses extended-discovery-timers;
            uses extended-discovery-policy-attributes;
          }

          list address-family {
            key "afi";
            description
              "Per-af params.";
            leaf afi {
              type ldp-address-family;
              description
                "Address family type value.";
            }

            container state {
              config false;
              description
                "Operational state data.";

              container ipv4 {
                when "../../afi = 'ipv4'" {
                  description
                    "For IPv4.";
                }
                description
                  "IPv4 address family.";
                list hello-adjacencies {
                  key "local-address adjacent-address";
                  description "List of hello adjacencies.";

                  leaf local-address {
                    type inet:ipv4-address;
                    description
                      "Local address of the hello adjacency.";
                  }
                  leaf adjacent-address {
                    type inet:ipv4-address;
                    description
                      "Neighbor address of the hello adjacency.";
                  }

                  uses adjacency-state-attributes;

                  leaf peer {
                    type leafref {
```

```
                    path "../../../../../../../../peers/peer/"
                      + "lsr-id";
                  }
                  description
                    "LDP peer from this adjacency.";
                }
              } // hello-adjacencies
            } // ipv4

            container ipv6 {
              when "../../afi = 'ipv6'" {
                description
                  "For IPv6.";
              }
              description
                "IPv6 address family.";
              list hello-adjacencies {
                key "local-address adjacent-address";
                description "List of hello adjacencies.";

                leaf local-address {
                  type inet:ipv6-address;
                  description
                    "Local address of the hello adjacency.";
                }
                leaf adjacent-address {
                  type inet:ipv6-address;
                  description
                    "Neighbor address of the hello adjacency.";
                }

                uses adjacency-state-attributes;

                leaf peer {
                  type leafref {
                    path "../../../../../../../../peers/peer/"
                      + "lsr-id";
                  }
                  description
                    "LDP peer from this adjacency.";
                }
              } // hello-adjacencies
            } // ipv6
          } // state

          container ipv4 {
            when "../afi = 'ipv4'" {
              description
```

```
            "For IPv4.";
          }
          description
            "IPv4 address family.";
          list target {
            key "adjacent-address";
            description
              "Targeted discovery params.";

            leaf adjacent-address {
              type inet:ipv4-address;
              description
                "Configures a remote LDP neighbor and enables
                 extended LDP discovery of the specified
                 neighbor.";
            }
            container config {
              description
                "Configuration data.";
              leaf enable {
                type boolean;
                description
                  "Enable the target.";
              }
              leaf local-address {
                type inet:ipv4-address;
                description
                  "The local address.";
              }
            }
            container state {
              config false;
              description
                "Operational state data.";
              leaf enable {
                type boolean;
                description
                  "Enable the target.";
              }
              leaf local-address {
                type inet:ipv4-address;
                description
                  "The local address.";
              }
            } // state
          }
        } // ipv4
        container ipv6 {
```

```
when "../afi = 'ipv6'" {
  description
    "For IPv6.";
}
description
  "IPv6 address family.";
list target {
  key "adjacent-address";
  description
    "Targeted discovery params.";

  leaf adjacent-address {
    type inet:ipv6-address;
    description
      "Configures a remote LDP neighbor and enables
       extended LDP discovery of the specified
       neighbor.";
  }
  container config {
    description
      "Configuration data.";
    leaf enable {
      type boolean;
      description
        "Enable the target.";
    }
    leaf local-address {
      type inet:ipv6-address;
      description
        "The local address.";
    }
  }
  container state {
    config false;
    description
      "Operational state data.";
    leaf enable {
      type boolean;
      description
        "Enable the target.";
    }
    leaf local-address {
      type inet:ipv6-address;
      description
        "The local address.";
    }
  } // state
}
```

```
            } // ipv6
          } // address-family
        } // targeted
      } // discovery

      container forwarding-nexthop {
        if-feature forwarding-nexthop-config;
        description
          "Configuration for forwarding nexthop.";

        container interfaces {
          description
            "A list of interfaces on which forwarding is
             disabled.";

          list interface {
            key "interface";
            description
              "List of LDP interfaces.";
            leaf interface {
              type mpls-interface-ref;
              description
                "Interface.";
            }
            list address-family {
              key "afi";
              description
                "Per-vrf per-af params.";
              leaf afi {
                type ldp-address-family;
                description
                  "Address family type value.";
              }
              container config {
                description
                  "Configuration data.";
                leaf ldp-disable {
                  type boolean;
                  description
                    "Disable LDP forwarding on the interface.";
                }
                leaf mldp-disable {
                  if-feature mldp;
                  type boolean;
                  description
                    "Disable mLDP forwarding on the interface.";
                }
              }
```

```
                container state {
                  config false;
                  description
                    "Operational state data.";
                  leaf ldp-disable {
                    type boolean;
                    description
                      "Disable LDP forwarding on the interface.";
                  }
                  leaf mldp-disable {
                    if-feature mldp;

                    type boolean;
                    description
                      "Disable mLDP forwarding on the interface.";
                  }
                }
              } // address-family
            } // list interface
          } // interfaces
        } // forwarding-nexthop
        uses policy-container {
          if-feature all-af-policy-config;
        }
      } // global

      container peers {
        description
          "Peers configuration attributes.";

        container config {
          description
            "Configuration data.";
          uses peer-authentication {
            if-feature global-session-authentication;
          }
          uses peer-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.";
          }
        }
      }
      container state {
        config false;
        description
          "Operational state data.";
        uses peer-authentication {
          if-feature global-session-authentication;
        }
        uses peer-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.";
          }
        }
      }

      list peer {
        key "lsr-id";
        description
          "List of peers.";

        leaf lsr-id {
          type yang:dotted-quad;
          description "LSR ID.";
        }

        container config {
          description
            "Configuration data.";
          leaf admin-down {
            type boolean;
            default false;
```

```
            description
              "'true' to disable the peer.";
          }

          container capability {
            description
              "Per peer capability";
            container mldp {
              if-feature mldp;
              description
                "mLDP capabilities.";
              uses mldp-capabilities;
            }
          }

          uses peer-af-policy-container {
            if-feature all-af-policy-config;
          }

          uses peer-authentication;

          uses graceful-restart-attributes-per-peer {
            if-feature per-peer-graceful-restart-config;
          }

          uses peer-attributes {
            if-feature per-peer-session-attributes-config;
          }

          container address-family {
            description
              "Per-vrf per-af params.";
            container ipv4 {
              description
                "IPv4 address family.";
              uses peer-af-policy-container;
            }
            container ipv6 {
              description
                "IPv6 address family.";
              uses peer-af-policy-container;
            } // ipv6
          } // address-family
        }
        container state {
          config false;
          description
            "Operational state data.";
```

```
            leaf admin-down {
              type boolean;
              default false;
              description
                "'true' to disable the peer.";
            }

            container capability {
              description
                "Per peer capability";
              container mldp {
                if-feature mldp;
                description
                  "mLDP capabilities.";
                uses mldp-capabilities;
              }
            }

            uses peer-af-policy-container {
              if-feature all-af-policy-config;
            }

            uses peer-authentication;

            uses graceful-restart-attributes-per-peer {
              if-feature per-peer-graceful-restart-config;
            }

            uses peer-attributes {
              if-feature per-peer-session-attributes-config;
            }

            container address-family {
              description
                "Per-vrf per-af params.";
              container ipv4 {
                description
                  "IPv4 address family.";
                uses peer-af-policy-container;

                list hello-adjacencies {
                  key "local-address adjacent-address";
                  description "List of hello adjacencies.";

                  leaf local-address {
                    type inet:ipv4-address;
                    description
                      "Local address of the hello adjacency.";
```

```
                }
                leaf adjacent-address {
                  type inet:ipv4-address;
                  description
                    "Neighbor address of the hello adjacency.";
                }

                uses adjacency-state-attributes;

                leaf interface {
                  type mpls-interface-ref;
                  description "Interface for this adjacency.";
                }
              } // hello-adjacencies
            } // ipv4
            container ipv6 {
              description
                "IPv6 address family.";
              uses peer-af-policy-container;

              list hello-adjacencies {
                key "local-address adjacent-address";
                description "List of hello adjacencies.";

                leaf local-address {
                  type inet:ipv6-address;
                  description
                    "Local address of the hello adjacency.";
                }
                leaf adjacent-address {
                  type inet:ipv6-address;
                  description
                    "Neighbor address of the hello adjacency.";
                }

                uses adjacency-state-attributes;

                leaf interface {
                  type mpls-interface-ref;
                  description "Interface for this adjacency.";
                }
              } // hello-adjacencies
            } // ipv6
          } // address-family

          uses peer-state-derived;
        } // state
      } // list peer
```

```
      } // peers
    } // container mpls-ldp
  }

  /*
   * RPCs
   */
  rpc mpls-ldp-clear-peer {
    description
      "Clears the session to the peer.";
    input {
      leaf lsr-id {
        type union {
          type yang:dotted-quad;
          type uint32;
        }
        description
          "LSR ID of peer to be cleared. If this is not provided
           then all peers are cleared";
      }
    }
  }

  rpc mpls-ldp-clear-hello-adjacency {
    description
      "Clears the hello adjacency";
    input {
      container hello-adjacency {
        description
          "Link adjacency or targettted adjacency. If this is not
           provided then all hello adjacencies are cleared";
        choice hello-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";
              }
            } // targeted
          }
          case link {
            container link {
```

```
              presence "Present to clear link adjacencies.";
              description
                "Clear link adjacencies.";
              leaf next-hop-interface {
                type mpls-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 "../next-hop-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
          }
        }
      }
    }
  }

  rpc mpls-ldp-clear-peer-statistics {
    description
      "Clears protocol statistics (e.g. sent and received
       counters).";
    input {
      leaf lsr-id {
        type union {
          type yang:dotted-quad;
          type uint32;
        }
        description
          "LSR ID of peer whose statistic are to be cleared.
           If this is not provided then all peers statistics are
           cleared";
      }
    }
  }

  /*
   * Notifications
```

```
    */
   notification mpls-ldp-peer-event {

     description
       "Notification event for a change of LDP peer operational
        status.";
     leaf event-type {
       type oper-status-event-type;
       description "Event type.";
     }
     uses ldp-peer-ref;
   }

   notification mpls-ldp-hello-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;
   }

   notification mpls-ldp-fec-event {
     description
       "Notification event for a change of FEC status.";
     leaf event-type {
       type oper-status-event-type;
       description "Event type.";
     }
     uses ldp-fec-event;
   }

   notification mpls-mldp-fec-event {
     description
       "Notification event for a change of FEC status.";
     leaf event-type {
       type oper-status-event-type;
       description "Event type.";
     }
     uses mldp-fec-event;
   }
 }

 <CODE ENDS>
```

Figure 22

7. Security Considerations

The configuration, state, action and notification data defined using YANG data models in this document are likely to be accessed via the protocols such as NETCONF [RFC6241] etc.

Hence, YANG implementations MUST comply with the security requirements specified in section 15 of [RFC6020]. Additionally, NETCONF implementations MUST comply with the security requirements specified in sections 2.2, 2.3 and 9 of [RFC6241] as well as section 3.7 of [RFC6536].

8. IANA Considerations

This document does not extend LDP or mLDP base protocol specifiction and hence there are no IANA considerations.

Note to the RFC Editor: Please remove IANA section before the publication.

9. Acknowledgments

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Resilient MPLS Rings
draft-ietf-mpls-rmr-02

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.

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Table of Contents

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].

The intent of this document is to handle rings that "occur naturally". Many access and aggregation networks in metros have their start as a simple ring. They may then grow into more complex topologies, for example, by adding parallel links to the ring, or by adding "express" links. The goal here is to discover these rings (with some guidance), and run MPLS over them efficiently. The intent is not to construct rings in a mesh network, and use those for protection.

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 <= i < n} of V. The directed edges {(R_i, R_i+1) and (R_i+1, R_i), 0 <= 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.

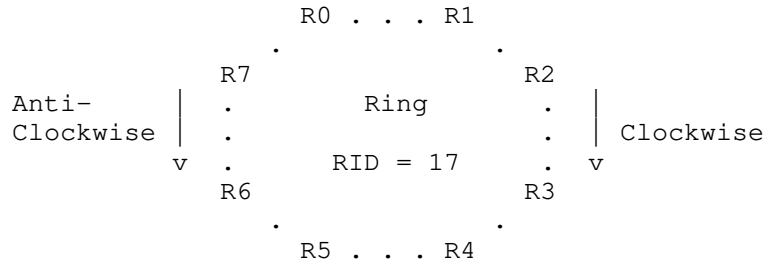


Figure 1: Ring with 8 nodes

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. A node may belong to multiple rings.

Ring node: A member of a ring. Note that a device may belong to several rings.

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 connnect ring neighbors.

Express links: Links that connnect 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

EX: 11 express link

Ring Identification: The process of discovering ring nodes, ring links, link directions, and express 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: A label allocated by R_j for RL_k in the CW direction.

AL_jk: A label allocated by R_j for RL_k in the 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 express 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 overriden 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. For every non-zero RID N hears from a neighbor, N joins the corresponding ring by taking on that RID. In many situations, the use of promiscuous mode means that only one or two nodes in a 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. RMR is primarily intended for operation at the packet layer; however, parallel links at the lambda or fiber layer result in parallel links at the packet layer.

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. Express Links

Express links are discovered once ring nodes, ring links and directions have been established. As defined earlier, express links are links joining non-neighboring ring nodes; often, this may be the

result of optically bypassing ring nodes. The use of express 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 bypass LSPs, 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. For RSVP-TE, this indication can be a PathErr or a Notify; other signaling protocols have similar indications. 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.

Note that the failure of a node or a link will not necessarily affect all ring LSPs. Thus, it is important to identify the affected LSPs (and switch them), but to leave the rest alone.

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.

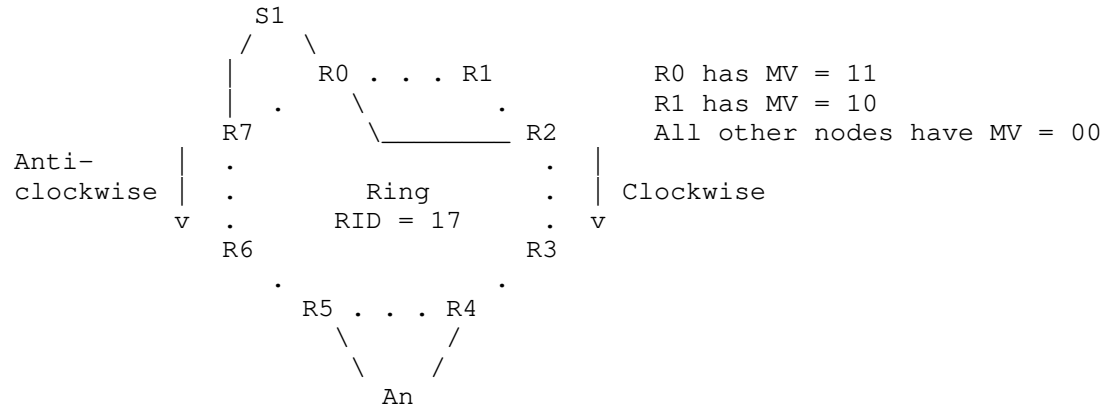
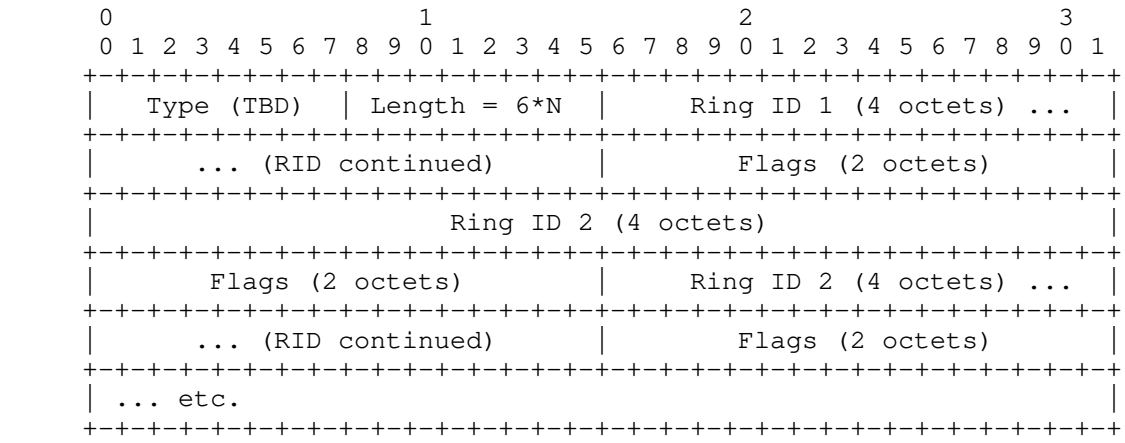
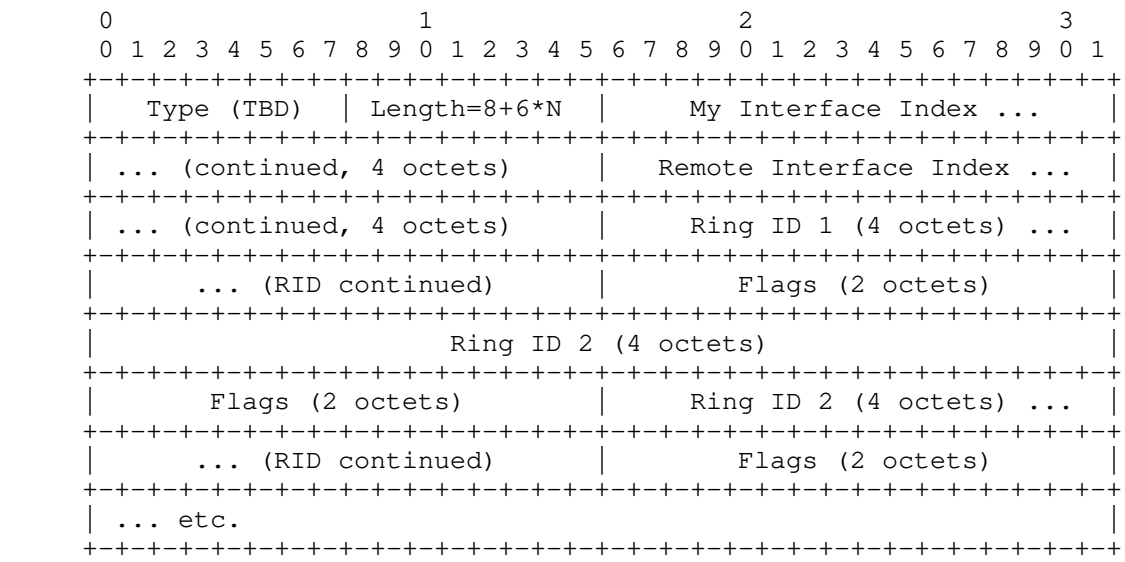


Figure 2: Ring with non-ring nodes and links

In what follows, we refer to a ring node and a rink link Type-Length-Value (TLV). These are new TLVs that contain RIDs and associated flags. A ring node TLV is a TLV that contains information for each ring that this node participates in. A ring link TLV identifies a link and contains information about every ring that that link is part of.



Ring Node TLV Format



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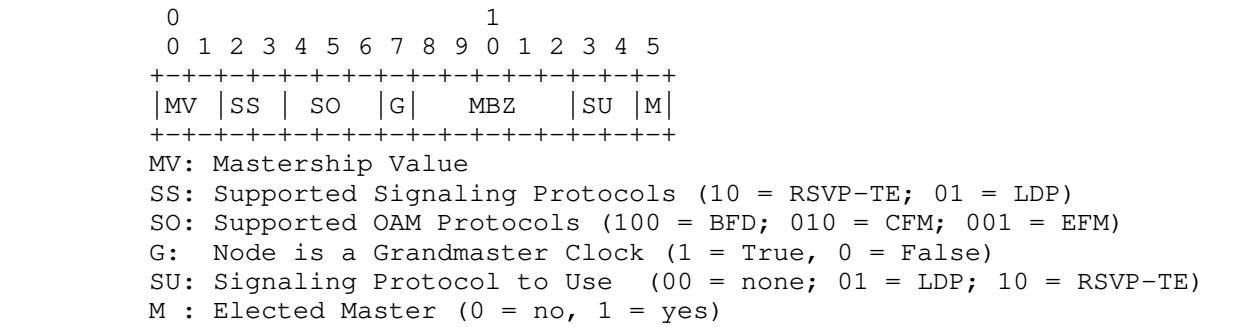
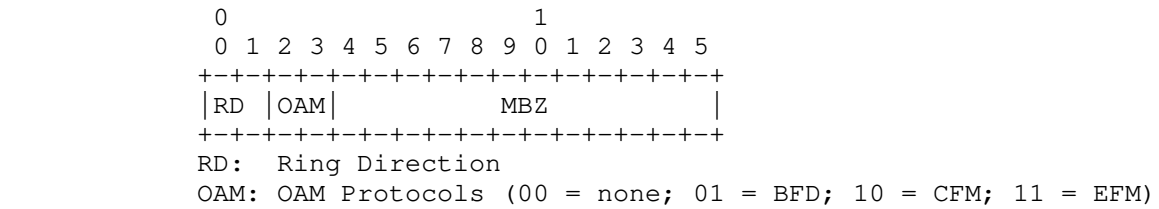


Flags for a Ring Node TLV



Flags for a Ring Link TLV

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. However, when it hears a ring node TLV from an IGP neighbor, it joins that ring, and sends its own ring node TLV with that RID.

The announcement phase allows a ring node to discover other ring nodes in the same ring so that a ring master can be elected.

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 readvertising 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 exaclty 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 express links. These are links connected to ring nodes that are not ring neighbors. X advertises ring link TLVs for express links by setting the link direction to "express link".

4.5. Ring Changes

The main changes to a ring are:

ring link addition;

ring link deletion;

ring node addition; and

ring node deletion.

The main goal of handling ring changes is (as much as possible) not to perturb existing ring operation. Thus, if the ring master hasn't changed, all of the above changes should be local to the point of change. Link adds just update the IGP; signaling should take advantage of the new capacity as soon as it learns. Link deletions in the case of parallel links also show up as a change in capacity (until the last link in the bundle is removed.)

The removal of the last ring link between two nodes, or the removal of a ring node is an event that triggers protection switching. In a simple ring, the result is a broken ring. However, if a ring has express links, then it may be able to converge to a smaller ring with protection. Details of this process will be given in a future version.

The addition of a new ring node can also be handled incrementally. Again, the details of this process will be given in a futre version.

5. Ring Signaling

A future version of this document will specify protocol-independent 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 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.

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10.1. Normative References

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Resilient MPLS Rings
draft-ietf-mpls-rmr-11

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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]. RMR LSPs can also be signaled with SPRING [RFC8402]; that will be described in a future document.

The intent of this document is to handle rings that "occur naturally". Many access and aggregation networks in metros have their start as a simple ring. They may then grow into more complex topologies, for example, by adding parallel links to the ring, or by adding "express" links. The goal here is to discover these rings (with some guidance), and run MPLS over them efficiently. The intent is not to construct rings in a mesh network, and use those for protection.

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 <= i < n} of V. The directed edges {(R_i, R_i+1) and (R_i+1, R_i), 0 <= 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.

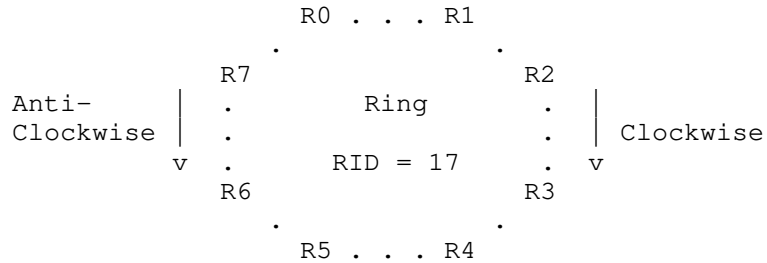

Figure 1: Ring with 8 nodes

The following terminology is used for ring LSPs:

Ring ID (RID): A non-negative number. When the RID identifies a ring, it must be positive and unique in some scope of a Service Provider's network. An RID of zero, when assigned to a node, indicates that the node must behave in "promiscuous mode" (see Section 3.2). A node may belong to multiple rings.

Ring node: A member of a ring. Note that a device may belong to several rings.

Node index: A logical numbering of nodes in a ring, from zero up to 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.

Express 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

EX: 11 express link

Ring Identification: The process of discovering ring nodes, ring links, link directions, and express 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: A label allocated by R_j for RL_k in the CW direction.

AL_jk: A label allocated by R_j for RL_k in the AC direction.

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 express 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 policy 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 overriden 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. For every non-zero RID N hears from a neighbor, N joins the corresponding ring by taking on that RID. In many situations, the use of promiscuous mode means that only one or two nodes in a 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 "auto-bundled" 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. RMR is primarily intended for operation at the packet layer; however, parallel links at the lambda or fiber layer result in parallel links at the packet layer.

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. Express Links

Express links are discovered once ring nodes, ring links and directions have been established. As defined earlier, express links are links joining non-neighboring ring nodes; often, this may be the result of optically bypassing ring nodes.

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, R_k can send OAM messages, for example, an MPLS ping or traceroute ([I-D.ietf-mpls-rfc4379bis]), using labels CL_k,k+1 and AL_k-1,k, to test the entire ring LSP anchored at R_k in both directions. Furthermore, if these LSPs use Ultimate Hop Popping, 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. Protection

In this scheme, there are no protection LSPs as such -- no node or link bypass LSPs, 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. For RSVP-TE, this indication can be a PathErr or a Notify; other signaling protocols have similar indications. 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.

Note that the failure of a node or a link will not necessarily affect all ring LSPs. Thus, it is important to identify the affected LSPs (and switch them), but to leave the rest alone.

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.

3.7. 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.

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.

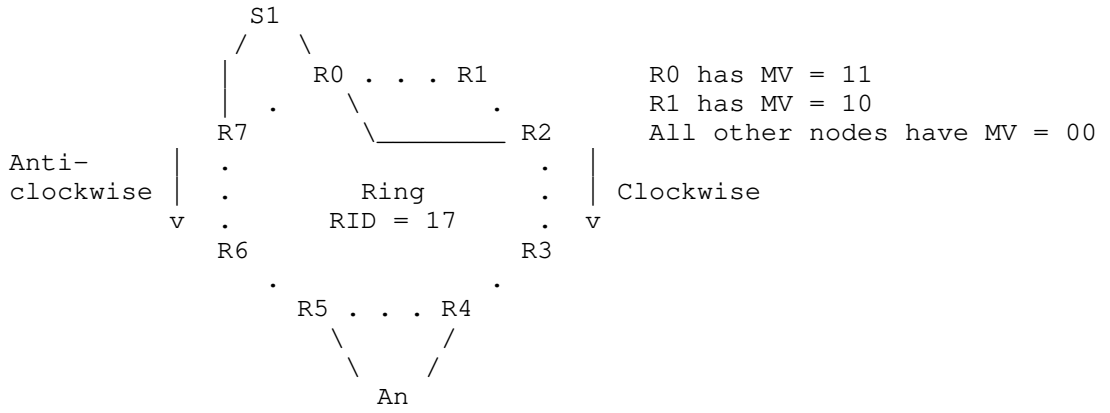

Figure 2: Ring with non-ring nodes and links

The format of an RMR Node Type-Length-Value (TLV) is given below. It consists of information pertaining to the node and optionally, sub-TLVs. A Neighbor sub-TLV contains information pertaining to the node's neighbors. Other sub-TLVs may be defined in the future. Details of the format specific to IS-IS and OSPF will be given in the corresponding IGP documents.

[RMR Node Type][RMR Node Length][RID][Node Flags][sub-TLVs]

Ring Node TLV Format

[RMR Nbr Type][RMR Nbr Length][Nbr Address][Nbr Flags]

Ring Neighbor Sub-TLV Format

MV: Mastership Value
SS: Supported Signaling Protocols
(100 = RSVP-TE; 010 = LDP; 001 = SPRING)
MBZ: Must be zero
SO: Supported OAM Protocols (100 = BFD; 010 = CFM; 001 = EFM)
SU: Signaling Protocol to Use (00 = none; 01 = LDP; 10 = RSVP-TE)
M : Elected Master (0 = no, 1 = yes)

Flags for a Ring Node TLV

RD: Ring Direction
OAM: OAM Protocol to use (00 = none; 01 = BFD; 10 = CFM; 11 = EFM)
MBZ: Must be zero

Flags for a Ring Neighbor TLV

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; this timer is to allow each node time to hear from all other nodes in the ring.

A node in promiscuous mode doesn't advertise any ring node TLVs. However, when it hears a ring node TLV from an IGP neighbor, it joins that ring, and sends its own ring node TLV with that RID.

The announcement phase allows a ring node to discover other ring nodes in the same ring so that a ring master can be elected.

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 readvertising 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.

Barring software bugs or malicious code, the principal reason for multiple nodes for setting their M bit is late-arriving ring announcements. Say nodes N1 and N2 have the highest mastership values, and N1 has the lowest loopback address, while N2 has the second lowest loopback address. If N1 makes its ring announcement just as N2's T1 timer fires, both N1 and N2 will think they are the master (since N2 will not have heard N1's announcment in time). However, in the next round, N2 will realize that N1 is indeed the master. In the worst case, the mastership phase will occur as many times as there are nodes in the ring.

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 express links. These are links connected to ring nodes that are not ring neighbors. X advertises ring link TLVs for express links by setting the link direction to "express link".

4.5. Ring Changes

The main changes to a ring are:

ring link addition;

ring link deletion;

ring node addition; and

ring node deletion.

The main goal of handling ring changes is (as much as possible) not to perturb existing ring operation. Thus, if the ring master hasn't changed, all of the above changes should be local to the point of change. Link adds just update the IGP; signaling should take advantage of the new capacity as soon as it learns. Link deletions in the case of parallel links also show up as a change in capacity (until the last link in the bundle is removed.)

The removal of the last ring link between two nodes, or the removal of a ring node is an event that triggers protection switching. In a simple ring, the result is a broken ring. However, if a ring has express links, then it may be able to converge to a smaller ring with protection.

The addition of a new ring node can also be handled incrementally.

5. Ring Signaling

The ring LSP signaling procedures will be described in separate documents describing signaling solution options.

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 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. Advanced Topics

7.1. Half-rings

In some cases, a ring H may be incomplete, either because H is permanently missing a link (not just because of a failure), or because the link required to complete H is in a different IGP area. Either way, the ring discovery algorithm will fail. We call such a ring a "half-ring". Half-rings are sufficiently common that finding a way to deal with them effectively is a useful problem to solve. This topic will not be addressed in this document; that task is left for a future document.

7.2. Hub Node Resilience

Let's call the node(s) that connect a ring to the rest of the network "hub node(s)" (usually, there are a pair of hub nodes.) Suppose a ring has two hub nodes H1 and H2. Suppose further that a non-hub ring node X wants to send traffic to some node Z outside the ring. This could be done, say, by having targeted LDP (T-LDP) sessions from H1 and H2 to X advertising LDP reachability to Z via H1 (H2); there would be a two-label stack from X to reach Z. Say that to reach Z, X prefers H1; thus, traffic from X to Z will first go to H1 via a ring LSP, then to Z via LDP.

If H1 fails, traffic from X to Z will drop until the T-LDP session from H1 to Z fails, the IGP reconverges, and H2's label to Z is chosen. Thereafter, traffic will go from X to H2 via a ring LSP, then to Z via LDP. However, this convergence could take a long time. Since this is a very common and important situation, it is again a useful problem to solve. However, this topic too will not be addressed in this document; that task is left for a future document.

8. Security Considerations

This document proposes extensions to IS-IS, OSPF, LDP and RSVP-TE, all of which have mechanisms to secure them. The extensions proposed do not represent per se a compromise to network security when the control plane is secured, since any manipulation of the content of the messages or even the control plane misinterpretation of the semantics are avoided.

9. 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.

10. IANA Considerations

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

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11.1. Normative References

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A YANG Data Model for Path Computation Element Communications Protocol (PCEP)
draft-ietf-pce-pcep-yang-01

Abstract

This document defines a YANG data model for the management of Path Computation Element communications Protocol (PCEP) for communications between a Path Computation Client (PCC) and a Path Computation Element (PCE), or between two PCEs. The data model includes configuration data and state data (status information and counters for the collection of statistics).

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, 2017.

Table of Contents

1. Introduction

The Path Computation Element (PCE) defined in [RFC4655] is an entity that is capable of computing a network path or route based on a network graph, and applying computational constraints. A Path

Computation Client (PCC) may make requests to a PCE for paths to be computed.

PCEP is the communication protocol between a PCC and PCE and is defined in [RFC5440]. PCEP interactions include path computation requests and path computation replies as well as notifications of specific states related to the use of a PCE in the context of Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Traffic Engineering (TE). [I-D.ietf-pce-stateful-pce] specifies extensions to PCEP to enable stateful control of MPLS TE LSPs.

This document defines a YANG [RFC6020] data model for the management of PCEP speakers. It is important to establish a common data model for how PCEP speakers are identified, configured, and monitored. The data model includes configuration data and state data (status information and counters for the collection of statistics).

This document contains a specification of the PCEP YANG module, "ietf-pcep" which provides the PCEP [RFC5440] data model.

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. Terminology and Notation

This document uses the terminology defined in [RFC4655] and [RFC5440]. In particular, it uses the following acronyms.

- Path Computation Request message (PCReq).
- Path Computation Reply message (PCRep).
- Notification message (PCNtf).
- Error message (PCErr).
- Request Parameters object (RP).
- Synchronization Vector object (SVEC).
- Explicit Route object (ERO).

This document also uses the following terms defined in [RFC7420]:

- PCEP entity: a local PCEP speaker.

- PCEP peer: to refer to a remote PCEP speaker.
- PCEP speaker: where it is not necessary to distinguish between local and remote.

Further, this document also uses the following terms defined in [I-D.ietf-pce-stateful-pce] :

- Stateful PCE, Passive Stateful PCE, Active Stateful PCE
- Delegation, Revocation, Redelegation
- LSP State Report, Path Computation Report message (PCRpt).
- LSP State Update, Path Computation Update message (PCUpd).

[I-D.ietf-pce-pce-initiated-lsp] :

- PCE-initiated LSP, Path Computation LSP Initiate Message (PCInitiate).

[I-D.ietf-pce-lsp-setup-type] :

- Path Setup Type (PST).

[I-D.ietf-pce-segment-routing] :

- Segment Routing (SR).

3.1. Tree Diagrams

A graphical representation of the complete data tree is presented in Section 5. The meaning of the symbols in these diagrams is as follows and as per [I-D.ietf-netmod-rfc6087bis]:

- Brackets "[" and "]" enclose list keys.
- Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- Symbols after data node names: "?" means an optional node, "!" means a presence container, and "*" denotes a list and leaf-list.
- Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- Ellipsis ("...") stands for contents of subtrees that are not shown.

3.2. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are often used without a prefix, as long as it is clear from the context in which YANG module each name is defined. Otherwise, names are prefixed using the standard prefix associated with the corresponding YANG module, as shown in Table 1.

Prefix	YANG module	Reference
yang	ietf-yang-types	[RFC6991]
inet	ietf-inet-types	[RFC6991]
te	ietf-te	[I-D.ietf-teas-yang-te]
te-types	ietf-te-types	[I-D.ietf-teas-yang-te]
key-chain	ietf-key-chain	[I-D.ietf-rtgwg-yang-key-chain]

Table 1: Prefixes and corresponding YANG modules

4. Objectives

This section describes some of the design objectives for the model:

- In case of existing implementations, it needs to map the data model defined in this document to their proprietary native data model. To facilitate such mappings, the data model should be simple.

- The data model should be suitable for new implementations to use as is.

- Mapping to the PCEP MIB Module should be clear.

- The data model should allow for static configurations of peers.

- The data model should include read-only counters in order to gather statistics for sent and received PCEP messages, received messages with errors, and messages that could not be sent due to errors.

- It should be fairly straightforward to augment the base data model for advanced PCE features.

5. The Design of PCEP Data Model

The module, "ietf-pcep", defines the basic components of a PCE speaker.

```
module: ietf-pcep
   +--rw pcep!
   |  +--rw entity
   |     +--rw addr                              inet:ip-address
   |     +--rw enabled?                          boolean
   |     +--rw role                              pcep-role
   |     +--rw description?                      string
   |     +--rw speaker-entity-id?                string {stateful-sync-opt}?
   |     +--rw domain
   |     |  +--rw domain* [domain-type domain]
   |     |     +--rw domain-type    domain-type
   |     |     +--rw domain         domain
   |     +--rw capability
   |     |  +--rw gmpls?                 boolean {gmpls}?
   |     |  +--rw bi-dir?                boolean
   |     |  +--rw diverse?               boolean
   |     |  +--rw load-balance?          boolean
   |     |  +--rw synchronize?           boolean {svec}?
   |     |  +--rw objective-function?    boolean {objective-function}?
   |     |  +--rw add-path-constraint?   boolean
   |     |  +--rw prioritization?        boolean
   |     |  +--rw multi-request?         boolean
   |     |  +--rw gco?                   boolean {gco}?
   |     |  +--rw p2mp?                  boolean {p2mp}?
   |     |  +--rw stateful {stateful}?
   |     |  |  +--rw enabled?                boolean
   |     |  |  +--rw active?                 boolean
   |     |  |  +--rw pce-initiated?          boolean {pce-initiated}?
   |     |  |  +--rw include-db-ver?         boolean {stateful-sync-opt}?
   |     |  |  +--rw trigger-resync?         boolean {stateful-sync-opt}?
   |     |  |  +--rw trigger-initial-sync?   boolean {stateful-sync-opt}?
   |     |  |  +--rw incremental-sync?       boolean {stateful-sync-opt}?
   |     |  +--rw sr {sr}?
   |     |     +--rw enabled?   boolean
   |     +--rw pce-info
   |     |  +--rw scope
   |     |  |  +--rw intra-area-scope?           boolean
   |     |  |  +--rw intra-area-pref?            uint8
   |     |  |  +--rw inter-area-scope?           boolean
   |     |  |  +--rw inter-area-scope-default?   boolean
   |     |  |  +--rw inter-area-pref?            uint8
   |     |  |  +--rw inter-as-scope?             boolean
   |     |  |  +--rw inter-as-scope-default?     boolean
```

```
|      |  |  +--rw inter-as-pref?              uint8
|      |  |  +--rw inter-layer-scope?          boolean
|      |  |  +--rw inter-layer-pref?           uint8
|      |  +--rw neigh-domains
|      |  |  +--rw domain* [domain-type domain]
|      |  |     +--rw domain-type    domain-type
|      |  |     +--rw domain         domain
|      |  +--rw path-key {path-key}?
|      |     +--rw enabled?         boolean
|      |     +--rw discard-timer?   uint32
|      |     +--rw reuse-time?      uint32
|      |     +--rw pce-id?          inet:ip-address
|      +--rw (auth-type-selection)?
|      |  +--:(auth-key-chain)
|      |  |  +--rw key-chain?                    key-chain:key-chain-ref
|      |  +--:(auth-key)
|      |  |  +--rw key?                          string
|      |  |  +--rw crypto-algorithm
|      |  |     +--rw (algorithm)?
|      |  |        +--:(hmac-sha-1-12) {crypto-hmac-sha-1-12}?
|      |  |        |  +--rw hmac-sha1-12?             empty
|      |  |        +--:(aes-cmac-prf-128) {aes-cmac-prf-128}?
|      |  |        |  +--rw aes-cmac-prf-128?         empty
|      |  |        +--:(md5)
|      |  |        |  +--rw md5?                      empty
|      |  |        +--:(sha-1)
|      |  |        |  +--rw sha-1?                    empty
|      |  |        +--:(hmac-sha-1)
|      |  |        |  +--rw hmac-sha-1?               empty
|      |  |        +--:(hmac-sha-256)
|      |  |        |  +--rw hmac-sha-256?             empty
|      |  |        +--:(hmac-sha-384)
|      |  |        |  +--rw hmac-sha-384?             empty
|      |  |        +--:(hmac-sha-512)
|      |  |        |  +--rw hmac-sha-512?             empty
|      |  |        +--:(clear-text) {clear-text}?
|      |  |        |  +--rw clear-text?               empty
|      |  |        +--:(replay-protection-only) {replay-protection-only}?
|      |  |           +--rw replay-protection-only?   empty
|      |  +--:(auth-tls) {tls}?
|      |     +--rw tls
|      +--rw connect-timer?               uint32
|      +--rw connect-max-retry?           uint32
|      +--rw init-backoff-timer?          uint32
|      +--rw max-backoff-timer?           uint32
|      +--rw open-wait-timer?             uint32
|      +--rw keep-wait-timer?             uint32
|      +--rw keep-alive-timer?            uint32
```

```
|      +--rw dead-timer?                    uint32
|      +--rw allow-negotiation?             boolean
|      +--rw max-keep-alive-timer?          uint32
|      +--rw max-dead-timer?                uint32
|      +--rw min-keep-alive-timer?          uint32
|      +--rw min-dead-timer?                uint32
|      +--rw sync-timer?                    uint32 {svec}?
|      +--rw request-timer?                 uint32
|      +--rw max-sessions?                  uint32
|      +--rw max-unknown-reqs?              uint32
|      +--rw max-unknown-msgs?              uint32
|      +--rw pcep-notification-max-rate     uint32
|      +--rw stateful-parameter {stateful}?
|      |  +--rw state-timeout?          uint32
|      |  +--rw redelegation-timeout?   uint32
|      |  +--rw rpt-non-pcep-lsp?       boolean
|      +--rw of-list {objective-function}?
|      |  +--rw objective-function* [of]
|      |     +--rw of    objective-function
|      +--rw peers
|         +--rw peer* [addr]
|            +--rw addr                inet:ip-address
|            +--rw description?        string
|            +--rw domain
|            |  +--rw domain* [domain-type domain]
|            |     +--rw domain-type    domain-type
|            |     +--rw domain         domain
|            +--rw capability
|            |  +--rw gmpls?                 boolean {gmpls}?
|            |  +--rw bi-dir?                boolean
|            |  +--rw diverse?               boolean
|            |  +--rw load-balance?          boolean
|            |  +--rw synchronize?           boolean {svec}?
|            |  +--rw objective-function?    boolean {objective-function}?
|            |  +--rw add-path-constraint?   boolean
|            |  +--rw prioritization?        boolean
|            |  +--rw multi-request?         boolean
|            |  +--rw gco?                   boolean {gco}?
|            |  +--rw p2mp?                  boolean {p2mp}?
|            |  +--rw stateful {stateful}?
|            |  |  +--rw enabled?                boolean
|            |  |  +--rw active?                 boolean
|            |  |  +--rw pce-initiated?          boolean {pce-initiated}?
|            |  |  +--rw include-db-ver?         boolean {stateful-sync-opt}?
|            |  |  +--rw trigger-resync?         boolean {stateful-sync-opt}?
|            |  |  +--rw trigger-initial-sync?   boolean {stateful-sync-opt}?
|            |  |  +--rw incremental-sync?       boolean {stateful-sync-opt}?
|            |  +--rw sr {sr}?
```

```
   |            |     +--rw enabled?   boolean
   |            +--rw scope
   |            |  +--rw intra-area-scope?           boolean
   |            |  +--rw intra-area-pref?            uint8
   |            |  +--rw inter-area-scope?           boolean
   |            |  +--rw inter-area-scope-default?   boolean
   |            |  +--rw inter-area-pref?            uint8
   |            |  +--rw inter-as-scope?             boolean
   |            |  +--rw inter-as-scope-default?     boolean
   |            |  +--rw inter-as-pref?              uint8
   |            |  +--rw inter-layer-scope?          boolean
   |            |  +--rw inter-layer-pref?           uint8
   |            +--rw neigh-domains
   |            |  +--rw domain* [domain-type domain]
   |            |     +--rw domain-type    domain-type
   |            |     +--rw domain         domain
   |            +--rw delegation-pref?    uint8 {stateful}?
   |            +--rw (auth-type-selection)?
   |            |  +--:(auth-key-chain)
   |            |  |  +--rw key-chain?          key-chain:key-chain-ref
   |            |  +--:(auth-key)
   |            |  |  +--rw key?                string
   |            |  |  +--rw crypto-algorithm
   |            |  |     +--rw (algorithm)?
   |            |  |        +--:(hmac-sha-1-12) {crypto-hmac-sha-1-12}?
   |            |  |        |  +--rw hmac-sha1-12?             empty
   |            |  |        +--:(aes-cmac-prf-128) {aes-cmac-prf-128}?
   |            |  |        |  +--rw aes-cmac-prf-128?         empty
   |            |  |        +--:(md5)
   |            |  |        |  +--rw md5?                      empty
   |            |  |        +--:(sha-1)
   |            |  |        |  +--rw sha-1?                    empty
   |            |  |        +--:(hmac-sha-1)
   |            |  |        |  +--rw hmac-sha-1?               empty
   |            |  |        +--:(hmac-sha-256)
   |            |  |        |  +--rw hmac-sha-256?             empty
   |            |  |        +--:(hmac-sha-384)
   |            |  |        |  +--rw hmac-sha-384?             empty
   |            |  |        +--:(hmac-sha-512)
   |            |  |        |  +--rw hmac-sha-512?             empty
   |            |  |        +--:(clear-text) {clear-text}?
   |            |  |        |  +--rw clear-text?               empty
   |            |  |        +--:(replay-protection-only) {replay-protection-only}
?
   |            |  |           +--rw replay-protection-only?   empty
   |            |  +--:(auth-tls) {tls}?
   |            |     +--rw tls
   |            +--rw of-list {objective-function}?
   |               +--rw objective-function* [of]
```

```
   |                +--rw of    objective-function
   +--ro pcep-state
      +--ro entity
         +--ro addr?                   inet:ip-address
         +--ro index?                  uint32
         +--ro admin-status?           pcep-admin-status
         +--ro oper-status?            pcep-admin-status
         +--ro role?                   pcep-role
         +--ro description?            string
         +--ro speaker-entity-id?      string {stateful-sync-opt}?
         +--ro domain
         |  +--ro domain* [domain-type domain]
         |     +--ro domain-type    domain-type
         |     +--ro domain         domain
         +--ro capability
         |  +--ro gmpls?                boolean {gmpls}?
         |  +--ro bi-dir?               boolean
         |  +--ro diverse?              boolean
         |  +--ro load-balance?         boolean
         |  +--ro synchronize?          boolean {svec}?
         |  +--ro objective-function?   boolean {objective-function}?
         |  +--ro add-path-constraint?  boolean
         |  +--ro prioritization?       boolean
         |  +--ro multi-request?        boolean
         |  +--ro gco?                  boolean {gco}?
         |  +--ro p2mp?                 boolean {p2mp}?
         |  +--ro stateful {stateful}?
         |  |  +--ro enabled?               boolean
         |  |  +--ro active?                boolean
         |  |  +--ro pce-initiated?         boolean {pce-initiated}?
         |  |  +--ro include-db-ver?        boolean {stateful-sync-opt}?
         |  |  +--ro trigger-resync?        boolean {stateful-sync-opt}?
         |  |  +--ro trigger-initial-sync?  boolean {stateful-sync-opt}?
         |  |  +--ro incremental-sync?      boolean {stateful-sync-opt}?
         |  +--ro sr {sr}?
         |     +--ro enabled?   boolean
         +--ro pce-info
         |  +--ro scope
         |  |  +--ro intra-area-scope?           boolean
         |  |  +--ro intra-area-pref?            uint8
         |  |  +--ro inter-area-scope?           boolean
         |  |  +--ro inter-area-scope-default?   boolean
         |  |  +--ro inter-area-pref?            uint8
         |  |  +--ro inter-as-scope?             boolean
         |  |  +--ro inter-as-scope-default?     boolean
         |  |  +--ro inter-as-pref?              uint8
         |  |  +--ro inter-layer-scope?          boolean
         |  |  +--ro inter-layer-pref?           uint8
```

```
          |  +--ro neigh-domains
          |  |  +--ro domain* [domain-type domain]
          |  |     +--ro domain-type    domain-type
          |  |     +--ro domain         domain
          |  +--ro path-key {path-key}?
          |     +--ro enabled?         boolean
          |     +--ro discard-timer?   uint32
          |     +--ro reuse-time?      uint32
          |     +--ro pce-id?          inet:ip-address
          +--ro (auth-type-selection)?
          |  +--:(auth-key-chain)
          |  |  +--ro key-chain?              key-chain:key-chain-ref
          |  +--:(auth-key)
          |  |  +--ro key?                    string
          |  |  +--ro crypto-algorithm
          |  |     +--ro (algorithm)?
          |  |        +--:(hmac-sha-1-12) {crypto-hmac-sha-1-12}?
          |  |        |  +--ro hmac-sha1-12?             empty
          |  |        +--:(aes-cmac-prf-128) {aes-cmac-prf-128}?
          |  |        |  +--ro aes-cmac-prf-128?         empty
          |  |        +--:(md5)
          |  |        |  +--ro md5?                      empty
          |  |        +--:(sha-1)
          |  |        |  +--ro sha-1?                    empty
          |  |        +--:(hmac-sha-1)
          |  |        |  +--ro hmac-sha-1?               empty
          |  |        +--:(hmac-sha-256)
          |  |        |  +--ro hmac-sha-256?             empty
          |  |        +--:(hmac-sha-384)
          |  |        |  +--ro hmac-sha-384?             empty
          |  |        +--:(hmac-sha-512)
          |  |        |  +--ro hmac-sha-512?             empty
          |  |        +--:(clear-text) {clear-text}?
          |  |        |  +--ro clear-text?               empty
          |  |        +--:(replay-protection-only) {replay-protection-only}?
          |  |           +--ro replay-protection-only?   empty
          |  +--:(auth-tls) {tls}?
          |     +--ro tls
          +--ro connect-timer?          uint32
          +--ro connect-max-retry?      uint32
          +--ro init-backoff-timer?     uint32
          +--ro max-backoff-timer?      uint32
          +--ro open-wait-timer?        uint32
          +--ro keep-wait-timer?        uint32
          +--ro keep-alive-timer?       uint32
          +--ro dead-timer?             uint32
          +--ro allow-negotiation?      boolean
          +--ro max-keep-alive-timer?   uint32
```

```
         +--ro max-dead-timer?         uint32
         +--ro min-keep-alive-timer?   uint32
         +--ro min-dead-timer?         uint32
         +--ro sync-timer?             uint32 {svec}?
         +--ro request-timer?          uint32
         +--ro max-sessions?           uint32
         +--ro max-unknown-reqs?       uint32
         +--ro max-unknown-msgs?       uint32
         +--ro stateful-parameter {stateful}?
         |  +--ro state-timeout?          uint32
         |  +--ro redelegation-timeout?   uint32
         |  +--ro rpt-non-pcep-lsp?       boolean
         +--ro lsp-db {stateful}?
         |  +--ro db-ver?             uint64 {stateful-sync-opt}?
         |  +--ro association-list* [id source global-source extended-id]
         |  |  +--ro type?            assoc-type
         |  |  +--ro id               uint16
         |  |  +--ro source           inet:ip-address
         |  |  +--ro global-source    uint32
         |  |  +--ro extended-id      string
         |  |  +--ro lsp* [plsp-id pcc-id]
         |  |     +--ro plsp-id    -> /pcep-state/entity/lsp-db/lsp/plsp-id
         |  |     +--ro pcc-id     -> /pcep-state/entity/lsp-db/lsp/pcc-id
         |  +--ro lsp* [plsp-id pcc-id]
         |     +--ro plsp-id               uint32
         |     +--ro pcc-id                inet:ip-address
         |     +--ro lsp-ref
         |     |  +--ro source?               -> /te:te/lsps-state/lsp/source
         |     |  +--ro destination?          -> /te:te/lsps-state/lsp/destinati
on
         |     |  +--ro tunnel-id?            -> /te:te/lsps-state/lsp/tunnel-id
         |     |  +--ro lsp-id?               -> /te:te/lsps-state/lsp/lsp-id
         |     |  +--ro extended-tunnel-id?   -> /te:te/lsps-state/lsp/extended-
tunnel-id
         |     |  +--ro type?                 -> /te:te/lsps-state/lsp/type
         |     +--ro admin-state?          boolean
         |     +--ro operational-state?    operational-state
         |     +--ro delegated
         |     |  +--ro enabled?   boolean
         |     |  +--ro pce?       -> /pcep-state/entity/peers/peer/addr
         |     |  +--ro srp-id?    uint32
         |     +--ro initiation {pce-initiated}?
         |     |  +--ro enabled?   boolean
         |     |  +--ro pce?       -> /pcep-state/entity/peers/peer/addr
         |     +--ro symbolic-path-name?   string
         |     +--ro last-error?           lsp-error
         |     +--ro pst?                  pst
         |     +--ro association-list* [id source global-source extended-id]
         |        +--ro id               -> /pcep-state/entity/lsp-db/associatio
n-list/id
         |        +--ro source           -> /pcep-state/entity/lsp-db/associatio
n-list/source
```

```
         |        +--ro global-source    -> /pcep-state/entity/lsp-db/associatio
n-list/global-source
         |        +--ro extended-id      -> /pcep-state/entity/lsp-db/associatio
n-list/extended-id
         +--ro path-keys {path-key}?
         |  +--ro path-keys* [path-key]
         |     +--ro path-key         uint16
         |     +--ro cps
         |     |  +--ro explicit-route-objects* [index]
         |     |     +--ro index                   uint8
         |     |     +--ro explicit-route-usage?   identityref
         |     |     +--ro (type)?
         |     |        +--:(ipv4-address)
         |     |        |  +--ro v4-address?             inet:ipv4-address
         |     |        |  +--ro v4-prefix-length?       uint8
         |     |        |  +--ro v4-loose?               boolean
         |     |        +--:(ipv6-address)
         |     |        |  +--ro v6-address?             inet:ipv6-address
         |     |        |  +--ro v6-prefix-length?       uint8
         |     |        |  +--ro v6-loose?               boolean
         |     |        +--:(as-number)
         |     |        |  +--ro as-number?              uint16
         |     |        +--:(unnumbered-link)
         |     |        |  +--ro router-id?              inet:ip-address
         |     |        |  +--ro interface-id?           uint32
         |     |        +--:(label)
         |     |           +--ro value?                 uint32
         |     +--ro pcc-original?    -> /pcep-state/entity/peers/peer/addr
         |     +--ro req-id?          uint32
         |     +--ro retrieved?       boolean
         |     +--ro pcc-retrieved?   -> /pcep-state/entity/peers/peer/addr
         |     +--ro creation-time?   yang:timestamp
         |     +--ro discard-time?    uint32
         |     +--ro reuse-time?      uint32
         +--ro of-list {objective-function}?
         |  +--ro objective-function* [of]
         |     +--ro of    objective-function
         +--ro peers
            +--ro peer* [addr]
               +--ro addr                    inet:ip-address
               +--ro role?                   pcep-role
               +--ro domain
               |  +--ro domain* [domain-type domain]
               |     +--ro domain-type    domain-type
               |     +--ro domain         domain
               +--ro capability
               |  +--ro gmpls?                boolean {gmpls}?
               |  +--ro bi-dir?               boolean
               |  +--ro diverse?              boolean
               |  +--ro load-balance?         boolean
```

```
|  +--ro synchronize?           boolean {svec}?
|  +--ro objective-function?    boolean {objective-function}?
|  +--ro add-path-constraint?   boolean
|  +--ro prioritization?        boolean
|  +--ro multi-request?         boolean
|  +--ro gco?                   boolean {gco}?
|  +--ro p2mp?                  boolean {p2mp}?
|  +--ro stateful {stateful}?
|  |  +--ro enabled?                boolean
|  |  +--ro active?                 boolean
|  |  +--ro pce-initiated?          boolean {pce-initiated}?
|  |  +--ro include-db-ver?         boolean {stateful-sync-opt}?
|  |  +--ro trigger-resync?         boolean {stateful-sync-opt}?
|  |  +--ro trigger-initial-sync?   boolean {stateful-sync-opt}?
|  |  +--ro incremental-sync?       boolean {stateful-sync-opt}?
|  +--ro sr {sr}?
|     +--ro enabled?   boolean
+--ro pce-info
|  +--ro scope
|  |  +--ro intra-area-scope?           boolean
|  |  +--ro intra-area-pref?            uint8
|  |  +--ro inter-area-scope?           boolean
|  |  +--ro inter-area-scope-default?   boolean
|  |  +--ro inter-area-pref?            uint8
|  |  +--ro inter-as-scope?             boolean
|  |  +--ro inter-as-scope-default?     boolean
|  |  +--ro inter-as-pref?              uint8
|  |  +--ro inter-layer-scope?          boolean
|  |  +--ro inter-layer-pref?           uint8
|  +--ro neigh-domains
|     +--ro domain* [domain-type domain]
|        +--ro domain-type    domain-type
|        +--ro domain         domain
+--ro delegation-pref?        uint8 {stateful}?
+--ro (auth-type-selection)?
|  +--:(auth-key-chain)
|  |  +--ro key-chain?              key-chain:key-chain-ref
|  +--:(auth-key)
|  |  +--ro key?                    string
|  |  +--ro crypto-algorithm
|  |     +--ro (algorithm)?
|  |        +--:(hmac-sha-1-12) {crypto-hmac-sha-1-12}?
|  |        |  +--ro hmac-sha1-12?             empty
|  |        +--:(aes-cmac-prf-128) {aes-cmac-prf-128}?
|  |        |  +--ro aes-cmac-prf-128?         empty
|  |        +--:(md5)
|  |        |  +--ro md5?                      empty
|  |        +--:(sha-1)
```

```
                |  |        |  +--ro sha-1?                    empty
                |  |        +--:(hmac-sha-1)
                |  |        |  +--ro hmac-sha-1?               empty
                |  |        +--:(hmac-sha-256)
                |  |        |  +--ro hmac-sha-256?             empty
                |  |        +--:(hmac-sha-384)
                |  |        |  +--ro hmac-sha-384?             empty
                |  |        +--:(hmac-sha-512)
                |  |        |  +--ro hmac-sha-512?             empty
                |  |        +--:(clear-text) {clear-text}?
                |  |        |  +--ro clear-text?               empty
                |  |        +--:(replay-protection-only) {replay-protection-only}
?
                |  |           +--ro replay-protection-only?   empty
                |  +--:(auth-tls) {tls}?
                |     +--ro tls
                +--ro of-list {objective-function}?
                |  +--ro objective-function* [of]
                |     +--ro of    objective-function
                +--ro discontinuity-time?     yang:timestamp
                +--ro initiate-session?       boolean
                +--ro session-exists?         boolean
                +--ro num-sess-setup-ok?      yang:counter32
                +--ro num-sess-setup-fail?    yang:counter32
                +--ro session-up-time?        yang:timestamp
                +--ro session-fail-time?      yang:timestamp
                +--ro session-fail-up-time?   yang:timestamp
                +--ro pcep-stats
                |  +--ro avg-rsp-time?              uint32
                |  +--ro lwm-rsp-time?              uint32
                |  +--ro hwm-rsp-time?              uint32
                |  +--ro num-pcreq-sent?            yang:counter32
                |  +--ro num-pcreq-rcvd?            yang:counter32
                |  +--ro num-pcrep-sent?            yang:counter32
                |  +--ro num-pcrep-rcvd?            yang:counter32
                |  +--ro num-pcerr-sent?            yang:counter32
                |  +--ro num-pcerr-rcvd?            yang:counter32
                |  +--ro num-pcntf-sent?            yang:counter32
                |  +--ro num-pcntf-rcvd?            yang:counter32
                |  +--ro num-keepalive-sent?        yang:counter32
                |  +--ro num-keepalive-rcvd?        yang:counter32
                |  +--ro num-unknown-rcvd?          yang:counter32
                |  +--ro num-corrupt-rcvd?          yang:counter32
                |  +--ro num-req-sent?              yang:counter32
                |  +--ro num-req-sent-pend-rep?     yang:counter32
                |  +--ro num-req-sent-ero-rcvd?     yang:counter32
                |  +--ro num-req-sent-nopath-rcvd?  yang:counter32
                |  +--ro num-req-sent-cancel-rcvd?  yang:counter32
                |  +--ro num-req-sent-error-rcvd?   yang:counter32
```

```
|  +--ro num-req-sent-timeout?       yang:counter32
|  +--ro num-req-sent-cancel-sent?   yang:counter32
|  +--ro num-req-rcvd?               yang:counter32
|  +--ro num-req-rcvd-pend-rep?      yang:counter32
|  +--ro num-req-rcvd-ero-sent?      yang:counter32
|  +--ro num-req-rcvd-nopath-sent?   yang:counter32
|  +--ro num-req-rcvd-cancel-sent?   yang:counter32
|  +--ro num-req-rcvd-error-sent?    yang:counter32
|  +--ro num-req-rcvd-cancel-rcvd?   yang:counter32
|  +--ro num-rep-rcvd-unknown?       yang:counter32
|  +--ro num-req-rcvd-unknown?       yang:counter32
|  +--ro svec {svec}?
|  |  +--ro num-svec-sent?       yang:counter32
|  |  +--ro num-svec-req-sent?   yang:counter32
|  |  +--ro num-svec-rcvd?       yang:counter32
|  |  +--ro num-svec-req-rcvd?   yang:counter32
|  +--ro stateful {stateful}?
|  |  +--ro num-pcrpt-sent?             yang:counter32
|  |  +--ro num-pcrpt-rcvd?             yang:counter32
|  |  +--ro num-pcupd-sent?             yang:counter32
|  |  +--ro num-pcupd-rcvd?             yang:counter32
|  |  +--ro num-rpt-sent?               yang:counter32
|  |  +--ro num-rpt-rcvd?               yang:counter32
|  |  +--ro num-rpt-rcvd-error-sent?    yang:counter32
|  |  +--ro num-upd-sent?               yang:counter32
|  |  +--ro num-upd-rcvd?               yang:counter32
|  |  +--ro num-upd-rcvd-unknown?       yang:counter32
|  |  +--ro num-upd-rcvd-undelegated?   yang:counter32
|  |  +--ro num-upd-rcvd-error-sent?    yang:counter32
|  |  +--ro initiation {pce-initiated}?
|  |     +--ro num-pcinitiate-sent?            yang:counter32
|  |     +--ro num-pcinitiate-rcvd?            yang:counter32
|  |     +--ro num-initiate-sent?              yang:counter32
|  |     +--ro num-initiate-rcvd?              yang:counter32
|  |     +--ro num-initiate-rcvd-error-sent?   yang:counter32
|  +--ro path-key {path-key}?
|  |  +--ro num-unknown-path-key?      yang:counter32
|  |  +--ro num-exp-path-key?          yang:counter32
|  |  +--ro num-dup-path-key?          yang:counter32
|  |  +--ro num-path-key-no-attempt?   yang:counter32
|  +--ro num-req-sent-closed?        yang:counter32
|  +--ro num-req-rcvd-closed?        yang:counter32
+--ro sessions
   +--ro session* [initiator]
      +--ro initiator               pcep-initiator
      +--ro state-last-change?      yang:timestamp
      +--ro state?                  pcep-sess-state
      +--ro session-creation?       yang:timestamp
```

```
                    +--ro connect-retry?          yang:counter32
                    +--ro local-id?               uint32
                    +--ro remote-id?              uint32
                    +--ro keepalive-timer?        uint32
                    +--ro peer-keepalive-timer?   uint32
                    +--ro dead-timer?             uint32
                    +--ro peer-dead-timer?        uint32
                    +--ro ka-hold-time-rem?       uint32
                    +--ro overloaded?             boolean
                    +--ro overload-time?          uint32
                    +--ro peer-overloaded?        boolean
                    +--ro peer-overload-time?     uint32
                    +--ro lspdb-sync?             sync-state {stateful}?
                    +--ro recv-db-ver?            uint64 {stateful,stateful-syn
c-opt}?
                    +--ro of-list {objective-function}?
                    |  +--ro objective-function* [of]
                    |     +--ro of    objective-function
                    +--ro speaker-entity-id?      string {stateful-sync-opt}?
                    +--ro discontinuity-time?     yang:timestamp
                    +--ro pcep-stats
                       +--ro avg-rsp-time?              uint32
                       +--ro lwm-rsp-time?              uint32
                       +--ro hwm-rsp-time?              uint32
                       +--ro num-pcreq-sent?            yang:counter32
                       +--ro num-pcreq-rcvd?            yang:counter32
                       +--ro num-pcrep-sent?            yang:counter32
                       +--ro num-pcrep-rcvd?            yang:counter32
                       +--ro num-pcerr-sent?            yang:counter32
                       +--ro num-pcerr-rcvd?            yang:counter32
                       +--ro num-pcntf-sent?            yang:counter32
                       +--ro num-pcntf-rcvd?            yang:counter32
                       +--ro num-keepalive-sent?        yang:counter32
                       +--ro num-keepalive-rcvd?        yang:counter32
                       +--ro num-unknown-rcvd?          yang:counter32
                       +--ro num-corrupt-rcvd?          yang:counter32
                       +--ro num-req-sent?              yang:counter32
                       +--ro num-req-sent-pend-rep?     yang:counter32
                       +--ro num-req-sent-ero-rcvd?     yang:counter32
                       +--ro num-req-sent-nopath-rcvd?  yang:counter32
                       +--ro num-req-sent-cancel-rcvd?  yang:counter32
                       +--ro num-req-sent-error-rcvd?   yang:counter32
                       +--ro num-req-sent-timeout?      yang:counter32
                       +--ro num-req-sent-cancel-sent?  yang:counter32
                       +--ro num-req-rcvd?              yang:counter32
                       +--ro num-req-rcvd-pend-rep?     yang:counter32
                       +--ro num-req-rcvd-ero-sent?     yang:counter32
                       +--ro num-req-rcvd-nopath-sent?  yang:counter32
                       +--ro num-req-rcvd-cancel-sent?  yang:counter32
```

```
                        +--ro num-req-rcvd-error-sent?    yang:counter32
                        +--ro num-req-rcvd-cancel-rcvd?   yang:counter32
                        +--ro num-rep-rcvd-unknown?       yang:counter32
                        +--ro num-req-rcvd-unknown?       yang:counter32
                        +--ro svec {svec}?
                        |  +--ro num-svec-sent?       yang:counter32
                        |  +--ro num-svec-req-sent?   yang:counter32
                        |  +--ro num-svec-rcvd?       yang:counter32
                        |  +--ro num-svec-req-rcvd?   yang:counter32
                        +--ro stateful {stateful}?
                        |  +--ro num-pcrpt-sent?             yang:counter32
                        |  +--ro num-pcrpt-rcvd?             yang:counter32
                        |  +--ro num-pcupd-sent?             yang:counter32
                        |  +--ro num-pcupd-rcvd?             yang:counter32
                        |  +--ro num-rpt-sent?               yang:counter32
                        |  +--ro num-rpt-rcvd?               yang:counter32
                        |  +--ro num-rpt-rcvd-error-sent?    yang:counter32
                        |  +--ro num-upd-sent?               yang:counter32
                        |  +--ro num-upd-rcvd?               yang:counter32
                        |  +--ro num-upd-rcvd-unknown?       yang:counter32
                        |  +--ro num-upd-rcvd-undelegated?   yang:counter32
                        |  +--ro num-upd-rcvd-error-sent?    yang:counter32
                        |  +--ro initiation {pce-initiated}?
                        |     +--ro num-pcinitiate-sent?            yang:counter
32
                        |     +--ro num-pcinitiate-rcvd?            yang:counter
32
                        |     +--ro num-initiate-sent?              yang:counter
32
                        |     +--ro num-initiate-rcvd?              yang:counter
32
                        |     +--ro num-initiate-rcvd-error-sent?   yang:counter
32
                        +--ro path-key {path-key}?
                           +--ro num-unknown-path-key?      yang:counter32
                           +--ro num-exp-path-key?          yang:counter32
                           +--ro num-dup-path-key?          yang:counter32
                           +--ro num-path-key-no-attempt?   yang:counter32
notifications:
   +---n pcep-session-up
   |  +--ro peer-addr?           -> /pcep-state/entity/peers/peer/addr
   |  +--ro session-initiator?   -> /pcep-state/entity/peers/peer/sessions/sessi
on/initiator
   |  +--ro state-last-change?   yang:timestamp
   |  +--ro state?               pcep-sess-state
   +---n pcep-session-down
   |  +--ro peer-addr?           -> /pcep-state/entity/peers/peer/addr
   |  +--ro session-initiator?   pcep-initiator
   |  +--ro state-last-change?   yang:timestamp
   |  +--ro state?               pcep-sess-state
   +---n pcep-session-local-overload
   |  +--ro peer-addr?           -> /pcep-state/entity/peers/peer/addr
   |  +--ro session-initiator?   -> /pcep-state/entity/peers/peer/sessions/sessi
on/initiator
   |  +--ro overloaded?          boolean
```

```
   |  +--ro overload-time?       uint32
   +---n pcep-session-local-overload-clear
   |  +--ro peer-addr?    -> /pcep-state/entity/peers/peer/addr
   |  +--ro overloaded?   boolean
   +---n pcep-session-peer-overload
   |  +--ro peer-addr?            -> /pcep-state/entity/peers/peer/addr
   |  +--ro session-initiator?    -> /pcep-state/entity/peers/peer/sessions/sess
ion/initiator
   |  +--ro peer-overloaded?      boolean
   |  +--ro peer-overload-time?   uint32
   +---n pcep-session-peer-overload-clear
      +--ro peer-addr?         -> /pcep-state/entity/peers/peer/addr
      +--ro peer-overloaded?   boolean
```

5.1. The Entity

The PCEP yang module may contain status information for the local PCEP entity.

The entity has an IP address (using ietf-inet-types [RFC6991]) and a "role" leaf (the local entity PCEP role) as mandatory.

Note that, the PCEP MIB module [RFC7420] uses an entity list and a system generated entity index as a primary index to the read only entity table. If the device implements the PCEP MIB, the "index" leaf MUST contain the value of the corresponding pcePcepEntityIndex and only one entity is assumed.

5.2. The Peer Lists

The peer list contains peer(s) that the local PCEP entity knows about. A PCEP speaker is identified by its IP address. If there is a PCEP speaker in the network that uses multiple IP addresses then it looks like multiple distinct peers to the other PCEP speakers in the network.

Since PCEP sessions can be ephemeral, the peer list tracks a peer even when no PCEP session currently exists to that peer. The statistics contained are an aggregate of the statistics for all successive sessions to that peer.

To limit the quantity of information that is stored, an implementation MAY choose to discard this information if and only if no PCEP session exists to the corresponding peer.

The data model for PCEP peer presented in this document uses a flat list of peers. Each peer in the list is identified by its IP address (addr-type, addr).

There is one list for static peer configuration ("/pcep/entity/peers"), and a separate list for the operational state of all peers (i.e. static as well as discovered)("/pcep-state/entity/peers"). The former is used to enable remote PCE configuration at PCC (or PCE) while the latter has the operational state of these peers as well as the remote PCE peer which were discovered and PCC peers that have initiated session.

5.3. The Session Lists

The session list contains PCEP session that the PCEP entity (PCE or PCC) is currently participating in. The statistics in session are semantically different from those in peer since the former applies to the current session only, whereas the latter is the aggregate for all sessions that have existed to that peer.

Although [RFC5440] forbids more than one active PCEP session between a given pair of PCEP entities at any given time, there is a window during session establishment where two sessions may exist for a given pair, one representing a session initiated by the local PCEP entity and the other representing a session initiated by the peer. If either of these sessions reaches active state first, then the other is discarded.

The data model for PCEP session presented in this document uses a flat list of sessions. Each session in the list is identified by its initiator. This index allows two sessions to exist transiently for a given peer, as discussed above.

There is only one list for the operational state of all sessions ("/pcep-state/entity/peers/peer/sessions/session").

5.4. Notifications

This YANG model defines a list of notifications to inform client of important events detected during the protocol operation. The notifications defined cover the PCEP MIB notifications.

6. Advanced PCE Features

This document contains a specification of the base PCEP YANG module, "ietf-pcep" which provides the basic PCEP [RFC5440] data model.

This document further handles advanced PCE features like -

- Capability and Scope
- Domain information (local/neighbour)

- Path-Key
- OF
- GCO
- P2MP
- GMPLS
- Inter-Layer
- Stateful PCE
- Segement Routing
- Authentication including PCEPS (TLS)

[Editor's Note - Some of them would be added in a future revision.]

6.1. Stateful PCE's LSP-DB

In the operational state of PCEP which supports stateful PCE mode, the list of LSP state are maintained in LSP-DB. The key is the PLSP-ID and the PCC IP address.

The PCEP data model contains the operational state of LSPs (/pcep-state/entity/lsp-db/lsp/) with PCEP specific attributes. The generic TE attributes of the LSP are defined in [I-D.ietf-teas-yang-te]. A reference to LSP state in TE model is maintained.

7. Open Issues and Next Step

This section is added so that open issues can be tracked. This section would be removed when the document is ready for publication.

7.1. The PCE-Initiated LSP

The TE Model at [I-D.ietf-teas-yang-te] should support creationg of tunnels at the controller (PCE) and marking them as PCE-Initiated. The LSP-DB in the PCEP Yang (/pcep-state/entity/lsp-db/lsp/ initiation) also marks the LSPs which are PCE-initiated.

7.2. PCEP over TLS (PCEPS)

A future version of this document would add TLS related configurations.

8. PCEP YANG Module

RFC Ed.: In this section, replace all occurrences of 'XXXX' with the actual RFC number and all occurrences of the revision date below with the date of RFC publication (and remove this note).

```
<CODE BEGINS> file "ietf-pcep@2016-10-27.yang"
module ietf-pcep {
    namespace "urn:ietf:params:xml:ns:yang:ietf-pcep";
    prefix pcep;

    import ietf-inet-types {
        prefix "inet";
    }

    import ietf-yang-types {
        prefix "yang";
    }

    import ietf-te {
        prefix "te";
    }

    import ietf-te-types {
       prefix "te-types";
    }

    import ietf-key-chain {
       prefix "key-chain";
    }


    organization
        "IETF PCE (Path Computation Element) Working Group";

    contact
        "WG Web:   <http://tools.ietf.org/wg/pce/>
         WG List:  <mailto:pce@ietf.org>
         WG Chair: JP Vasseur
                   <mailto:jpv@cisco.com>
         WG Chair: Julien Meuric
                   <mailto:julien.meuric@orange.com>
         WG Chair: Jonathan Hardwick
                   <mailto:Jonathan.Hardwick@metaswitch.com>
         Editor:   Dhruv Dhody
                   <mailto:dhruv.ietf@gmail.com>";
```

```
    description
        "The YANG module defines a generic configuration and
         operational model for PCEP common across all of the
         vendor implementations.";


    revision 2016-10-27 {
        description "Initial revision.";
        reference
            "RFC XXXX:  A YANG Data Model for Path Computation
                        Element Communications Protocol
                        (PCEP)";
    }

    /*
     * Identities
     */

    identity pcep {
        description "Identity for the PCEP protocol.";
    }

    /*
     * Typedefs
     */
    typedef pcep-role {
        type enumeration {
            enum unknown {
                value "0";
                description
                "An unknown role";
            }
            enum pcc {
                value "1";
                description
                "The role of a Path Computation Client";
            }
            enum pce {
                value "2";
                description
                "The role of Path Computation Element";
            }
            enum pcc-and-pce {
                value "3";
                description
                "The role of both Path Computation Client and
                 Path Computation Element";
            }
```

```
        }

        description
            "The role of a PCEP speaker.
             Takes one of the following values
             - unknown(0): the role is not known.
             - pcc(1): the role is of a Path Computation
               Client (PCC).
             - pce(2): the role is of a Path Computation
               Server (PCE).
             - pccAndPce(3): the role is of both a PCC and
               a PCE.";

    }

    typedef pcep-admin-status {
        type enumeration {
                enum admin-status-up {
                value "1";
                description
                "Admin Status is Up";
            }
            enum admin-status-down {
                value "2";
                description
                "Admin Status is Down";
            }
        }

        description
        "The Admin Status of the PCEP entity.
         Takes one of the following values
             - admin-status-up(1): Admin Status is Up.
             - admin-status-down(2): Admin Status is Down";
    }

    typedef pcep-oper-status {
        type enumeration {
            enum oper-status-up {
                value "1";
                description
                "The PCEP entity is active";
            }
            enum oper-status-down {
                value "2";
                description
                "The PCEP entity is inactive";
            }
```

```
            enum oper-status-going-up {
                value "3";
                description
                "The PCEP entity is activating";
            }
            enum oper-status-going-down {
                value "4";
                description
                "The PCEP entity is deactivating";
            }
            enum oper-status-failed {
                value "5";
                description
                "The PCEP entity has failed and will recover
                 when possible.";
            }
            enum oper-status-failed-perm {
                value "6";
                description
                "The PCEP entity has failed and will not recover
                 without operator intervention";
            }
        }
        description
        "The operational status of the PCEP entity.
         Takes one of the following values
             - oper-status-up(1): Active
             - oper-status-down(2): Inactive
             - oper-status-going-up(3): Activating
             - oper-status-going-down(4): Deactivating
             - oper-status-failed(5): Failed
             - oper-status-failed-perm(6): Failed Permanantly";
    }

    typedef pcep-initiator {
        type enumeration {
            enum local {
                value "1";
                description
                "The local PCEP entity initiated the session";
            }

            enum remote {
                value "2";
                description
                "The remote PCEP peer initiated the session";
            }
        }
```

```
        description
        "The initiator of the session, that is, whether the TCP
         connection was initiated by the local PCEP entity or
         the remote peer.
         Takes one of the following values
             - local(1): Initiated locally
             - remote(2): Initiated remotely";
    }

    typedef pcep-sess-state {
        type enumeration {
            enum tcp-pending {
                value "1";
                description
                    "The tcp-pending state of PCEP session.";
            }

            enum open-wait {
                value "2";
                description
                    "The open-wait state of PCEP session.";
            }

            enum keep-wait {
                value "3";
                description
                    "The keep-wait state of PCEP session.";
            }

            enum session-up {
                value "4";
                description
                    "The session-up state of PCEP session.";
            }
        }
        description
            "The current state of the session.
             The set of possible states excludes the idle state
             since entries do not exist in the idle state.
             Takes one of the following values
                - tcp-pending(1): PCEP TCP Pending state
                - open-wait(2): PCEP Open Wait state
                - keep-wait(3): PCEP Keep Wait state
                - session-up(4): PCEP Session Up state";
    }

    typedef domain-type {
        type enumeration {
```

```
            enum ospf-area {
                value "1";
                description
                    "The OSPF area.";
            }
            enum isis-area {
                value "2";
                description
                    "The IS-IS area.";
            }
            enum as {
                value "3";
                description
                    "The Autonomous System (AS).";
            }
        }
        description
            "The PCE Domain Type";
    }

    typedef domain-ospf-area {
        type union {
            type uint32;
            type yang:dotted-quad;
       }
       description
            "OSPF Area ID.";
    }

    typedef domain-isis-area {
        type string {
            pattern '[0-9A-Fa-f]{2}\.([0-9A-Fa-f]{4}\.){0,3}';
        }
        description
            "IS-IS Area ID.";
    }

    typedef domain-as {
        type uint32;
        description
            "Autonomous System number.";

    }

    typedef domain {
        type union {
            type domain-ospf-area;
            type domain-isis-area;
```

```
            type domain-as;
        }
        description
            "The Domain Information";
    }

    typedef operational-state {
        type enumeration {
            enum down {
                value "0";
                description
                    "not active.";
            }
            enum up {
                value "1";
                description
                    "signalled.";
            }
            enum active {
                value "2";
                description
                    "up and carrying traffic.";
            }
            enum going-down {
                value "3";
                description
                    "LSP is being torn down, resources are
                     being released.";
            }
            enum going-up {
                value "4";
                description
                    "LSP is being signalled.";
            }
        }
        description
            "The operational status of the LSP";
    }

    typedef lsp-error {
        type enumeration {
            enum no-error {
                value "0";
                description
                    "No error, LSP is fine.";
            }
            enum unknown {
                value "1";
```

```
                description
                    "Unknown reason.";
            }
            enum limit {
                value "2";
                description
                    "Limit reached for PCE-controlled LSPs.";
            }
            enum pending {
                value "3";
                description
                    "Too many pending LSP update requests.";
            }
            enum unacceptable {
                value "4";
                description
                    "Unacceptable parameters.";
            }
            enum internal {
                value "5";
                description
                    "Internal error.";
            }
            enum admin {
                value "6";
                description
                    "LSP administratively brought down.";
            }
            enum preempted {
                value "7";
                description
                    "LSP preempted.";
            }
            enum rsvp {
                value "8";
                description
                    "RSVP signaling error.";
            }
        }
        description
            "The LSP Error Codes.";
    }

    typedef sync-state {
        type enumeration {
            enum pending {
                value "0";
                description
```

```
                    "The state synchronization
                     has not started.";
            }
            enum ongoing {
                value "1";
                description
                    "The state synchronization
                     is ongoing.";
            }
            enum finished {
                value "2";
                description
                    "The state synchronization
                     is finished.";
            }
        }
        description
            "The LSP-DB state synchronization operational status.";
    }

    typedef pst{
        type enumeration{
            enum rsvp-te{
                value "0";
                description
                    "RSVP-TE signaling protocol";
            }
            enum sr{
                value "1";
                description
                    "Segment Routing Traffic Engineering";
            }
        }
        description
            "The Path Setup Type";
    }

    typedef assoc-type{
        type enumeration{
            enum protection{
                value "1";
                description
                    "Path Protection Association Type";
            }
        }
        description
            "The PCEP Association Type";
    }
```

```
    typedef objective-function{
        type enumeration{
            enum mcp{
                value "1";
                description
                    "Minimum Cost Path (MCP)";
            }
            enum mlp{
                value "2";
                description
                    "Minimum Load Path (MLP)";
            }
            enum mbp{
                value "3";
                description
                    "Maximum residual Bandwidth Path (MBP)";
            }
            enum mbc{
                value "4";
                description
                    "Minimize aggregate Bandwidth Consumption (MBC)";
            }
            enum mll{
                value "5";
                description
                    "Minimize the Load of the most loaded Link (MLL)";
            }
            enum mcc{
                value "6";
                description
                    "Minimize the Cumulative Cost of a set of paths
                    (MCC)";
            }
            enum spt{
                value "7";
                description
                    "Shortest Path Tree (SPT)";
            }
            enum mct{
                value "8";
                description
                    "Minimum Cost Tree (MCT)";
            }
            enum mplp{
                value "9";
                description
                    "Minimum Packet Loss Path (MPLP)";
            }
```

```
            enum mup{
                value "10";
                description
                    "Maximum Under-Utilized Path (MUP)";
            }
            enum mrup{
                value "11";
                description
                    "Maximum Reserved Under-Utilized Path (MRUP)";
            }
        }
        description
            "The PCEP Objective functions";
    }

    /*
     * Features
     */

    feature svec {
        description
            "Support synchronized path computation.";
    }

    feature gmpls {
        description
            "Support GMPLS.";
    }

    feature objective-function {
        description
            "Support OF as per RFC 5541.";
    }

    feature gco {
        description
            "Support GCO as per RFC 5557.";
    }

    feature path-key {
        description
            "Support path-key as per RFC 5520.";
    }

    feature p2mp {
        description
            "Support P2MP as per RFC 6006.";
    }
```

```
    feature stateful {
        description
            "Support stateful PCE.";
    }

    feature stateful-sync-opt {
        description
            "Support stateful sync optimization";
    }

    feature pce-initiated {
        description
            "Support PCE-Initiated LSP.";
    }

    feature tls {
        description
            "Support PCEP over TLS.";
    }

    feature sr {
        description
            "Support Segment Routing for PCE.";
    }

    /*
     * Groupings
     */



    grouping pcep-entity-info{
        description
            "This grouping defines the attributes for PCEP entity.";
        leaf connect-timer {
            type uint32 {
                range "1..65535";
            }
            units "seconds";
            default 60;
            description
                "The time in seconds that the PCEP entity will wait
                 to establish a TCP connection with a peer.  If a
                 TCP connection is not established within this time
                 then PCEP aborts the session setup attempt.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
```

```
        }

        leaf connect-max-retry {
            type uint32;
            default 5;
            description
                "The maximum number of times the system tries to
                 establish a TCP connection to a peer before the
                 session with the peer transitions to the idle
                 state.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

        leaf init-backoff-timer {
            type uint32 {
                range "1..65535";
            }
            units "seconds";
            description
               "The initial back-off time in seconds for retrying
                a failed session setup attempt to a peer.
                The back-off time increases for each failed
                session setup attempt, until a maximum back-off
                time is reached.  The maximum back-off time is
                max-backoff-timer.";
        }

        leaf max-backoff-timer {
            type uint32;
            units "seconds";
            description
               "The maximum back-off time in seconds for retrying
                a failed session setup attempt to a peer.
                The back-off time increases for each failed session
                setup attempt, until this maximum value is reached.
                Session setup attempts then repeat periodically
                without any further increase in back-off time.";
        }

        leaf open-wait-timer {
            type uint32 {
                range "1..65535";
            }
            units "seconds";
            default 60;
            description
```

```
                "The time in seconds that the PCEP entity will wait
                 to receive an Open message from a peer after the
                 TCP connection has come up.
                 If no Open message is received within this time then
                 PCEP terminates the TCP connection and deletes the
                 associated sessions.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

        leaf keep-wait-timer {
            type uint32 {
                range "1..65535";
            }
            units "seconds";
            default 60;
            description
                "The time in seconds that the PCEP entity will wait
                 to receive a Keepalive or PCErr message from a peer
                 during session initialization after receiving an
                 Open message.  If no Keepalive or PCErr message is
                 received within this time then PCEP terminates the
                 TCP connection and deletes the associated
                 sessions.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

        leaf keep-alive-timer {
            type uint32 {
                range "0..255";
            }
            units "seconds";
            default 30;
            description
                "The keep alive transmission timer that this PCEP
                 entity will propose in the initial OPEN message of
                 each session it is involved in.  This is the
                 maximum time between two consecutive messages sent
                 to a peer. Zero means that the PCEP entity prefers
                 not to send Keepalives at all.
                 Note that the actual Keepalive transmission
                 intervals, in either direction of an active PCEP
                 session, are determined by negotiation between the
                 peers as specified by RFC 5440, and so may differ
                 from this configured value.";
```

```
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

        leaf dead-timer {
            type uint32 {
                range "0..255";
            }
            units "seconds";
            must "(. > ../keep-alive-timer)" {
                error-message "The dead timer must be "
                       + "larger than the keep alive timer";
                description
                    "This value MUST be greater than
                     keep-alive-timer.";

            }
            default 120;
            description
                "The dead timer that this PCEP entity will propose
                 in the initial OPEN message of each session it is
                 involved in. This is the time after which a peer
                 should declare a session down if it does not
                 receive any PCEP messages. Zero suggests that the
                 peer does not run a dead timer at all." ;
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

        leaf allow-negotiation{
            type boolean;
            description
                "Whether the PCEP entity will permit negotiation of
                 session parameters.";
        }

        leaf max-keep-alive-timer{
            type uint32 {
                range "0..255";
            }
            units "seconds";
            description
                "In PCEP session parameter negotiation in seconds,
                 the maximum value that this PCEP entity will
                 accept from a peer for the interval between
                 Keepalive transmissions. Zero means that the PCEP
```

```
                entity will allow no Keepalive transmission at
                all." ;
        }

        leaf max-dead-timer{
            type uint32 {
                range "0..255";
            }
            units "seconds";
            description
                "In PCEP session parameter negotiation in seconds,
                 the maximum value that this PCEP entity will accept
                 from a peer for the Dead timer.  Zero means that
                 the PCEP entity will allow not running a Dead
                 timer.";
        }

        leaf min-keep-alive-timer{
            type uint32 {
                range "0..255";
            }
            units "seconds";
            description
                "In PCEP session parameter negotiation in seconds,
                 the minimum value that this PCEP entity will
                 accept for the interval between Keepalive
                 transmissions. Zero means that the PCEP entity
                 insists on no Keepalive transmission at all.";
        }

        leaf min-dead-timer{
            type uint32 {
                range "0..255";
            }
            units "seconds";
            description
                 "In PCEP session parameter negotiation in
                  seconds, the minimum value that this PCEP entity
                  will accept for the Dead timer.  Zero means that
                  the PCEP entity insists on not running a Dead
                  timer.";
        }

        leaf sync-timer{
            if-feature svec;
            type uint32 {
                range "0..65535";
            }
```

```
            units "seconds";
            default 60;
            description
                "The value of SyncTimer in seconds is used in the
                 case of synchronized path computation request
                 using the SVEC object. Consider the case where a
                 PCReq message is received by a PCE that contains
                 the SVEC object referring to M synchronized path
                 computation requests.  If after the expiration of
                 the SyncTimer all the M path computation requests
                 have not been, received a protocol error is
                 triggered and the PCE MUST cancel the whole set
                 of path computation requests.
                 The aim of the SyncTimer is to avoid the storage
                 of unused synchronized requests should one of
                 them get lost for some reasons (for example, a
                 misbehaving PCC).
                 Zero means that the PCEP entity does not use the
                 SyncTimer.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }


        leaf request-timer{
            type uint32 {
                range "1..65535";
            }
            units "seconds";
            description
                "The maximum time that the PCEP entity will wait
                 for a response to a PCReq message.";
        }

        leaf max-sessions{
            type uint32;
            description
               "Maximum number of sessions involving this PCEP
                entity that can exist at any time.";
        }

        leaf max-unknown-reqs{
            type uint32;
            default 5;
            description
              "The maximum number of unrecognized requests and
               replies that any session on this PCEP entity is
```

```
                willing to accept per minute before terminating
                the session.
                A PCRep message contains an unrecognized reply
                if it contains an RP object whose request ID
                does not correspond to any in-progress request
                sent by this PCEP entity.
                A PCReq message contains an unrecognized request
                if it contains an RP object whose request ID is
                zero.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

        leaf max-unknown-msgs{
            type uint32;
            default 5;
            description
             "The maximum number of unknown messages that any
              session on this PCEP entity is willing to accept
              per minute before terminating the session.";
            reference
                "RFC 5440: Path Computation Element (PCE)
                           Communication Protocol (PCEP)";
        }

    }//pcep-entity-info

    grouping pce-scope{
        description
            "This grouping defines PCE path computation scope
             information which maybe relevant to PCE selection.
             This information corresponds to PCE auto-discovery
             information.";
        reference
            "RFC 5088: OSPF Protocol Extensions for Path
                       Computation Element (PCE)
                       Discovery
             RFC 5089: IS-IS Protocol Extensions for Path
                       Computation Element (PCE)
                       Discovery";
        leaf intra-area-scope{
            type boolean;
            default true;
            description
                "PCE can compute intra-area paths.";
        }
        leaf intra-area-pref{
```

```
            type uint8{
                range "0..7";
            }
            description
              "The PCE's preference for intra-area TE LSP
              computation.";
        }
        leaf inter-area-scope{
            type boolean;
            default false;
            description
                "PCE can compute inter-area paths.";
        }
        leaf inter-area-scope-default{
            type boolean;
            default false;
            description
                "PCE can act as a default PCE for inter-area
                 path computation.";
        }
        leaf inter-area-pref{
            type uint8{
                range "0..7";
            }
            description
              "The PCE's preference for inter-area TE LSP
              computation.";
        }
        leaf inter-as-scope{
            type boolean;
            default false;
            description
                "PCE can compute inter-AS paths.";
        }
        leaf inter-as-scope-default{
            type boolean;
            default false;
            description
                "PCE can act as a default PCE for inter-AS
                 path computation.";
        }
        leaf inter-as-pref{
            type uint8{
                range "0..7";
            }
            description
              "The PCE's preference for inter-AS TE LSP
              computation.";
```

```
        }
        leaf inter-layer-scope{
            type boolean;
            default false;
            description
                "PCE can compute inter-layer paths.";
        }
        leaf inter-layer-pref{
            type uint8{
                range "0..7";
            }
            description
              "The PCE's preference for inter-layer TE LSP
              computation.";
        }
    }//pce-scope

    grouping domain{
        description
            "This grouping specifies a Domain where the
             PCEP speaker has topology visibility.";
        leaf domain-type{
            type domain-type;
            description
              "The domain type.";
        }
        leaf domain{
            type domain;
            description
              "The domain Information.";
        }
    }//domain

    grouping capability{
        description
            "This grouping specifies a capability
             information of local PCEP entity. This maybe
             relevant to PCE selection as well. This
             information corresponds to PCE auto-discovery
             information.";
        reference
            "RFC 5088: OSPF Protocol Extensions for Path
                       Computation Element (PCE)
                       Discovery
             RFC 5089: IS-IS Protocol Extensions for Path
                       Computation Element (PCE)
                       Discovery";
        leaf gmpls{
```

```
            if-feature gmpls;
            type boolean;
            description
              "Path computation with GMPLS link
               constraints.";
          }
          leaf bi-dir{
            type boolean;
            description
              "Bidirectional path computation.";
          }
          leaf diverse{
            type boolean;
            description
              "Diverse path computation.";
          }
          leaf load-balance{
            type boolean;
            description
              "Load-balanced path computation.";
          }
          leaf synchronize{
            if-feature svec;
            type boolean;
            description
              "Synchronized paths computation.";
          }
          leaf objective-function{
            if-feature objective-function;
            type boolean;
            description
              "Support for multiple objective functions.";
          }
          leaf add-path-constraint{
            type boolean;
            description
              "Support for additive path constraints (max
               hop count, etc.).";
          }
          leaf prioritization{
            type boolean;
            description
              "Support for request prioritization.";
          }
          leaf multi-request{
            type boolean;
            description
              "Support for multiple requests per message.";
```

```
        }
        leaf gco{
            if-feature gco;
            type boolean;
            description
              "Support for Global Concurrent Optimization
               (GCO).";
        }
        leaf p2mp{
            if-feature p2mp;
            type boolean;
            description
              "Support for P2MP path computation.";
        }

        container stateful{
            if-feature stateful;
            description
                "If stateful PCE feature is present";
            leaf enabled{
                type boolean;
                description
                    "Enabled or Disabled";
            }
            leaf active{
                type boolean;
                description
                  "Support for active stateful PCE.";
            }
            leaf pce-initiated{
                if-feature pce-initiated;
                type boolean;
                description
                  "Support for PCE-initiated LSP.";
            }
            leaf include-db-ver{
                if-feature stateful-sync-opt;
                type boolean;
                description
                    "Support inclusion of LSP-DB-VERSION
                    in LSP object";
            }
            leaf trigger-resync{
                if-feature stateful-sync-opt;
                type boolean;
                description
                    "Support PCE triggered re-synchronization";
            }
```

```
            leaf trigger-initial-sync{
                if-feature stateful-sync-opt;
                type boolean;
                description
                    "PCE triggered initial synchronization";
            }
            leaf incremental-sync{
                if-feature stateful-sync-opt;
                type boolean;
                description
                    "Support incremental (delta) sync";
            }
        }
        container sr{
            if-feature sr;
            description
                "If segment routing is supported";
            leaf enabled{
                type boolean;
                description
                    "Enabled or Disabled";
            }

        }
    }//capability

    grouping info{
        description
            "This grouping specifies all information which
             maybe relevant to both PCC and PCE.
             This information corresponds to PCE auto-discovery
             information.";
        container domain{
            description
                "The local domain for the PCEP entity";
            list domain{
                key "domain-type domain";
                description
                    "The local domain.";
                uses domain{
                    description
                        "The local domain for the PCEP entity.";
                }
            }
        }
        container capability{
            description
                "The PCEP entity capability";
```

```
            uses capability{
                description
                    "The PCEP entity supported
                    capabilities.";
            }
        }


    }//info

    grouping pce-info{
        description
            "This grouping specifies all PCE information
             which maybe relevant to the PCE selection.
             This information corresponds to PCE auto-discovery
             information.";
        container scope{
            description
                "The path computation scope";
            uses pce-scope;
        }

        container neigh-domains{
            description
                "The list of neighbour PCE-Domain
                 toward which a PCE can compute
                 paths";
            list domain{
                key "domain-type domain";

                description
                    "The neighbour domain.";
                uses domain{
                    description
                        "The PCE neighbour domain.";
                }
            }
        }
    }//pce-info

    grouping pcep-stats{
        description
            "This grouping defines statistics for PCEP. It is used
             for both peer and current session.";
        leaf avg-rsp-time{
            type uint32;
            units "milliseconds";
            must "(/pcep-state/entity/peers/peer/role != 'pcc'" +
```

```
                 " or " +
                 "(/pcep-state/entity/peers/peer/role = 'pcc'" +
                 " and (. = 0)))" {
                error-message
                    "Invalid average response time";
                description
                    "If role is pcc then this leaf is meaningless
                     and is set to zero.";
            }
            description
              "The average response time.
               If an average response time has not been
               calculated then this leaf has the value zero.";
        }

        leaf lwm-rsp-time{
            type uint32;
            units "milliseconds";
            must "(/pcep-state/entity/peers/peer/role != 'pcc'" +
                 " or " +
                 "(/pcep-state/entity/peers/peer/role = 'pcc'" +
                 " and (. = 0)))" {
                error-message
                    "Invalid smallest (low-water mark)
                     response time";
                description
                    "If role is pcc then this leaf is meaningless
                     and is set to zero.";
            }
            description
             "The smallest (low-water mark) response time seen.
              If no responses have been received then this
              leaf has the value zero.";
        }

        leaf hwm-rsp-time{
            type uint32;
            units "milliseconds";
            must "(/pcep-state/entity/peers/peer/role != 'pcc'" +
                 " or " +
                 "(/pcep-state/entity/peers/peer/role = 'pcc'" +
                 " and (. = 0)))" {
                error-message
                    "Invalid greatest (high-water mark)
                     response time seen";
                description
                    "If role is pcc then this field is
                     meaningless and is set to zero.";
```

```
            }
            description
             "The greatest (high-water mark) response time seen.
              If no responses have been received then this object
              has the value zero.";
        }

        leaf num-pcreq-sent{
            type yang:counter32;
            description
             "The number of PCReq messages sent.";
        }

        leaf num-pcreq-rcvd{
            type yang:counter32;
            description
              "The number of PCReq messages received.";
        }

        leaf num-pcrep-sent{
            type yang:counter32;
            description
              "The number of PCRep messages sent.";
        }

        leaf num-pcrep-rcvd{
            type yang:counter32;
            description
              "The number of PCRep messages received.";
        }

        leaf num-pcerr-sent{
            type yang:counter32;
            description
              "The number of PCErr messages sent.";
        }

        leaf num-pcerr-rcvd{
            type yang:counter32;
            description
              "The number of PCErr messages received.";
        }

        leaf num-pcntf-sent{
            type yang:counter32;
            description
              "The number of PCNtf messages sent.";
        }
```

```
        leaf num-pcntf-rcvd{
            type yang:counter32;
            description
              "The number of PCNtf messages received.";
        }

        leaf num-keepalive-sent{
            type yang:counter32;
            description
              "The number of Keepalive messages sent.";
        }

        leaf num-keepalive-rcvd{
            type yang:counter32;
            description
              "The number of Keepalive messages received.";
        }

        leaf num-unknown-rcvd{
            type yang:counter32;
            description
              "The number of unknown messages received.";
        }

        leaf num-corrupt-rcvd{
            type yang:counter32;
            description
              "The number of corrupted PCEP message received.";
        }

        leaf num-req-sent{
            type yang:counter32;
            description
              "The number of requests sent.  A request corresponds
               1:1 with an RP object in a PCReq message. This might
               be greater than num-pcreq-sent because multiple
               requests can be batched into a single PCReq
               message.";
        }

        leaf num-req-sent-pend-rep{
            type yang:counter32;
            description
              "The number of requests that have been sent for
               which a response is still pending.";
        }

        leaf num-req-sent-ero-rcvd{
```

```
            type yang:counter32;
            description
               "The number of requests that have been sent for
                which a response with an ERO object was received.
                Such responses indicate that a path was
                successfully computed by the peer.";
        }

        leaf num-req-sent-nopath-rcvd{
            type yang:counter32;
            description
              "The number of requests that have been sent for
               which a response with a NO-PATH object was
               received. Such responses indicate that the peer
               could not find a path to satisfy the
               request.";
        }

        leaf num-req-sent-cancel-rcvd{
            type yang:counter32;
            description
              "The number of requests that were cancelled with
               a PCNtf message.
               This might be different than num-pcntf-rcvd because
               not all PCNtf messages are used to cancel requests,
               and a single PCNtf message can cancel multiple
               requests.";
        }

        leaf num-req-sent-error-rcvd{
            type yang:counter32;
            description
             "The number of requests that were rejected with a
              PCErr message.
              This might be different than num-pcerr-rcvd because
              not all PCErr messages are used to reject requests,
              and a single PCErr message can reject multiple
              requests.";
        }

        leaf num-req-sent-timeout{
            type yang:counter32;
            description
             "The number of requests that have been sent to a peer
             and have been abandoned because the peer has taken too
             long to respond to them.";
        }
```

```
        leaf num-req-sent-cancel-sent{
            type yang:counter32;
            description
             "The number of requests that were sent to the peer and
              explicitly cancelled by the local PCEP entity sending
              a PCNtf.";
        }

        leaf num-req-rcvd{
            type yang:counter32;
            description
             "The number of requests received.  A request
              corresponds 1:1 with an RP object in a PCReq
              message.
              This might be greater than num-pcreq-rcvd because
              multiple requests can be batched into a single
              PCReq message.";
        }

        leaf num-req-rcvd-pend-rep{
            type yang:counter32;
            description
             "The number of requests that have been received for
              which a response is still pending.";
        }

        leaf num-req-rcvd-ero-sent{
            type yang:counter32;
            description
             "The number of requests that have been received for
              which a response with an ERO object was sent.  Such
              responses indicate that a path was successfully
              computed by the local PCEP entity.";
        }

        leaf num-req-rcvd-nopath-sent{
            type yang:counter32;
            description
             "The number of requests that have been received for
              which a response with a NO-PATH object was sent. Such
              responses indicate that the local PCEP entity could
              not find a path to satisfy the request.";
        }

        leaf num-req-rcvd-cancel-sent{
            type yang:counter32;
            description
             "The number of requests received that were cancelled
```

```
              by the local PCEP entity sending a PCNtf message.
              This might be different than num-pcntf-sent because
              not all PCNtf messages are used to cancel requests,
              and a single PCNtf message can cancel multiple
              requests.";
        }

        leaf num-req-rcvd-error-sent{
            type yang:counter32;
            description
             "The number of requests received that were cancelled
              by the local PCEP entity sending a PCErr message.
              This might be different than num-pcerr-sent because
              not all PCErr messages are used to cancel requests,
              and a single PCErr message can cancel multiple
              requests.";
        }

        leaf num-req-rcvd-cancel-rcvd{
            type yang:counter32;
            description
             "The number of requests that were received from the
              peer and explicitly cancelled by the peer sending
              a PCNtf.";
        }

        leaf num-rep-rcvd-unknown{
            type yang:counter32;
            description
              "The number of responses to unknown requests
               received. A response to an unknown request is a
               response whose RP object does not contain the
               request ID of any request that is currently
               outstanding on the session.";
        }

        leaf num-req-rcvd-unknown{
            type yang:counter32;
            description
              "The number of unknown requests that have been
               received. An unknown request is a request
               whose RP object contains a request ID of
               zero.";
        }

        container svec{
            if-feature svec;
            description
```

```
                "If synchronized path computation is supported";
            leaf num-svec-sent{
                type yang:counter32;
                description
                  "The number of SVEC objects sent in PCReq messages.
                   An SVEC object represents a set of synchronized
                   requests.";
            }

            leaf num-svec-req-sent{
                type yang:counter32;
                description
                  "The number of requests sent that appeared in one
                   or more SVEC objects.";
            }

            leaf num-svec-rcvd{
                type yang:counter32;
                description
                 "The number of SVEC objects received in PCReq
                  messages. An SVEC object represents a set of
                  synchronized requests.";
            }

            leaf num-svec-req-rcvd{
                type yang:counter32;
                description
                  "The number of requests received that appeared
                   in one or more SVEC objects.";
            }
        }
        container stateful{
            if-feature stateful;
            description
                "Stateful PCE related statistics";
            leaf num-pcrpt-sent{
                type yang:counter32;
                description
                 "The number of PCRpt messages sent.";
            }

            leaf num-pcrpt-rcvd{
                type yang:counter32;
                description
                  "The number of PCRpt messages received.";
            }

            leaf num-pcupd-sent{
```

```
            type yang:counter32;
            description
             "The number of PCUpd messages sent.";
          }

          leaf num-pcupd-rcvd{
            type yang:counter32;
            description
              "The number of PCUpd messages received.";
          }

          leaf num-rpt-sent{
            type yang:counter32;
            description
              "The number of LSP Reports sent.  A LSP report
               corresponds 1:1 with an LSP object in a PCRpt
               message. This might be greater than
               num-pcrpt-sent because multiple reports can
               be batched into a single PCRpt message.";
          }

          leaf num-rpt-rcvd{
            type yang:counter32;
            description
             "The number of LSP Reports received.  A LSP report
              corresponds 1:1 with an LSP object in a PCRpt
              message.
              This might be greater than num-pcrpt-rcvd because
              multiple reports can be batched into a single
              PCRpt message.";
          }

          leaf num-rpt-rcvd-error-sent{
            type yang:counter32;
            description
              "The number of reports of LSPs received that were
              responded by the local PCEP entity by sending a
              PCErr message.";
          }

          leaf num-upd-sent{
            type yang:counter32;
            description
              "The number of LSP updates sent.  A LSP update
               corresponds 1:1 with an LSP object in a PCUpd
               message. This might be greater than
               num-pcupd-sent because multiple updates can
               be batched into a single PCUpd message.";
```

```
            }

            leaf num-upd-rcvd{
                type yang:counter32;
                description
                 "The number of LSP Updates received.  A LSP update
                  corresponds 1:1 with an LSP object in a PCUpd
                  message.
                  This might be greater than num-pcupd-rcvd because
                  multiple updates can be batched into a single
                  PCUpd message.";
            }

            leaf num-upd-rcvd-unknown{
                type yang:counter32;
                description
                  "The number of updates to unknown LSPs
                   received. An update to an unknown LSP is a
                   update whose LSP object does not contain the
                   PLSP-ID of any LSP that is currently
                   present.";
            }

            leaf num-upd-rcvd-undelegated{
                type yang:counter32;
                description
                  "The number of updates to not delegated LSPs
                   received. An update to an undelegated LSP is a
                   update whose LSP object does not contain the
                   PLSP-ID of any LSP that is currently
                   delegated to current PCEP session.";
            }

            leaf num-upd-rcvd-error-sent{
                type yang:counter32;
                description
                  "The number of updates to LSPs received that were
                  responded by the local PCEP entity by sending a
                  PCErr message.";
            }
            container initiation {
                if-feature pce-initiated;
                description
                    "PCE-Initiated related statistics";
                leaf num-pcinitiate-sent{
                    type yang:counter32;
                    description
                     "The number of PCInitiate messages sent.";
```

```
                }

                leaf num-pcinitiate-rcvd{
                    type yang:counter32;
                    description
                      "The number of PCInitiate messages received.";
                }

                leaf num-initiate-sent{
                    type yang:counter32;
                    description
                      "The number of LSP Initiation sent via PCE.
                       A LSP initiation corresponds 1:1 with an LSP
                       object in a PCInitiate message. This might be
                       greater than num-pcinitiate-sent because
                       multiple initiations can be batched into a
                       single PCInitiate message.";
                }

                leaf num-initiate-rcvd{
                    type yang:counter32;
                    description
                      "The number of LSP Initiation received from
                       PCE.  A LSP initiation corresponds 1:1 with
                       an LSP object in a PCInitiate message. This
                       might be greater than num-pcinitiate-rcvd
                       because multiple initiations can be batched
                       into a single PCInitiate message.";
                }

                leaf num-initiate-rcvd-error-sent{
                    type yang:counter32;
                    description
                      "The number of initiations of LSPs received
                       that were responded by the local PCEP entity
                       by sending a PCErr message.";
                }
            }
        }
        container path-key {
            if-feature path-key;
            description
                "If Path-Key is supported";
            leaf num-unknown-path-key{
                type yang:counter32;
                description
                 "The number of attempts to expand an unknown
                 path-key.";
```

```
            }
            leaf num-exp-path-key{
                type yang:counter32;
                description
                 "The number of attempts to expand an expired
                 path-key.";
            }
            leaf num-dup-path-key{
                type yang:counter32;
                description
                 "The number of duplicate attempts to expand same
                 path-key.";
            }
            leaf num-path-key-no-attempt{
                type yang:counter32;
                description
                 "The number of expired path-keys with no attempt to
                 expand it.";
            }
        }
    }//pcep-stats

    grouping lsp-state{
        description
            "This grouping defines the attributes for LSP in LSP-DB.
             These are the attributes specifically from the PCEP
             perspective";
        leaf plsp-id{
            type uint32{
                range "1..1048575";
            }
            description
                "A PCEP-specific identifier for the LSP.  A PCC
                 creates a unique PLSP-ID for each LSP that is
                 constant for the lifetime of a PCEP session.
                 PLSP-ID is 20 bits with 0 and 0xFFFFF are
                 reserved";
        }
        leaf pcc-id{
            type inet:ip-address;
            description
                "The local internet address of the PCC, that
                 generated the PLSP-ID.";
        }

        container lsp-ref{
            description
                "reference to ietf-te lsp state";
```

```
            leaf source {
                type leafref {
                    path "/te:te/te:lsps-state/te:lsp/te:source";
                }
                description
                  "Tunnel sender address extracted from
                  SENDER_TEMPLATE  object";
                reference "RFC3209";
            }
            leaf destination {
                type leafref {
                    path "/te:te/te:lsps-state/te:lsp/te:"
                         + "destination";
                }
                description
                    "Tunnel endpoint address extracted from
                    SESSION object";
                reference "RFC3209";
            }
            leaf tunnel-id {
                type leafref {
                    path "/te:te/te:lsps-state/te:lsp/te:tunnel-id";
                }
                description
                    "Tunnel identifier used in the SESSION
                    that remains constant over the life
                    of the tunnel.";
                reference "RFC3209";
            }
            leaf lsp-id {
                type leafref {
                    path "/te:te/te:lsps-state/te:lsp/te:lsp-id";
                }
                description
                    "Identifier used in the SENDER_TEMPLATE
                    and the FILTER_SPEC that can be changed
                    to allow a sender to share resources with
                    itself.";
                reference "RFC3209";
            }
            leaf extended-tunnel-id {
                type leafref {
                    path "/te:te/te:lsps-state/te:lsp/te:"
                    + "extended-tunnel-id";
                }
                description
                    "Extended Tunnel ID of the LSP.";
                reference "RFC3209";
```

```
            }
            leaf type {
                type leafref {
                    path "/te:te/te:lsps-state/te:lsp/te:type";
                }
                description "LSP type P2P or P2MP";
            }
        }

        leaf admin-state{
            type boolean;
            description
                "The desired operational state";
        }
        leaf operational-state{
            type operational-state;
            description
                "The operational status of the LSP";
        }
        container delegated{
            description
                "The delegation related parameters";
            leaf enabled{
                type boolean;
                description
                    "LSP is delegated or not";
            }
            leaf pce{
                type leafref {
                    path "/pcep-state/entity/peers/peer/addr";
                }
                must "(../enabled = true())"
                {
                    error-message
                        "The LSP must be delegated";
                    description
                        "When LSP is a delegated LSP";
                }
                description
                    "The reference to the PCE peer to
                    which LSP is delegated";
            }
            leaf srp-id{
                type uint32;
                description
                    "The last SRP-ID-number associated with this
                    LSP.";
            }
```

```
        }
        container initiation {
            if-feature pce-initiated;
            description
                "The PCE initiation related parameters";
            leaf enabled{
                type boolean;
                description
                    "LSP is PCE-initiated or not";
            }
            leaf pce{
                type leafref {
                    path "/pcep-state/entity/peers/peer/addr";
                }
                must "(../enabled = true())"
                {
                    error-message
                        "The LSP must be PCE-Initiated";
                    description
                        "When the LSP must be PCE-Initiated";
                }
                description
                    "The reference to the PCE
                    that initiated this LSP";
            }
        }
        leaf symbolic-path-name{
            type string;
            description
                "The symbolic path name associated with the LSP.";
        }
        leaf last-error{
            type lsp-error;
            description
                "The last error for the LSP.";
        }
        leaf pst{
            type pst;
            default "rsvp-te";
            description
                "The Path Setup Type";

        }

    }//lsp-state

    grouping notification-instance-hdr {
        description
```

```
            "This group describes common instance specific data
             for notifications.";

        leaf peer-addr {
            type leafref {
                path "/pcep-state/entity/peers/peer/addr";
            }
            description
                "Reference to peer address";
        }

    }// notification-instance-hdr

    grouping notification-session-hdr {
        description
        "This group describes common session instance specific
         data for notifications.";

        leaf session-initiator {
            type leafref {
            path "/pcep-state/entity/peers/peer/sessions/" +
                 "session/initiator";
            }
            description
                "Reference to pcep session initiator leaf";
        }
    }// notification-session-hdr

    grouping stateful-pce-parameter {
        description
        "This group describes stateful PCE specific
         parameters.";
        leaf state-timeout{
            type uint32;
            units "seconds";
            description
                "When a PCEP session is terminated, a PCC
                 waits for this time period before flushing
                 LSP state associated with that PCEP session
                 and reverting to operator-defined default
                 parameters or behaviours.";
        }
        leaf redelegation-timeout{
            type uint32;
            units "seconds";
            must "((/pcep-state/entity/role = 'pcc')" +
                 " or " +
                 "(/pcep-state/entity/role = 'pcc-and-pce'))" +
```

```
                 " and " +
                 "(/pcep/entity/capability/stateful/active"
                             + "= true())"
            {
                error-message "The PCEP entity must be PCC";
                description
                    "When PCEP entity is PCC";
            }
            description
                "When a PCEP session is terminated, a PCC
                 waits for this time period before revoking
                 LSP delegation to a PCE and attempting to
                 redelegate LSPs associated with the
                 terminated PCEP session to an alternate
                 PCE.";
        }
        leaf rpt-non-pcep-lsp{
            type boolean;
            must "((/pcep-state/entity/role = 'pcc')" +
                 " or " +
                 "(/pcep-state/entity/role = 'pcc-and-pce'))"
            {
                error-message "The PCEP entity must be PCC";
                description
                    "When PCEP entity is PCC";
            }
            description
                "If set, a PCC reports LSPs that are not
                controlled by any PCE (for example, LSPs
                that are statically configured at the
                PCC). ";
        }

    }

    grouping authentication {
        description "Authentication Information";
        choice auth-type-selection {
            description
                "Options for expressing authentication setting.";
            case auth-key-chain {
                leaf key-chain {
                    type key-chain:key-chain-ref;
                    description
                        "key-chain name.";
                }
            }
            case auth-key {
```

```
                leaf key {
                    type string;
                description
                    "Key string in ASCII format.";
                }
                container crypto-algorithm {
                    uses key-chain:crypto-algorithm-types;
                        description
                            "Cryptographic algorithm associated
                             with key.";
                }
            }
            case auth-tls {
                if-feature tls;
                container tls {
                    description
                        "TLS related information - TBD";
                }
            }
        }
    }

    grouping path-key {
        description "Path-key related information";
        leaf enabled{
            type boolean;
            description
                "Enabled or Disabled";
        }
        leaf discard-timer {
            type uint32;
            units "minutes";
            default 10;
            description
                "A timer to discard unwanted path-keys";
        }
        leaf reuse-time {
            type uint32;
            units "minutes";
            default 30;
            description
                "A time after which the path-keys could be reused";
        }
        leaf pce-id {
            type inet:ip-address;
            description
                "PCE Address to be used in each Path-Key Subobject
                (PKS)";
```

```
        }
    }

    grouping path-key-state {
        description "Table to allow inspection of path-keys";
        list path-keys{
            key "path-key";

            description
                "The list of path-keys generated by the PCE";

            leaf path-key {
                type uint16;
                description
                    "The identifier, or token used to represent
                     the Confidential Path Segment (CPS) within
                     the context of the PCE";
            }
            container cps {
                description
                    "The Confidential Path Segment (CPS)";
                list explicit-route-objects {
                    key "index";
                    description
                        "List of explicit route objects";
                    leaf index {
                        type uint8 {
                            range "0..255";
                        }
                        description
                            "Index of this explicit route object";
                    }
                    leaf explicit-route-usage {
                        type identityref {
                            base te-types:route-usage-type;
                        }
                        description
                            "An explicit-route hop action.";
                    }
                    uses te-types:explicit-route-subobject;
                }
            }
            leaf pcc-original {
                type leafref {
                    path "/pcep-state/entity/peers/peer/addr";
                }
                description
                    "Reference to PCC peer address of
```

```
                the original request";
            }
            leaf req-id {
                type uint32;
                description
                    "The request ID of the original PCReq.";
            }
            leaf retrieved  {
                type boolean;
                description
                    "If path-key has been retrieved yet";
            }
            leaf pcc-retrieved {
                type leafref {
                    path "/pcep-state/entity/peers/peer/addr";
                }
                must "(../retrieved = true())"
                {
                    error-message
                        "The Path-key should be retreived";
                    description
                        "When Path-Key has been retreived";
                }
                description
                    "Reference to PCC peer address which
                    retreived the path-key";
            }
            leaf creation-time {
                type yang:timestamp;
                description
                    "The timestamp value at the time this Path-Key was
                    created.";
            }
            leaf discard-time {
                type uint32;
                units "minutes";
                description
                    "A time after which this path-keys will be
                    discarded";
            }
            leaf reuse-time {
                type uint32;
                units "minutes";
                description
                    "A time after which this path-keys could be
                    reused";
            }
        }
```

```
    }

    grouping of-list {
        description "List of OF";
        list objective-function{
            key "of";

            description
                "The list of authorized OF";

            leaf of {
                type objective-function;
                description
                    "The OF authorized";
            }
        }
    }
    grouping association {
        description
            "Generic Association parameters";
        leaf type {
            type "assoc-type";
            description
                "The PCEP association type";
        }
        leaf id {
            type uint16;
            description
                "PCEP Association ID";
        }
        leaf source {
          type inet:ip-address;
          description
                "PCEP Association Source.";
        }
        leaf global-source {
          type uint32;
          description
                "PCEP Association Global
                Source.";
        }
        leaf extended-id{
            type string;
            description
                "Additional information to
                support unique identification.";
        }
    }
```

```
    grouping association-ref {
        description
            "Generic Association parameters";
        leaf id {
            type leafref {
                path "/pcep-state/entity/lsp-db/"
                + "association-list/id";
            }
            description
                "PCEP Association ID";
        }
        leaf source {
            type leafref {
                path "/pcep-state/entity/lsp-db/"
                + "association-list/source";
            }
          description
                "PCEP Association Source.";
        }
        leaf global-source {
            type leafref {
                path "/pcep-state/entity/lsp-db/"
                + "association-list/global-source";
            }
          description
                "PCEP Association Global
                Source.";
        }
        leaf extended-id{
            type leafref {
                path "/pcep-state/entity/lsp-db/"
                + "association-list/extended-id";
            }
            description
                "Additional information to
                support unique identification.";
        }
    }
    /*
     * Configuration data nodes
     */
    container pcep{

        presence
            "The PCEP is enabled";

            description
            "Parameters for list of configured PCEP entities
```

```
             on the device.";

        container entity {

            description
                "The configured PCEP entity on the device.";

            leaf addr {
                type inet:ip-address;
                mandatory true;
                description
                    "The local Internet address of this PCEP
                    entity.
                    If operating as a PCE server, the PCEP
                    entity listens on this address.
                    If operating as a PCC, the PCEP entity
                    binds outgoing TCP connections to this
                    address.
                    It is possible for the PCEP entity to
                    operate both as a PCC and a PCE Server, in
                    which case it uses this address both to
                    listen for incoming TCP connections and to
                    bind outgoing TCP connections.";
            }

            leaf enabled {
                type boolean;
                default true;
                description
                    "The administrative status of this PCEP
                     Entity.";
            }

            leaf role {
                type pcep-role;
                mandatory true;
                description
                    "The role that this entity can play.
                     Takes one of the following values.
                     - unknown(0): this PCEP Entity role is not
                       known.
                     - pcc(1): this PCEP Entity is a PCC.
                     - pce(2): this PCEP Entity is a PCE.
                     - pcc-and-pce(3): this PCEP Entity is both
                       a PCC and a PCE.";
            }

            leaf description {
```

```
                type string;
                description
                    "Description of the PCEP entity configured
                     by the user";
            }

            leaf speaker-entity-id{
                if-feature stateful-sync-opt;
                type string;
                description
                    "The Speaker Entity Identifier";
            }

            uses info {
                description
                    "Local PCEP entity information";
            }


            container pce-info {
                must "((/pcep-state/entity/role = 'pce')" +
                 " or " +
                 "(/pcep-state/entity/role = 'pcc-and-pce'))"
                {
                    error-message "The PCEP entity must be PCE";
                    description
                        "When PCEP entity is PCE";
                }
                uses pce-info {
                    description
                        "Local PCE information";
                }
                container path-key {
                    if-feature path-key;
                    uses path-key {
                        description
                            "Path-Key Configuration";
                    }
                    description
                        "Path-Key Configuration";
                }

                description
                    "The Local PCE Entity PCE information";
            }

            uses authentication {
                description
```

```
                "Local PCEP entity authentication information";
            }


            uses pcep-entity-info {
                description
                    "The configuration related to the PCEP
                     entity.";
            }



            leaf pcep-notification-max-rate {
                type uint32;
                mandatory true;
                description
                    "This variable indicates the maximum number of
                     notifications issued per second. If events occur
                     more rapidly, the implementation may simply fail
                     to emit these notifications during that period,
                     or may queue them until an appropriate time. A
                     value of 0 means no notifications are emitted
                     and all should be discarded (that is, not
                     queued).";
            }

            container stateful-parameter{
                if-feature stateful;
                must "(/pcep/entity/capability/stateful/enabled" +
                     " = true())"
                {
                    error-message
                        "The Stateful PCE must be enabled";
                    description
                        "When PCEP entity is stateful
                         enabled";
                }
                uses stateful-pce-parameter;

                description
                    "The configured stateful parameters";
            }

            container of-list{
                if-feature objective-function;
                must "((/pcep/entity/role = 'pce')" +
                     " or " +
                     "(/pcep/entity/role = 'pcc-and-pce'))"
```

```
                {
                    error-message
                        "The PCEP entity must be PCE";
                    description
                        "The authorized OF-List at PCE";
                }
                uses of-list;

                description
                    "The authorized OF-List at PCE for all peers";
            }


            container peers{
                must "((/pcep/entity/role = 'pcc')" +
                     " or " +
                     "(/pcep/entity/role = 'pcc-and-pce'))"
                {
                    error-message
                        "The PCEP entity must be PCC";
                    description
                        "When PCEP entity is PCC, as remote
                         PCE peers are configured.";
                }
                description
                    "The list of configured peers for the
                     entity (remote PCE)";
                list peer{
                    key "addr";

                    description
                        "The peer configured for the entity.
                         (remote PCE)";

                    leaf addr {
                        type inet:ip-address;
                        description
                            "The local Internet address of this
                             PCEP peer.";
                    }

                    leaf description {
                        type string;
                        description
                            "Description of the PCEP peer
                             configured by the user";
                    }
                    uses info {
```

```
                    description
                        "PCE Peer information";
                }
                uses pce-info {
                    description
                        "PCE Peer information";
                }

                leaf delegation-pref{
                    if-feature stateful;
                    type uint8{
                        range "0..7";
                    }
                    must "(/pcep/entity/capability/stateful/active"
                         + "= true())"
                    {
                        error-message
                            "The Active Stateful PCE must be
                             enabled";
                        description
                            "When PCEP entity is active stateful
                             enabled";
                    }
                    description
                        "The PCE peer delegation preference.";
                }
                uses authentication {
                    description
                        "PCE Peer authentication";
                }
                container of-list{
                    if-feature objective-function;
                    must "((/pcep/entity/role = 'pce')" +
                    " or " +
                    "(/pcep/entity/role = 'pcc-and-pce'))"
                    {
                        error-message
                            "The PCEP entity must be PCE";
                        description
                            "The authorized OF-List at PCE";
                    }
                    uses of-list;

                    description
                        "The authorized OF-List a specific peer";
                }
            }//peer
        }//peers
```

```
        }//entity
    }//pcep

    /*
     * Operational data nodes
     */

    container pcep-state{
        config false;
        description
            "The list of operational PCEP entities on the
             device.";

        container entity{
            description
                "The operational PCEP entity on the device.";

            leaf addr {
                type inet:ip-address;
                description
                    "The local Internet address of this PCEP
                    entity.
                    If operating as a PCE server, the PCEP
                    entity listens on this address.
                    If operating as a PCC, the PCEP entity
                    binds outgoing TCP connections to this
                    address.
                    It is possible for the PCEP entity to
                    operate both as a PCC and a PCE Server, in
                    which case it uses this address both to
                    listen for incoming TCP connections and to
                    bind outgoing TCP connections.";
            }

            leaf index{
                type uint32;
                description
                    "The index of the operational PECP
                     entity";
            }


            leaf admin-status {
                type pcep-admin-status;
                description
                    "The administrative status of this PCEP Entity.
                     This is the desired operational status as
                     currently set by an operator or by default in
```

```
                the implementation.  The value of enabled
                represents the current status of an attempt
                to reach this desired status.";
            }

            leaf oper-status {
                type pcep-admin-status;
                description
                   "The operational status of the PCEP entity.
                    Takes one of the following values.
                    - oper-status-up(1): the PCEP entity is
                      active.
                    - oper-status-down(2): the PCEP entity is
                      inactive.
                    - oper-status-going-up(3): the PCEP entity is
                      activating.
                    - oper-status-going-down(4): the PCEP entity is
                      deactivating.
                    - oper-status-failed(5): the PCEP entity has
                      failed and will recover when possible.
                    - oper-status-failed-perm(6): the PCEP entity
                      has failed and will not recover without
                      operator intervention.";
            }

            leaf role {
                type pcep-role;
                description
                    "The role that this entity can play.
                     Takes one of the following values.
                     - unknown(0): this PCEP entity role is
                       not known.
                     - pcc(1): this PCEP entity is a PCC.
                     - pce(2): this PCEP entity is a PCE.
                     - pcc-and-pce(3): this PCEP entity is
                       both a PCC and a PCE.";
            }

            leaf description {
                type string;
                description
                    "Description of the PCEP entity configured
                     by the user";
            }

            leaf speaker-entity-id{
                if-feature stateful-sync-opt;
                type string;
```

```
                description
                    "The Speaker Entity Identifier";
            }

            uses info {
                description
                    "Local PCEP entity information";
            }

            container pce-info {
                when "((/pcep-state/entity/role = 'pce')" +
                 " or " +
                 "(/pcep-state/entity/role = 'pcc-and-pce'))"
                {
                    description
                        "When PCEP entity is PCE";
                }
                uses pce-info {
                    description
                        "Local PCE information";
                }

                container path-key {
                    if-feature path-key;
                    uses path-key {
                        description
                            "Path-Key Configuration";
                    }
                    description
                        "Path-Key Configuration";
                }

                description
                    "The Local PCE Entity PCE information";
            }

            uses authentication {
                description
                    "Local PCEP Entity authentication information";
            }

            uses pcep-entity-info{
                description
                    "The operational information related to the
                     PCEP entity.";
            }

            container stateful-parameter{
```

```
                if-feature stateful;
                must "(/pcep/entity/capability/stateful/enabled" +
                     " = true())"
                {
                    error-message
                        "The Stateful PCE must be enabled";
                    description
                        "When PCEP entity is stateful
                         enabled";
                }
                uses stateful-pce-parameter;

                description
                    "The operational stateful parameters";
            }



            container lsp-db{
                if-feature stateful;
                description
                    "The LSP-DB";
                leaf db-ver{
                    if-feature stateful-sync-opt;
                    type uint64;
                     must "((/pcep/entity/role = 'pcc')" +
                     " or " +
                     "(/pcep/entity/role = 'pcc-and-pce'))"
                    {
                        error-message
                            "The PCEP entity must be PCC";
                        description
                            "When PCEP entity is PCC, as remote
                             PCE peers are configured.";
                    }

                    description
                        "The LSP State Database Version Number";
                }
                list association-list {
                    key "id source global-source extended-id";
                    description
                        "List of all PCEP associations";
                    uses association {
                        description
                            "The Association attributes";
                    }
                    list lsp {
```

```
                        key "plsp-id pcc-id";
                        description
                            "List of all LSP in this association";
                        leaf plsp-id {
                            type leafref {
                                path "/pcep-state/entity/lsp-db/"
                                + "lsp/plsp-id";
                            }
                            description
                                "Reference to PLSP-ID in LSP-DB";
                        }
                        leaf pcc-id {
                            type leafref {
                                path "/pcep-state/entity/lsp-db/"
                                + "lsp/pcc-id";
                            }
                            description
                                "Reference to PCC-ID in LSP-DB";
                        }
                    }
                }
                list lsp{
                    key "plsp-id pcc-id";
                    description
                        "List of all LSPs in LSP-DB";
                    uses lsp-state{
                        description
                            "The PCEP specific attributes for
                             LSP-DB.";
                    }
                    list association-list {
                        key "id source global-source extended-id";
                        description
                            "List of all PCEP associations";
                        uses association-ref {
                            description
                                "Reference to the Association
                                 attributes";
                        }
                    }

                }
            }
            container path-keys {
                if-feature path-key;
                must "((/pcep-state/entity/role = 'pce')" +
                 " or " +
                 "(/pcep-state/entity/role = 'pcc-and-pce'))"
```

```
                {
                    error-message
                        "The PCEP entity must be PCE";
                    description
                        "When PCEP entity is PCE";
                }
                uses path-key-state;
                description
                    "The path-keys generated by the PCE";
            }
            container of-list{
                if-feature objective-function;
                must "((/pcep/entity/role = 'pce')" +
                     " or " +
                     "(/pcep/entity/role = 'pcc-and-pce'))"
                {
                    error-message
                        "The PCEP entity must be PCE";
                    description
                        "The authorized OF-List at PCE";
                }
                uses of-list;

                description
                    "The authorized OF-List at PCE for all peers";
            }
            container peers{
                description
                        "The list of peers for the entity";

                list peer{
                    key "addr";

                    description
                        "The peer for the entity.";

                    leaf addr {
                        type inet:ip-address;
                        description
                            "The local Internet address of this PCEP
                             peer.";
                    }

                    leaf role {
                        type pcep-role;
                        description
                            "The role of the PCEP Peer.
                             Takes one of the following values.
```

```
                - unknown(0): this PCEP peer role
                  is not known.
                - pcc(1): this PCEP peer is a PCC.
                - pce(2): this PCEP peer is a PCE.
                - pcc-and-pce(3): this PCEP peer
                  is both a PCC and a PCE.";
            }


            uses info {
                description
                    "PCEP peer information";
            }


            container pce-info {
                when "((/pcep-state/entity/role = 'pcc')" +
                     " or " +
                     "(/pcep-state/entity/role " +
                     "= 'pcc-and-pce'))"
                {
                    description
                        "When PCEP entity is PCE";
                }
                uses pce-info {
                    description
                        "PCE Peer information";
                }
            description
                "The PCE Peer information";
            }

            leaf delegation-pref{
                if-feature stateful;
                type uint8{
                    range "0..7";
                }
                must "((/pcep-state/entity/role = 'pcc')" +
                     " or " +
                     "(/pcep-state/entity/role" +
                     " = 'pcc-and-pce'))"
                {
                    error-message
                        "The PCEP entity must be PCC";
                    description
                        "When PCEP entity is PCC";
                }
                must "(/pcep/entity/capability/stateful/active"
```

```
                    + "= true())"
                {
                    error-message
                        "The Active Stateful PCE must be
                         enabled";
                    description
                        "When PCEP entity is active stateful
                         enabled";
                }
                description
                    "The PCE peer delegation preference.";
            }

            uses authentication {
                description
                    "PCE Peer authentication";
            }

            container of-list{
                if-feature objective-function;
                must "((/pcep/entity/role = 'pce')" +
                " or " +
                "(/pcep/entity/role = 'pcc-and-pce'))"
                {
                    error-message
                        "The PCEP entity must be PCE";
                    description
                        "The authorized OF-List at PCE";
                }
                uses of-list;

                description
                    "The authorized OF-List of a specific
                    peer";
            }
            leaf discontinuity-time {
                type yang:timestamp;
                description
                    "The timestamp of the time when the
                     information and statistics were
                     last reset.";
            }

            leaf initiate-session {
                type boolean;
                description
                    "Indicates whether the local PCEP
                     entity initiates sessions to this peer,
```

```
                or waits for the peer to initiate a
                session.";
            }

            leaf session-exists{
                type boolean;
                description
                    "Indicates whether a session with
                     this peer currently exists.";
            }

            leaf num-sess-setup-ok{
                type yang:counter32;
                description
                    "The number of PCEP sessions successfully
                     successfully established with the peer,
                     including any current session.  This
                     counter is incremented each time a
                     session with this peer is successfully
                     established.";
            }

            leaf num-sess-setup-fail{
                type yang:counter32;
                description
                   "The number of PCEP sessions with the peer
                    that have been attempted but failed
                    before being fully established. This
                    counter is incremented each time a
                    session retry to this peer fails.";
            }

            leaf session-up-time{
                type yang:timestamp;
                must "(../num-sess-setup-ok != 0  or " +
                    "(../num-sess-setup-ok = 0  and "  +
                    "(. = 0)))" {
                        error-message
                            "Invalid Session Up timestamp";
                        description
                            "If num-sess-setup-ok is zero,
                             then this leaf contains zero.";
                    }
                description
                   "The timestamp value of the last time a
                    session with this peer was successfully
                    established.";
            }
```

```
                leaf session-fail-time{
                    type yang:timestamp;
                    must "(../num-sess-setup-fail != 0  or " +
                        "(../num-sess-setup-fail = 0  and "  +
                        "(. = 0)))" {
                            error-message
                                "Invalid Session Fail timestamp";
                            description
                                "If num-sess-setup-fail is zero,
                                 then this leaf contains zero.";
                        }
                    description
                      "The timestamp value of the last time a
                       session with this peer failed to be
                       established.";
                }

                leaf session-fail-up-time{
                    type yang:timestamp;
                    must "(../num-sess-setup-ok != 0  or "     +
                        "(../num-sess-setup-ok = 0  and "     +
                        "(. = 0)))" {
                            error-message
                                "Invalid Session Fail from
                                 Up timestamp";
                            description
                                "If num-sess-setup-ok is zero,
                                 then this leaf contains zero.";
                        }
                    description
                      "The timestamp value of the last time a
                       session with this peer failed from
                       active.";
                }

                container pcep-stats {
                    description
                        "The container for all statistics at peer
                         level.";
                    uses pcep-stats{
                        description
                            "Since PCEP sessions can be
                            ephemeral, the peer statistics tracks
                            a peer even when no PCEP session
                            currently exists to that peer. The
                            statistics contained are an aggregate
                            of the statistics for all successive
                            sessions to that peer.";
```

```
            }

            leaf num-req-sent-closed{
                type yang:counter32;
                description
                    "The number of requests that were
                     sent to the peer and implicitly
                     cancelled when the session they were
                     sent over was closed.";
            }

            leaf num-req-rcvd-closed{
                type yang:counter32;
                description
                    "The number of requests that were
                     received from the peer and
                     implicitly cancelled when the
                     session they were received over
                     was closed.";
            }
        }//pcep-stats



        container sessions {
            description
                "This entry represents a single PCEP
                 session in which the local PCEP entity
                 participates.
                 This entry exists only if the
                 corresponding PCEP session has been
                 initialized by some event, such as
                 manual user configuration, auto-
                 discovery of a peer, or an incoming
                 TCP connection.";

            list session {
                key "initiator";

                description
                    "The list of sessions, note that
                     for a time being two sessions
                     may exist for a peer";

                leaf initiator {
                    type pcep-initiator;
                    description
                        "The initiator of the session,
```

```
                    that is, whether the TCP
                    connection was initiated by
                    the local PCEP entity or the
                    peer.
                    There is a window during
                    session initialization where
                    two sessions can exist between
                    a pair of PCEP speakers, each
                    initiated by one of the
                    speakers. One of these
                    sessions is always discarded
                    before it leaves OpenWait state.
                    However, before it is discarded,
                    two sessions to the given peer
                    appear transiently in this MIB
                    module. The sessions are
                    distinguished by who initiated
                    them, and so this field is the
                    key.";
                }

                leaf state-last-change {
                    type yang:timestamp;
                    description
                        "The timestamp value at the
                         time this session entered its
                         current state as denoted by
                         the state leaf.";
                }

                leaf state {
                    type pcep-sess-state;
                    description
                        "The current state of the
                         session.
                         The set of possible states
                         excludes the idle state since
                         entries do not exist in the
                         idle state.";
                }

                leaf session-creation {
                    type yang:timestamp;
                    description
                        "The timestamp value at the
                         time this session was
                         created.";
                }
```

```
                    leaf connect-retry {
                        type yang:counter32;
                        description
                             "The number of times that the
                              local PCEP entity has
                              attempted to establish a TCP
                              connection for this session
                              without success. The PCEP
                              entity gives up when this
                              reaches connect-max-retry.";
                    }

                    leaf local-id {
                        type uint32 {
                          range "0..255";
                        }
                        description
                             "The value of the PCEP session
                              ID used by the local PCEP
                              entity in the Open message
                              for this session.
                              If state is tcp-pending then
                              this is the session ID that
                              will be used in the Open
                              message. Otherwise, this is
                              the session ID that was sent
                              in the Open message.";
                    }

                    leaf remote-id {
                        type uint32 {
                            range "0..255";
                        }
                        must "((../state != 'tcp-pending'" +
                             "and " +
                             "../state != 'open-wait' )" +
                             "or " +
                             "((../state = 'tcp-pending'" +
                             " or " +
                             "../state = 'open-wait' )" +
                             "and (. = 0)))" {
                                error-message
                                    "Invalid remote-id";
                                description
                                     "If state is tcp-pending
                                      or open-wait then this
                                      leaf is not used and
                                      MUST be set to zero.";
```

```
            }
        description
             "The value of the PCEP session
              ID used by the peer in its
              Open message for this
              session.";
    }

    leaf keepalive-timer {
        type uint32 {
          range "0..255";
        }
        units "seconds";
        must "(../state = 'session-up'" +
             "or " +
             "(../state != 'session-up'" +
             "and (. = 0)))" {
                error-message
                    "Invalid keepalive
                     timer";
                description
                    "This field is used if
                     and only if state is
                     session-up. Otherwise,
                     it is not used and
                     MUST be set to
                     zero.";
            }
        description
             "The agreed maximum interval at
              which the local PCEP entity
              transmits PCEP messages on this
              PCEP session.  Zero means that
              the local PCEP entity never
              sends Keepalives on this
              session.";
    }

    leaf peer-keepalive-timer {
        type uint32 {
          range "0..255";
        }
        units "seconds";
        must "(../state = 'session-up'" +
             "or "   +
             "(../state != 'session-up'" +
             "and " +
             "(. = 0)))" {
```

```
                    error-message
                        "Invalid Peer keepalive
                         timer";
                    description
                        "This field is used if
                         and only if state is
                         session-up. Otherwise,
                         it is not used and MUST
                         be set to zero.";
                }
            description
                 "The agreed maximum interval at
                  which the peer transmits PCEP
                  messages on this PCEP session.
                  Zero means that the peer never
                  sends Keepalives on this
                  session.";
        }

        leaf dead-timer {
            type uint32 {
              range "0..255";
            }
            units "seconds";
            description
                 "The dead timer interval for
                  this PCEP session.";
        }

        leaf peer-dead-timer {
            type uint32 {
              range "0..255";
            }
            units "seconds";
            must "((../state != 'tcp-pending'" +
                 "and " +
                 "../state != 'open-wait' )" +
                 "or " +
                 "((../state = 'tcp-pending'" +
                 " or " +
                 "../state = 'open-wait' )" +
                 "and " +
                 "(. = 0)))" {
                    error-message
                        "Invalid Peer Dead
                         timer";
                    description
                        "If state is tcp-
```

```
                    pending or open-wait
                    then this leaf is not
                    used and MUST be set to
                    zero.";
                }
            description
                 "The peer's dead-timer interval
                  for this PCEP session.";
        }

        leaf ka-hold-time-rem {
            type uint32 {
              range "0..255";
            }
            units "seconds";
            must "((../state != 'tcp-pending'" +
                 "and " +
                 "../state != 'open-wait' ) " +
                 "or " +
                 "((../state = 'tcp-pending'" +
                 "or " +
                 "../state = 'open-wait' )" +
                 "and " +
                 "(. = 0)))" {
                    error-message
                        "Invalid Keepalive hold
                         time remaining";
                    description
                        "If state is tcp-pending
                         or open-wait then this
                         field is not used and
                         MUST be set to zero.";
                }
            description
                 "The keep alive hold time
                  remaining for this session.";
        }

        leaf overloaded {
            type boolean;
            description
                 "If the local PCEP entity has
                  informed the peer that it is
                  currently overloaded, then this
                  is set to true.  Otherwise, it
                  is set to false.";
        }
```

```
                        leaf overload-time {
                            type uint32;
                            units "seconds";
                            must "((../overloaded = true()) or" +
                                "((../overloaded != true()) and" +
                                " (. = 0)))" {
                                    error-message
                                        "Invalid overload-time";
                                    description
                                        "This field is only used
                                         if overloaded is set to
                                         true. Otherwise, it is
                                         not used and MUST be set
                                         to zero.";
                                }
                            description
                                 "The interval of time that is
                                  remaining until the local PCEP
                                  entity will cease to be
                                  overloaded on this session.";
                        }

                        leaf peer-overloaded {
                            type boolean;
                            description
                                 "If the peer has informed the
                                  local PCEP entity that it is
                                  currently overloaded, then this
                                  is set to true. Otherwise, it
                                  is set to false.";
                        }

                        leaf peer-overload-time {
                            type uint32;
                            units "seconds";
                            must "((../peer-overloaded = true())" +
                                 " or " +
                                 "((../peer-overloaded != true())" +
                                 " and " +
                                 "(. = 0)))" {
                                    error-message
                                        "Invalid peer overload
                                         time";
                                    description
                                        "This field is only used
                                         if peer-overloaded is
                                         set to true. Otherwise,
                                         it is not used and MUST
```

```
                    be set to zero.";
                }
            description
                 "The interval of time that is
                  remaining until the peer will
                  cease to be overloaded.  If it
                  is not known how long the peer
                  will stay in overloaded state,
                  this leaf is set to zero.";
        }
        leaf lspdb-sync {
            if-feature stateful;
            type sync-state;
            description
                "The LSP-DB state synchronization
                status.";
        }
        leaf recv-db-ver{
            if-feature stateful;
            if-feature stateful-sync-opt;
            type uint64;
             must "((/pcep-state/entity/peers/" +
                  "peer/role = 'pcc')" +
                  " or " +
                  "(/pcep-state/entity/peers/" +
                  "peer/role = 'pcc-and-pce'))"
            {
                error-message
                    "The PCEP peer must be PCC";
                description
                    "The PCEP peer must be PCC";
            }

            description
                "The last received LSP State
                Database Version Number";
        }

        container of-list{
            if-feature objective-function;
            must "((/pcep/entity/role = 'pcc')" +
            " or " +
            "(/pcep/entity/role = 'pcc-and-pce'))"
            {
                error-message
                    "The PCEP entity must be PCC";
                description
                    "The OF-list received on the
```

```
                                        session";
                                    }
                                    uses of-list;

                                    description
                                        "Indicate the list of supported OF
                                        on this session";
                                }

                                leaf speaker-entity-id{
                                    if-feature stateful-sync-opt;
                                    type string;
                                    description
                                        "The Speaker Entity Identifier";
                                }

                                leaf discontinuity-time {
                                    type yang:timestamp;
                                    description
                                         "The timestamp value of the time
                                          when the statistics were last
                                          reset.";
                                }

                                container pcep-stats {
                                    description
                                        "The container for all statistics
                                         at session level.";
                                    uses pcep-stats{
                                        description
                                            "The statistics contained are
                                             for the current sessions to
                                             that peer. These are lost
                                             when the session goes down.
                                             ";
                                    }
                                }//pcep-stats

                            } // session
                        } // sessions
                    }//peer
                }//peers
            }//entity
        }//pcep-state

        /*
         * Notifications
         */
```

```
    notification pcep-session-up {
        description
            "This notification is sent when the value of
             '/pcep/pcep-state/peers/peer/sessions/session/state'
             enters the 'session-up' state.";

        uses notification-instance-hdr;

        uses notification-session-hdr;

        leaf state-last-change {
            type yang:timestamp;
            description
                "The timestamp value at the time this session entered
                its current state as denoted by the state leaf.";
        }

        leaf state {
            type pcep-sess-state;
            description
                "The current state of the session.
                 The set of possible states excludes the idle state
                 since entries do not exist in the idle state.";
        }
    } //notification

    notification pcep-session-down {
        description
            "This notification is sent when the value of
             '/pcep/pcep-state/peers/peer/sessions/session/state'
             leaves the 'session-up' state.";

        uses notification-instance-hdr;

        leaf session-initiator {
            type pcep-initiator;
            description
                "The initiator of the session.";
        }

        leaf state-last-change {
            type yang:timestamp;
            description
                "The timestamp value at the time this session entered
                its current state as denoted by the state leaf.";
        }

        leaf state {
```

```
            type pcep-sess-state;
            description
                "The current state of the session.
                 The set of possible states excludes the idle state
                 since entries do not exist in the idle state.";
        }
    } //notification

    notification pcep-session-local-overload {
        description
            "This notification is sent when the local PCEP entity
            enters overload state for a peer.";

        uses notification-instance-hdr;

        uses notification-session-hdr;

        leaf overloaded {
            type boolean;
            description
                 "If the local PCEP entity has informed the peer that
                 it is currently overloaded, then this is set to
                 true. Otherwise, it is set to false.";
        }

        leaf overload-time {
            type uint32;
            units "seconds";
            description
                 "The interval of time that is remaining until the
                 local PCEP entity will cease to be overloaded on
                 this session.";
        }
    } //notification

    notification pcep-session-local-overload-clear {
        description
            "This notification is sent when the local PCEP entity
            leaves overload state for a peer.";

        uses notification-instance-hdr;

        leaf overloaded {
            type boolean;
            description
                 "If the local PCEP entity has informed the peer
                 that it is currently overloaded, then this is set
                 to true.  Otherwise, it is set to false.";
```

```
        }
    } //notification

    notification pcep-session-peer-overload {
        description
            "This notification is sent when a peer enters overload
            state.";

        uses notification-instance-hdr;

        uses notification-session-hdr;

        leaf peer-overloaded {
            type boolean;
            description
                "If the peer has informed the local PCEP entity that
                it is currently overloaded, then this is set to true.
                Otherwise, it is set to false.";
        }

        leaf peer-overload-time {
            type uint32;
            units "seconds";
            description
                "The interval of time that is remaining until the
                peer will cease to be overloaded.  If it is not known
                how long the peer will stay in overloaded state, this
                leaf is set to zero.";
        }
    } //notification

    notification pcep-session-peer-overload-clear {
        description
            "This notification is sent when a peer leaves overload
            state.";

        uses notification-instance-hdr;

        leaf peer-overloaded {
            type boolean;
            description
                "If the peer has informed the local PCEP entity that
                it is currently overloaded, then this is set to true.
                Otherwise, it is set to false.";
        }
    } //notification
}//module
```

<CODE ENDS>

9. Security Considerations

The YANG module defined in this memo 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 NETCONF access control model [RFC6536] provides the means 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 data nodes defined in the YANG module which 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.

TBD: List specific Subtrees and data nodes and their sensitivity/ vulnerability.

10. Manageability Considerations

10.1. Control of Function and Policy

10.2. Information and Data Models

10.3. Liveness Detection and Monitoring

10.4. Verify Correct Operations

10.5. Requirements On Other Protocols

10.6. Impact On Network Operations

11. IANA Considerations

This document registers a URI in the "IETF XML Registry" [RFC3688]. Following the format in RFC 3688, the following registration has been made.

URI: urn:ietf:params:xml:ns:yang:ietf-pcep

Registrant Contact: The PCE WG of the IETF.

XML: N/A; the requested URI is an XML namespace.

This document registers a YANG module in the "YANG Module Names" registry [RFC6020].

```
Name:         ietf-pcep
Namespace:    urn:ietf:params:xml:ns:yang:ietf-pcep
Prefix:       pcep
Reference:    This I-D
```

12. Acknowledgements

The initial document is based on the PCEP MIB [RFC7420]. Further this document structure is based on Routing Yang Module [I-D.ietf-netmod-routing-cfg]. We would like to thank the authors of aforementioned documents.

13. References

13.1. Normative References

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July 6, 2016

OTN Service YANG Model
draft-sharma-ccamp-otn-service-model-00

Abstract

This document describes the YANG data model for OTN Services.

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 January 7, 2017.

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1. Introduction

OTN transport networks can carry various types of client services. In many cases, the client service is an OTN service across connected domains in a multi-domain network. These OTN services can either be transported or switched in the OTN network. If an OTN service is switched then additional parameters need to be provided to create a Mux OTN service.

This document provides YANG model for creating OTN service. The model augments the TE Tunnel model, which is an abstract model to create TE Tunnels.

2. Model Overview

This section provides an overview of the OTN Service Model.

2.1. OTN Mux Service

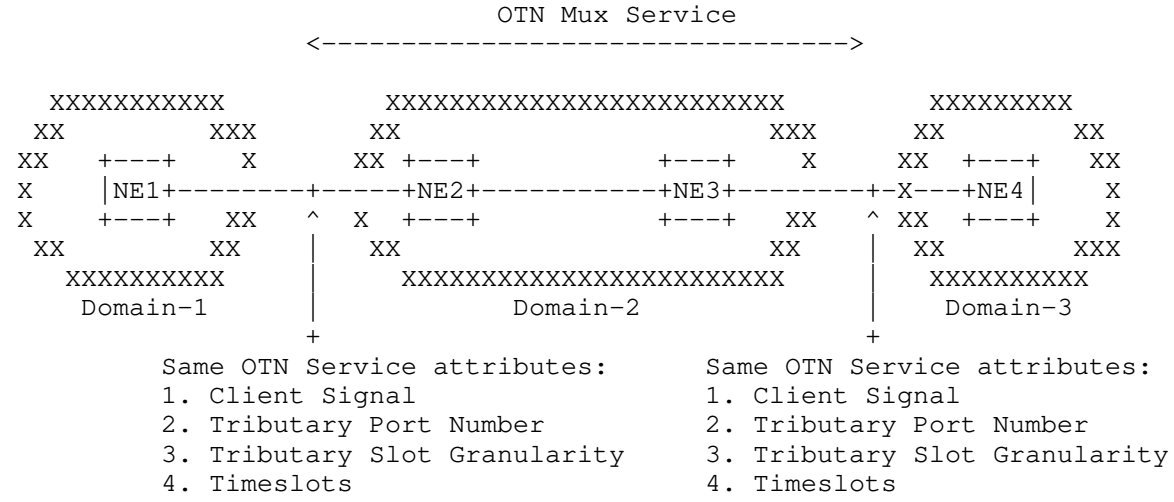

Figure 1: OTN Mux Service in a multi-domain network topology

Figure 1 shows a multi-domain OTN network with three domains. In this example, user wants to setup an end-to-end OTN service that passes through Domain-2. In order to create an OTN mux service in Domain-2, user will need to specify the exact details of the client side LO-ODU on NE2 and NE3, so that these service endpoints can be paired with the LO-ODU endpoints on NE1 and NE4, respectively.

Let's assume that ODU4 is the client side HO-ODU on NE2 and NE3, and the client signal is ODU2. User will need to specify the OTN client signal (ODU2 in this example), the Tributary Port Number (TPN), Tributary Slot Granularities (TSG) and timeslots to be used. As shown in the figure above, these service parameters must be the same between NE1 and NE2, and NE3 and NE4.

Once the OTN Mux service is setup in Domain-2, the incoming signal from either NE1 and/or NE4 will be switched inside Domain-2, and delivered to NE at the other end.

2.2. Model Tree

```
module: ietf-otn-service
augment /te:te/te:tunnels/te:tunnel/te:config:
   +--rw payload-treatment?    enumeration
   +--rw src-client-signal?    identityref
   +--rw src-tpn?              uint16
   +--rw src-tsg?              identityref
   +--rw src-timeslot-count?   uint16
   +--rw src-timeslots
   |  +--rw values*   uint8
   +--rw dst-client-signal?    identityref
   +--rw dst-tpn?              uint16
   +--rw dst-tsg?              identityref
   +--rw dst-timeslot-count?   uint16
   +--rw dst-timeslots
      +--rw values*   uint8
augment /te:te/te:tunnels/te:tunnel/te:state:
   +--ro payload-treatment?    enumeration
   +--ro src-client-signal?    identityref
   +--ro src-tpn?              uint16
   +--ro src-tsg?              identityref
   +--ro src-timeslot-count?   uint16
   +--ro src-timeslots
   |  +--ro values*   uint8
   +--ro dst-client-signal?    identityref
   +--ro dst-tpn?              uint16
   +--ro dst-tsg?              identityref
   +--ro dst-timeslot-count?   uint16
   +--ro dst-timeslots
      +--ro values*   uint8
```

2.3. OTN Service YANG Model

```
<CODE BEGINS> file "ietf-otn-service@2016-06-24.yang"

module ietf-otn-service {
```

```
yang-version 1;
namespace "urn:ietf:params:xml:ns:yang:ietf-otn-service";
prefix "otn-svc";

import ietf-te { prefix "te"; }
import ietf-transport-types { prefix "tran-types"; }
import yang-ext { prefix ext; revision-date 2013-07-09; }

organization
    "IETF CCAMP Working Group";

contact
    "WG Web: <http://tools.ietf.org/wg/ccamp/>
    WG List: <mailto:ccamp@ietf.org>

    Editor: Anurag Sharma
            <mailto:AnSharma@infinera.com>

    Editor: Rajan Rao
            <mailto:rrao@infinera.com>

    Editor: Xian Zhang
            <mailto:zhang.xian@huawei.com>";

description
    "This module defines a model for OTN Services.";

revision "2016-06-24" {
    description "Initial revision";
    reference "TBD";
}

grouping otn-tunnel-endpoint {
    description "Parameters for OTN service.";

            leaf payload-treatment {
        type enumeration {
            enum switching;
            enum transport;
        }
        default switching;
        description
            "Treatment of the incoming payload. Payload can
            either be switched, or transported as is.";
    }

    leaf src-client-signal {
            type identityref {
```

```
                        base tran-types:client-signal;
                }
                description
                        "Client signal at the source endpoint of
                        the tunnel.";
        }

        leaf src-tpn {
            type uint16 {
                range "0..4095";
            }
            description
                "Tributary Port Number. Applicable in case of mux
                services.";
            reference
                "RFC7139: GMPLS Signaling Extensions for Control of
                Evolving G.709 Optical Transport Networks.";
        }

        leaf src-tsg {
            type identityref {
                base tran-types:tributary-slot-granularity;
            }
            description
                "Tributary slot granularity. Applicable in case of mux
                services.";
            reference
                "G.709/Y.1331, February 2012: Interfaces for the
                Optical Transport Network (OTN)";
        }

        leaf src-timeslot-count {
             type uint16;
             description
                 "Number of timeslots used at the source.";
        }

        container src-timeslots {
            description
                 "A list of tributary timeslots used by the
                 client service. Applicable in case of mux
                 services.";
            leaf-list values {
                type uint8;
                description
                        "Tributary timeslot value.";
                reference
                    "G.709/Y.1331, February 2012: Interfaces for the
```

```
                    Optical Transport Network (OTN)";
            }
        }

        leaf dst-client-signal {
                type identityref {
                        base tran-types:client-signal;
                }
                description
                        "Client signal at the destination endpoint of
                        the tunnel.";
        }

        leaf dst-tpn {
            type uint16 {
                range "0..4095";
            }
            description
                "Tributary Port Number. Applicable in case of mux
                services.";
            reference
                "RFC7139: GMPLS Signaling Extensions for Control of
                Evolving G.709 Optical Transport Networks.";
        }

        leaf dst-tsg {
            type identityref {
                base tran-types:tributary-slot-granularity;
            }
            description
                "Tributary slot granularity. Applicable in case of mux
                services.";
            reference
                "G.709/Y.1331, February 2012: Interfaces for the
                Optical Transport Network (OTN)";
        }

        leaf dst-timeslot-count {
             type uint16;
             description
                 "Number of timeslots used at the destination.";
        }

        container dst-timeslots {
             description
                "A list of tributary timeslots used by the
                client service. Applicable in case of mux
                services.";
```

```
            leaf-list values {
                type uint8;
                description
                        "Tributary timeslot value.";
                reference
                    "G.709/Y.1331, February 2012: Interfaces for the
                        Optical Transport Network (OTN)";
            }
        }
    }

    /*
    Note: Comment has been given to authors of TE Tunnel model to add
    tunnel-types to the model in order to identify the technology
    type of the service.

    grouping otn-service-type {
        description
          "Identifies the OTN Service type.";
        container otn-service {
          presence "Indicates OTN Service.";
          description
            "Its presence identifies the OTN Service type.";
        }
      } // otn-service-type

    augment "/te:te/te:tunnels/te:tunnel/te:tunnel-types" {
        description
                "Introduce OTN service type for tunnel.";
        ext:augment-identifier otn-service-type-augment;
        uses otn-service-type;
    }
    */

    /*
    Note: Comment has been given to authors of TE Tunnel model to add
    list of endpoints under config to support P2MP tunnel.
    */
    augment "/te:te/te:tunnels/te:tunnel/te:config" {
        description
                "Augment with additional parameters required for OTN
                service.";
        ext:augment-identifier otn-tunnel-endpoint-config-augment;
        uses otn-tunnel-endpoint;
    }

    augment "/te:te/te:tunnels/te:tunnel/te:state" {
        description
```

```
                "Augment with additional parameters required for OTN
                service.";
            ext:augment-identifier otn-tunnel-endpoint-state-augment;
            uses otn-tunnel-endpoint;
        }

        /*
        Note: Comment has been given to authors of TE Tunnel model to add
        tunnel-lifecycle-event to the model. This notification is reported
        for all lifecycle changes (create, delete, and update) to the
        tunnel or lsp.
        augment "/te:tunnel-lifecycle-event" {
            description
              "OTN service event";
            uses otn-service-type;
            uses otn-tunnel-params;
            list endpoint {
              key
                "endpoint-address tp-id";
              description
                "List of Tunnel Endpoints.";
              uses te:tunnel-endpoint;
              uses otn-tunnel-params;
            }
          }
        */
    }

    <CODE ENDS>
```

2.4. Transport Types YANG Model

```
    <CODE BEGINS> file "ietf-transport-types@2016-06-24.yang"

     module ietf-transport-types {
        yang-version 1;
        namespace "urn:ietf:params:xml:ns:yang:ietf-transport-types";
        prefix "tran-types";

        organization
            "IETF CCAMP Working Group";
        contact
            "WG Web: <http://tools.ietf.org/wg/ccamp/>
            WG List: <mailto:ccamp@ietf.org>

            Editor: Anurag Sharma
                    <mailto:AnSharma@infinera.com>
```

```
            Editor: Rajan Rao
                    <mailto:rrao@infinera.com>

            Editor: Xian Zhang
                    <mailto:zhang.xian@huawei.com>";

        description
            "This module defines transport types.";

        revision "2016-06-24" {
            description "Initial revision";
            reference "TBD";
        }

        identity tributary-slot-granularity {
            description
                    "Tributary slot granularity.";
            reference
                    "G.709/Y.1331, February 2012: Interfaces for the
                            Optical Transport Network (OTN)";
        }

        identity tsg-1.25G {
            base tributary-slot-granularity;
            description
                    "1.25G tributary slot granularity.";
        }

        identity tsg-2.5G {
            base tributary-slot-granularity;
            description
                    "2.5G tributary slot granularity.";
        }

        identity tributary-protocol-type {
            description
                    "Base identity for protocol framing used by
                    tributary signals.";
        }

        identity prot-OTU1 {
            base tributary-protocol-type;
            description
                    "OTU1 protocol (2.66G)";
        }

        identity prot-OTU1e {
            base tributary-protocol-type;
```

```
            description
                    "OTU1e protocol (11.04G)";
        }


        identity prot-OTU2 {
            base tributary-protocol-type;
            description
                    "OTU2 protocol (10.70G)";
        }

        identity prot-OTU2e {
            base tributary-protocol-type;
            description
                    "OTU2e protocol (11.09G) for 10G LAN PHY";
        }

        identity prot-OTU2f {
            base tributary-protocol-type;
            description
                    "OTU2f protocol (11.32G) for transporting a 10
                    fiber channel.";
        }

        identity prot-OTU3 {
            base tributary-protocol-type;
            description
                    "OTU3 protocol (43.01G)";
        }

        identity prot-OTU3e {
            base tributary-protocol-type;
            description
                    "OTU3e protocol (44.57G) for transporting four OTU2e
                    signals.";
        }

        identity prot-OTU3e2 {
            base tributary-protocol-type;
            description
                    "OTU3e2 protocol (44.58G).";
        }


        identity prot-OTU4 {
            base tributary-protocol-type;
            description
                    "OTU4 protocol (112G) for transporting 100GE
```

```
                signal.";
        }

        identity prot-OTUCn {
            base tributary-protocol-type;
            description
                    "OTUCn protocol (beyond 100G) for transporting
                    more than 100G signals.";
        }

        identity prot-ODU0 {
            base tributary-protocol-type;
            description
                    "ODU0 protocol (1.24G).";
        }

        identity prot-ODU1 {
            base tributary-protocol-type;
            description
                    "ODU1 protocol (2.49G).";
        }

        identity prot-ODU1e {
            base tributary-protocol-type;
            description
                    "ODU1e protocol (10.35G).";
        }

        identity prot-ODU2 {
            base tributary-protocol-type;
            description
                    "ODU2 protocol (10.03G).";
        }

        identity prot-ODU2e {
            base tributary-protocol-type;
            description
                     "ODU2e protocol (10.39G).";
        }

        identity prot-ODU3 {
            base tributary-protocol-type;
            description
                    "ODU 3 protocol (40.31G).";
        }

        identity prot-ODU3e2 {
            base tributary-protocol-type;
```

```
            description
                    "ODU3e2 protocol (41.78G).";
        }

        identity prot-ODU4 {
            base tributary-protocol-type;
            description
                    "ODU4 protocol (104.79G).";
        }

        identity prot-ODUFlex-cbr {
            base tributary-protocol-type;
            description
                    "ODU Flex CBR protocol for transporting constant bit
                    rate signal.";
        }

        identity prot-ODUFlex-gfp {
            base tributary-protocol-type;
            description
                    "ODU Flex GFP protocol for transporting stream
                    of packets using Generic Framing Procedure.";
        }

        identity prot-ODUCn {
            base tributary-protocol-type;
            description
                    "ODUCn protocol (beyond 100G).";
        }

        identity prot-1GbE {
            base tributary-protocol-type;
            description
                    "1G Ethernet protocol";
        }

        identity prot-10GbE-LAN {
            base tributary-protocol-type;
            description
                    "10G Ethernet LAN protocol";
        }

        identity prot-40GbE {
            base tributary-protocol-type;
            description
                    "40G Ethernet protocol";
        }
```

```
      identity prot-100GbE {
          base tributary-protocol-type;
          description
                  "100G Ethernet protocol";
      }

      identity client-signal {
          description
                  "Base identity from which specific client signals
                  for the tunnel are derived.";
        }

      identity client-signal-1GbE {
          base client-signal;
          description
                  "Client signal type of 1GbE";
        }

      identity client-signal-10GbE-LAN {
          base client-signal;
          description
                  "Client signal type of 10GbE LAN";
        }

      identity client-signal-10GbE-WAN {
          base client-signal;
          description
                  "Client signal type of 10GbE WAN";
        }

      identity client-signal-40GbE {
          base client-signal;
          description
                  "Client signal type of 40GbE";
        }

      identity client-signal-100GbE {
          base client-signal;
          description
                  "Client signal type of 100GbE";
        }

      identity client-signal-OC3_STM1 {
          base client-signal;
          description
                  "Client signal type of OC3 and STM1";
        }
```

```
      identity client-signal-OC12_STM4 {
          base client-signal;
          description
                  "Client signal type of OC12 and STM4";
        }

      identity client-signal-OC48_STM16 {
          base client-signal;
          description
                  "Client signal type of OC48 and STM16";
        }

      identity client-signal-OC192_STM64 {
          base client-signal;
          description
                  "Client signal type of OC192 and STM64";
        }

      identity client-signal-OC768_STM256 {
          base client-signal;
          description
                  "Client signal type of OC768 and STM256";
        }

      identity client-signal-OTU1 {
          base client-signal;
          description
                  "Client signal type of OTU1 (2.66G)";
      }

      identity client-signal-OTU2 {
          base client-signal;
          description
                  "Client signal type of OTU2 (10.70G)";
      }

      identity client-signal-OTU2e {
          base client-signal;
          description
                  "Client signal type of OTU2e (11.09G)";
      }

      identity client-signal-OTU2f {
          base client-signal;
          description
                  "Client signal type of OTU2f (11.32G)";
      }
```

```
      identity client-signal-OTU3 {
          base client-signal;
          description
                  "Client signal type of OTU3 (43.01G)";
      }

      identity client-signal-OTU3e {
          base client-signal;
          description
                  "Client signal type of OTU3e (44.58G)";
      }

      identity client-signal-OTU4 {
          base client-signal;
          description
                  "Client signal type of OTU4 (112G)";
      }

      identity client-signal-OTUCn {
          base client-signal;
          description
                  "Client signal type of OTUCn (beyond 100G)";
      }

      identity client-signal-ODU0 {
          base client-signal;
          description
                  "Client signal type of ODU0 (1.24G)";
      }

      identity client-signal-ODU1 {
          base client-signal;
          description
                  "ODU1 protocol (2.49G)";
      }

      identity client-signal-ODU2 {
          base client-signal;
          description
                  "Client signal type of ODU2 (10.03G)";
      }

      identity client-signal-ODU2e {
          base client-signal;
          description
                  "Client signal type of ODU2e (10.39G)";
      }
```

```
    identity client-signal-ODU3 {
        base client-signal;
        description
                "Client signal type of ODU 3 (40.31G)";
    }

    identity client-signal-ODU3e2 {
        base client-signal;
        description
                "Client signal type of ODU3e2 (41.78G)";
    }

    identity client-signal-ODU4 {
        base client-signal;
        description
                "Client signal type of ODU4 (104.79G)";
    }

    identity client-signal-ODUFlex-cbr {
        base client-signal;
        description
                "Client signal type of ODU Flex CBR";
    }

    identity client-signal-ODUFlex-gfp {
        base client-signal;
        description
                "Client signal type of ODU Flex GFP";
    }

    identity client-signal-ODUCn {
        base client-signal;
        description
                "Client signal type of ODUCn (beyond 100G).";
    }

    identity client-signal-FC400 {
        base client-signal;
        description
                "Client signal type of Fibre Channel FC400.";
    }

    identity client-signal-FC800 {
        base client-signal;
        description
                "Client signal type of Fibre Channel FC800.";
    }
```

```
        identity client-signal-FICON-4G {
            base client-signal;
            description
                    "Client signal type of Fibre Connection 4G.";
        }

        identity client-signal-FICON-8G {
            base client-signal;
            description
                    "Client signal type of Fibre Connection 8G.";
        }
    }

    <CODE ENDS>
```

3. Security Considerations

TBD

4. IANA Considerations

TBD

5. Acknowledgements

6. Normative References

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October 13, 2016

Service Chaining using MPLS Source Routing
draft-xu-mpls-service-chaining-00

Abstract

Source Packet Routing in Networking (SPRING) WG is developing an MPLS source routing mechanism. This MPLS source routing mechanism can be leveraged to realize the service path layer functionality of the service function chaining (i.e., steering the selected traffic through a particular service function path) by encoding the service function path information as an MPLS label stack. This document describes how to use the MPLS source routing mechanism as developed by the SPRING WG to realize the service path layer functionality of service function chaining.

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].

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 April 16, 2017.

Table of Contents

1. Introduction

When applying a particular Service Function Chain (SFC) [RFC7665] to the traffic selected by a service classifier, the traffic need to be steered through an ordered set of Service Functions (SF) in the network. This ordered set of SFs in the network indicates the Service Function Path (SFP) associated with the above SFC. In order to steer the selected traffic through the required ordered list of SFs, the service classifier needs to attach information to the packet specifying which Service Function Forwarders (SFFs) and which SFs are to be visited by the selected traffic. The Source Packet Routing in Networking (SPRING) WG is developing an MPLS source routing mechanism which can be used to steer traffic through an ordered set of routers (i.e., an explicit path) and instruct nodes on that path to execute

specific operations on the packet. This MPLS source routing mechanism thus can be leveraged to realize the service path layer functionality of the SFC (i.e., steering traffic through a particular SFP) by encoding the SFP information as a label stack. This document describes how to use the MPLS source routing mechanisms to realize the service path layer functionality of the service function chaining. Note that this approach is aligned with the Transport Derived SFF mode as described in Section 4.3.1 of [RFC7665].

2. Terminology

This memo makes use of the terms defined in [I-D.ietf-spring-segment-routing-mpls] and [RFC7665].

3. Solution Description

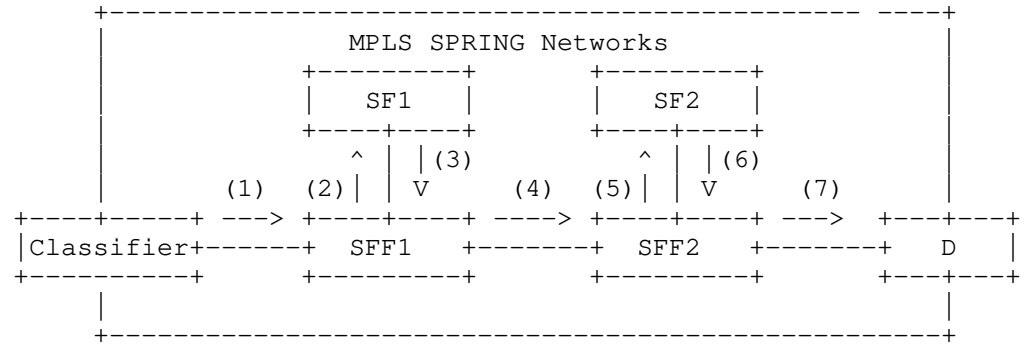

Figure 1: Service Function Chaining in MPLS-SPRING Networks

As shown in Figure 1, SFF1 and SFF2 are two MPLS-SPRING-capable nodes. They are also SFFs, each with one SF attached. In addition, they have allocated and advertised Segment IDs (SID) for their locally attached SFs. In the MPLS-SPRING context, SIDs are encoded as MPLS labels. For example, SFF1 allocates and advertises a SID (i.e., SID(SF1)) for SF1 while SFF2 allocates and advertises an SID (i.e., SID(SF2)) for SF2. These SIDs, which are used to indicate SFs are referred to as SF SIDs. To encode the SFP information as an MPLS label stack, those SF SIDs as mentioned above would be interpreted as local MPLS labels. More specifically, local MPLS labels are allocated from SFFs' (e.g., SFF1 in Figure 1) label spaces to identify their attached SFs (e.g., SF1 in Figure 1), whilst the SFFs are identified by either nodal SIDs or adjacency SIDs depending on how strictly the network path needs to be specified. In addition, assume node SIDs for SFF1 and SFF2 are SID(SFF1) and SID(SFF2) respectively. Now assume a given traffic flow destined for destination D is selected by the service classifier to go through a particular SFC (i.e., SF1-> SF2) before reaching its final

destination D. Section 3.1 describes how to use the MPLS-based source routing mechanism to realize the service path functionality of the service function chaining (i.e., by encoding the SFP information within an MPLS label stack).

3.1. Encoding SFP Information by an MPLS Label Stack

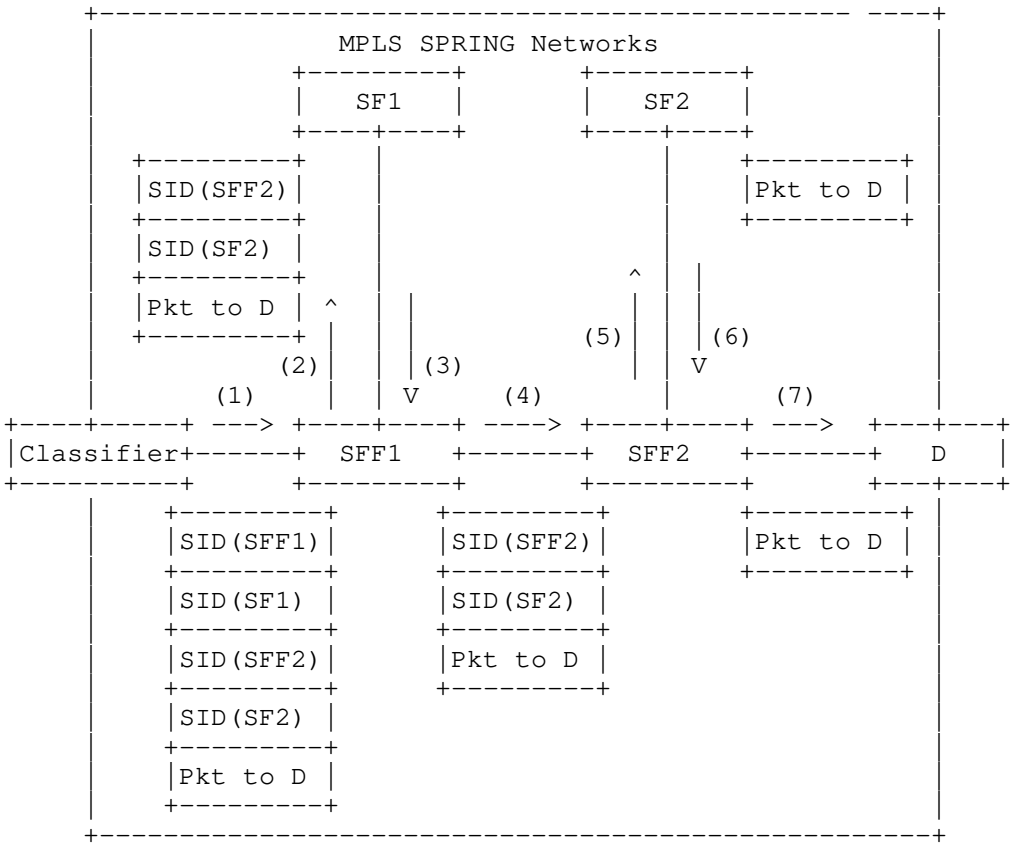

Figure 2: Packet Walk in MPLS Source Routing based SFC

As shown in Figure 2, since the selected packet needs to travel through an SFC (i.e., SF1->SF2), the service classifier would attach a segment list of (i.e., SID(SFF1)->SID(SF1)->SID(SFF2)-> SID(SF2)) which indicates the corresponding SFP to the packet. This segment list is represented by an MPLS label stack. To some extent, the MPLS label stack here could be looked as a specific implementation of the SFC encapsulation used for containing the SFP information [RFC7665]. When the encapsulated packet arrives at SFF1, SFF1 would know which SF should be performed according to the top label (i.e., SID (SF1)) of the received MPLS packet. We first consider the case where SF1 is

an encapsulation aware SF, i.e., it understands how to process a packet with a pre-pended MPLS label stack. In this case the packet would be sent to SF1 by SFF1 with the label stack SID(SFF2)-> SID(SF2). SF1 would perform the required service function on the received MPLS packet where the payload is constrained to be an IP packet, and the SF needs to process both IPv4 and IPv6 packets (note that the SF would use the first nibble of the MPLS payload to identify the payload type). After the MPLS packet is returned from SF1, SFF1 would send it to SFF2 according to the top label (i.e., SID (SFF2)).

If SF1 is a legacy SF, i.e. one that is unable to process the MPLS label stack, the remaining MPLS label stack (i.e., SID(SFF2)->SID(SF2)) MUST be saved and stripped from the packet before sending the packet to SF1. When the packet is returned from SF1, SFF1 would re-impose the MPLS label stack which had been previously stripped and then send the packet to SFF2 according to the current top label (i.e., SID (SFF2)). As for how to associate the corresponding MPLS label stack with the packets returned from legacy SFs, those mechanisms as described in [I-D.song-sfc-legacy-sf-mapping] could be considered.

When the encapsulated packet arrives at SFF2, SFF2 would perform the similar action to that described above.

If there is no MPLS LSP towards the next node segment (i.e., the next SFF identified by the current top label), the corresponding IP-based tunnel (e.g., MPLS-in-IP/GRE tunnel [RFC4023], MPLS-in-UDP tunnel [RFC7510] or MPLS-in-L2TPv3 tunnel [RFC4817]) would be used instead (for more details about this special usage, please refer to [I-D.xu-mpls-spring-islands-connection-over-ip]). Since the transport (i.e., the underlay) could be IPv4, IPv6 or even MPLS networks, the above approach of encoding the SFP information by an MPLS label stack is fully transport-independent which is one of the major requirements for the SFC encapsulation [RFC7665].

4. Acknowledgements

The authors would like to thank Loa Andersson, Andrew G. Malis, Adrian Farrel, Alexander Vainshtein and Joel M. Halpern for their valuable comments and suggestions on the document

5. IANA Considerations

This document makes no request of IANA.

6. Security Considerations

It is fundamental to the SFC design that the classifier is a trusted resource which determines the processing that the packet will be subject to, including for example the firewall. It is also fundamental to the SPRING design that packets are routed through the network using the path specified by the node imposing the SIDs. Where an SF is not encapsulation aware the packet may exist as an IP packet, however this is an intrinsic part of the SFC design which needs to define how a packet is protected in that environment. Where a tunnel is used to link two non-MPLS domains, the tunnel design needs to specify how it is secured. Thus the secutity vulnerabilities are addressed in the underlying technologies used by this design, which itself does not introduce any new security vulnerabilities.

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June 29, 2017

Service Chaining using Unified Source Routing Instructions
draft-xu-mpls-service-chaining-03

Abstract

Source Packet Routing in Networking (SPRING) WG is developing an MPLS source routing mechanism. The MPLS source routing mechanism can be leveraged to realize a unified source routing instruction which works across both IPv4 and IPv6 underlays in addition to the MPLS underlay. This document describes how to leverage the unified source routing instruction to realize a transport-independent service function chaining by encoding the service function path information or service function chain information as an MPLS label stack.

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].

Status of This Memo

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This Internet-Draft will expire on December 31, 2017.

Table of Contents

1. Introduction

When applying a particular Service Function Chain (SFC) [RFC7665] to the traffic selected by a service classifier, the traffic need to be steered through an ordered set of Service Functions (SF) in the network. This ordered set of SFs in the network indicates the Service Function Path (SFP) associated with the above SFC. In order

to steer the selected traffic through the required ordered list of SFs, the service classifier needs to attach information to the packet specifying exactly which Service Function Forwarders (SFFs) and which SFs are to be visited by traffic), the SFC, or the partially specified SFP which is in between the former two extremes.

The Source Packet Routing in Networking (SPRING) WG is developing an MPLS source routing mechanism which can be used to steer traffic through an ordered set of routers (i.e., an explicit path) and instruct nodes on that path to execute specific operations on the packet. By leveraging the MPLS source routing mechanism, [I-D.xu-mpls-unified-source-routing-instruction] describes a unified source routing instruction which works across both IPv4 and IPv6 underlays in addition to the MPLS underlay. This document describes how to leverage the unified source routing instruction to realize a transport-independent service function chaining by encoding the service function path information or service function chain information as an MPLS label stack.

2. Terminology

This memo makes use of the terms defined in [I-D.ietf-spring-segment-routing-mpls], [I-D.xu-mpls-unified-source-routing-instruction] and [RFC7665].

3. Solution Description

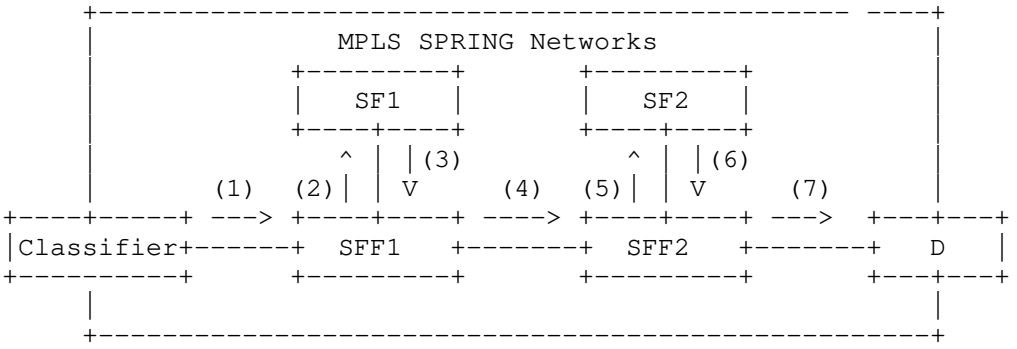

Figure 1: Service Function Chaining in MPLS-SPRING Networks

As shown in Figure 1, SFF1 and SFF2 are two MPLS-SPRING-capable nodes. They are also SFFs, each with one SF attached. In addition, they have allocated and advertised MPLS labels for their locally attached SFs. For example, SFF1 allocates and advertises a label (i.e., L(SF1)) for SF1 while SFF2 allocates and advertises a label (i.e., L(SF2)) for SF2. These labels, which are used to indicate SFs are referred to as SF labels. To encode the SFP information as an

MPLS label stack, local MPLS labels are allocated from SFFs' (e.g., SFF1 in Figure 1) label spaces to identify their locally attached SFs (e.g., SF1 in Figure 1), whilst the SFFs are identified by either nodal SIDs or adjacency SIDs depending on how strictly the network path needs to be specified. In addition, assume node SIDs for SFF1 and SFF2 are L(SFF1) and L(SFF2) respectively. In contrast, to encode the SFC information by an MPLS label stack, those SF labels MUST be domain-wide unique MPLS labels.

Now assume a given traffic flow destined for destination D is selected by the service classifier to go through a particular SFC (i.e., SF1-> SF2) before reaching its final destination D. Section 3.1 and 3.2 describe approaches of leveraging the MPLS- based source routing mechanisms to realize the service function chaining by encoding the SFP information within an MPLS label stack and by encoding the SFC information within an MPLS label stack respectively. Since the encoding of the partially specified SFP is just a simple combination of the encoding of the SFP and the encoding of the SFC, this document would not describe how to encode the partially specified SFP anymore.

3.1. Encoding SFP Information by an MPLS Label Stack

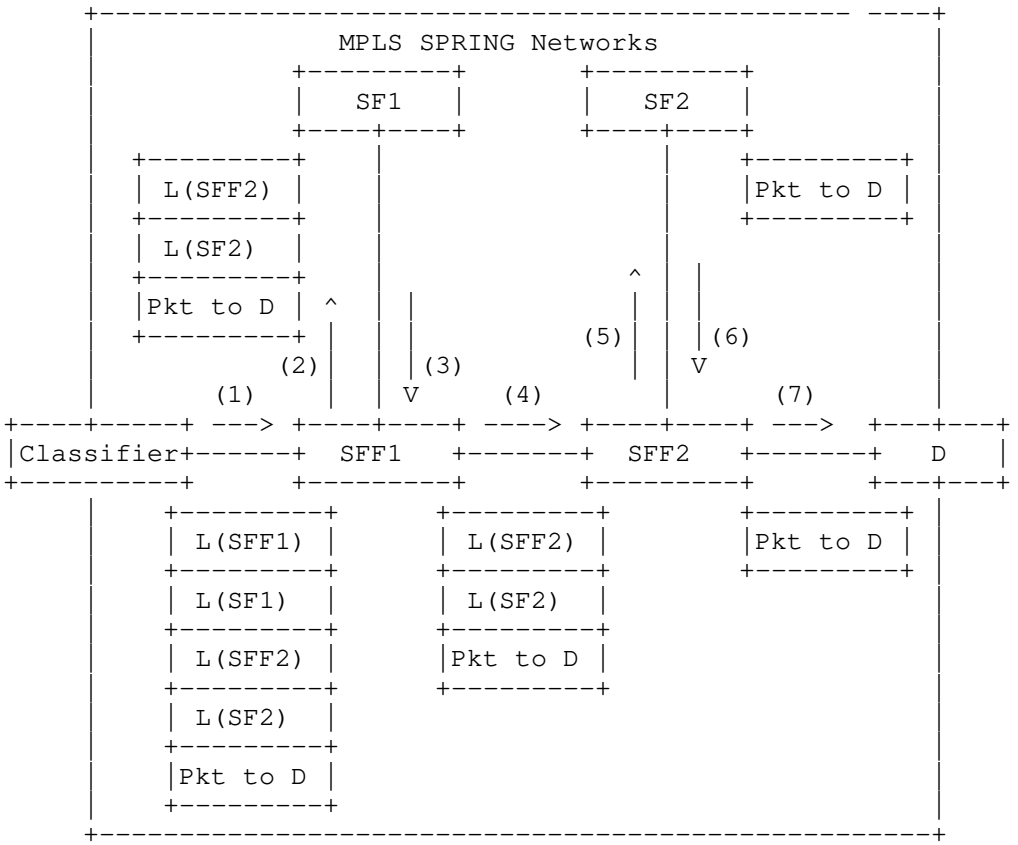

Figure 2: Packet Walk in MPLS underlay

As shown in Figure 2, since the selected packet needs to travel through an SFC (i.e., SF1->SF2), the service classifier would attach a segment list of (i.e., SID(SFF1)->SID(SF1)->SID(SFF2)-> SID(SF2)) which indicates the corresponding SFP to the packet. This segment list is represented by an MPLS label stack. To some extent, the MPLS label stack here could be looked as a specific implementation of the SFC encapsulation used for containing the SFP information [RFC7665]. When the encapsulated packet arrives at SFF1, SFF1 would know which SF should be performed according to the top label (i.e., SID (SF1)) of the received MPLS packet. We first consider the case where SF1 is an encapsulation aware SF, i.e., it understands how to process a packet with a pre-pended MPLS label stack. In this case the packet would be sent to SF1 by SFF1 with the label stack SID(SFF2)-> SID(SF2). SF1 would perform the required service function on the received MPLS packet where the payload is constrained to be an IP packet, and the SF needs to process both IPv4 and IPv6 packets (note that the SF would use the first nibble of the MPLS payload to

identify the payload type). After the MPLS packet is returned from SF1, SFF1 would send it to SFF2 according to the top label (i.e., SID (SFF2)).

If SF1 is a legacy SF, i.e. one that is unable to process the MPLS label stack, the remaining MPLS label stack (i.e., SID(SFF2)->SID(SF2)) MUST be saved and stripped from the packet before sending the packet to SF1. When the packet is returned from SF1, SFF1 would re-impose the MPLS label stack which had been previously stripped and then send the packet to SFF2 according to the current top label (i.e., SID (SFF2)). As for how to associate the corresponding MPLS label stack with the packets returned from legacy SFs, those mechanisms as described in [I-D.song-sfc-legacy-sf-mapping] could be considered.

When the encapsulated packet arrives at SFF2, SFF2 would perform the similar action to that described above.

As shown in Figure 3, if there is no MPLS LSP towards the next node segment (i.e., the next SFF identified by the current top label), the corresponding IP-based tunnel for MPLS (e.g., MPLS-in-IP/GRE tunnel [RFC4023], MPLS-in-UDP tunnel [RFC7510] or MPLS-in-L2TPv3 tunnel [RFC4817]) would be used instead, according to the unified source routing instruction as described in [I-D.xu-mpls-unified-source-routing-instruction].

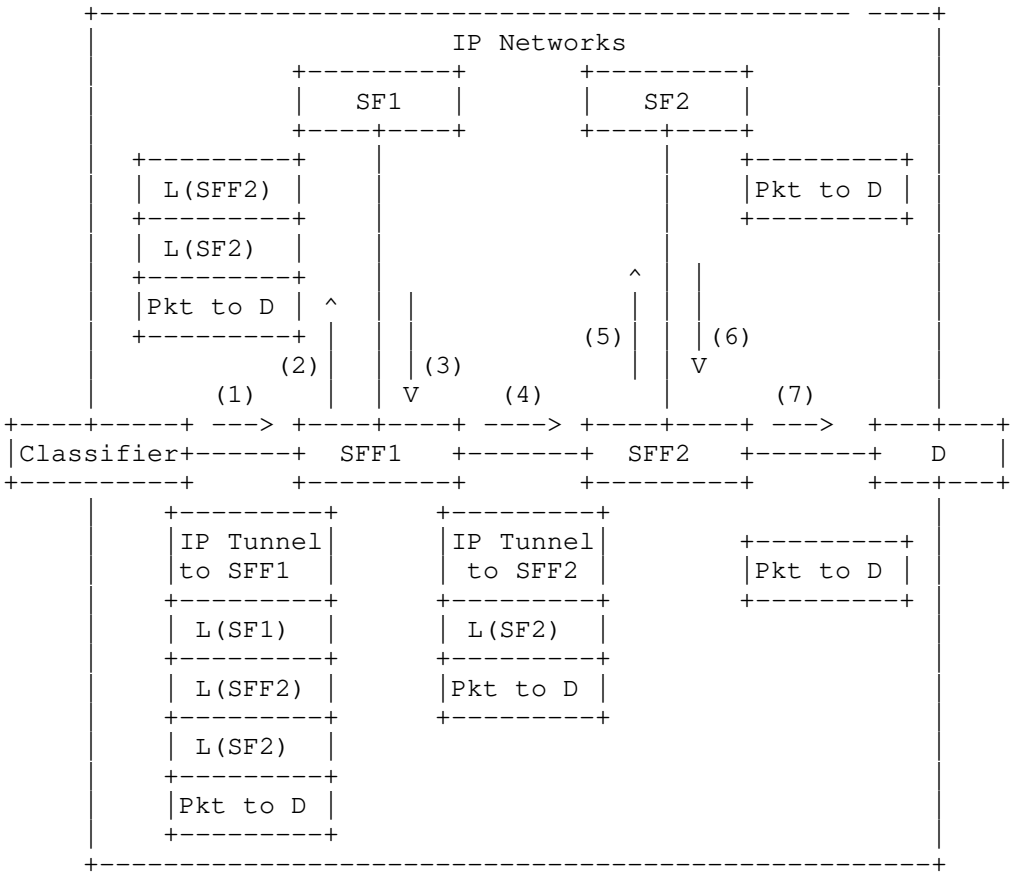

Figure 3: Packet Walk in IP underlay

Since the transport (i.e., the underlay) could be IPv4, IPv6 or even MPLS networks, the above approach of encoding the SFP information by an MPLS label stack is fully transport-independent which is one of the major requirements for the SFC encapsulation [RFC7665].

3.2. Encoding SFC Information by an MPLS Label Stack

Since the selected packet needs to travel through an SFC (i.e., SF1->SF2), the service classifier would attach an MPLS label stack (i.e., L(SF1)->L(SF2)) which indicates that SFC to the packet. Since it's known to the service classifier that SFF1 is attached with an instance of SF1, the service classifier would therefore send the MPLS encapsulated packet through either an MPLS LSP tunnel or an IP-based tunnel towards SFF1 (as shown in Figure 4 and 5 respectively). When the MPLS encapsulated packet arrives at SFF1, SFF1 would know which SF should be performed according to the current top label (i.e.,

L(SF1)). Similarly, SFF1 would send the packet returned from SF1 to SFF2 through either an MPLS LSP tunnel or an IP-based tunnel towards SFF2 since it's known to SFF1 that SFF2 is attached with an instance of SF2. When the encapsulated packet arrives at SFF2, SFF2 would do the similar action as what has been done by SFF1. Since the transport (i.e., the underlay) could be IPv4, IPv6 or even MPLS networks, the above approach of encoding the SFC information by an MPLS label stack is fully transport-independent which is one of the major requirements for the SFC encapsulation [RFC7665].

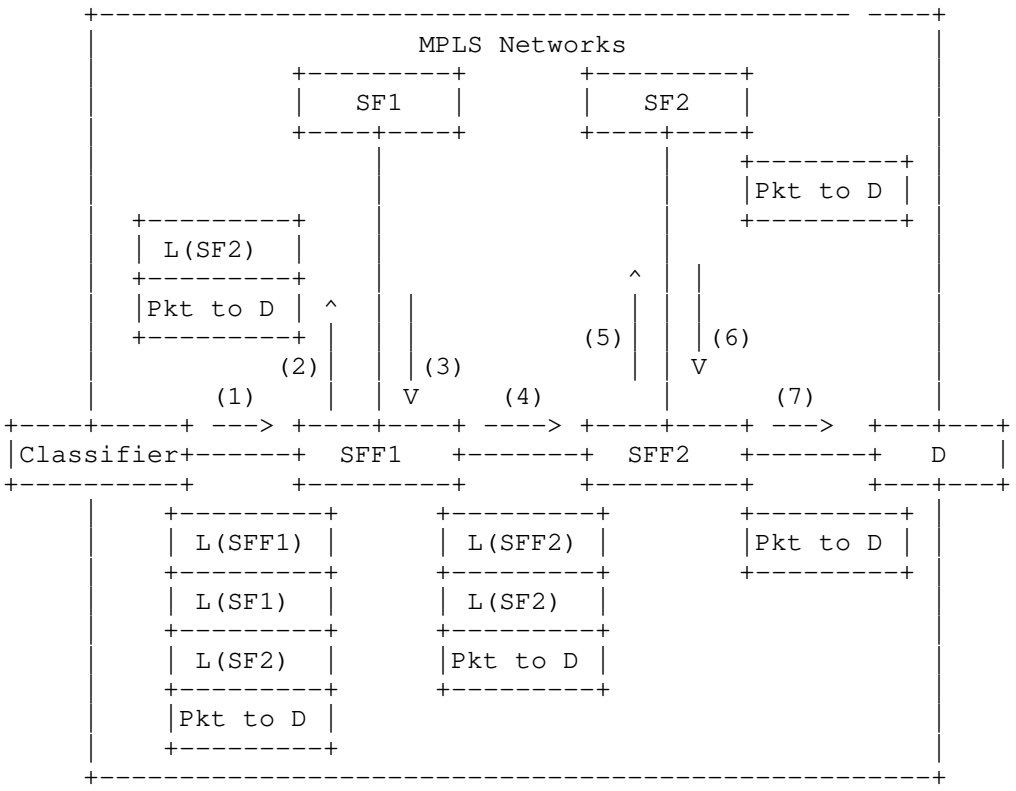

Figure 4: Packet Walk in MPLS underlay

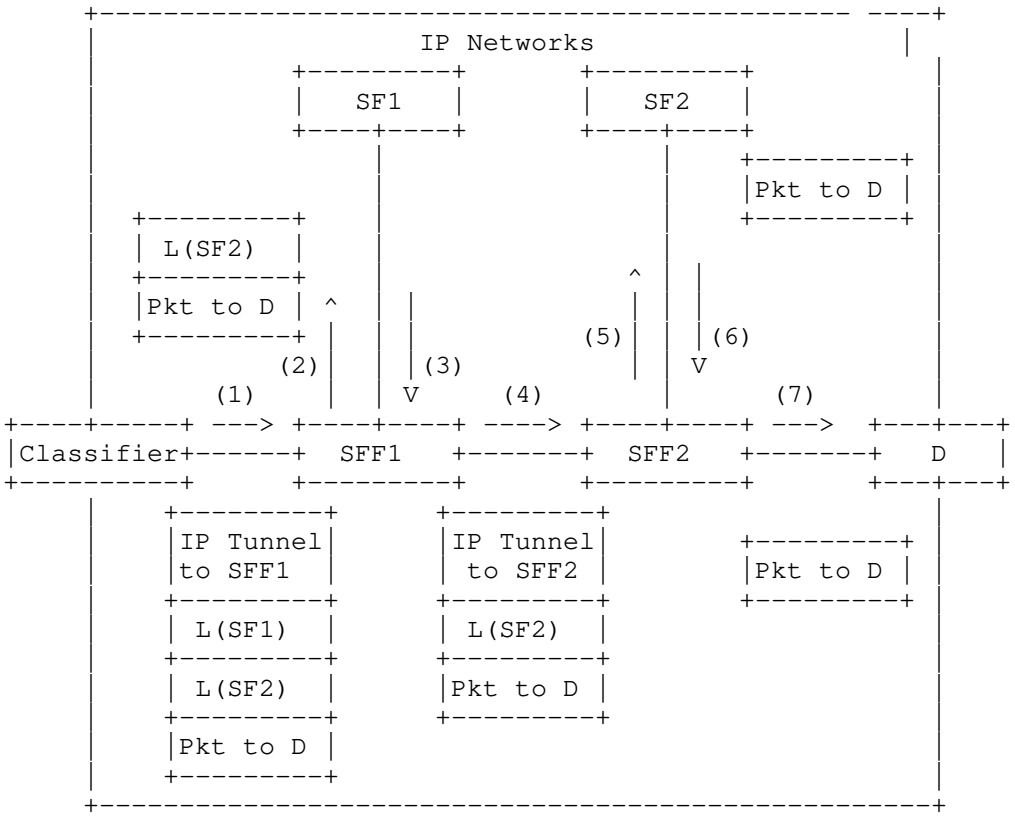

Figure 5: Packet Walk in IP underlay

3.3. How to Contain Metadata within an MPLS Packet

Since the MPLS encapsulation has no explicit protocol identifier field to indicate the protocol type of the MPLS payload, how to indicate the presence of metadata (i.e., the NSH which is only used as a metadata containner) in an MPLS packet is a potential issue to be addressed. One possible way to address the above issue is: SFFs allocate two different labels for a given SF, one indicates the presence of NSH while the other indicates the absence of NSH. This approach has no change to the current MPLS architecture but it would require more than one label binding for a given SF. Another possible way is to introduce a protocol identifier field within the MPLS packet as described in [I-D.xu-mpls-payload-protocol-identifier].

More details about how to contain metadata within an MPLS packet would be considered in the future version of this draft.

4. Acknowledgements

The authors would like to thank Loa Andersson, Andrew G. Malis, Adrian Farrel, Alexander Vainshtein and Joel M. Halpern for their valuable comments and suggestions on the document.

5. IANA Considerations

This document makes no request of IANA.

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7. References

7.1. Normative References

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7.2. Informative References

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[I-D.xu-mpls-payload-protocol-identifier]
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Connecting MPLS-SPRING Islands over IP Networks
draft-xu-mpls-spring-islands-connection-over-ip-00

Abstract

MPLS-SPRING is an MPLS-based source routing paradigm in which a sender of a packet is allowed to partially or completely specify the route the packet takes through the network by imposing stacked MPLS labels to the packet. To facilitate the incremental deployment of this new technology, this document describes a mechanism which allows the outermost LSP be replaced by an IP-based tunnel.

Status of This Memo

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This Internet-Draft will expire on April 15, 2017.

Table of Contents

1. Introduction

MPLS-SPRING [I-D.ietf-spring-segment-routing-mpls] is a MPLS-based source routing paradigm in which a sender of a packet is allowed to partially or completely specify the route the packet takes through the network by imposing stacked MPLS labels to the packet. To facilitate the incremental deployment of this new technology, this document describes a mechanism which allows the outermost LSP to be replaced by an IP-based tunnel (e.g., MPLS-in-IP/GRE tunnel [RFC4023], MPLS-in-UDP tunnel [RFC7510] or MPLS-in-L2TPv3 tunnel [RFC4817] and etc) when the nexthop along the LSP is not MPLS-SPRING-enabled. The tunnel destination address would be the address of the egress of the outmost LSP (e.g., the egress of the active node segment).

This mechanism is much useful in the MPLS-SPRING-based Service Function Chainning (SFC) case [I-D.xu-sfc-using-mpls-spring] where only a few specific routers (e.g., Service Function Forwarders (SFF) and classifiers) are required to be MPLS-SPRING-capable while the remaining routers are just required to support IP forwarding capability. In addition, this mechanism is also useful in some specific Traffic Engineering scenarios where only a few routers (e.g., the entry and exit nodes of each plane in the dual-plane network) are specified as segments of explicit paths. In this way,

only a few routers are required to support the MPLS-SPRING capability while all the other routers just need to support IP forwarding capability, which would significantly reduce the deployment cost of this new technology. Furthermore, since there is no need to run any other label distribution protocol (e.g., LDP), the network provisioning is greatly simplified, which is one of the major claimed benefits of the MPLS-SPRING technology.

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].

2. Terminology

This memo makes use of the terms defined in [RFC3031] and [I-D.ietf-spring-segment-routing-mpls].

3. Packet Forwarding Procedures

Assume an MPLS-SPRING-enabled router X prepares to forward an MPLS packet to the next node segment (i.e., the node segment of MPLS-SPRING- enabled router Y) which is identified by the top label of the MPLS packet. If the next-hop router of the best path to Y is a non-MPLS router, X couldn't map the packet's top label into an Next Hop Label Forwarding Entry (NHLFE) , even though the top label itself is a valid incoming label. Acorrding to the following specification as quoted from Section 3.22 of [RFC3031], the MPLS packet would be discarded in the currenet MPLS implementations:

> "When a labeled packet is traveling along an LSP, it may occasionally happen that it reaches an LSR at which the ILM does not map the packet's incoming label into an NHLFE, even though the incoming label is itself valid...Unless it can be determined (through some means outside the scope of this document) that neither of these situations obtains, the only safe procedure is to discard the packet. "

This document proposes an improved procedure to deal with the above case. The basic idea is to set an IP tunnel towards the egress of topmost LSP as the NHLFE of that incoming label. More specifically, if the label is not a Penultimate Hop Popping (PHP) label (i.e., the NP-flag [I-D.ietf-isis-segment-routing-extensions] associated with the corresponding prefix SID of that top label is set), X SHOULD swap the label to the corresponding label significant to Y and then encapsulate the MPLS packet into the IP-based tunnel towards Y. The tunnel destination address is the IP address of Y (e.g., the /32 or

/128 prefix FEC associated with that top label) and the tunnel source address is the IP address of X. If the label is a PHP label and not at the bottom of the label stack, X SHOULD pop that label before performing the above MPLS over IP encapsulation. The IP encapsulated MPLS packet would be forwarded according to the IP routing table. Upon receipt of that IP encapsulated MPLS packet, Y would decapsulate it and then process the decapsulated MPLS packet accordingly. As for which tunnel encapsulation type should be used by X, it can be manually specified on X or be learnt from Y's advertisement of its tunnel encapsulation capability. How to advertise the tunnel encapsulation capability using IS-IS or OSPF are specified in [I-D.xu-isis-encapsulation-cap] and [I-D.ietf-ospf-encapsulation-cap] respectively.

4. Acknowledgements

Thanks Joel Halpern, Bruno Decraene and Loa Andersson for their insightful comments on this draft.

5. IANA Considerations

No IANA action is required.

6. Security Considerations

TBD.

7. References

7.1. Normative References

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A YANG Data Model for Optical Transport Network Topology
draft-zhang-ccamp-l1-topo-yang-05

Abstract

A transport network is a server-layer network designed to provide connectivity services for a client-layer network to carry the client traffic transparently across the server-layer network resources. A transport network can be constructed from equipments utilizing any of a number of different transport technologies such as the evolving Optical Transport Networks (OTN) or packet transport as provided by the MPLS-Transport Profile (MPLS-TP).

This draft describes a YANG data model to describe the topologies of an Optical Transport Network (OTN). It is independent of control plane protocols and captures topological and resource related information pertaining to OTN. This model enables clients, which interact with a transport domain controller via a REST interface, for OTN topology related operations such as obtaining the relevant topology resource information.

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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Table of Contents

1. Introduction

A transport network is a server-layer network designed to provide connectivity services for a client-layer network to carry the client traffic transparently across the server-layer network resources. A transport network can be constructed of equipments utilizing any of a number of different transport technologies such as the Optical Transport Networks (OTN) or packet transport as provided by the MPLS-Transport Profile (MPLS-TP).

This document defines a data model of an OTN network topology, using YANG [RFC6020]. The model can be used by an application exposing to a transport controller via a REST interface. Furthermore, it can be used by an application for the following purposes (but not limited to):

- To obtain a whole view of the network topology information of its interest;
- To receive notifications with regard to the information change of the OTN topology;
- To enforce the establishment and update of a network topology with the characteristic specified in the data model, e.g., by a client controller;

The YANG model defined in this draft is independent of control plane protocols and captures topology related information pertaining to an Optical Transport Networks (OTN)-electrical layer, as the scope specified by [RFC7062] and [RFC7138]. Furthermore, it is not a stand-alone model, but augmenting from the TE topology YANG model defined in [I-D.ietf-teas-yang-te-topo].

Optical network technologies, including fixed Dense Wavelength Switched Optical Network (WSON) and flexible optical networks (a.k.a., flexi-grid networks), are covered in [I-D.ietf-ccamp-wson-yang] and [I-D.vergara-ccamp-flexigrid-yang], respectively.

2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this draft is defined in [I-D.ietf-netmod-rfc6087bis]. They are provided below for reference.

- Brackets "[" and "]" enclose list keys.
- Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- Symbols after data node names: "?" means an optional node, "!" means a presence container, and "*" denotes a list and leaf-list.
- Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").

   o Ellipsis ("...") stands for contents of subtrees that are not shown.

3. YANG Data Model for OTN Topology

3.1. the YANG Tree

```
module: ietf-otn-topology
augment /nd:networks/nd:network/nd:network-types/tet:te-topology:
   +--rw otn-topology!
augment /nd:networks/nd:network:
   +--rw name?   string
augment /nd:networks/nd:network/nd:node:
   +--rw name?   string
augment /nd:networks/nd:network/lnk:link/tet:te/tet:config:
   +--rw available-odu-info* [priority]
   |  +--rw priority    uint8
   |  +--rw odulist* [odu-type]
   |     +--rw odu-type    identityref
   |     +--rw number?     uint16
   +--rw distance?             uint32
augment /nd:networks/nd:network/lnk:link/tet:te/tet:state:
   +--ro available-odu-info* [priority]
   |  +--ro priority    uint8
   |  +--ro odulist* [odu-type]
   |     +--ro odu-type    identityref
   |     +--ro number?     uint16
   +--ro distance?             uint32
augment /nd:networks/nd:network/nd:node/lnk:termination-point
/tet:te/tet:config:
   +--rw client-facing?             empty
   +--rw tpn?                       uint16
   +--rw tsg?                       identityref
   +--rw protocol-type?             identityref
   +--rw adaptation-type?           adaptation-type
   +--rw sink-adapt-active?         boolean
   +--rw source-adapt-active?       boolean
   +--rw tributaryslots
   |  +--rw values*   uint8
   +--rw supported-payload-types* [index]
      +--rw index           uint16
      +--rw payload-type?   string
augment /nd:networks/nd:network/nd:node/lnk:termination-point/
tet:te/tet:state:
   +--ro client-facing?             empty
   +--ro tpn?                       uint16
```

```
      +--ro tsg?                          identityref
      +--ro protocol-type?                identityref
      +--ro adaptation-type?              adaptation-type
      +--ro sink-adapt-active?            boolean
      +--ro source-adapt-active?          boolean
      +--ro tributaryslots
      |  +--ro values*   uint8
      +--ro supported-payload-types* [index]
         +--ro index           uint16
         +--ro payload-type?   string
```

3.2. Explanation of the OTN Topology Data Model

As can be seen, from the data tree shown in Section 3.1, the YANG module presented in this draft augments from a more generic Traffic Engineered (TE) network topology data model, i.e., the ietf-te-topology.yang as specified in [I-D.ietf-teas-yang-te-topo]. The entities and their attributes, such as node, termination points and links, are still applicable for describing an OTN topology and the model presented in this draft only specifies with technology-specific attributes/information. For example, if the data plane complies with ITU-T G.709 (2012) standards, the switching-capability and encoding attributes MUST be filled as OTN-TDM and G.709 ODUk(Digital Path) respectively.

Note the model in this draft re-uses some attributes defined in ietf-transport-types.yang, which is specified in [I-D.sharma-ccamp-otn-service-model].

One of the main augmentations in this model is that it allows to specify the type of ODU container and the number a link can support per priority level. For example, for a ODU3 link, it may advertise 32*ODU0, 16*ODU1, 4*ODU2 available, assuming only a single priority level is supported. If one of ODU2 resource is taken to establish a ODU path, then the availability of this ODU link is updated as 24*ODU0, 12*ODU1, 3*ODU2 available. If there are equipment hardware limitations, then a subset of potential ODU type SHALL be advertised. For instance, an ODU3 link may only support 4*ODU2.

3.3. The YANG Code

<CODE BEGINS> file " ietf-otn-topology@2016-10-26.yang"

```
module ietf-otn-topology {
```

```
    yang-version 1;

    namespace "urn:ietf:params:xml:ns:yang:ietf-otn-topology";
    prefix "otntopo";

    import ietf-network {
     prefix "nd";
    }

    import ietf-network-topology {
     prefix "lnk";
    }

    import ietf-te-topology {
     prefix "tet";
    }

    import ietf-transport-types {
     prefix "tran-types";
    }

    organization
     "Internet Engineering Task Force (IETF) CCAMP WG";
    contact
     "
     WG List: <mailto:ccamp@ietf.org>

     ID-draft editor:
      Xian ZHANG (zhang.xian@huawei.com);
      Anurag Sharma (AnSharma@infinera.com);
     ";

    description
     "This module defines a protocol independent Layer 1/ODU
     topology data model.";

    revision 2016-10-26 {
     description
      "Initial version.";
     reference
      "draft-zhang-ccamp-l1-topo-yang-04.txt";
    }

    /*
    typedef
    */

    typedef adaptation-type {
```

```
     type enumeration {
      enum CBR {
       description "Constant Bit Rate.";
      }
      enum ATMvp {
       description "ATM VP.";
      }
      enum GFP {
       description "Generic Framing Procedure.";
      }
      enum NULL {
       description "NULL";
      }
      enum PRBS {
       description "Pseudo Random Binary Sequence";
      }
      enum RSn {
       description "SDH/SONET section";
      }
      enum ODUj-21 {
       description "ODU payload type 21";
      }
      enum ETHERNET_PP-OS {
       description "ETHERNET_PP-OS, for ODU 2 only";
      }
      enum CBRx {
       description "CBRx(0.. 1.25G), for ODU0 only";
      }
      enum ODU {
       description "Optical Data Unit";
      }
     }

     description
      "Defines a type representing the adaptation type
      on the termination point.";
    }


    /*
    Groupings
    */

    grouping otn-topology-type {
     container otn-topology {
      presence "indicates a topology type of Optical
       Transport Network (OTN)-electrical layer.";
       description "otn topology type";
```

```
     }
     description "otn-topology-type";
    }

    grouping otn-topology-attributes {
     leaf name {
      type string;
      description "the topology name";
     }
     description "name attribute for otn topology";
    }

    grouping otn-node-attributes {
     description "otn-node-attributes";
     leaf name {
      type string;
      description "a name for this node.";
     }
    }

    grouping otn-link-attributes {
     description "otn link attributes";

     list available-odu-info{
      key "priority";
      max-elements "8";

      description
       "List of ODU type and number on this link";
      leaf priority {
       type uint8 {
        range "0..7";
       }
       description "priority";
      }

      list odulist {
       key "odu-type";

       description
        "the list of available ODUs per priority level";

       leaf odu-type {
        type identityref{
         base tran-types:tributary-protocol-type;
        }
        description "the type of ODU";
       }
```

```
       leaf number {
        type uint16;
        description "the number of odu type supported";
       }
      }
     }

     leaf distance {
      type uint32;
      description "distance in the unit of kilometers";
     }
   }

    grouping otn-tp-attributes {
     description "otn-tp-attributes";

     leaf client-facing {
      type empty;
      description
       "if present, it means this tp is a client-facing tp.
       adding/dropping client signal flow.";
     }

     leaf tpn {
      type uint16 {
       range "0..4095";
      }
      description
       "Tributary Port Number. Applicable in case of mux services.";
       reference
      "RFC7139: GMPLS Signaling Extensions for Control of Evolving
      G.709 Optical Transport Networks.";
     }

     leaf tsg {
      type identityref {
       base tran-types:tributary-slot-granularity;
      }
      description "Tributary slot granularity.";
      reference
      "G.709/Y.1331, February 2012: Interfaces for the Optical
      Transport Network (OTN)";
     }

     leaf protocol-type {
      type identityref {
       base tran-types:tributary-protocol-type;
      }
```

```
      description "Protocol type for the Termination Point.";
     }

     leaf adaptation-type {
      type adaptation-type;
      description
      "This attribute indicates the type of the supported
      adaptation function at the termination point.";
      reference
      "G.874.1, January 2002: Optical transport network (OTN):
      Protocol-neutral management information model for the
      network element view.";
     }

     leaf sink-adapt-active {
      type boolean;
      description
      "This attribute allows for activation or deactivation of
      the sink adaptation function. The value of TRUE means active.";

      reference
      "G.874.1, January 2002: Optical transport network (OTN):
      Protocol-neutral management information model for the
      network element view ";
     }

     leaf source-adapt-active {
      type boolean;
      description
      "This attribute allows for activation or deactivation of
      the sink adaptation function. The value of TRUE
      means active.";
      reference
      "G.874.1, January 2002: Optical transport network (OTN):
      Protocol-neutral management information model for
      the network element view ";
     }

      container tributaryslots {
       description
       "A list of tributary slots used by the ODU
       Termination Point.";
       leaf-list values {
        type uint8;
        description
        "Tributary slot value.";
        reference
        "G.709/Y.1331, February 2012: Interfaces for the
```

```
        Optical Transport Network (OTN)";
       }
     }

     list supported-payload-types{
      key "index";

      description "supported payload types of a TP";

      leaf index {
       type uint16;
       description "payload type index";
      }

      leaf payload-type {
       type string;
       description "the payload type supported by this client
       tp";
       reference
       "http://www.iana.org/assignments/gmpls-sig-parameters
       /gmpls-sig-parameters.xhtml
       not: the payload type is defined as the generalized PIDs
       in GMPLS.";
      }
     }
    }


    /*
    * Data nodes
    */
    augment "/nd:networks/nd:network/nd:network-types/tet:te-topology" {
     uses otn-topology-type;
     description "augment network types to include otn newtork";
    }

    augment "/nd:networks/nd:network" {
     when "nd:network-types/tet:te-topology/otn-topology" {
      description "Augment only for otn network";
     }
     uses otn-topology-attributes;
     description "Augment network configuration";
    }

    augment "/nd:networks/nd:network/nd:node" {
     when "../nd:network-types/tet:te-topology/otn-topology" {
      description "Augment only for otn network";
     }
```

```
     description "Augment node configuration";
     uses otn-node-attributes;
    }

    augment "/nd:networks/nd:network/lnk:link/tet:te/tet:config" {
     when "../../../nd:network-types/tet:te-topology/otn-topology" {
      description "Augment only for otn network.";
     }
     description "Augment link configuration";

     uses otn-link-attributes;
    }

    augment "/nd:networks/nd:network/lnk:link/tet:te/tet:state" {
     when "../../../nd:network-types/tet:te-topology/otn-topology" {
      description "Augment only for otn network.";
     }
     description "Augment link state";

     uses otn-link-attributes;
    }

    augment "/nd:networks/nd:network/nd:node/"
     +"lnk:termination-point/tet:te/tet:config" {
     when "../../../../nd:network-types/tet:te-topology/otn-topology" {
      description "Augment only for otn network";
     }
     description "OTN TP attributes config in a ODU topology.";
     uses otn-tp-attributes;
    }

    augment "/nd:networks/nd:network/nd:node/"
     +"lnk:termination-point/tet:te/tet:state" {
     when "../../../../nd:network-types/tet:te-topology/otn-topology" {
      description "Augment only for otn network";
     }
     description "OTN TP attributes state in a ODU topology.";
     uses otn-tp-attributes;
    }
   }

   <CODE ENDS>
```

4. IANA Considerations

TBD.

5. Manageability Considerations

TBD.

6. Security Considerations

The data following the model defined in this draft is exchanged via, for example, the interface between an orchestrator and a transport network controller. The security concerns mentioned in [I-D.ietf-teas-yang-te-topo] for using ietf-te-topology.yang model also applies to this draft.

The YANG module defined in this document can be accessed via the RESTCONF protocol defined in [I-D.ietf-netconf-restconf], or maybe via the NETCONF protocol [RFC6241].

There are a number of data nodes defined in the YANG module which 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., POST) to these data nodes without proper protection can have a negative effect on network operations.

Editors note: to list specific subtrees and data nodes and their sensitivity/vulnerability.

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