

TEAS Working Group
Internet Draft
Intended status: Standard Track
Expires: May 2020

Italo Busi (Ed.)
Huawei
Sergio Belotti (Ed.)
Nokia
Victor Lopez
Oscar Gonzalez de Dios
Telefonica
Anurag Sharma
Google
Yan Shi
China Unicom
Ricard Vilalta
CTTC
Karthik Sethuraman
NEC

November 18, 2019

**Yang model for requesting Path Computation
draft-ietf-teas-yang-path-computation-07.txt**

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), its areas, and its working groups. Note that other groups may also distribute working documents as Internet-Drafts.

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."

The list of current Internet-Drafts can be accessed at <http://www.ietf.org/ietf/1id-abstracts.txt>

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

This Internet-Draft will expire on May 18, 2020.

Copyright Notice

Copyright (c) 2019 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the [Trust Legal Provisions](#) and are provided without warranty as described in the Simplified BSD License.

Abstract

There are scenarios, typically in a hierarchical SDN context, where the topology information provided by a TE network provider may not be sufficient for its client to perform end-to-end path computation. In these cases the client would need to request the provider to calculate some (partial) feasible paths.

This document defines a YANG data model for a stateless RPC to request path computation. This model complements the stateful solution defined in [[TE-TUNNEL](#)].

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

Table of Contents

1.	Introduction.....	3
1.1.	Terminology.....	5
2.	Use Cases.....	5
2.1.	Packet/Optical Integration.....	5
2.2.	Multi-domain TE Networks.....	10
2.3.	Data center interconnections.....	12
2.4.	Backward Recursive Path Computation scenario.....	14
2.5.	Hierarchical PCE scenario.....	15
3.	Motivations.....	17

3.1. Motivation for a YANG Model.....	17
3.1.1. Benefits of common data models.....	17
3.1.2. Benefits of a single interface.....	18
3.1.3. Extensibility.....	19
3.2. Interactions with TE Topology.....	19
3.2.1. TE Topology Aggregation.....	20
3.2.2. TE Topology Abstraction.....	23
3.2.3. Complementary use of TE topology and path computation	24
3.3. Stateless and Stateful Path Computation.....	27
3.3.1. Temporary reporting of the computed path state.....	29
4. Path Computation and Optimization for multiple paths.....	31
5. YANG Model for requesting Path Computation.....	32
5.1. Synchronization of multiple path computation requests....	32
5.2. Returned metric values.....	34
5.3. Path Associations.....	36
6. YANG model for stateless TE path computation.....	38
6.1. YANG Tree.....	38
6.2. YANG Module.....	49
7. Security Considerations.....	64
8. IANA Considerations.....	64
9. References.....	65
9.1. Normative References.....	65
9.1. Informative References.....	66
10. Acknowledgments.....	67
Appendix A. Examples of dimensioning the "detailed connectivity matrix".....	68
Appendix B. New proposed YANG Tree overview.....	74

1. Introduction

There are scenarios, typically in a hierarchical SDN context, where the topology information provided by a TE network provider may not be sufficient for its client to perform end-to-end path computation. In these cases the client would need to request the provider to calculate some (partial) feasible paths, complementing his topology knowledge, to make his end-to-end path computation feasible.

This type of scenarios can be applied to different interfaces in different reference architectures:

- o ABNO control interface [[RFC7491](#)], in which an Application Service Coordinator can request ABNO controller to take in charge path calculation (see Figure 1 in [[RFC7491](#)]).

- o ACTN [[RFC8453](#)], where a 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). [[RFC8454](#)] 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. [[OTN-TOPO](#)] for OTN 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.

Note: This document assumes that the client of the YANG data model defined in this document may not implement a "PCE" functionality, as defined in [[RFC4655](#)].

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 proposes a YANG model for a path computation request defined as a stateless RPC, which complements the stateful solution defined in [[TE-TUNNEL](#)].

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

1.1. Terminology

TED: The traffic engineering database is a collection of all TE information about all TE nodes and TE links in a given network.

PCE: A Path Computation Element (PCE) is an entity that is capable of computing a network path or route based on a network graph, and of applying computational constraints during the computation. The PCE entity is an application that can be located within a network node or component, on an out-of-network server, etc. For example, a PCE would be able to compute the path of a TE LSP by operating on the TED and considering bandwidth and other constraints applicable to the TE LSP service request. [[RFC4655](#)]

2. Use Cases

This section presents some use cases, where a client needs to request underlying SDN controllers for path computation.

The use of the YANG model defined in this document is not restricted to these use cases but can be used in any other use case when deemed useful.

The presented uses cases have been grouped, depending on the different underlying topologies: a) Packet-Optical integration; b) Multi-domain Traffic Engineered (TE) Networks; and c) Data center interconnections. Use cases d) and e) respectively present how to apply this Yang model for standard multi-domain PCE i.e. Backward Recursive Path Computation [[RFC5441](#)] and Hierarchical PCE [[RFC6805](#)].

2.1. Packet/Optical Integration

In this use case, an Optical network is used to provide connectivity to some nodes of a Packet network (see Figure 1).

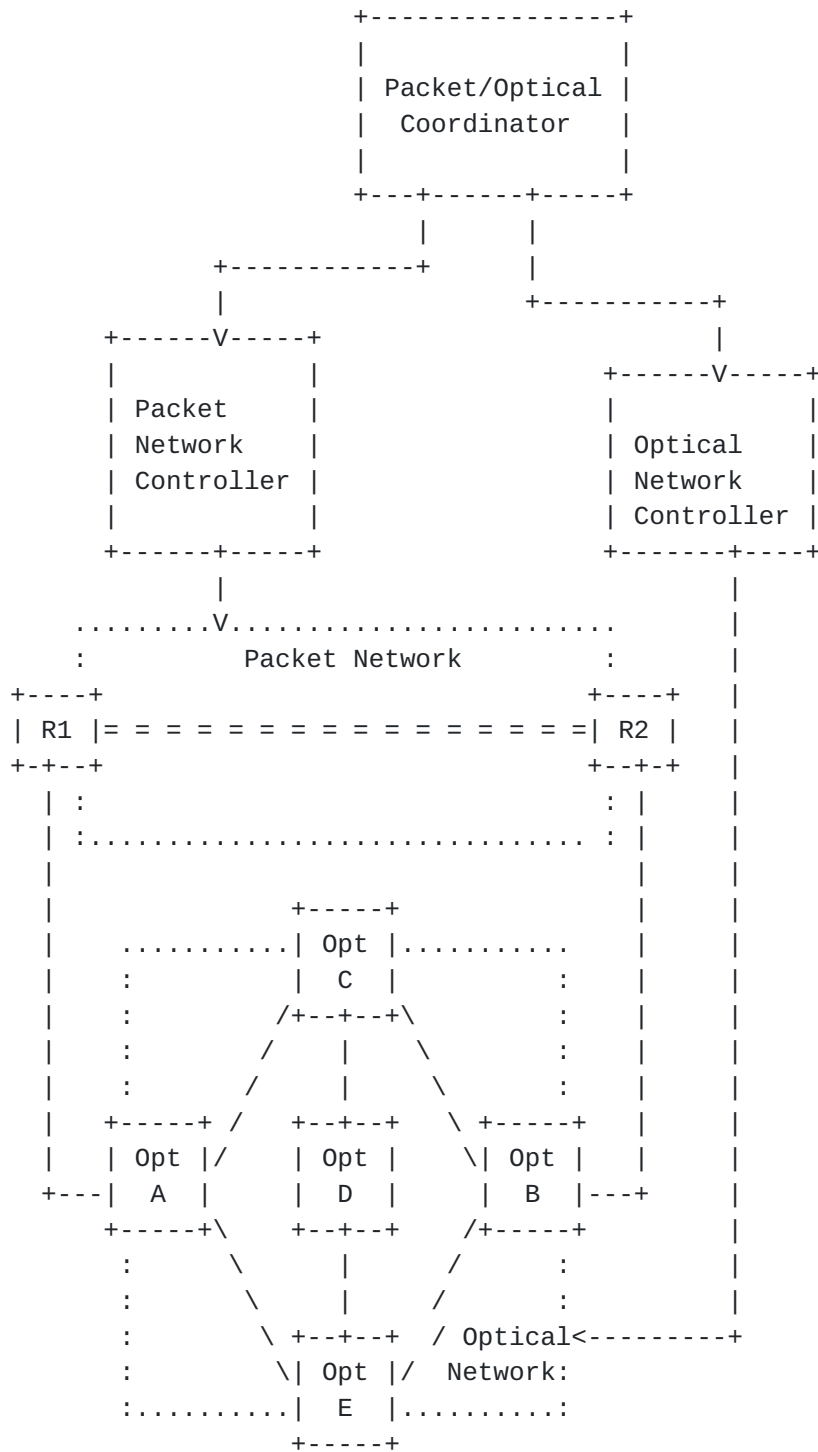


Figure 1 - Packet/Optical Integration Use Case

Figure 1 as well as Figure 2 below only show a partial view of the packet network connectivity, before additional packet connectivity is provided by the Optical network.

It is assumed that the Optical network controller provides to the packet/optical coordinator an abstracted view of the Optical network. A possible abstraction could be to represent the whole optical network as one "virtual node" with "virtual ports" connected to the access links, as shown in Figure 2.

It is also assumed that Packet network controller can provide the packet/optical coordinator the information it needs to setup connectivity between packet nodes through the Optical network (e.g., the access links).

The path computation request helps the coordinator to know the real connections that can be provided by the optical network.

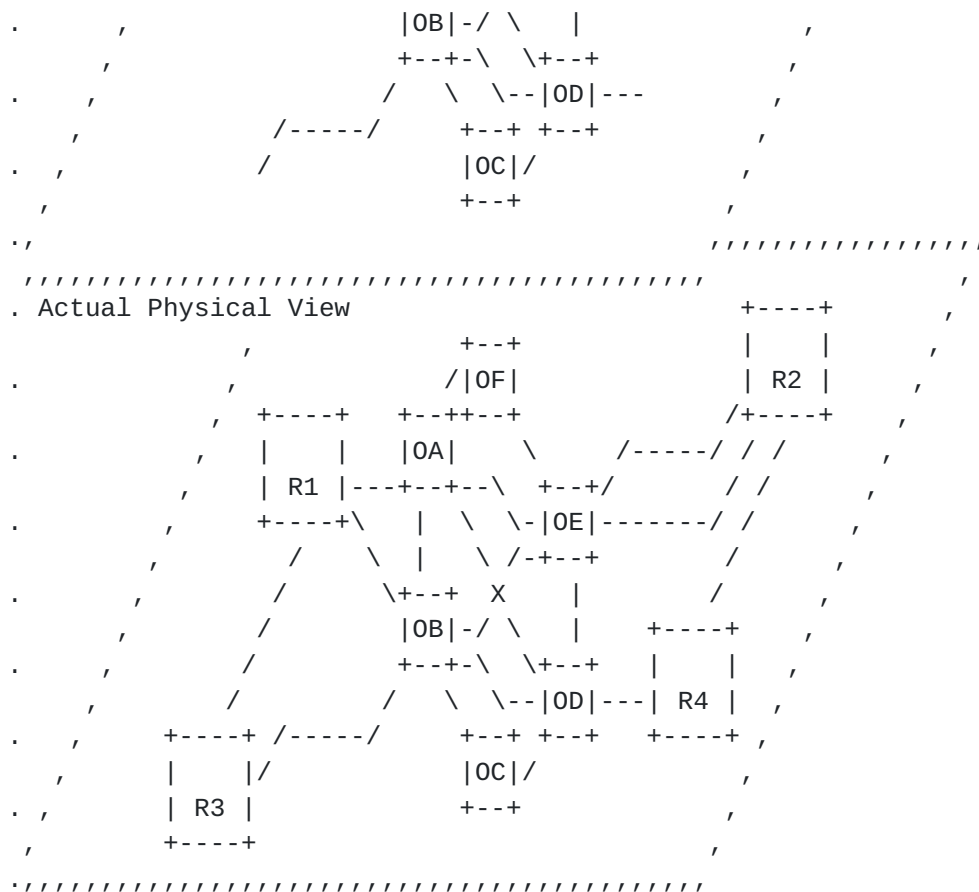


Figure 2 - Packet and Optical Topology Abstractions

In this use case, the coordinator needs to setup an optimal underlying path for an IP link between R1 and R2.

As depicted in Figure 2, the coordinator 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 coordinator 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 end-to-end path crossing optical network.

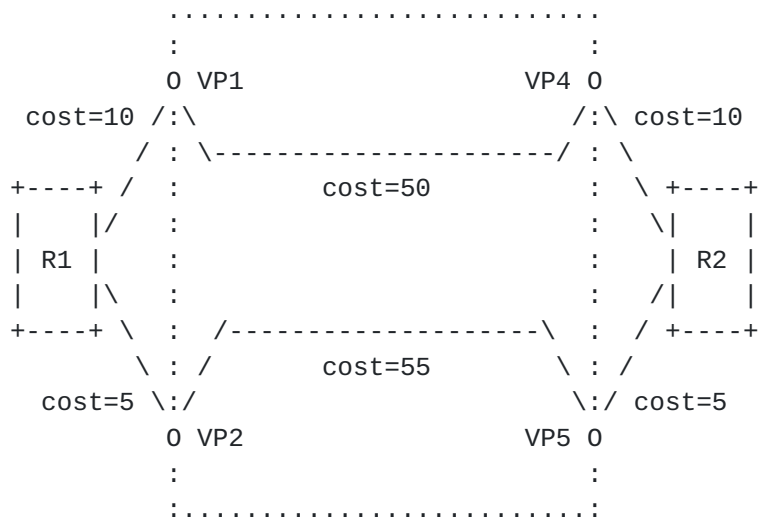


Figure 3 - Packet/Optical Path Computation Example

For example, in Figure 3, the Coordinator can request the Optical network 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 network controller when requested by the Coordinator is no longer valid/available when the Coordinator requests it to be setup up. This is further discussed in [section 3.3](#).

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.

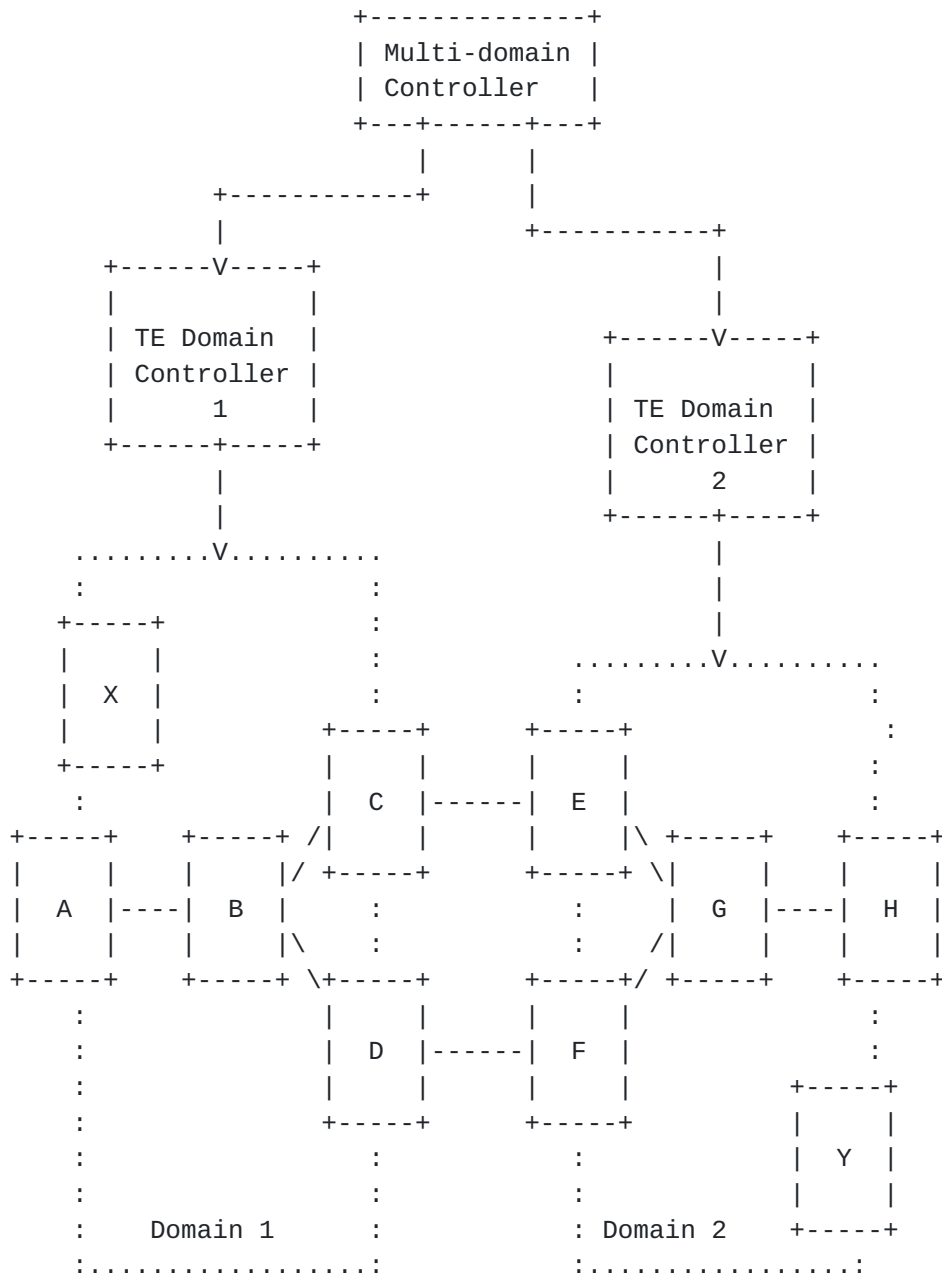


Figure 4 - Multi-domain multi-link interconnection

In order to setup an end-to-end multi-domain TE path (e.g., between nodes A and H), the multi-domain controller 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), the multi-domain controller 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:

- o The multi-domain controller asks TE domain controllers to provide set of paths between A-C, A-D, E-H and F-H
- o 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)
- o The multi-domain controller 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
- o If there are multiple feasible paths, the multi-domain controller 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 multi-domain controller)

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 TE domain controllers to limit the number of potential optimal end-to-end paths and then request path computation to fewer TE domain controllers in order to decide what the optimal path within this limited set is.

For more details, see [section 3.2.3](#).

[2.3. Data center interconnections](#)

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

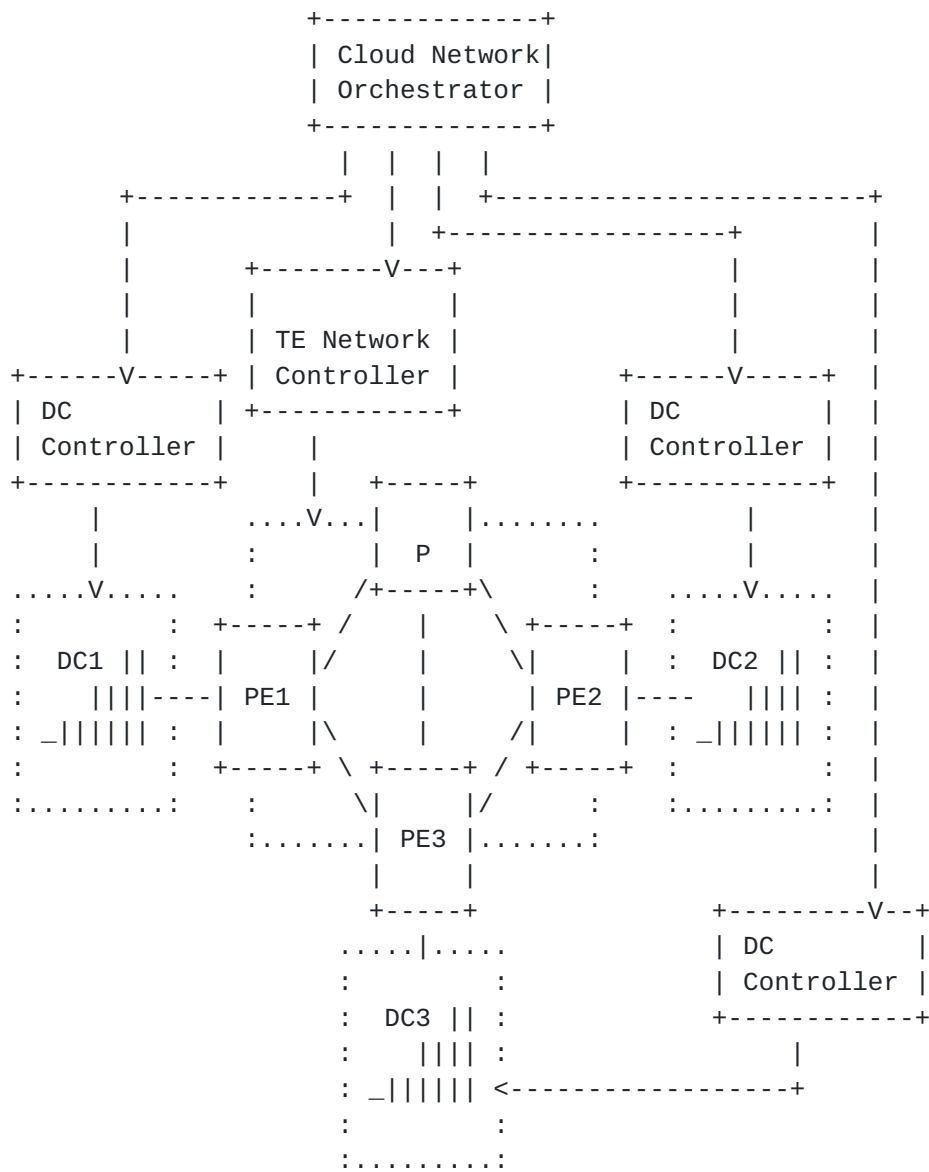


Figure 5 - Data Center Interconnection Use Case

In this use case, there is need to transfer data from Data Center 1 (DC1) to either DC2 or DC3 (e.g. workload migration).

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

The cloud network orchestrator needs to make a decision for optimal connection based on TE Network constraints and data centers

resources. It 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 network orchestrator can request to the TE network controller to compute the cost of the possible TE paths (e.g., DC1-DC2 and DC1-DC3) and to the DC controller to provide the information it needs about the required data center resources within DC2 and DC3 and then it can take the decision about the optimal solution based on this information and its policy.

2.4. Backward Recursive Path Computation scenario

[RFC5441] has defined the Virtual Source Path Tree (VSPT) TLV within PCE Reply Object in order to compute inter-domain paths following a "Backward Recursive Path Computation" (BRPC) method. The main principle is to forward the PCE request message up to the destination domain. Then, each PCE involved in the computation will compute its part of the path and send it back to the requester through PCE Response message. The resulting computation is spread from destination PCE to source PCE. Each PCE is in charge of merging the path it received with the one it calculated. At the end, the source PCE merges its local part of the path with the received one to achieve the end-to-end path.

Figure 6 below show a typical BRPC scenario where 3 PCEs cooperate to compute inter-domain paths.

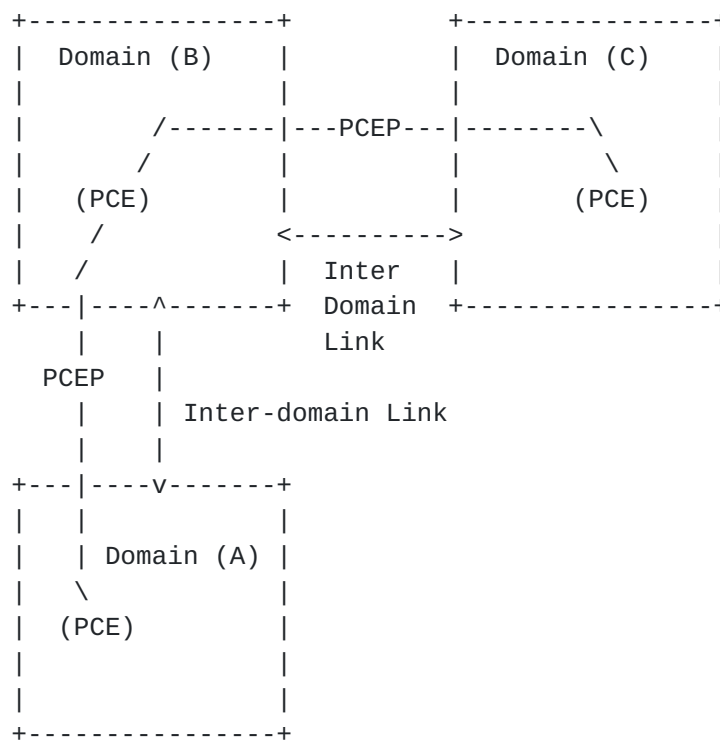


Figure 6 - BRPC Scenario

In this use case, a client can use the YANG model defined in this document to request path computation to the PCE that controls the source of the tunnel. For example, a client can request to the PCE of domain A to compute a path from a source S, within domain A, to a destination D, within domain C. Then PCE of domain A will use PCEP protocol, as per [\[RFC5441\]](#), to compute the path from S to D and in turn gives the final answer to the requester.

2.5. Hierarchical PCE scenario

[RFC6805] has defined an architecture and extensions to the PCE standard to compute inter-domain path following a hierarchical method. Two new roles have been defined: Parent PCE and child PCE. The parent PCE is in charge to coordinate the end-to-end path computation. For that purpose it sends to each child PCE involve in the multi-domain path computation a PCE Request message to obtain the local part of the path. Once received all answer through PCE Response message, the Parent PCE will merge the different local parts of the path to achieve the end-to-end path.

Figure 7 below shows a typical hierarchical scenario where a Parent PCE request end-to-end path to the different child PCE. Note that a

PCE could take independently the role of Child or Parent PCE depending of which PCE will request the path.

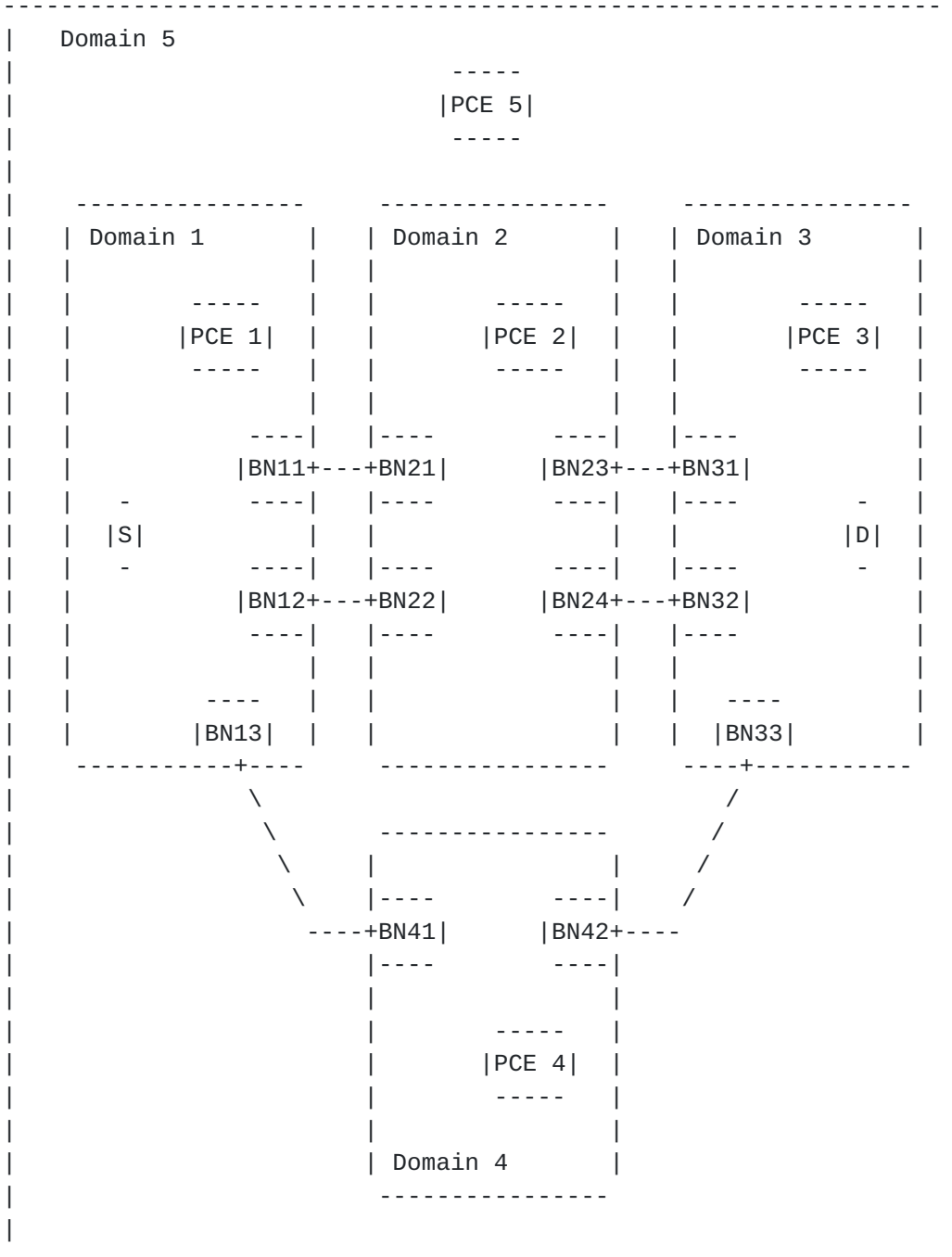


Figure 7 - Hierarchical domain topology from [[RFC6805](#)]

In this use case, a client can use the YANG model defined in this document to request to the Parent PCE a path from a source S to a destination D. The Parent PCE will in turn contact the child PCEs through PCEP protocol to compute the end-to-end path and then return the computed path to the client, using the YANG model defined in this document. For example the YANG model can be used to request to PCE5 acting as Parent PCE to compute a path from source S, within domain 1, to destination D, within domain 3. PCE5 will contact child PCEs of domain 1, 2 and 3 to obtain local part of the end-to-end path through the PCEP protocol. Once received the PCE Response message, it merges the answers to compute the end-to-end path and send it back to the client.

3. Motivations

This section provides the motivation for the YANG model defined in this document.

[Section 3.1](#) describes the motivation for a YANG model to request path computation.

[Section 3.2](#) describes the motivation for a YANG model which complements the TE Topology YANG model defined in [\[TE-TOPO\]](#).

[Section 3.3](#) describes the motivation for a stateless YANG RPC which complements the TE Tunnel YANG model defined in [\[TE-TUNNEL\]](#).

[3.1. Motivation for a YANG Model](#)

[3.1.1. Benefits of common data models](#)

The YANG data model for requesting path computation is 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., [\[TE-TUNNEL\]](#).

There are many benefits in aligning the data model used for path computation requests with the YANG data models used for TE topology information and for TE Tunnels configuration and management:

- o There is no need for an error-prone mapping or correlation of information.
- o It is possible to use the same endpoint identifiers in path computation requests and in the topology modeling.

- o The attributes used for path computation constraints are the same as those used when setting up a TE Tunnel.

3.1.2. Benefits of a single interface

The system integration effort is typically lower if a single, consistent interface is used by controllers, 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.

3.1.3. 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.

3.2. 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 its client thus allowing a PCE available within its client to perform multi-domain path computation by its own, without requesting path computations to the underlying SDN controllers.

In case the client does not implement a PCE function, as discussed in [section 1](#), it could not perform path computation based on TE Topology information and would instead need to request path computation to the underlying controllers to get the information it needs to compute the optimal end-to-end path.

This section analyzes the need for a client to request underlying SDN controllers for path computation even in case it implements a

PCE functionality, 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 PCE, when implemented by the client, to take optimal path computation decisions by its own versus sending too many requests to underlying SDN Domain Controllers to compute a set of feasible optimal intra-domain TE paths.

3.2.1. TE Topology Aggregation

Using the TE Topology model, as defined in [[TE-TOP0](#)], the underlying SDN controller can export the whole TE domain as a single abstract TE node with a "detailed connectivity matrix".

The concept of a "detailed connectivity matrix" is defined in [TE-TOP0] to provide specific TE attributes (e.g., delay, SRLGs and summary TE metrics) as an extension of the "basic connectivity matrix", which is based on the "connectivity matrix" defined in [[RFC7446](#)].

The information provided by the "detailed connectivity matrix" would be equivalent to the information that should be provided by "virtual link model" as defined in [[RFC7926](#)].

For example, in the Packet/Optical integration use case, described in [section 2.1](#), the Optical network controller can make the information shown in Figure 3 available to the Coordinator as part of the TE Topology information and the Coordinator could use this information to calculate by its own the optimal path between R1 and R2, without requesting any additional information to the Optical network Controller.

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

Figure 8 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).

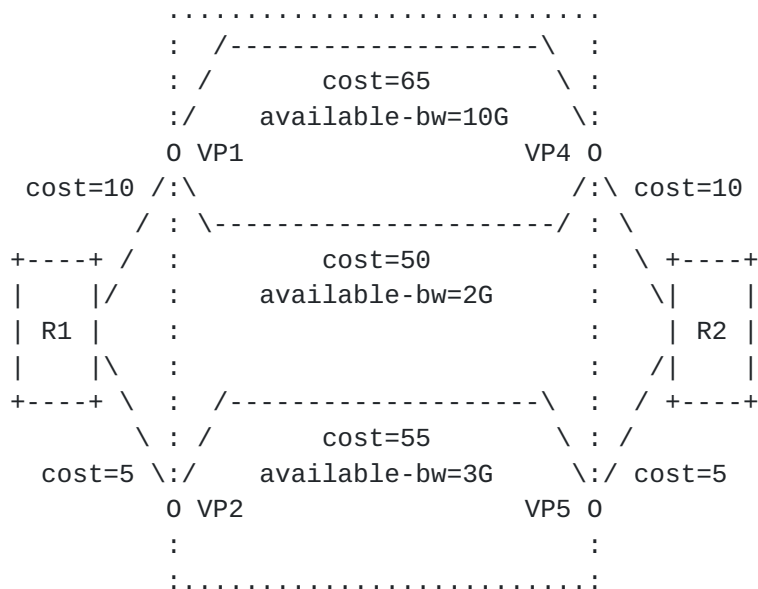


Figure 8 - Packet/Optical Path Computation Example with multiple choices

Reporting all the information, as in Figure 8, using the "detailed 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.

Examples of how the "detailed connectivity matrix" can be dimensioned are described in [Appendix A](#).

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 "basic 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 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 connectivity matrix" while not changing the feasibility of the path.

The "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 "detailed connectivity matrix" updated which means that there another tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the client'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 client's PCE computes paths using not updated information.

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

Instead, if the information in the "detailed connectivity matrix" is not complete/accurate, we can have the following drawbacks considering for example the case in Figure 8:

- o If only the VP1-VP4 path with available bandwidth of 2 Gb/s and cost 50 is reported, the client's PCE will fail to compute a 5 Gb/s path between routers R1 and R2, although this would be feasible;
- o If only the VP1-VP4 path with available bandwidth of 10 Gb/s and cost 60 is reported, the client'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 through the VP1-VP4 sub-path (with cost 50) within the Optical domain.

Using the approach proposed in this document, the client, 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:

- o 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 through this Optical path;
- o 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 through the VP1-VP4 sub-path (with cost 50) within the Optical domain.

3.2.2. TE Topology Abstraction

Using the TE Topology model, as defined in [\[TE-TOP0\]](#), the underlying SDN controller can export an abstract TE Topology, composed by a set of TE nodes and TE links, representing the abstract view of 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 multi-domain controller 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:

- o Multi-domain controller'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
- o 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
- o So what the multi-domain controller computed is not good and need to re-start the path computation from scratch

As discussed in [section 3.2.1](#), providing more extensive abstract information from the TE domain controllers to the multi-domain controller 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.

[3.2.3](#). 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 9. 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.

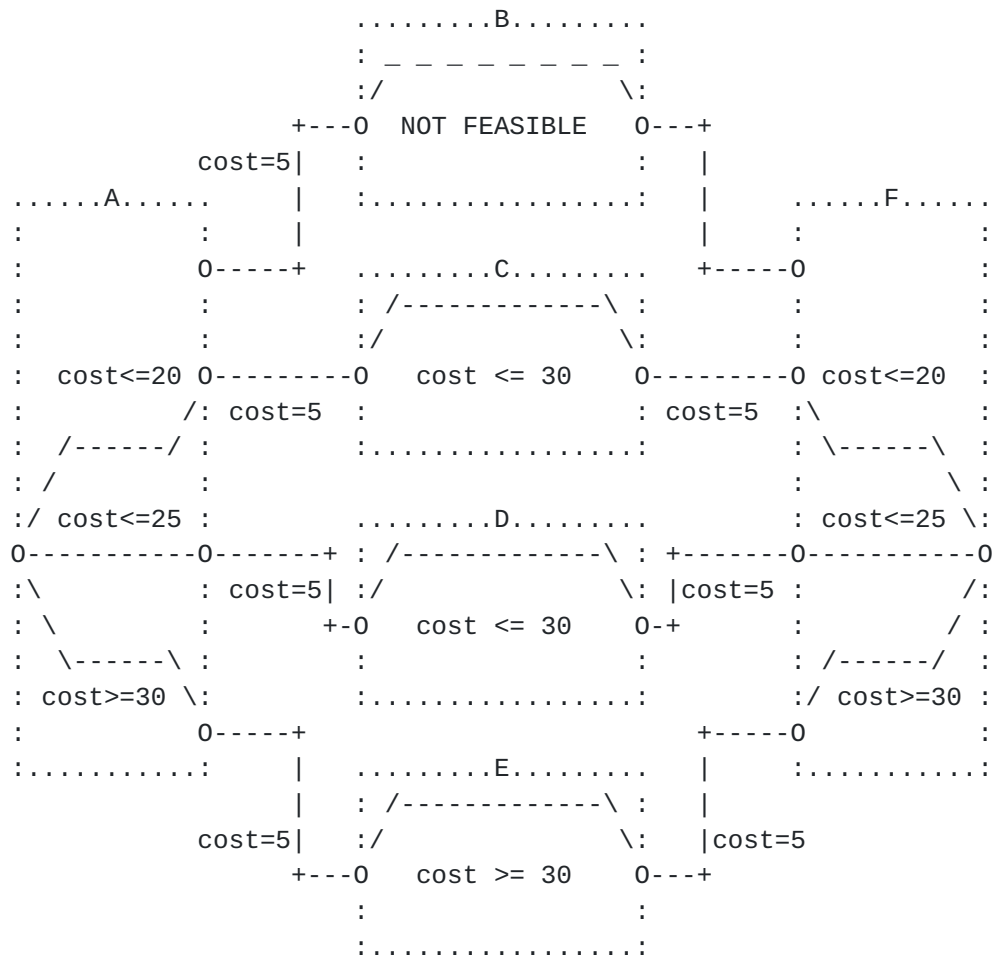


Figure 9 - Multi-domain with many domains (Topology information)

The actual cost of each intra-domain path is not known a priori from the abstract topology information. The Multi-domain controller 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 Multi-domain controller can understand by its own that:

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

- o Domain E cannot be selected as a transit domain since it is known 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 Multi-domain controller can understand by its own that the optimal multi-domain path could be either A-D-F or A-E-F but it cannot know which one of the two possible options actually provides the optimal end-to-end path.

The Multi-domain controller 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).

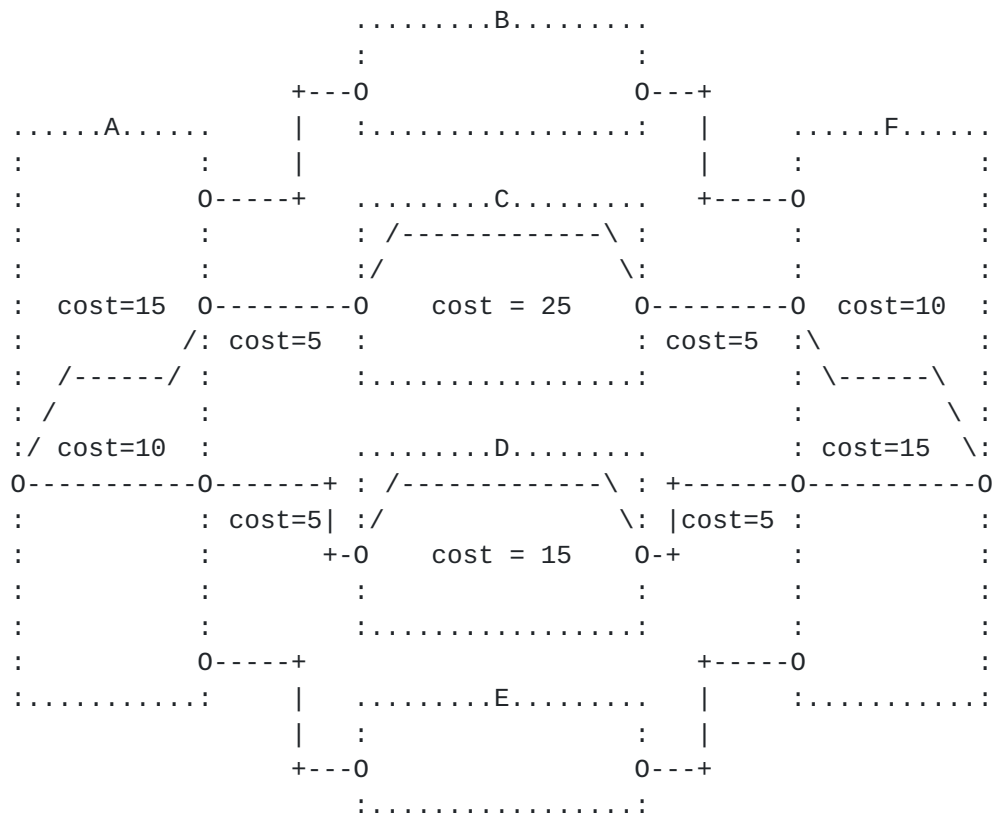


Figure 10 - Multi-domain with many domains (Path Computation information)

Based on these requests, the Multi-domain controller can know the actual cost of each intra-domain paths which belongs to potential

optimal end-to-end paths, as shown in Figure 10, 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).

3.3. Stateless and Stateful Path Computation

The TE Tunnel YANG model, defined in [\[TE-TUNNEL\]](#), can support the need to request path computation.

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 section 3.3.1 of [\[TE-TUNNEL\]](#).

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.

It is very useful to provide options for both stateless and stateful path computation mechanisms. It is suggested to use stateless mechanisms as much as possible and to rely on stateful path computation when really needed.

Stateless RPC allows requesting path computation using a simple atomic operation and it is the natural option/choice, especially with stateless PCE. The stateless path computation solution assumes that the underlying SDN controller (e.g., a PNC) will compute a path twice during the process to setup an LSP: at time T1, when its client (e.g., an MDSC) sends a path computation RPC request to it, and later, at time T2, when the same client (MDSC) creates a te-tunnel requesting the setup of the LSP. The underlying assumption is that, if network conditions have not changed, the same path that has been computed at time T1 is also computed at time T2 by the underlying SDN controller (e.g. PNC) and therefore the path that is setup at time T2 is exactly the same path that has been computed at time T1.

Since the operation is stateless, there is no guarantee that the returned path would still be available when path setup is requested: this does not cause major issues in case the time between path computation and path setup is short (especially if compared with the time that would be needed to update the information of a very detailed connectivity matrix).

In most of the cases, there is even no need to guarantee that the path that has been setup is the exactly same as the path that has been returned by path computation, especially if it has the same or even better metrics. Depending on the abstraction level applied by the server, the client may also not know the actual computed path.

The most important requirement is that the required global objectives (e.g., multi-domain path metrics and constraints) are met. For this reason a path verification phase is necessary to verify that the actual path that has been setup meets the global objectives (for example in a multi-domain network, the resulting end-to-end path meets the required end-to-end metrics and constraints).

In most of the cases, even if the setup path is not exactly the same as the path returned by path computation, its metrics and constraints are "good enough" (the path verification passes successfully). In the few corner cases where the path verification fails, it is possible repeat the whole process (path computation, path setup and path verification).

In case the stateless solution is not sufficient and it would be the need to setup at T2 exactly the same path computed at T1 a stateful solution, based on "compute-only" TE tunnel, could be used to get notifications in case the computed path has been changed. In this case at time T1, the client (MDSC) creates a te-tunnel in a compute-only mode in the config DS and later, at time T2, changes the configuration of that te-tunnel (not to be any more in a compute-only mode) to trigger the setup of the LSP.

It is worth noting that also the stateful solution, although increasing the likelihood that the computed path is available at path setup, does not guaranteed that because notifications may not be reliable or delivered on time. Path verification is needed also when stateful path computation is used.

The stateful path computation has also the following drawbacks:

- o Several messages required for any path computation
- o Requires persistent storage in the provider controller
- o Need for garbage collection for stranded paths

- o Process burden to detect changes on the computed paths in order to provide notifications update

3.3.1. Temporary reporting of the computed path state

This section describes an optional extension to the stateless behavior where the underlying SDN controller, after having received a path computation RPC request, maintains some "temporary state" associated with the computed path, allowing the client to request the setup of exactly that path, if still available.

This is similar to the stateful solution but, to avoid the drawbacks of the stateful approach, is leveraging the path computation RPC and the separation between configuration and operational DS, as defined in the NMDA architecture [[RFC8342](#)].

The underlying SDN controller, after having computed a path, as requested by a path computation RPC, also creates a te-tunnel instance within the operational DS, to store that computed path. This would be similar to the stateful solution with the only difference that there is no associated te-tunnel instance within the running DS.

Since underlying SDN controller stores in the operational DS the computed path based on an abstract topology it exposes, it also remembers, internally, which is the actual native path (physical path), within its native topology (physical topology), associated with that compute-only te-tunnel instance.

Afterwards, the client (e.g., MDSC) can request to setup that specific path by creating a te-tunnel instance (not in compute-only mode) in the running DS using the same tunnel-name of the existing te-tunnel in the operational datastore: this will trigger the underlying SDN controller to setup that path, if still available.

There are still cases where the path being setup is not exactly the same as the path that has been computed:

- o When the tunnel is configured with path constraints which are not compatible with the computed path
- o When the tunnel setup is requested after the resources of the computed path are no longer available

- o When the tunnel setup is requested after the computed path is no longer known (e.g. due to a server reboot) by the underlying SDN controller

In all these cases, the underlying SDN controller should compute and setup a new path.

Therefore the "path verification" phase, as described in [section 3.3](#) above, is still needed to check that the path that has been setup is still "good enough".

Since this new approach is not completely stateless, garbage collection is implemented using a timeout that, when it expires, triggers the removal of the computed path from the operational DS. This operation is fully controlled by the underlying SDN controller without the need for any action to be taken by the client that is not able to act on the operational datastore. The default value of this timeout is 10 minutes but a different value may be configured by the client.

In addition, it is possible for the client to tag each path computation requests with a transaction-id allowing for a faster removal of all the paths associated with a transaction-id, without waiting for their timers to expire.

The underlying SDN controller can remove from the operational DS all the paths computed with a given transaction-id which have not been setup either when it receives a Path Delete RPC request for that transaction-id or, automatically, right after the setup up of a path that have been previously computed with that transaction-id.

This possibility is useful when multiple paths are computed but, at most, only one is setup (e.g., in multi-domain path computation scenario scenarios). After the selected path has been setup (e.g, in one domain during multi-domain path setup), all the other alternative computed paths can be automatically deleted by the underlying SDN controller (since no longer needed). The client can also request, using the Path Delete RPC request, the underlying SDN controller to remove all the computed paths, if none of them is going to be setup (e.g., in a transit domain not being selected by multi-domain path computation and so not being automatically deleted).

This approach is complimentary and not alternative to the timer which is always needed to avoid stranded computed paths being stored

in the operational DS when no path is setup and no explicit delete RPC is received.

4. Path Computation and Optimization for multiple paths

There are use cases, where it is advantageous to request path computation for a set of paths, through a network or through a network domain, using a single request [[RFC5440](#)].

In this case, sending a single request for multiple path computations, instead of sending multiple requests for each path computation, would reduce the protocol overhead and it would consume less resources (e.g., threads in the client and server).

In the context of a typical multi-domain TE network, there could be multiple choices for the ingress/egress points of a domain and the Multi-domain controller needs to request path computation between all the ingress/egress pairs to select the best pair. For example, in the example of [section 2.2](#), the Multi-domain controller needs to request the TE network controller 1 to compute the A-C and the A-D paths and to the TE network controller 2 to compute the E-H and the F-H paths.

It is also possible that the Multi-domain controller receives a request to setup a group of multiple end to end connections. The multi-domain controller needs to request each TE domain controller to compute multiple paths, one (or more) for each end to end connection.

There are also scenarios where it can be needed to request path computation for a set of paths in a synchronized fashion.

One example could be computing multiple diverse paths. Computing a set of diverse paths in a not-synchronized fashion, leads to the possibility of not being able to satisfy the diversity requirement. In this case, it is preferable to compute a sub-optimal primary path for which a diversely routed secondary path exists.

There are also scenarios where it is needed to request optimizing a set of paths using objective functions that apply to the whole set of paths, see [[RFC5541](#)], e.g. to minimize the sum of the costs of all the computed paths in the set.

5. YANG Model for requesting Path Computation

This document define a YANG stateless RPC to request path computation as an "augmentation" of tunnel-rpc, defined in [TE-TUNNEL]. This model provides the RPC input attributes that are needed to request path computation and the RPC output attributes that are needed to report the computed paths.

```
augment /te:tunnels-rpc/te:input/te:tunnel-info:
  +---- path-request* [request-id]
  | +---- request-id                uint32
  | .....
  |
  +---- response* [response-id]
  | +--ro response-id              uint32
  | +--ro (response-type)?
  | | +--:(no-path-case)
  | | | +--ro no-path!
  | | +--:(path-case)
  | | | +--ro computed-path
  | | .....
  |
```

This model extensively re-uses the grouping defined in [TE-TUNNEL] to ensure maximal syntax and semantics commonality.

This YANG model allows one RPC to include multiple path requests, each path request being identified by a request-id. Therefore, one RPC can return multiple responses, one for each path request, being identified by a response-id equal to the corresponding request-id.

5.1. Synchronization of multiple path computation requests

The YANG model permits to synchronize a set of multiple path requests (identified by specific request-id) all related to a "svec" container emulating the syntax of "SVEC" PCEP object [RFC5440].

```
+---- synchronization* [synchronization-id]
  +---- synchronization-id    uint32
  +---- svec
  | +---- relaxable?          boolean
  | +---- disjointness?      te-types:te-path-disjointness
```



```

| +---- request-id-number*   uint32
+---- svec-constraints
| +---- path-metric-bound* [metric-type]
|   +---- metric-type       identityref
|   +---- upper-bound?     uint64
+---- path-srlgs-values
| +---- usage?             identityref
| +---- values*            srlg
+---- path-srlgs-names
| +---- path-srlgs-name* [usage]
|   +---- usage             identityref
|   +---- srlg-name* [name]
|     +---- name            string
+---- exclude-objects
.....
+---- optimizations
  +---- (algorithm)?
    +--:(metric)
      | +---- optimization-metric* [metric-type]
      |   +---- metric-type       identityref
      |   +---- weight?          uint8
    +--:(objective-function)
      +---- objective-function
        +---- objective-function-type? identityref

```

The model, in addition to the metric types, defined in [[TE-TUNNEL](#)], which can be applied to each individual path request, defines additional specific metrics types that apply to a set of synchronized requests, as referenced in [[RFC5541](#)].

```

identity svec-metric-type {
  description
    "Base identity for svec metric type";
}

identity svec-metric-cumul-te {
  base svec-metric-type;
  description
    "TE cumulative path metric";
}

```

```
identity svec-metric-cumul-igp {
  base svec-metric-type;
  description
    "IGP cumulative path metric";
}

identity svec-metric-cumul-hop {
  base svec-metric-type;
  description
    "Hop cumulative path metric";
}

identity svec-metric-aggregate-bandwidth-consumption {
  base svec-metric-type;
  description
    "Cumulative bandwith consumption of the set of
    synchronized paths";
}

identity svec-metric-load-of-the-most-loaded-link {
  base svec-metric-type;
  description
    "Load of the most loaded link";
}
```

5.2. Returned metric values

This YANG model provides a way to return the values of the metrics computed by the path computation in the output of RPC, together with other important information (e.g. srlg, affinities, explicit route), emulating the syntax of the "C" flag of the "METRIC" PCEP object [[RFC5440](#)]:

```
augment /te:tunnels-rpc/te:output/te:result:
  +--ro response* [response-id]
    +--ro response-id      uint32
    +--ro (response-type)?
      +--:(no-path-case)
        | +--ro no-path!
```

```

+--:(path-case)
  +--ro computed-path
    +--ro path-id?          yang-types:uuid
    +--ro path-properties
      +--ro path-metric* [metric-type]
        | +--ro metric-type      identityref
        | +--ro accumulative-value? uint64
      +--ro path-affinities-values
        | +--ro path-affinities-value* [usage]
        |   +--ro usage      identityref
        |   +--ro value?    admin-groups
      +--ro path-affinity-names
        | +--ro path-affinity-name* [usage]
        |   +--ro usage      identityref
        |   +--ro affinity-name* [name]
        |     +--ro name      string
      +--ro path-srlgs-values
        | +--ro usage?      identityref
        | +--ro values*     srlg
      +--ro path-srlgs-names
        | +--ro path-srlgs-name* [usage]
        |   +--ro usage      identityref
        |   +--ro srlg-name* [name]
        |     +--ro name      string
      +--ro path-route-objects
      .....

```

It also allows to request in the input of RPC which information (metrics, srlg and/or affinities) should be returned:

```

module: ietf-te-path-computation
  augment /te:tunnels-rpc/te:input/te:tunnel-info:
    +---- path-request* [request-id]
      | +---- request-id          uint32
      | .....
      | +---- requested-metrics* [metric-type]
      | | +---- metric-type      identityref
      | +---- return-srlgs?      boolean
      | +---- return-affinities? boolean
      | .....

```

This feature is essential for using a stateless path computation in a multi-domain TE network as described in [section 2.2](#). In this case, the metrics returned by a path computation requested to a given TE network controller must be used by the client to compute the best end-to-end path. If they are missing the client cannot compare different paths calculated by the TE network controllers and choose the best one for the optimal e2e path.

5.3. Path Associations

Note - This section describes the models changes that are proposed and not yet defined in [section 6](#).

The YANG model allows including multiple path requests intended to be used within the same tunnel or within different tunnels.

Multiple path requests that are intended to be used within the same tunnel needs to be associated, indicating also the role of the path being requested within the intended tunnel (e.g., primary or secondary path).

The choice below is proposed to be added to the model to distinguish whether the requested path is intended to be associated with other requested paths within one tunnel, or not:

```
+---- (tunnel-information)?
| +----:(tunnel-association)
| | .....
| +----:(tunnel-attributes)
| | .....
```

The tunnel-attributes case will provide the set of attributes that are usually configured on per-tunnel basis rather than on per-path basis (e.g., tunnel-name, source/destination TTP, encoding and switching-type).

The tunnel-association case provides the information needed to associate multiple path requests that are intended to be used within the same tunnel.

For this purpose, it is proposed to define a tunnel-associations list:

```

+---- tunnel-associations* [tunnel-association-id]
| +---- tunnel-association-id?          uint32
| +---- tunnel-name?                    string
| .....

```

The path requests that are intended to be used within the same tunnel should reference the same tunnel-association-id. The tunnel-associations list allows also to configure the per-tunnel attributes common to all these path requests. This allow:

- o avoiding repeating the same set of per-tunnel parameters on all the requested path that are intended to belong to the same tunnel;
- o the server to understand what attributes (e.g., associations) are intended to be configured per-tunnel and what attributes (e.g., associations) are intended to be configured per-path, which could be useful especially when the server also creates a te-tunnel instance within the operational DS to report the computed paths, as described in [section 3.3.1](#).

In order to indicate the role of the path being requested within the intended tunnel (e.g., primary or secondary path), the following choice is proposed to be added to the:

```

+---- (path-role)?
| +----:(candidate-primary-path)
| | +---- candidate-primary-path      empty
| +----:(candidate-secondary-path)
| | +---- candidate-secondary-path
| | | .....

```

The candidate-secondary-path container references another requested path that is intended to be the primary path associated with this requested secondary path.

The YANG model allows also including path requests intended to be used to modify existing tunnel (e.g., adding a protection path for an existing un-protected tunnel). In this case, the path request needs to be associated with existing path(s) within an existing tunnel.

Moreover, also the per-tunnel attributes are already provided in the existing te-tunnel instance and do not need to be re-configured in the RPC. Therefore, the tunnel-association list will not be used, but the requested path(s) are proposed to be associated by referencing the existing te-tunnel:

```
+----:(tunnel-association)
| +---- (tunnel-exist)?
| | +----:(tunnel-ref)
| | | +---- tunnel-ref          leafref
| | +----:(tunnel-association-id)
| | | +---- tunnel-association-id  uint32
| .....

```

Open issue: need to evaluate whether this te-tunnel instance should be within the operational DS or within the intended DS, or maybe, on either one of the two DS

Moreover, a requested secondary path can either be associated with another requested primary path or with an existing primary path, as described in the proposal below:

```
+---- candidate-secondary-path
| +---- (primary-path-exist)?
| | +----:(primary-path-reference)
| | | +---- primary-path-ref      leafref
| | +----:(primary-path-request)
| | | +---- primary-path-request-id  uint32
| .....

```

6. YANG model for stateless TE path computation

6.1. YANG Tree

Figure 11 below shows the tree diagram of the YANG model defined in module ietf-te-path-computation.yang.

```
module: ietf-te-path-computation
  augment /te:tunnels-rpc/te:input/te:tunnel-info:
    +-- path-request* [request-id]
    |   +-- request-id          uint32
    |   +-- encoding?          identityref

```

```

| +-- switching-type?          identityref
| +-- source?                  inet:ip-address
| +-- destination?             inet:ip-address
| +-- src-tp-id?               binary
| +-- dst-tp-id?               binary
| +-- bidirectional?           boolean
| +-- te-topology-identifier
| | +-- provider-id?   te-global-id
| | +-- client-id?    te-global-id
| | +-- topology-id?  te-topology-id
| +-- explicit-route-objects-always
| | +-- route-object-exclude-always* [index]
| | | +-- index          uint32
| | | +-- (type)?
| | |   +--:(numbered-node-hop)
| | |   | +-- numbered-node-hop
| | |   | | +-- node-id      te-node-id
| | |   | | +-- hop-type?   te-hop-type
| | |   +--:(numbered-link-hop)
| | |   | +-- numbered-link-hop
| | |   | | +-- link-tp-id   te-tp-id
| | |   | | +-- hop-type?   te-hop-type
| | |   | | +-- direction?  te-link-direction
| | |   +--:(unnumbered-link-hop)
| | |   | +-- unnumbered-link-hop
| | |   | | +-- link-tp-id   te-tp-id
| | |   | | +-- node-id     te-node-id
| | |   | | +-- hop-type?   te-hop-type
| | |   | | +-- direction?  te-link-direction
| | |   +--:(as-number)
| | |   | +-- as-number-hop
| | |   | | +-- as-number   inet:as-number
| | |   | | +-- hop-type?   te-hop-type
| | |   +--:(label)
| | |   | +-- label-hop
| | |   | +-- te-label
| | |   | +-- (technology)?
| | |   | +--:(generic)

```

```

| | | | +-- generic? rt-types:generalized-
label
| | | +-- direction? te-label-direction
| | +-- route-object-include-exclude* [index]
| | +-- explicit-route-usage? identityref
| | +-- index uint32
| | +-- (type)?
| | +--:(numbered-node-hop)
| | | +-- numbered-node-hop
| | | | +-- node-id te-node-id
| | | | +-- hop-type? te-hop-type
| | +--:(numbered-link-hop)
| | | +-- numbered-link-hop
| | | | +-- link-tp-id te-tp-id
| | | | +-- hop-type? te-hop-type
| | | | +-- direction? te-link-direction
| | +--:(unnumbered-link-hop)
| | | +-- unnumbered-link-hop
| | | | +-- link-tp-id te-tp-id
| | | | +-- node-id te-node-id
| | | | +-- hop-type? te-hop-type
| | | | +-- direction? te-link-direction
| | +--:(as-number)
| | | +-- as-number-hop
| | | | +-- as-number inet:as-number
| | | | +-- hop-type? te-hop-type
| | +--:(label)
| | | +-- label-hop
| | | | +-- te-label
| | | | +-- (technology)?
| | | | | +--:(generic)
| | | | | +-- generic? rt-types:generalized-
label
| | | | +-- direction? te-label-direction
| | +--:(srlg)
| | | +-- srlg
| | | +-- srlg? uint32
| +-- path-constraints
| +-- te-bandwidth

```



```

| | | +-- (technology)?
| | |   +--:(generic)
| | |     +-- generic?   te-bandwidth
| | +-- link-protection?   identityref
| | +-- setup-priority?    uint8
| | +-- hold-priority?     uint8
| | +-- signaling-type?    identityref
| | +-- path-metric-bounds
| | |   +-- path-metric-bound* [metric-type]
| | |     +-- metric-type   identityref
| | |     +-- upper-bound?  uint64
| | +-- path-affinities-values
| | |   +-- path-affinities-value* [usage]
| | |     +-- usage         identityref
| | |     +-- value?       admin-groups
| | +-- path-affinity-names
| | |   +-- path-affinity-name* [usage]
| | |     +-- usage         identityref
| | |     +-- affinity-name* [name]
| | |       +-- name        string
| | +-- path-srlgs-lists
| | |   +-- path-srlgs-list* [usage]
| | |     +-- usage         identityref
| | |     +-- values*       srlg
| | +-- path-srlgs-names
| | |   +-- path-srlgs-name* [usage]
| | |     +-- usage         identityref
| | |     +-- names*        string
| | +-- disjointness?      te-path-disjointness
+-- optimizations
| | +-- (algorithm)?
| |   +--:(metric) {path-optimization-metric}?
| |     | +-- optimization-metric* [metric-type]
| |     | | +-- metric-type           identityref
| |     | | +-- weight?               uint8
| |     | | +-- explicit-route-exclude-objects
| |     | | | +-- route-object-exclude-object* [index]
| |     | | |   +-- index               uint32
| |     | | |   +-- (type)?

```

```

| | | | | +--:(numbered-node-hop)
| | | | | | +-- numbered-node-hop
| | | | | |   +-- node-id      te-node-id
| | | | | |   +-- hop-type?    te-hop-type
| | | | | +--:(numbered-link-hop)
| | | | | | +-- numbered-link-hop
| | | | | |   +-- link-tp-id    te-tp-id
| | | | | |   +-- hop-type?    te-hop-type
| | | | | |   +-- direction?   te-link-
direction
| | | | | +--:(unnumbered-link-hop)
| | | | | | +-- unnumbered-link-hop
| | | | | |   +-- link-tp-id    te-tp-id
| | | | | |   +-- node-id      te-node-id
| | | | | |   +-- hop-type?    te-hop-type
| | | | | |   +-- direction?   te-link-
direction
| | | | | +--:(as-number)
| | | | | | +-- as-number-hop
| | | | | |   +-- as-number      inet:as-number
| | | | | |   +-- hop-type?    te-hop-type
| | | | | +--:(label)
| | | | | | +-- label-hop
| | | | | |   +-- te-label
| | | | | |     +-- (technology)?
| | | | | |       | +--:(generic)
| | | | | |       |   +-- generic?  rt-
types:generalized-label
| | | | | |   +-- direction?    te-label-
direction
| | | | | +--:(srlg)
| | | | |   +-- srlg
| | | | |     +-- srlg?    uint32
| | | | | +-- explicit-route-include-objects
| | | | |   +-- route-object-include-object* [index]
| | | | |     +-- index                                uint32
| | | | |     +-- (type)?
| | | | |   +--:(numbered-node-hop)
| | | | |     | +-- numbered-node-hop

```

```

| | | | | +-- node-id      te-node-id
| | | | | +-- hop-type?   te-hop-type
| | | | | +---:(numbered-link-hop)
| | | | | | +-- numbered-link-hop
| | | | | | +-- link-tp-id   te-tp-id
| | | | | | +-- hop-type?   te-hop-type
| | | | | | +-- direction?  te-link-
direction
| | | | | +---:(unnumbered-link-hop)
| | | | | | +-- unnumbered-link-hop
| | | | | | +-- link-tp-id   te-tp-id
| | | | | | +-- node-id     te-node-id
| | | | | | +-- hop-type?   te-hop-type
| | | | | | +-- direction?  te-link-
direction
| | | | | +---:(as-number)
| | | | | | +-- as-number-hop
| | | | | | +-- as-number    inet:as-number
| | | | | | +-- hop-type?   te-hop-type
| | | | | | +---:(label)
| | | | | | | +-- label-hop
| | | | | | | +-- te-label
| | | | | | | | +-- (technology)?
| | | | | | | | | +---:(generic)
| | | | | | | | | +-- generic?  rt-
types:generalized-label
| | | | | +-- direction?    te-label-
direction
| | | | | | +-- tiebreakers
| | | | | | | +-- tiebreaker* [tiebreaker-type]
| | | | | | | +-- tiebreaker-type  identityref
| | | | | | +---:(objective-function) {path-optimization-objective-
function}?
| | | | | | | +-- objective-function
| | | | | | | +-- objective-function-type?  identityref
| | | | | | +-- path-in-segment!
| | | | | | +-- label-restrictions
| | | | | | | +-- label-restriction* [index]
| | | | | | | +-- restriction?  enumeration

```

```

| |      +-- index          uint32
| |      +-- label-start
| |      | +-- te-label
| |      |   +-- (technology)?
| |      |   | +--:(generic)
| |      |   |   +-- generic?  rt-types:generalized-
label
| |      |   +-- direction?      te-label-direction
| |      +-- label-end
| |      | +-- te-label
| |      |   +-- (technology)?
| |      |   | +--:(generic)
| |      |   |   +-- generic?  rt-types:generalized-
label
| |      |   +-- direction?      te-label-direction
| |      +-- label-step
| |      | +-- (technology)?
| |      |   +--:(generic)
| |      |   +-- generic?  int32
| |      +-- range-bitmap?  yang:hex-string
| +-- path-out-segment!
| |   +-- label-restrictions
| |       +-- label-restriction* [index]
| |           +-- restriction?  enumeration
| |           +-- index          uint32
| |           +-- label-start
| |           | +-- te-label
| |           |   +-- (technology)?
| |           |   | +--:(generic)
| |           |   |   +-- generic?  rt-types:generalized-
label
| |           |   +-- direction?      te-label-direction
| |           +-- label-end
| |           | +-- te-label
| |           |   +-- (technology)?
| |           |   | +--:(generic)
| |           |   |   +-- generic?  rt-types:generalized-
label
| |           |   +-- direction?      te-label-direction

```

```

| |      +-- label-step
| |      | +-- (technology)?
| |      |   +--:(generic)
| |      |     +-- generic?   int32
| |      +-- range-bitmap?   yang:hex-string
| +-- requested-metrics* [metric-type]
| |   +-- metric-type      identityref
| +-- return-srlgs?        boolean
| +-- return-affinities?   boolean
| +-- requested-state!
|   +-- timer?             uint16
|   +-- transaction-id?    string
|   +-- tunnel-name?       string
|   +-- (path)?
|       +--:(primary)
|       | +-- primary-path-name?   string
|       +--:(secondary)
|       +-- secondary-path-name?   string
+-- synchronization* [synchronization-id]
    +-- synchronization-id   uint32
    +-- svec
    |   +-- relaxable?        boolean
    |   +-- disjointness?     te-path-disjointness
    |   +-- request-id-number* uint32
    +-- svec-constraints
    |   +-- path-metric-bound* [metric-type]
    |   +-- metric-type      identityref
    |   +-- upper-bound?     uint64
    +-- path-srlgs-lists
    |   +-- path-srlgs-list* [usage]
    |   +-- usage            identityref
    |   +-- values*          srlg
    +-- path-srlgs-names
    |   +-- path-srlgs-name* [usage]
    |   +-- usage            identityref
    |   +-- names*           string
    +-- exclude-objects
    |   +-- excludes* [index]
    |   +-- index                uint32

```

```

|     +-- (type)?
|     +--:(numbered-node-hop)
|     |   +-- numbered-node-hop
|     |   |   +-- node-id      te-node-id
|     |   |   +-- hop-type?   te-hop-type
|     +--:(numbered-link-hop)
|     |   +-- numbered-link-hop
|     |   |   +-- link-tp-id   te-tp-id
|     |   |   +-- hop-type?   te-hop-type
|     |   |   +-- direction?  te-link-direction
|     +--:(unnumbered-link-hop)
|     |   +-- unnumbered-link-hop
|     |   |   +-- link-tp-id   te-tp-id
|     |   |   +-- node-id     te-node-id
|     |   |   +-- hop-type?   te-hop-type
|     |   |   +-- direction?  te-link-direction
|     +--:(as-number)
|     |   +-- as-number-hop
|     |   |   +-- as-number   inet:as-number
|     |   |   +-- hop-type?   te-hop-type
|     +--:(label)
|     |   +-- label-hop
|     |   |   +-- te-label
|     |   |   |   +-- (technology)?
|     |   |   |   |   +--:(generic)
|     |   |   |   |   |   +-- generic?   rt-types:generalized-
label
|     |   |   |   |   |   +-- direction?   te-label-direction
+-- optimizations
+-- (algorithm)?
+--:(metric) {te-types:path-optimization-metric}?
|   +-- optimization-metric* [metric-type]
|   |   +-- metric-type   identityref
|   |   +-- weight?      uint8
+--:(objective-function) {te-types:path-optimization-
objective-function}?
+-- objective-function
+-- objective-function-type?   identityref
augment /te:tunnels-rpc/te:output/te:result:

```

```

+--ro response* [response-id]
  +--ro response-id          uint32
  +--ro (response-type)?
    +--:(no-path-case)
      | +--ro no-path!
    +--:(path-case)
      +--ro computed-path
        +--ro path-properties
          | +--ro path-metric* [metric-type]
          | | +--ro metric-type          identityref
          | | +--ro accumulative-value?  uint64
          | +--ro path-affinities-values
          | | +--ro path-affinities-value* [usage]
          | |   +--ro usage          identityref
          | |   +--ro value?        admin-groups
          | +--ro path-affinity-names
          | | +--ro path-affinity-name* [usage]
          | |   +--ro usage          identityref
          | |   +--ro affinity-name* [name]
          | |     +--ro name        string
          | +--ro path-srlgs-lists
          | | +--ro path-srlgs-list* [usage]
          | |   +--ro usage          identityref
          | |   +--ro values*        srlg
          | +--ro path-srlgs-names
          | | +--ro path-srlgs-name* [usage]
          | |   +--ro usage          identityref
          | |   +--ro names*        string
          | +--ro path-route-objects
          |   +--ro path-route-object* [index]
          |   +--ro index              uint32
          |   +--ro (type)?
          |     +--:(numbered-node-hop)
          |     | +--ro numbered-node-hop
          |     | | +--ro node-id        te-node-id
          |     | | +--ro hop-type?      te-hop-type
          |     +--:(numbered-link-hop)
          |     | +--ro numbered-link-hop
          |     | | +--ro link-tp-id      te-tp-id

```

```

|           |      +--ro hop-type?      te-hop-type
|           |      +--ro direction?     te-link-
direction
|           +--:(unnumbered-link-hop)
|           |      +--ro unnumbered-link-hop
|           |      +--ro link-tp-id      te-tp-id
|           |      +--ro node-id        te-node-id
|           |      +--ro hop-type?      te-hop-type
|           |      +--ro direction?     te-link-
direction
|           +--:(as-number)
|           |      +--ro as-number-hop
|           |      +--ro as-number      inet:as-number
|           |      +--ro hop-type?      te-hop-type
|           +--:(label)
|           |      +--ro label-hop
|           |      +--ro te-label
|           |      +--ro (technology)?
|           |      |      +--:(generic)
|           |      |      +--ro generic?  rt-
types:generalized-label
|           |      +--ro direction?      te-
label-direction
+--ro tunnel-ref?          te:tunnel-ref
+--ro (path)?
+--:(primary)
| +--ro primary-path-ref?  ->
/te:te/tunnels/tunnel[te:name=current()/../tunnel-ref]/p2p-primary-
paths/p2p-primary-path/name
+--:(secondary)
+--ro secondary-path-ref?  ->
/te:te/tunnels/tunnel[te:name=current()/../tunnel-ref]/p2p-
secondary-paths/p2p-secondary-path/name
augment /te:tunnels-rpc/te:input/te:tunnel-info:
+-- deleted-paths-transaction-id*  string
augment /te:tunnels-rpc/te:output/te:result:
+-- deleted-paths-transaction-id*  string

```

Figure 11 - TE path computation YANG tree

6.2. YANG Module

```
<CODE BEGINS>file "ietf-te-path-computation@2019-03-11.yang"
module ietf-te-path-computation {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-te-path-computation";
  // replace with IANA namespace when assigned

  prefix "tepc";

  import ietf-inet-types {
    prefix "inet";
  }

  import ietf-te {
    prefix "te";
  }

  import ietf-te-types {
    prefix "te-types";
  }

  organization
    "Traffic Engineering Architecture and Signaling (TEAS)
    Working Group";

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

    WG Chair: Lou Berger
              <mailto:lberger@labn.net>

    WG Chair: Vishnu Pavan Beeram
              <mailto:vbeeram@juniper.net>

    ";

  description "YANG model for stateless TE path computation";
```

```
revision "2019-03-11" {
  description
    "Initial revision";
  reference
    "draft-ietf-teas-yang-path-computation";
}

/*
 * Features
 */

feature stateless-path-computation {
  description
    "This feature indicates that the system supports
    stateless path computation.";
}

/*
 * Groupings
 */

grouping path-info {
  uses te-types:generic-path-properties;
  description "Path computation output information";
}

grouping requested-info {
  description
    "This grouping defines the information (e.g., metrics)
    which must be returned in the response";
  list requested-metrics {
    key 'metric-type';
    description
      "The list of the requested metrics
      The metrics listed here must be returned in the response.
      Returning other metrics in the response is optional.";
    leaf metric-type {
      type identityref {
```

```
        base te-types:path-metric-type;
    }
    description
        "The metric that must be returned in the response";
    }
}
leaf return-srlgs {
    type boolean;
    default false;
    description
        "If true, path srlgs must be returned in the response.
        If false, returning path srlgs in the response optional.";
}
leaf return-affinities {
    type boolean;
    default false;
    description
        "If true, path affinities must be returned in the response.
        If false, returning path affinities in the response is
        optional.";
}
}

grouping requested-state {
    description
        "Configuration for the transient state used
        to report the computed path";
    leaf timer {
        type uint16;
        units minutes;
        default 10;
        description
            "The timeout after which the transient state reporting
            the computed path should be removed.";
    }
    leaf transaction-id {
        type string;
        description
            "

```

The transaction-id associated with this path computation to be used for fast deletion of the transient states associated with multiple path computations.

This transaction-id can be used to explicitly delete all the transient states of all the computed paths associated with the same transaction-id.

When one path associated with a transaction-id is setup, the transient states of all the other computed paths with the same transaction-id are automatically removed.

If not specified, the transient state is removed only when the timer expires (when the timer is specified) or not created at all (stateless path computation, when the timer is not specified).

```
    ";
  }
  leaf tunnel-name {
    type string;
    description
      "
        The suggested name to be assigned to the te-tunnel
        instance which is created to report the computed path.

        In case multiple paths are requested with the same
        suggested name, the server will create only one te-tunnel
        instance to report all the computed paths
        with the same suggested name.

        A different name can be assigned by server (e.g., when a
        te-tunnel with this name already exists).
      ";
  }
  choice path {
    description
      "The transient state of the computed path can be reported
        as a primary or a secondary path of a te-tunnel";
    case primary {
```

```
leaf primary-path-name {
  type string;
  description
    "
      The suggested name to be assigned to the
      p2p-primary-path instance which is created
      to report the computed path.

      A different name can be assigned by the server
      (e.g., when a p2p-primary-path with this name
      already exists).
    ";
}
}
case secondary {
  leaf secondary-path-name {
    type string;
    description
      "
        The suggested name to be assigned to the
        p2p-secondary-path instance which is created
        to report the computed path.

        A different name can be assigned by the server
        (e.g., when a p2p-secondary-path with this
        name already exists).

        If not specified, the a p2p-primary-path is created
        by the server.
      ";
  }
}
}
}

grouping reported-state {
  description
    "Information about the transient state created
    to report the computed path";
```

```
leaf tunnel-ref {
  type te:tunnel-ref;
  description
    "
      Reference to the tunnel that reports the transient state
      of the computed path.

      If no transient state is created, this attribute is empty.
    ";
}
choice path {
  description
    "The transient state of the computed path can be reported
    as a primary or a secondary path of a te-tunnel";
  case primary {
    leaf primary-path-ref {
      type leafref {
        path "/te:te/te:tunnels/" +
          "te:tunnel[te:name=current()/../tunnel-ref]/" +
          "te:p2p-primary-paths/te:p2p-primary-path/" +
          "te:name";
      }
      must "../tunnel-ref" {
        description
          "The primary-path-name can only be reported
          if also the tunnel is reported
          to provide the complete reference.";
      }
    }
    description
      "
        Reference to the p2p-primary-path that reports
        the transient state of the computed path.

        If no transient state is created,
        this attribute is empty.
      ";
  }
}
```

```
case secondary {
  leaf secondary-path-ref {
    type leafref {
      path "/te:te/te:tunnels/" +
        "te:tunnel[te:name=current()../tunnel-ref]/" +
        "te:p2p-secondary-paths/te:p2p-secondary-path/" +
        "te:name";
    }
    must "../tunnel-ref" {
      description
        "The secondary-path-name can only be reported
        if also the tunnel is reported to provide
        the complete reference.";
    }
    description
      "
        Reference to the p2p-secondary-path that reports
        the transient state of the computed path.

        If no transient state is created,
        this attribute is empty.
      ";
  }
}
}
}

identity svec-metric-type {
  description
    "Base identity for svec metric type";
}

identity svec-metric-cumul-te {
  base svec-metric-type;
  description
    "TE cumulative path metric";
}

identity svec-metric-cumul-igp {
```

```
    base svec-metric-type;
    description
      "IGP cumulative path metric";
  }

  identity svec-metric-cumul-hop {
    base svec-metric-type;
    description
      "Hop cumulative path metric";
  }

  identity svec-metric-aggregate-bandwidth-consumption {
    base svec-metric-type;
    description
      "Cumulative bandwith consumption of the set of
       synchronized paths";
  }

  identity svec-metric-load-of-the-most-loaded-link {
    base svec-metric-type;
    description
      "Load of the most loaded link";
  }

  grouping svec-metrics-bounds_config {
    description
      "TE path metric bounds grouping for computing a set of
       synchronized requests";
    leaf metric-type {
      type identityref {
        base svec-metric-type;
      }
      description "TE path metric type usable for computing a set of
        synchronized requests";
    }
    leaf upper-bound {
      type uint64;
      description "Upper bound on end-to-end svec path metric";
    }
  }
```



```
}

grouping svec-metrics-optimization_config {
  description
    "TE path metric bounds grouping for computing a set of
    synchronized requests";

  leaf metric-type {
    type identityref {
      base svec-metric-type;
    }
    description "TE path metric type usable for computing a set of
    synchronized requests";
  }
  leaf weight {
    type uint8;
    description "Metric normalization weight";
  }
}

grouping svec-exclude {
  description "List of resources to be excluded by all the paths
  in the SVEC";
  container exclude-objects {
    description "resources to be excluded";
    list excludes {
      key index;
      ordered-by user;
      leaf index {
        type uint32;
        description "XRO subobject index";
      }
      description
        "List of explicit route objects to always exclude
        from synchronized path computation";
      uses te-types:explicit-route-hop;
    }
  }
}
```

```
grouping synchronization-constraints {
  description "Global constraints applicable to synchronized
    path computation";
  container svec-constraints {
    description "global svec constraints";
    list path-metric-bound {
      key metric-type;
      description "list of bound metrics";
      uses svec-metrics-bounds_config;
    }
  }
  uses te-types:generic-path-srlgs;
  uses svec-exclude;
}

grouping synchronization-optimization {
  description "Synchronized request optimization";
  container optimizations {
    description
      "The objective function container that includes attributes
        to impose when computing a synchronized set of paths";

    choice algorithm {
      description "Optimizations algorithm.";
      case metric {
        if-feature te-types:path-optimization-metric;
        list optimization-metric {
          key "metric-type";
          description "svec path metric type";
          uses svec-metrics-optimization_config;
        }
      }
      case objective-function {
        if-feature te-types:path-optimization-objective-function;
        container objective-function {
          description
            "The objective function container that includes
              attributes to impose when computing a TE path";

```

```
        leaf objective-function-type {
            type identityref {
                base te-types:objective-function-type;
            }
            default te-types:of-minimize-cost-path;
            description "Objective function entry";
        }
    }
}
}
}

grouping synchronization-info {
    description "Information for sync";
    list synchronization {
        key "synchronization-id";
        description "sync list";
        leaf synchronization-id {
            type uint32;
            description "index";
        }
    }
    container svec {
        description
            "Synchronization VECtor";
        leaf relaxable {
            type boolean;
            default true;
            description
                "If this leaf is true, path computation process is
                 free to ignore svec content.
                 Otherwise, it must take into account this svec.";
        }
    }
    uses te-types:generic-path-disjointness;
    leaf-list request-id-number {
        type uint32;
        description
            "This list reports the set of path computation
             requests that must be synchronized.";
    }
}
```

```
    }
  }
  uses synchronization-constraints;
  uses synchronization-optimization;
}
}

grouping no-path-info {
  description "no-path-info";
  container no-path {
    presence "Response without path information, due to failure
      performing the path computation";
    description "if path computation cannot identify a path,
      rpc returns no path.";
  }
}

/*
 * These groupings should be removed when defined in te-types
 */

grouping encoding-and-switching-type {
  description
    "Common grouping to define the LSP encoding and
      switching types";

  leaf encoding {
    type identityref {
      base te-types:lsp-encoding-types;
    }
    description "LSP encoding type";
    reference "RFC3945";
  }
  leaf switching-type {
    type identityref {
      base te-types:switching-capabilities;
    }
    description "LSP switching type";
    reference "RFC3945";
  }
}
```

```
    }
  }

  grouping tunnel-p2p-common-params {
    description
      "Common grouping to define the TE tunnel parameters";

    uses encoding-and-switching-type;
    leaf source {
      type inet:ip-address;
      description "TE tunnel source address.";
    }
    leaf destination {
      type inet:ip-address;
      description "P2P tunnel destination address";
    }
    leaf src-tp-id {
      type binary;
      description
        "TE tunnel source termination point identifier.";
    }
    leaf dst-tp-id {
      type binary;
      description
        "TE tunnel destination termination point identifier.";
    }
    leaf bidirectional {
      type boolean;
      default 'false';
      description "TE tunnel bidirectional";
    }
  }
}

/*
 * AUGMENTS TO TE RPC
 */

augment "/te:tunnels-rpc/te:input/te:tunnel-info" {
  description "Path Computation RPC input";
```

```
list path-request {
  key "request-id";
  description "request-list";
  leaf request-id {
    type uint32;
    mandatory true;
    description
      "Each path computation request is uniquely identified
       by the request-id-number.";
  }
  uses tunnel-p2p-common-params;
  uses te-types:te-topology-identifier;
  uses te-types:path-constraints-route-objects;
  uses te-types:generic-path-constraints;
  uses te-types:generic-path-optimization;
  uses te:path-access-segment-info;
  uses requested-info;
  container requested-state {
    presence
      "Request temporary reporting of the computed path state";
    description
      "Configures attributes for the temporary reporting of the
       computed path state (e.g., expiration timer).";
    uses requested-state;
  }
}
uses synchronization-info;
}

augment "/te:tunnels-rpc/te:output/te:result" {
  description "Path Computation RPC output";
  list response {
    key "response-id";
    config false;
    description "response";
    leaf response-id {
      type uint32;
      description
        "The response-id has the same value of the corresponding
```

```
        request-id.";
    }
    choice response-type {
        config false;
        description "response-type";
        case no-path-case {
            uses no-path-info;
        }
        case path-case {
            container computed-path {
                uses path-info;
                uses reported-state;
                description "Path computation service.";
            }
        }
    }
}

}

}

}

augment "/te:tunnels-rpc/te:input/te:tunnel-info" {
    description "Path Delete RPC input";
    leaf-list deleted-paths-transaction-id {
        type string;
        description
            "The list of the transaction-id values of the
             transient states to be deleted";
    }
}

augment "/te:tunnels-rpc/te:output/te:result" {
    description "Path Delete RPC output";
    leaf-list deleted-paths-transaction-id {
        type string;
        description
            "The list of the transaction-id values of the
             transient states that have been successfully deleted";
    }
}
}
```

<CODE ENDS>

Figure 12 - TE path computation YANG module

7. Security Considerations

This document describes use cases of requesting Path Computation using YANG models, which could be used at the ABNO Control Interface [RFC7491] and/or between controllers in ACTN [RFC8453]. As such, it does not introduce any new security considerations compared to the ones related to YANG specification, ABNO specification and ACTN Framework defined in [RFC7950], [RFC7491] and [RFC8453].

The YANG module defined in this draft is designed to be accessed via the NETCONF protocol [RFC6241] or RESTCONF protocol [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

This document also defines common data types using the YANG data modeling language. The definitions themselves have no security impact on the Internet, but the usage of these definitions in concrete YANG modules might have. The security considerations spelled out in the YANG specification [RFC7950] apply for this document as well.

The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

Note - The security analysis of each leaf is for further study.

8. IANA Considerations

This document registers the following URIs 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-te-path-computation
XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [[RFC7950](#)].

name: ietf-te-path-computation

namespace: urn:ietf:params:xml:ns:yang:ietf-te-path-computation

prefix: tepc

9. References

9.1. Normative References

- [RFC3688] Mealling, M., "The IETF XML Registry", [RFC 3688](#), January 2004.
- [RFC5440] Vasseur, JP., Le Roux, JL. et al., "Path Computation Element (PCE) Communication Protocol (PCEP)", [RFC 5440](#), March 2009.
- [RFC5441] Vasseur, JP., Ed., Zhang, R., Bitar, N., and JL. Le Roux, "A Backward-Recursive PCE-Based Computation (BRPC) Procedure to Compute Shortest Constrained Inter-Domain Traffic Engineering Label Switched Paths", [RFC 5441](#), DOI 10.17487/RFC5441, April 2009, <<https://www.rfc-editor.org/info/rfc5441>>.
- [RFC5541] Le Roux, JL. et al., "Encoding of Objective Functions in the Path Computation Element Communication Protocol (PCEP)", [RFC 5541](#), June 2009.
- [RFC6241] Enns, R., Ed., Bjorklund, M., Ed., Schoenwaelder, J., Ed., and A. Bierman, Ed., "Network Configuration Protocol (NETCONF)", [RFC 6241](#), June 2011.
- [RFC6242] Wasserman, M., "Using the NETCONF Protocol over Secure Shell (SSH)", [RFC 6242](#), June 2011.
- [RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", [RFC 8040](#), January 2017.
- [RFC8341] Bierman, A., and M. Bjorklund, "Network Configuration Access Control Model", [RFC 8341](#), March 2018.

- [RFC7491] Farrel, A., King, D., "A PCE-Based Architecture for Application-Based Network Operations", [RFC 7491](#), March 2015.
- [RFC7926] Farrel, A. et al., "Problem Statement and Architecture for Information Exchange Between Interconnected Traffic Engineered Networks", [RFC 7926](#), July 2016.
- [RFC7950] Bjorklund, M., "The YANG 1.1 Data Modeling Language", [RFC 7950](#), August 2016.
- [RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", [RFC 8040](#), January 2017.
- [RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", [RFC 8446](#), August 2018.
- [RFC8453] Ceccarelli, D., Lee, Y. et al., "Framework for Abstraction and Control of TE Networks (ACTN)", [RFC8453](#), August 2018.
- [RFC8454] Lee, Y. et al., "Information Model for Abstraction and Control of TE Networks (ACTN)", [RFC8454](#), September 2018.
- [TE-TOP0] Liu, X. et al., "YANG Data Model for TE Topologies", [draft-ietf-teas-yang-te-topo](#), work in progress.
- [TE-TUNNEL] Saad, T. et al., "A YANG Data Model for Traffic Engineering Tunnels and Interfaces", [draft-ietf-teas-yang-te](#), work in progress.

[9.1. Informative References](#)

- [RFC4655] Farrel, A. et al., "A Path Computation Element (PCE)-Based Architecture", [RFC 4655](#), August 2006.
- [RFC6805] King, D., Ed. and A. Farrel, Ed., "The Application of the Path Computation Element Architecture to the Determination of a Sequence of Domains in MPLS and GMPLS", [RFC 6805](#), DOI 10.17487/RFC6805, November 2012, <<https://www.rfc-editor.org/info/rfc6805>>.
- [RFC7139] Zhang, F. et al., "GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks", [RFC 7139](#), March 2014.

- [RFC7446] Lee, Y. et al., "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", [RFC 7446](#), February 2015.
- [RFC8233] Dhody, D. et al., "Extensions to the Path Computation Element Communication Protocol (PCEP) to Compute Service-Aware Label Switched Paths (LSPs)", [RFC 8233](#), September 2017
- [RFC8342] Bjorklund, M. et al. "Network Management Datastore Architecture (NMDA)", [RFC 8342](#), March 2018
- [OTN-TOP0] Zheng, H. et al., "A YANG Data Model for Optical Transport Network Topology", [draft-ietf-ccamp-otn-topo-yang](#), work in progress.
- [ITU-T G.709-2016] ITU-T Recommendation G.709 (06/16), "Interface for the optical transport network", June 2016.

10. Acknowledgments

The authors would like to thank Igor Bryskin and Xian Zhang for participating in the initial discussions that have triggered this work and providing valuable insights.

The authors would like to thank the authors of the TE Tunnel YANG model [[TE-TUNNEL](#)], in particular Igor Bryskin, Vishnu Pavan Beeram, Tarek Saad and Xufeng Liu, for their inputs to the discussions and support in having consistency between the Path Computation and TE Tunnel YANG models.

The authors would like to thank Adrian Farrel, Dhruv Dhody, Igor Bryskin, Julien Meuric and Lou Berger for their valuable input to the discussions that has clarified that the path being setup is not necessarily the same as the path that have been previously computed and, in particular to Dhruv Dhody, for his suggestion to describe the need for a path verification phase to check that the actual path being setup meets the required end-to-end metrics and constraints.

This document was prepared using 2-Word-v2.0.template.dot.

Appendix A. Examples of dimensioning the "detailed connectivity matrix"

In the following table, a list of the possible constraints, associated with their potential cardinality, is reported.

The maximum number of potential connections to be computed and reported is, in first approximation, the multiplication of all of them.

Constraint	Cardinality
End points	$N(N-1)/2$ if connections are bidirectional (OTN and WDM), $N(N-1)$ for unidirectional connections.
Bandwidth	In WDM networks, bandwidth values are expressed in GHz. On fixed-grid WDM networks, the central frequencies are on a 50GHz grid and the channel width of the transmitters are typically 50GHz such that each central frequency can be used, i.e., adjacent channels can be placed next to each other in terms of central frequencies. On flex-grid WDM networks, the central frequencies are on a 6.25GHz grid and the channel width of the transmitters can be multiples of 12.5GHz. For fixed-grid WDM networks typically there is only one possible bandwidth value (i.e., 50GHz) while for flex-grid WDM networks typically there are 4 possible bandwidth values (e.g., 37.5GHz, 50GHz, 62.5GHz, 75GHz). In OTN (ODU) networks, bandwidth values are expressed as pairs of ODU type and, in case of ODUFlex, ODU rate in bytes/sec as described in section 5 of [RFC7139] . For "fixed" ODUk types, 6 possible bandwidth values are possible (i.e., ODU0, ODU1, ODU2, ODU2e, ODU3, ODU4). For ODUFlex(GFP), up to 80 different bandwidth values can be specified, as defined in Table 7-8 of [ITU-T G.709-2016]. For other ODUFlex types, like ODUFlex(CBR), the number of possible bandwidth values depends on the rates of the

clients that could be mapped over these ODUflex types, as shown in Table 7.2 of [ITU-T G.709-2016], which in theory could be a continuum of values. However, since different ODUflex bandwidths that use the same number of TSs on each link along the path are equivalent for path computation purposes, up to 120 different bandwidth ranges can be specified.

Ideas to reduce the number of ODUflex bandwidth values in the detailed connectivity matrix, to less than 100, are for further study.

Bandwidth specification for ODUCn is currently for further study but it is expected that other bandwidth values can be specified as integer multiples of 100Gb/s.

In IP we have bandwidth values in bytes/sec. In principle, this is a continuum of values, but in practice we can identify a set of bandwidth ranges, where any bandwidth value inside the same range produces the same path.

The number of such ranges is the cardinality, which depends on the topology, available bandwidth and status of the network. Simulations (Note: reference paper submitted for publication) show that values for medium size topologies (around 50-150 nodes) are in the range 4-7 (5 on average) for each end points couple.

Metrics IGP, TE and hop number are the basic objective metrics defined so far. There are also the 2 objective functions defined in [[RFC5541](#)]: Minimum Load Path (MLP) and Maximum Residual Bandwidth Path (MBP). Assuming that one only metric or objective function can be optimized at once, the total cardinality here is 5.

With [[RFC8233](#)], a number of additional metrics are defined, including Path Delay metric, Path Delay Variation metric and Path Loss metric, both for point-to-point and point-to-multipoint paths. This increases the cardinality to 8.

Bounds Each metric can be associated with a bound in order to find a path having a total value of that metric lower than the given bound. This has a potentially very high cardinality (as any value for the bound is allowed). In

practice there is a maximum value of the bound (the one with the maximum value of the associated metric) which results always in the same path, and a range approach like for bandwidth in IP should produce also in this case the cardinality. Assuming to have a cardinality similar to the one of the bandwidth (let say 5 on average) we should have 6 (IGP, TE, hop, path delay, path delay variation and path loss; we don't consider here the two objective functions of [[RFC5541](#)] as they are conceived only for optimization)*5 = 30 cardinality.

Technology

constraints For further study

Priority We have 8 values for setup priority, which is used in path computation to route a path using free resources and, where no free resources are available, resources used by LSPs having a lower holding priority.

Local prot It's possible to ask for a local protected service, where all the links used by the path are protected with fast reroute (this is only for IP networks, but line protection schemas are available on the other technologies as well). This adds an alternative path computation, so the cardinality of this constraint is 2.

Administrative

Colors Administrative colors (aka affinities) are typically assigned to links but when topology abstraction is used affinity information can also appear in the detailed connectivity matrix.

There are 32 bits available for the affinities. Links can be tagged with any combination of these bits, and path computation can be constrained to include or exclude any or all of them. The relevant cardinality is 3 (include-any, exclude-any, include-all) times 2^{32} possible values. However, the number of possible values used in real networks is quite small.

Included Resources

A path computation request can be associated to an ordered set of network resources (links, nodes) to be included along the computed path. This constraint would

have a huge cardinality as in principle any combination of network resources is possible. However, as far as the Orchestrator doesn't know details about the internal topology of the domain, it shouldn't include this type of constraint at all (see more details below).

Excluded Resources

A path computation request can be associated to a set of network resources (links, nodes, SRLGs) to be excluded from the computed path. Like for included resources, this constraint has a potentially very high cardinality, but, once again, it can't be actually used by the Orchestrator, if it's not aware of the domain topology (see more details below).

As discussed above, the Orchestrator can specify include or exclude resources depending on the abstract topology information that the domain controller exposes:

- o In case the domain controller exposes the entire domain as a single abstract TE node with his own external terminations and detailed connectivity matrix (whose size we are estimating), no other topological details are available, therefore the size of the detailed connectivity matrix only depends on the combination of the constraints that the Orchestrator can use in a path computation request to the domain controller. These constraints cannot refer to any details of the internal topology of the domain, as those details are not known to the Orchestrator and so they do not impact size of the detailed connectivity matrix exported.

- o Instead in case the domain controller exposes a topology including more than one abstract TE nodes and TE links, and their attributes (e.g. SRLGs, affinities for the links), the Orchestrator knows these details and therefore could compute a path across the domain referring to them in the constraints. The detailed connectivity matrixes, whose size need to be estimated here, are the ones relevant to the abstract TE nodes exported to the Orchestrator. These detailed connectivity matrixes and therefore theirs sizes, while cannot depend on the other abstract TE nodes and TE links, which are external to the given abstract node, could depend to SRLGs (and other attributes, like affinities) which could be present also in the portion of the topology represented by the abstract nodes, and therefore contribute to the size of the related detailed connectivity matrix.

We also don't consider here the possibility to ask for more than one path in diversity or for point-to-multi-point paths, which are for further study.

Considering for example an IP domain without considering SRLG and affinities, we have an estimated number of paths depending on these estimated cardinalities:

Endpoints = $N(N-1)$, Bandwidth = 5, Metrics = 6, Bounds = 20,
Priority = 8, Local prot = 2

The number of paths to be pre-computed by each IP domain is therefore $24960 * N(N-1)$ where N is the number of domain access points.

This means that with just 4 access points we have nearly 300000 paths to compute, advertise and maintain (if a change happens in the domain, due to a fault, or just the deployment of new traffic, a substantial number of paths need to be recomputed and the relevant changes advertised to the upper controller).

This seems quite challenging. In fact, if we assume a mean length of 1K for the json describing a path (a quite conservative estimate), reporting 300000 paths means transferring and then parsing more than 300 Mbytes for each domain. If we assume that 20% (to be checked) of this paths change when a new deployment of traffic occurs, we have 60 Mbytes of transfer for each domain traversed by a new end-to-end path. If a network has, let say, 20 domains (we want to estimate the load for a non-trivial domain setup) in the beginning a total

initial transfer of 6Gigs is needed, and eventually, assuming 4-5 domains are involved in mean during a path deployment we could have 240-300 Mbytes of changes advertised to the higher order controller.

Further bare-bone solutions can be investigated, removing some more options, if this is considered not acceptable; in conclusion, it seems that an approach based only on the information provided by the detailed connectivity matrix is hardly feasible, and could be applicable only to small networks with a limited meshing degree between domains and renouncing to a number of path computation features.

Appendix B. New proposed YANG Tree overview

This Appendix provides an overview of the YANG Tree that would results from the proposed changes described in [section 5.3](#).

```

module: ietf-te-path-computation
  augment /te:tunnels-rpc/te:input/te:tunnel-info:
    +---- path-request* [request-id]
      | +--- request-id                               uint32
      | +---- (tunnel-information)?
      | | +----:(tunnel-association)
      | | | +---- (tunnel-exist)?
      | | | | +----:(tunnel-ref)
      | | | | | +---- tunnel-ref                     leafref
      | | | | | +----:(tunnel-association-id)
      | | | | | +---- tunnel-association-id           uint32
      | | | +---- path-name?                          string
      | | | +---- (path-role)?
      | | | | +----:(candidate-primary-path)
      | | | | | +---- candidate-primary-path          empty
      | | | | | +----:(candidate-secondary-path)
      | | | | | +---- candidate-secondary-path
      | | | | | | +---- (primary-path-exist)?
      | | | | | | | +----:(primary-path-reference)
      | | | | | | | | +---- primary-path-ref
leafref
      | | | | | | | | +----:(primary-path-request)
      | | | | | | | | +---- primary-path-request-id
uint32
      | | +----:(tunnel-attributes)
      | | | +---- tunnel-name?                        string
      | | | | +---- (path-role)?
      | | | | | +---:(primary)
      | | | | | | +---- primary-path-name?            string
      | | | | | | +---:(secondary)
      | | | | | | +---- secondary-path-name?          string
      | | | +--- encoding?                            identityref
      | | | +--- switching-type?                       identityref
      | | | +--- source?                               inet:ip-
address

```

```

address | | | +--- destination?                inet:ip-
| | | +--- src-tp-id?                    binary
| | | +--- dst-tp-id?                    binary
| | | +--- bidirectional?                boolean
| | | +--- te-topology-identifier
| | | | +--- provider-id?    te-global-id
| | | | +--- client-id?      te-global-id
| | | | +--- topology-id?    te-topology-id
| +---- explicit-route-objects-always
| | .....
| +---- path-constraints
| | +---- preference?                uint8
| | .....
| +---- optimizations
| | .....
| +---- path-in-segment!
| | .....
| +---- path-out-segment!
| | .....
| +---- requested-metrics* [metric-type]
| | +---- metric-type    identityref
| +---- return-srlgs?                boolean
| +---- return-affinities?            boolean
| +---- requested-state!
| | +---- timer?                uint16
| | +---- transaction-id?        string
+---- tunnel-associations* [tunnel-association-id]
| +---- tunnel-association-id?        uint32
| +---- tunnel-name?                  string
| +---- encoding?                      identityref
| +---- switching-type?                identityref
| +---- source?                        inet:ip-address
| +---- destination?                  inet:ip-address
| +---- src-tp-id?                    binary
| +---- dst-tp-id?                    binary
| +---- bidirectional?                boolean
| +---- te-topology-identifier
| | +---- provider-id?    te-global-id

```

```

| | +---- client-id?      te-global-id
| | +---- topology-id?   te-topology-id
| +---- preference?      uint8
| +---- association-objects
| | .....
| +---- protection-type?          identityref
| +---- restoration-type?        identityref
| +---- te-bandwidth
| | .....
| +---- link-protection?          identityref
| +---- setup-priority?           uint8
| +---- hold-priority?            uint8
| +---- signaling-type?           identityref
+---- synchronization* [synchronization-id]
      .....
.....

```

Contributors

Dieter Beller
Nokia
Email: dieter.beller@nokia.com

Gianmarco Bruno
Ericsson
Email: gianmarco.bruno@ericsson.com

Francesco Lazzeri
Ericsson
Email: francesco.lazzeri@ericsson.com

Young Lee
Huawei
Email: leeyoung@huawei.com

Carlo Perocchio
Ericsson
Email: carlo.perocchio@ericsson.com

Olivier Dugeon
Orange Labs
Email: olivier.dugeon@orange.com

Julien Meuric
Orange Labs
Email: julien.meuric@orange.com

Authors' Addresses

Italo Busi (Editor)
Huawei
Email: italo.busi@huawei.com

Sergio Belotti (Editor)
Nokia
Email: sergio.belotti@nokia.com

Victor Lopez
Telefonica
Email: victor.lopezalvarez@telefonica.com

Oscar Gonzalez de Dios
Telefonica
Email: oscar.gonzalezdedios@telefonica.com

Anurag Sharma
Google
Email: ansha@google.com

Yan Shi
China Unicom
Email: shiyan49@chinaunicom.cn

Ricard Vilalta
CTTC
Email: ricard.vilalta@cttc.es

Karthik Sethuraman
NEC
Email: karthik.sethuraman@necam.com

Michael Scharf
Nokia
Email: michael.scharf@gmail.com

Daniele Ceccarelli
Ericsson
Email: daniele.ceccarelli@ericsson.com