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Generalized Multiprotocol Label Switching (GMPLS) External Network Network Interface (E-NNI): Virtual Link Enhancements for the Overlay Model

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Status of this Memo

Abstract

This memo is a companion document to [RFC4208]. It describes how the client domain networking in the overlay model can be enhanced via presenting to the client the network domain as an overlay topology made of Virtual TE Links.

Conventions used in this document

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

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1. Introduction

[RFC4208] discusses how GMPLS can be applied to the overlay model, which it defines to be a client network that uses a server network to dynamically instantiate LSPs between the client network's nodes. In the client network such an LSP is a link between two adjacent client nodes, while in the server network the LSP may transit multiple links and nodes; the client network is unaware of the server network topology.

While the client network is unaware of the server network topology, [RFC4208] does suggest that there may be an exchange of routing information between the server network and the client network. Building on this premise, this memo describes how introducing a representation of server network domain resources into a client network domain topology enhances client networking in the overlay model

This document is designed to be a companion document to [RFC4208], but because routing is generally not considered to be part of the definition of a UNI, this document uses the term ‘External Network Network Interface (E-NNI)’. ‘E-NNI’ is generally used to indicate a control plane (routing and signaling) reference point for exchange of information between two control plane instances. In this document, the term ‘ENNI’ (as described in [OVERLAY-FWK]) is specifically used to describe the interface between two network domains that allows the exchange of routing and signaling information.

2. Hybrid Topology

Two adjacent domains in the overlay model represent, generally speaking, regions of dissimilar transport technology. When an end-to-end service crosses a boundary between the domains, it is necessary to execute distinct forms of service activation within each domain.

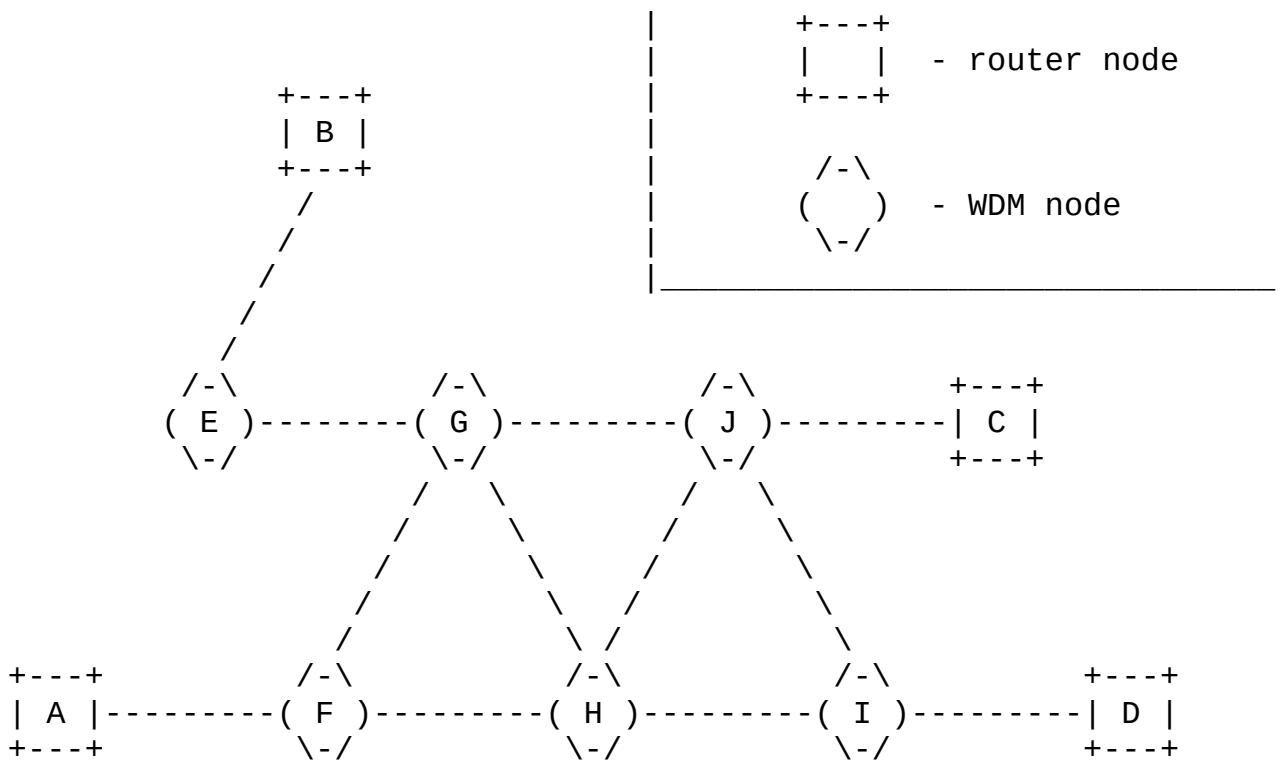


Figure 1: Sample hybrid topology

For example, in the hybrid network illustrated in Fig 1, provisioning a transport service between two GMPLS-enabled IP routers (clients) on either side of the optical WDM transport topology (server network domain) requires operations in two distinct layer networks; the client layer network interconnecting the routers themselves, and the server layer network interconnecting the optical transport elements in between the routers.

The activation of the end-to-end service begins with a path determination process, followed by the initiation of a signaling process from the ingress client network element along the determined path, per the example illustrated in Fig 2a-c.

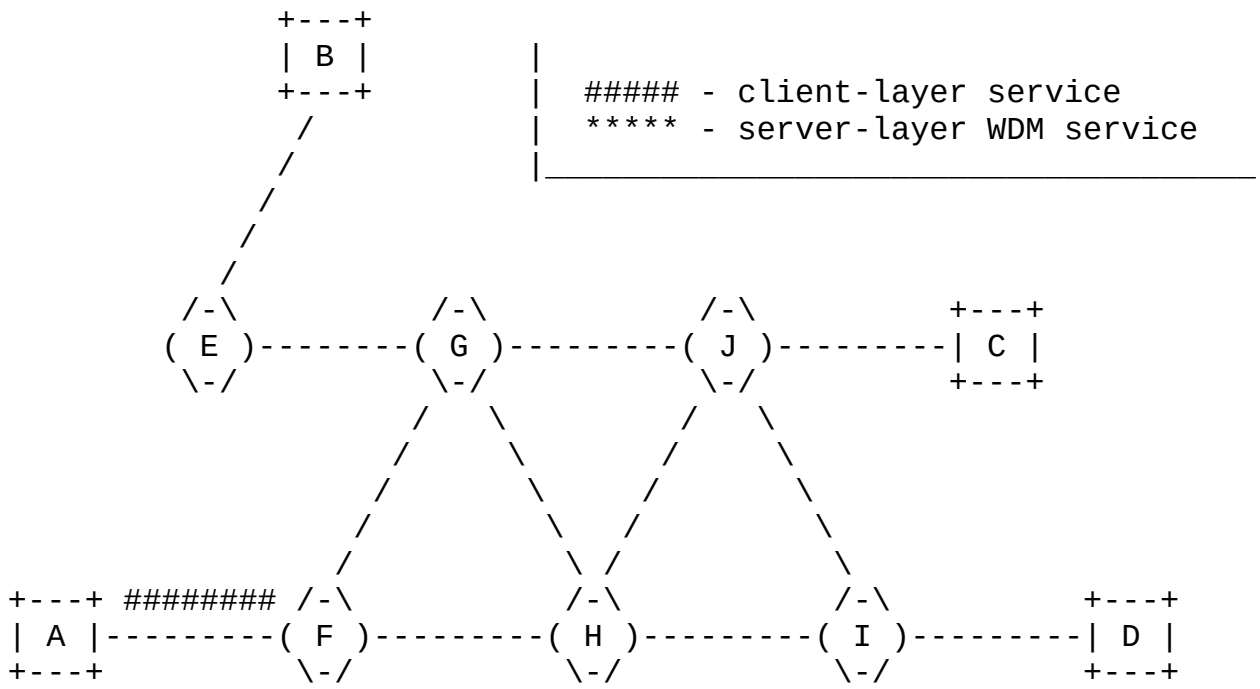


Figure 2a: Hierarchical service activation -
Client-layer service setup is initiated.

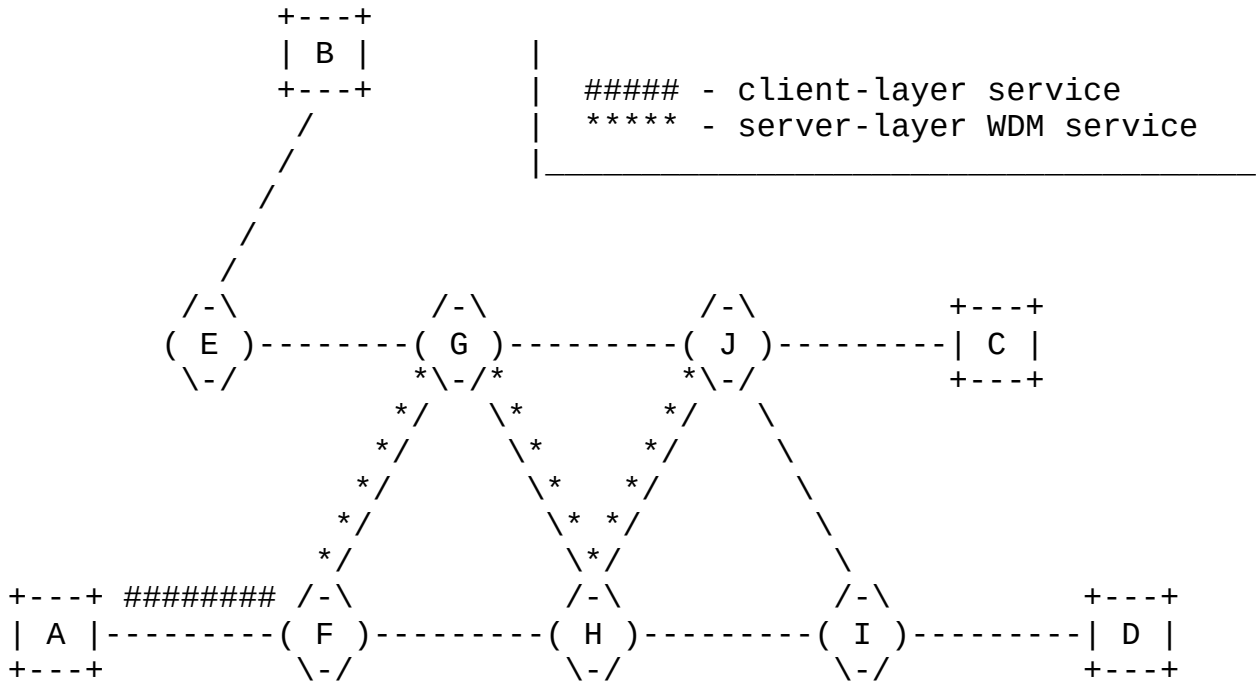


Figure 2b: Hierarchical service activation - Server-layer WDM service that caters to the client-layer service is established within the core.

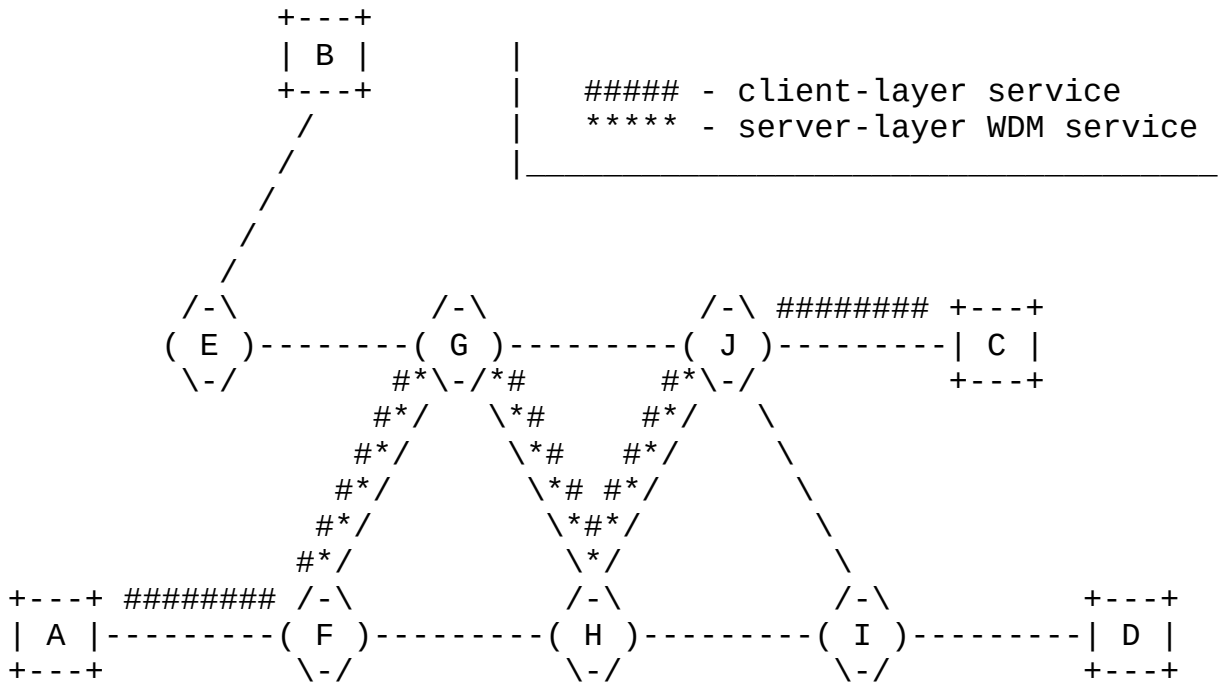


Figure 2c: Hierarchical service activation - Client-layer service setup is resumed and the end-to-end connection is established.

3. Traffic Engineering

The previous section outlines the basic method for activating end-to-end services across a multi-domain/multi-layer network. As a necessary part of that process an initial path selection process is to be performed, whereby an appropriate path between the desired endpoints is to be determined through some means. Further, per expectations set through current practices with regard to service provisioning in homogeneous networks, operators expect that the underlying control plane system provides automated mechanisms for computing the desired path(s) between network endpoints.

In particular, operators do not expect under normal circumstances to be required to explicitly specify the end-to-end path; rather, they expect to be able to specify just the endpoints of the path and rely on an automated computational process to identify and qualify all the elements and links on the path between them. Hence when operating a hybrid multi-layer network such as that described in Fig 1, it is necessary to extend existing traffic engineering and path computation mechanisms to operate in a similar manner.

Path computation and qualification operations occur at the path computation element (PCE – RFC4655) selected by ingress network element of an end-to-end service. In order to be able to compute and qualify paths, the PCE should be provided with information regarding the traffic engineering capabilities of the layer network to which it is associated with, in particular, the topology of the layer network and what layer-specific transport capabilities exist at the various nodes and links in that topology.

It is important to note that topology information is layer-specific; e.g. path computation and qualification operations occur within a given layer, and hence information about topology and resource availability are required for the specific layer to which the connection belongs. The topology and resource availability information required by a path computation element in the client layer is quite distinct from that required by a path computation element in the server layer network. Hence, the actual server layer traffic engineering links are of no importance for the client layer network. In fact, it can be desirable to block their advertisements into the client TE domain by the border nodes.

For example, in the sample hybrid network (Fig 1) there are multiple transport elements supporting client the connection (in this memo terms “connection” and “LSP” are used interchangeably) between the GMPLS-enabled clients A and C, the server layer topology between them includes several nodes and links. However, in this example the optical network elements are not capable of switching traffic with the client layer granularity (i.e. IP/MPLS packets), as the optical network elements are lambda switches, not IP/MPLS switches. Hence, while the intervening server layer network elements may physically exist along the path, they are not a part of the topology required by the client layer nodes for the purposes of traffic engineering in the client layer network.

An example of what the client layer Traffic Engineering topology would look like for the sample hybrid network is shown in the top half of Fig 3.

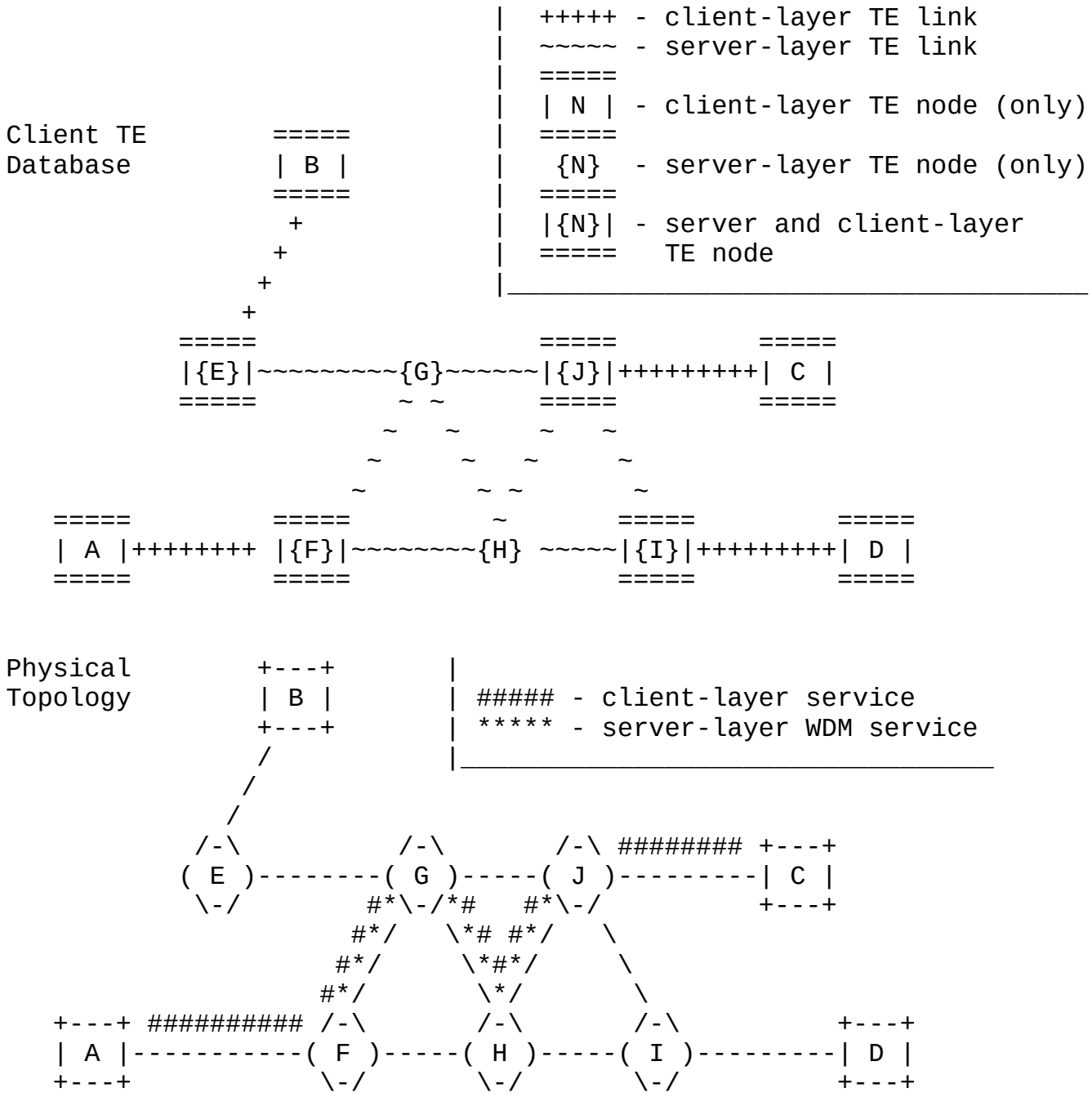


Figure 3: Traffic engineering - ERO with "loose hop"
[Path = {A,F,J,C} (with J loose)].

In this example, the TE topology associated with the client layer network is indicated by the links marked with '+' and nodes marked without brackets, whereas the TE topology associated with the server layer network is indicated by the links marked with '~' and nodes marked in '{}'. The nodes at the edge of the server layer network are visible in both the topologies. The client topology is capable of switching traffic within the client layer, whereas the server topology is capable of switching traffic within the server layer.

In this example, if the "B" router attempts to determine a path to the "D" router it will be unable to do so, as the client topology to which the B and D routers is connected does not include a full path made of just client layer links between them. The only way to setup an end-to-end path in this case is to use an ERO with a "loose hop" across the server layer domain as illustrated in Fig 3. This would cause the server layer to create the necessary link in the client layer topology on the fly. However, this approach has a few drawbacks - [a] the necessity for the operator to specify the ERO with the "loose" hop; [b] potential sub-optimal usage of server layer network resources; [c] unpredictability with regard to the fate-sharing of the new link (that is created on the fly) with other links of the client layer topology.

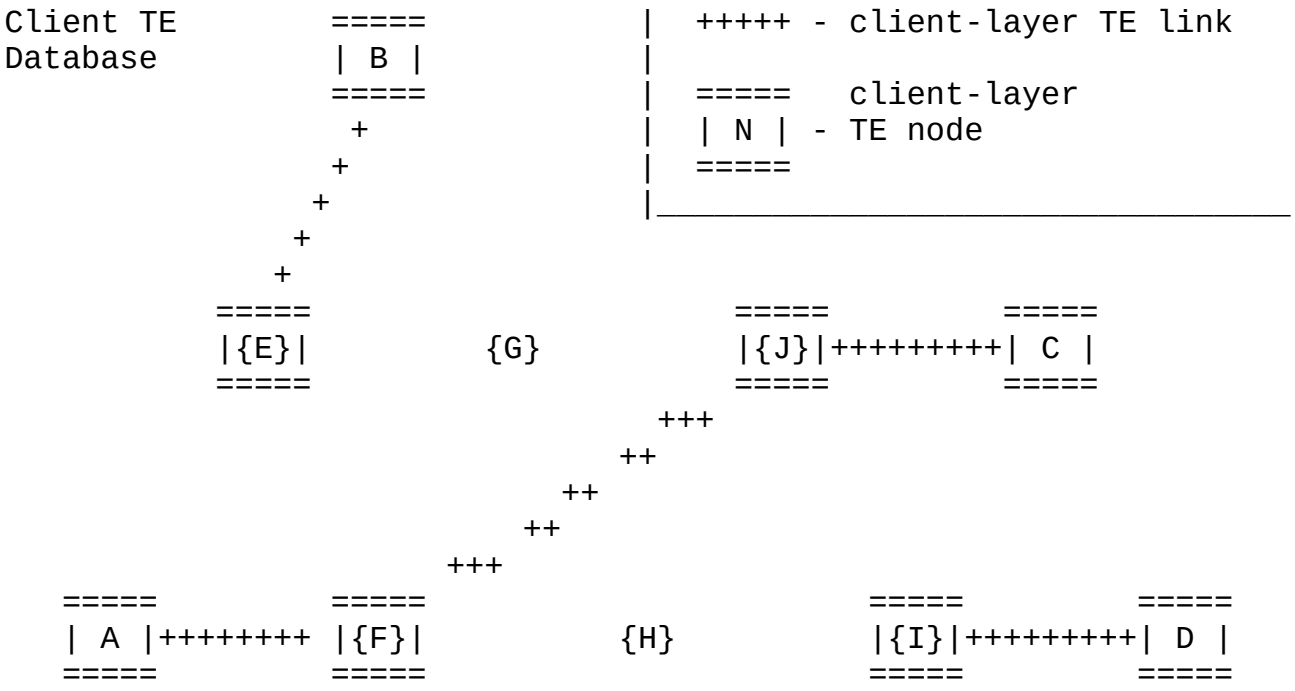
In order to be able to compute an end-to-end path between the two client layer endpoints, the client topology must be sufficiently augmented to indicate where there are paths through the server topology, which can provide connectivity between nodes in the client topology. In other words, in order for a client to compute path(s) across the server layer network to other clients, the feasible paths across the server layer network should be made available (in terms of TE links and nodes that exist in the client layer network) to all the clients. This is discussed in detail in the next section.

As it is mentioned already, in the overlay model the client and network domains, generally speaking, exist in separate layer-networks. One important use case, however, is when the client and network topologies belong to the same layer network. For example, IP routers, connected via GMPLS ENNI to a WDM network, could be capable of terminating optical trails being lambda switched by the network. The method described in the following sections allows also partitioning a single layer network into domains. Those domains do not need to leak the full routing information to their neighboring domains but rather provide sufficient information for a path

computation engine to route connections across a multi-domain network.

3.1. Augmenting the Client layer Topology

In the example hybrid network, shown below in Fig 4, consider a scenario, where each GMPLS-enabled IP router is connected to the optical WDM transport network via a transponder. Further, consider the situation, where the transponder on node F can be connected to the transponder on node J via the optical path F-G-H-J. Suppose, a lambda LSP is provisioned in the server layer along this path and advertised (as a TE link) into the client layer network. With the availability of this TE link, the path computation function at node



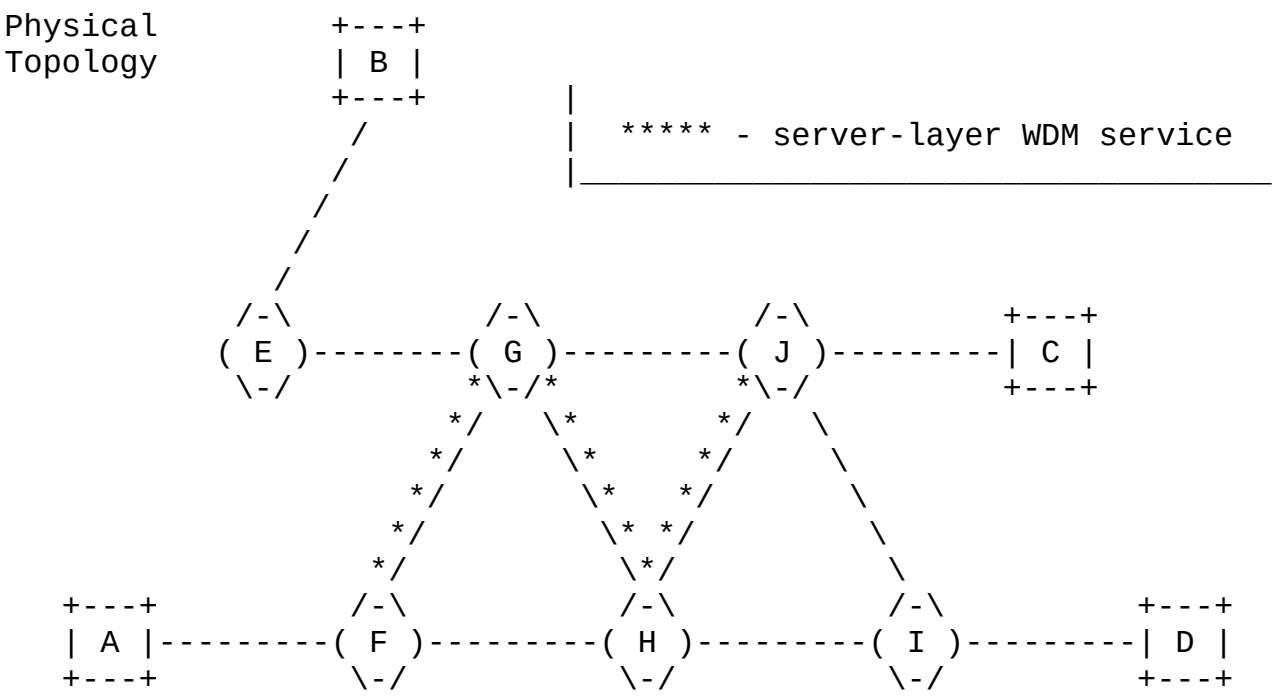


Figure 4: Traffic engineering - end-to-end path computation.[The client layer "TE link" between F and J is produced by creating the underlying server-layer connection; Node A has visibility to end-to-end (A to C) client-layer links and can do CSPF]

A is able to compute an end-to-end path from A to C. In this example, in order for the TE link to be made available in the client layer network topology, the network resources supporting the underlying server layer LSP are fully committed beforehand.

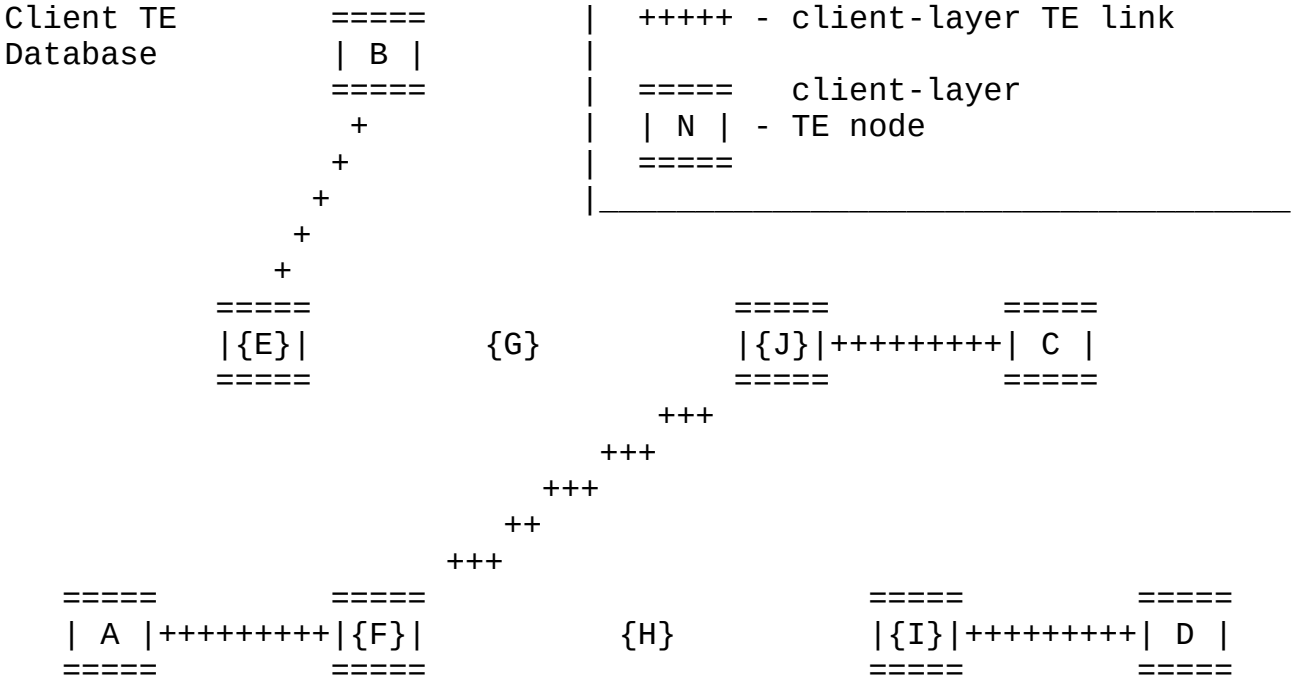
As another scenario, consider a network configuration, where the transponders on nodes E, F, J and I are connected to each other via directionless ROADM technology. In this case it is physically possible to connect any transponder to any other transponder in the server layer network. As there are transport capabilities available in the server layer network between every pair of elements with an adaptation function to the client layer network, the operator in

this case would not wish to commit any network resources in the server layer network until a client LSP is signaled. The next section proposes a method to address this common operational requirement.

3.1.1. Virtual TE Links

A “Virtual TE Link” as defined in section 7.3.3 of [RFC4847] is a TE link that is advertised into the client layer network. The advertisement includes information about available but not necessarily reserved/committed resources in the server layer network necessary to support that TE link. In other words, Virtual TE Links represent specific transport capabilities available in the server layer network, which can support the establishment of LSPs in the client layer network.

The two fundamental properties of a Virtual TE Link are: [a] it is advertised just like a real TE link and thus contributes to the buildup of the client layer network topology; and [b] it does not require allocation of resources at the server layer until used, thus allowing the mutually exclusive sharing of server layer network resources with other Virtual TE Links.



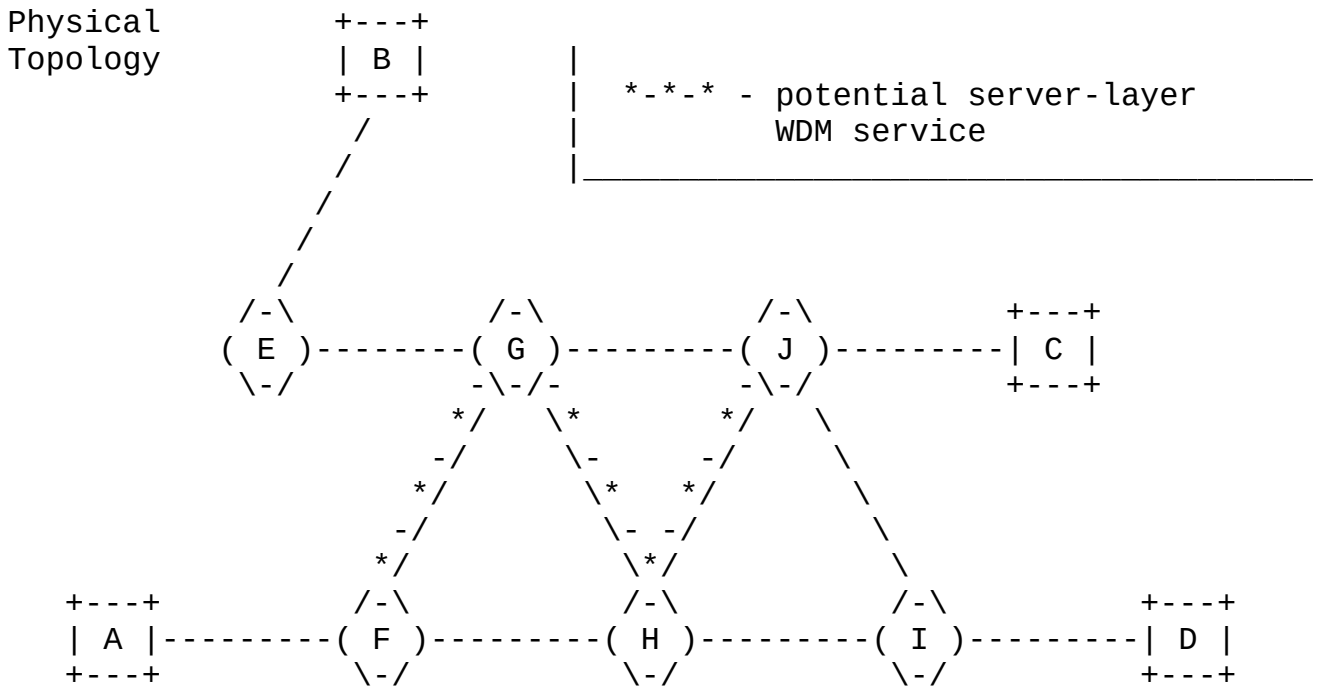


Figure 5: Traffic engineering - end-to-end path computation with "Virtual TE Links". [The "Virtual TE link" between F and J is created in the client layer without actually instantiating the underlying server-layer connection; Node A has visibility to end-to-end client-layer links and can do CSPF]

In the example shown in Fig 5, the availability of a lambda channel along the path F-G-H-J results in the advertisement by nodes F and J of a Virtual TE Link between F and J into the client layer network topology (+++ line). With the advertisement of this Virtual TE Link, the path computation function at node A is able to compute an end-to-end path from A to C.

Whenever a Virtual TE Link gets selected and signaled in the ERO of a client layer LSP, it ceases temporarily to be “virtual” and transforms into a regular TE link. When this transformation takes place, the clients will notice the change in the advertised available bandwidth of this TE link. Also, all other Virtual TE Links that share in a mutual exclusive way some of server layer resources with the TE link in question SHOULD start advertising “zero” available bandwidth. Likewise, the TE network image reverts back to the original form as soon as the last client layer LSP, going through the TE link in question, is released, i.e. Virtual TE Link becomes “virtual” again.

The overlay topology, advertised into the client domain as a set of Virtual TE Links, along with access TE links (the TE links interconnecting client network elements with the network domain) makes up the topology that in the overlay model allows for the client domain path computation function to compute end-to-end paths interconnecting client network elements across the network domain.

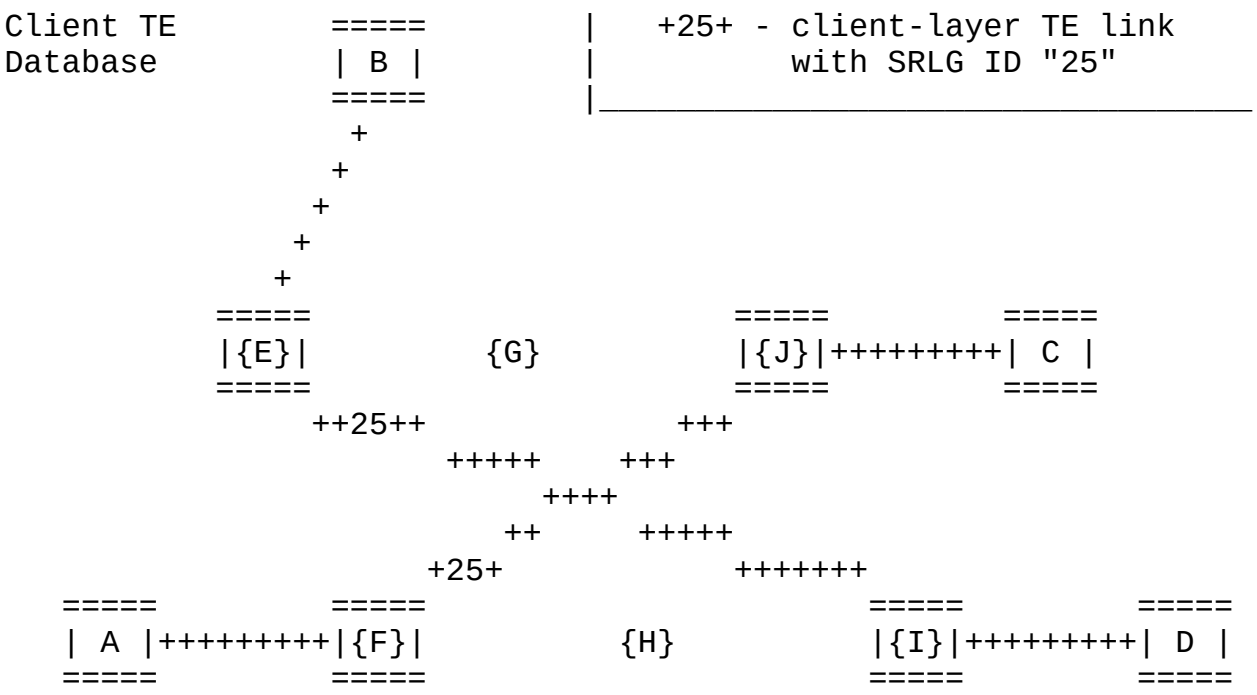
3.2. Macro SRLGs

The Virtual TE Links, which are advertised into the client layer network topology, cannot be assumed to be independent. It is quite possible for a given Virtual TE Link to share fate with one or more other Virtual TE Link(s). This is because the underlying server layer LSPs (established or potential) can traverse the same server layer network link and/or node, and failure of any such shared link/node would make all such LSPs inoperable (along with the Virtual TE Links supported by the LSPs). If diverse end-to-end paths for client layer LSPs are to be computed, the fate sharing information of the Virtual TE Links needs to be taken into account. The standard way of addressing this problem is via the concept of Shared Risk Link Group (SRLG). Specifically, a network resource shared by two or more TE links is identified via a network scope unique number (SRLG ID) and advertised within each such TE link advertisement.

A “traditional” SRLG (per [RFC4202]) represents a shared physical network resource, upon which normal function of a link depends. Such SRLGs can also be referred to as physical SRLGs. Zero, one or more physical SRLGs could be identified and advertised for every TE link in a given layer network. There is a scalability issue with physical SRLGs in multi-layer environments. For example, if a server layer LSP serves a client layer link, every server layer link and node traversed by the LSP must be considered as a separate SRLG. The number of server layer SRLGs to be advertised to client layer per

TE link is directly proportional to the number of hops traversed by the underlying server layer LSP.

This document introduces a notion of Macro SRLGs, which addresses this scaling problem. Macro SRLGs have the same protocol format as their physical counterparts and can be assigned automatically for each TE link that is advertised into the client layer network supported by an underlying server layer LSP (instantiated or otherwise). A Macro SRLG represents a shared path segment that is traversed by two or more of the underlying server layer LSPs. Each shared path segment can be viewed as a set of shared server layer resources. The actual procedure for deriving the Macro SRLGs is beyond the scope of this document.



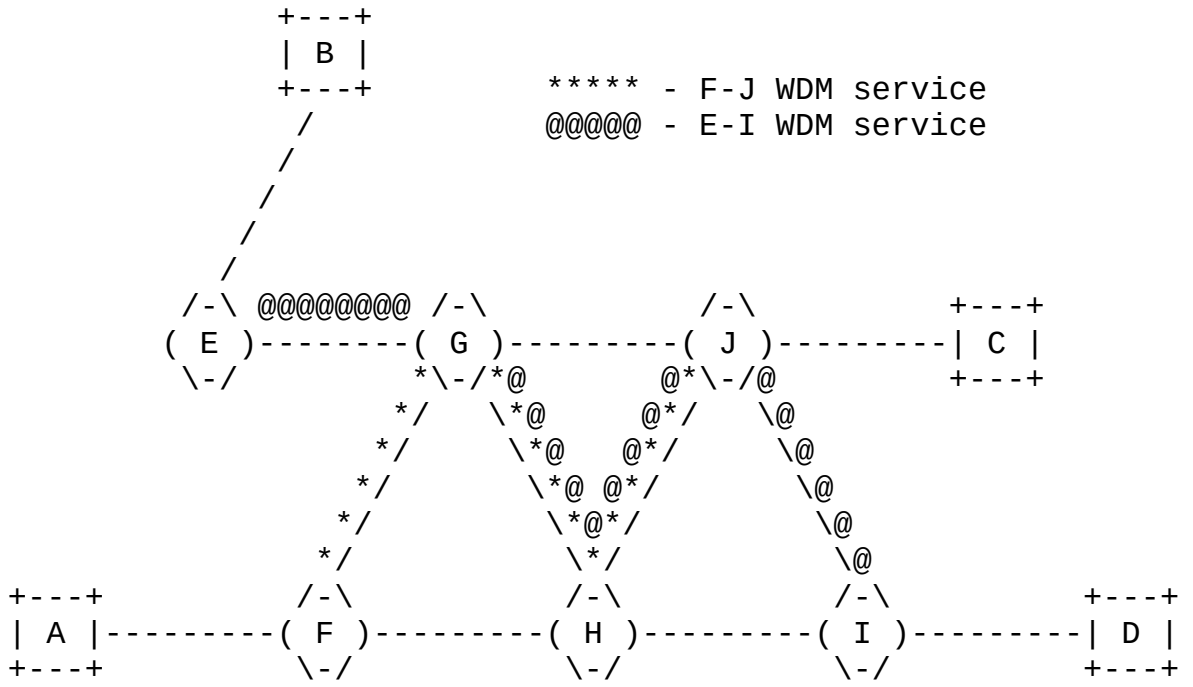


Figure 6: Macro SRLGs – ["TE links" E-I and F-J share fate since the underlying server-layer connections traverse the same path segments [G-H][H-I]. Macro SRLG-ID "25" is assigned to both "TE links"]

3.3. MELGs

If two or more Virtual TE Links share fate, it means that the links could be concurrently activated and used by client LSPs with a caveat that the links could be taken out of service by a single network failure, and, thus, cannot be used in the same protection scheme. There could be a stronger (than fate sharing) relationship between two or more Virtual TE Links. Because a set of Virtual TE Links can depend on the same uncommitted network resources, the situation can arise, when only one Virtual TE Link from the set could be activated at any given time. In other words, two or more Virtual TE Links can be mutually exclusive.

One example of the mutually exclusive relationship of Virtual TE Links is when the paths for the server layer network LSPs supporting the Virtual TE Links not only intersect, but also require usage of the same resource (e.g. lambda channel) on the intersection (see Figure 7). Another example is when the said paths depend on a common

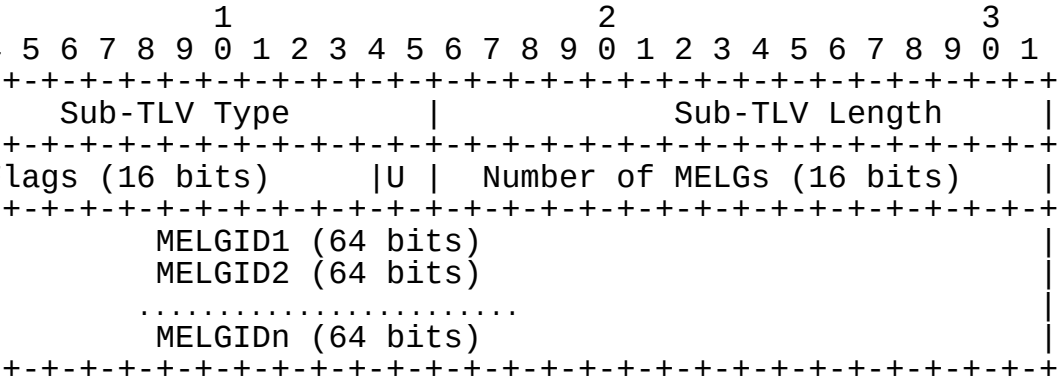
physical resource (e.g. transponder, regenerator, wavelength converter, etc.) that could be used only by one LSP at a time.

For a client path computation function (especially a centralized one capable of concurrent computation of multiple paths) it is important to know about such mutually exclusive relationship between Virtual TE Links. This document introduces a concept of Mutually Exclusive Link Group (MELG) and suggests a new sub-TLV – MELGs sub-TLV – to be added to the top level TE Link TLV. The purpose of the MELGs sub-TLV is:

- To indicate via a separate network unique number (MELG ID) an element or a situation that makes the advertised Virtual TE Link to belong to one or more Mutually Exclusive Link Groups. Path computing element will be able to decide on whether two or more Virtual TE Links are mutually exclusive or not by finding an overlap of advertised MELGs (similar to deciding on whether two or more TE links share fate or not by finding common SRLGs)
- To indicate whether the advertised Virtual TE Link is committed or not at the moment of the advertising. Such information is important for a path computation element: committing new Virtual TE links (vs. re-using already committed ones) has a consequence of allocating more server layer resources and disabling other Virtual TE Links that have common MELGs with newly committed Virtual TE Links.

The format of the MELGs sub-TLV is defined as follows:

Name: MELGs
Type: TBD
Length: Variable

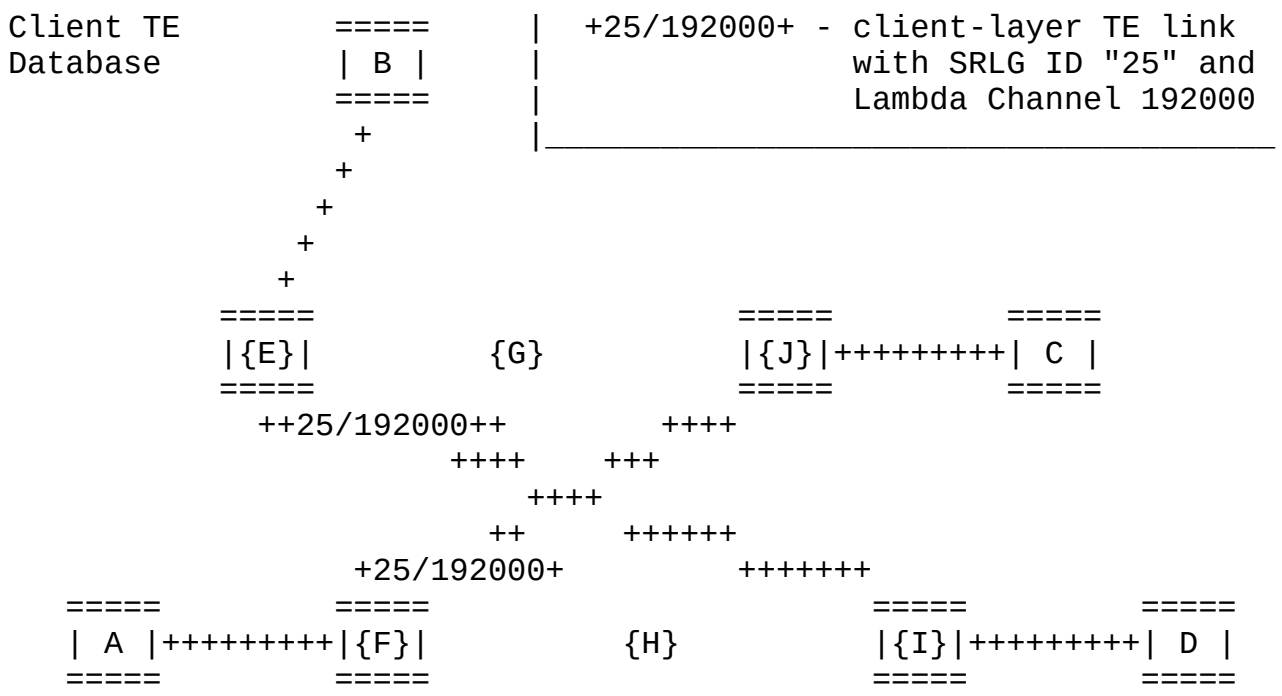


Number of MELGs: number of MELGS advertised for the

	Virtual TE Link;
Flags:	Virtual TE Link specific flags;
MELGID1,MELGID2,...,MELGIDn:	64-bit network domain unique numbers associated with each of the advertised MELGs

Currently defined Virtual TE Link specific flags are:
U bit (bit 1) : Uncommitted ,if set, the Virtual TE Link is uncommitted at the time of the advertising (i.e. the server layer network LSP is not set up); if cleared, the Virtual TE Link is committed (i.e. the server layer LSP is fully provisioned and functioning). All other bits of the “Flags” field are reserved for future use and MUST be cleared.

Note: A Virtual TE Link advertisement MAY include MELGs sub-TLV with zero MELGs for the purpose of communicating to the TE domain whether the Virtual TE Link is currently committed or not.



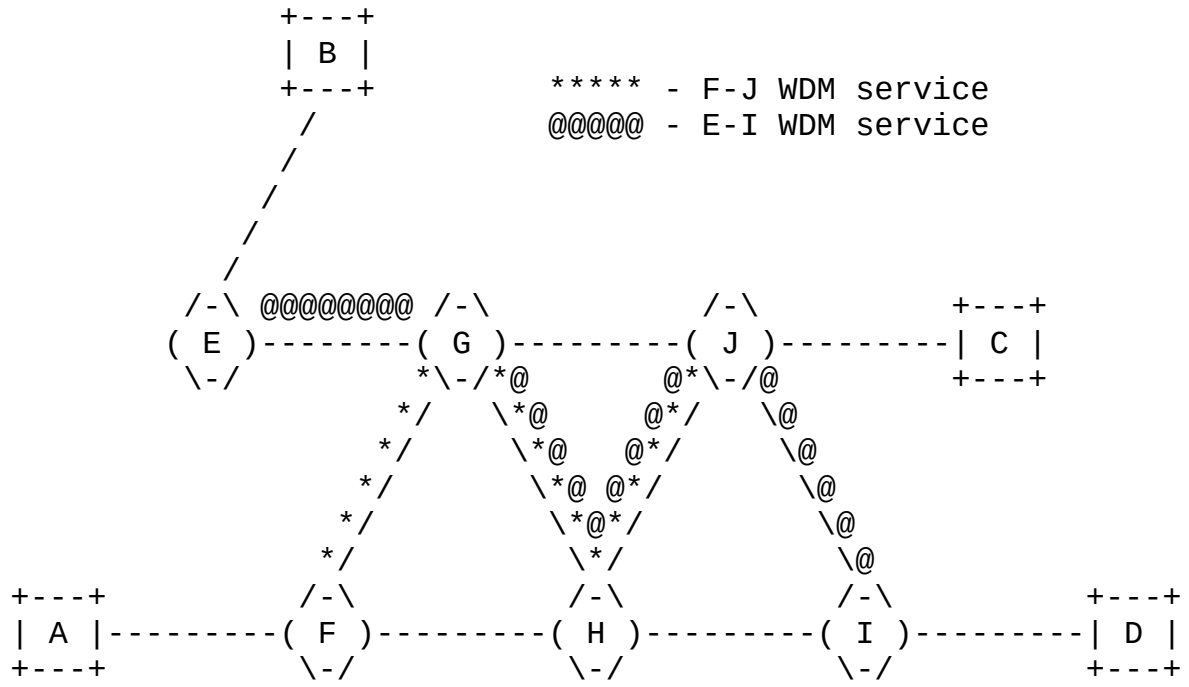


Figure 7: MELGs – ["TE links" E-I and F-J are mutually exclusive (server paths require usage of the same resource: lambda channel 192000). Same MELG ID is assigned to both TE links]

3.4. Switching Constraints

Generally speaking, it SHOULD NOT be assumed that a Virtual TE Link advertised by a given network domain border node can be cross-connected within a client LSP with every access TE link advertised by the said node. This circumstance necessitates the specification of connectivity constraints by network domain border nodes. If such information is not available for client domain path computers, there is a significant risk of provisioning failures of client LSPs, if/when they are signaled with the computed paths (see, Fig 7). This document recommends the use of the advertisements specified in [GEN_CNSTR] and [OSPF_GEN_CONSTR] to address the network element switching limitations problem.

Access TE-links:	TE links served By the server domain:	Valid paths:
a1-b1, c3-d1	b3-c1	[a1-b1][b3-c1][c3-d1]
a2-b2, c4-d2	b4-c2	[a2-b2][b4-c2][c4-d2]

Binding constraints:	Invalid paths:
b1<->b3	[a1-b1][b4-c2]...
b2<->b4	[a2-b2][b3-c1]...
c1<->c3	[a1-b1][b3-c1][c4-d2]
c2<->c4	[a2-b2][b4-c2][c3-d1]

Figure 7: Switching Constraints

4. Connection Setup

Experience with control plane operations in multi-layer networks indicates some benefits in coordinating certain signaling operations of client layer network LSPs and underlying server layer network LSPs in the following manner. Consider the scenario, where the network is a WDM layer topology comprising of ROADMs. The set-up time for a service at the WDM layer can be fairly long, as it can involve time-consuming power-equalization procedures, amongst other layer specific operations. This means that at very least, the setup timers for the client LSPs would need to be somehow coordinated with that of the server LSPs. To avoid this operationally awkward issue, a phased LSP setup process as depicted in Fig 8 is proposed.

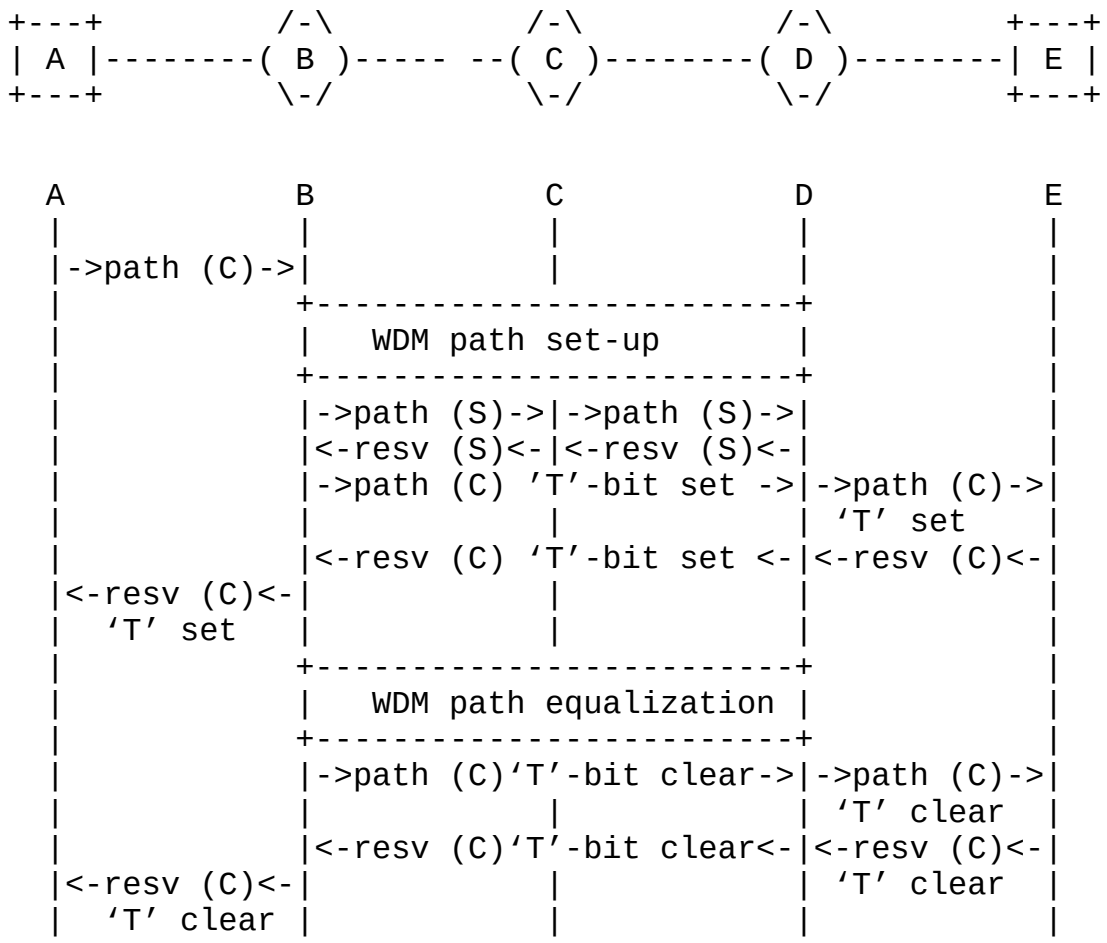


Figure 8: connection set-up

As long as the server LSP is not completely established (i.e. successfully power equalized), the server layer network border nodes, through which the client LSP passes, would signal PATH/RESV messages with the T (Testing) bit set in the ADMIN_STATUS. The T bit would be cleared in these messages only after all server LSPs supporting links taken by the client LSP in question are deemed fully operable.

5. GMPLS ENNI and Multiple Server Network Domains

In the previous sections a single server network domain GMPLS ENNI configuration was considered. The said configuration is modeled as a set of client nodes, belonging to one or more client domains, connected to a single server network domain. The connectivity is realized via access links in the data plane and GMPLS ENNI interfaces in the control plane. The server domain is independent from the client domain(s) (administratively and from the Traffic Engineering and control/management plane point of view). The network domain exposes its resources to the clients in a form of Virtual TE Links, thus, enabling the clients to influence the way their LSPs are routed across the network domain.

There are important use cases that require client LSPs to traverse more than one server network domains. In such use cases the server domains, generally speaking, are independent from each other and from each of the client domains. In such configurations the clients would still want to control the routing of their LSPs in each of the server domains, the LSPs are going through, for the same reasons it is necessary to do so in the single server domain configuration (e.g. diversity, fate sharing, MELG considerations, etc.). Fortunately, the Virtual TE Link approach allows for exposing of the resources of multiple network domains in the same way as in the single server domain case, and, thus, provides the same tools for dynamic provisioning of client LSPs across either single or multiple server network domains.

Multiple server network domains are modeled as separate independent networks interconnected with each other on their respective border nodes via inter-domain links in the data plane and GMPLS ENNI interfaces in the control plane. A network border node sees no difference between an access link and an inter-domain link terminated on the node (nor can it tell whether it is connected via a given link to a client node or a border node of a neighboring server network domain). Just like in the single-domain case, each server domain exposes its resources to other server and client network domains via Virtual TE Links configured in accordance with local domain policies. It is responsibility of server domain border nodes to advertise into the neighboring domains all access, inter-domain and Virtual TE Links it locally terminates, as well as imposed on them switching limitations. The said advertisements are flooded into the client domains and populate the client path computer’s TEDs. Successful path computations produce end-to-end paths in the form of access, Virtual and inter-domain TE link chains.

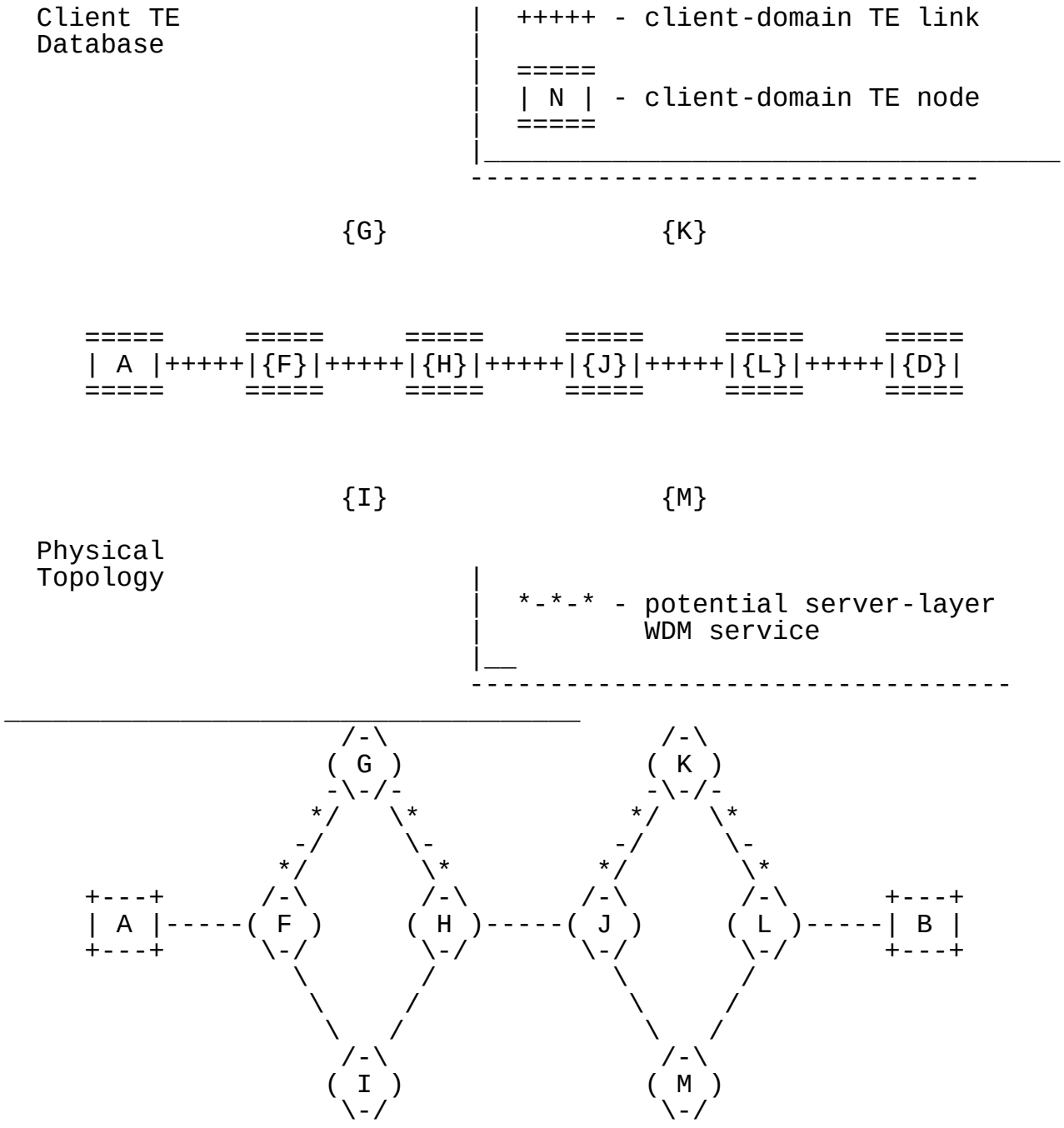


Figure 9: Multiple Network Domains ([F,G,H,I] belong to Sever Network Domain 1;[J,K,L,M] belong to Server Network domain 2)

6. Path computation aspects

It is assumed that a client domain path computation function makes use of advertised access TE links as well as Virtual TE Links, while computing end-to-end paths for client LSPs. The said path computation function could be local (i.e. located on client LSP ingress nodes, as stipulated by [RFC4655] Composite PCE node) or remote (i.e. on network PCEs). Path computations could be triggered by client nodes or NMS. Generally speaking, the responsibility of the client domain path computation function is to (concurrently) compute one or several paths for each source-destination pair (potential client LSP termination points) specified in a single path computation request. The path computation SHOULD be subject to one or more path optimization criterions (such as minimal cost, minimal latency, etc.) and a set of path computation constraints (such as link unreserved bandwidth, link colors, layer-specific constraints, explicit inclusions and exclusions, etc.)

As the overlay topology hides actual server domain/layer links and nodes, it is RECOMMENDED to support SRLG diverse computation of two or more paths.

Furthermore, the path computation SHOULD consider the connectivity/switching limitation constraint (when available) in addition to all other path computation constraints.

The use of the PCE architecture and PCEP protocol is governed by [RFC5440], [RFC5521] and [RFC5541].

As described in section 3.3., two or more Virtual TE Links may not only share risk, but also may exclusively depend on the same server layer resources. Therefore, paths, computed on network topologies containing Virtual TE Links, have an increased probability of LSP setup failures (two LSPs, for example, could be routed over two Virtual TE Links that exclusively depend on the same server layer resource). In such cases concurrent path computation, taking in consideration MELG information, will address this problem. PCEP supports concurrent path computation per [RFC5440]. Specifying MELG diversity constraint in path computation requests is out of scope of this document.

In addition MELG may carry information on the establishment of server-layer resources. A Path computation request MAY constraint the path computation to TE-Links that are fully provisioned only. This information MAY also be used in PCE path computation policies.

7. Access and Virtual TE link addressing

[RFC4208] implies that access TE links could be named from the same address space as network domain TE links or from a separate address space. This memo requires the following:

- It MAY be possible to assign addresses for access TE links from the same address space as the one used for naming network internal TE links (i.e. TE links interconnecting network domain devices);
- It MUST be possible to assign addresses for access TE links from a separate address space, independent from the space used for addressing network internal TE links;
- Virtual TE Links MUST share the address space with any access TE links they are allowed to be cross-connected within a client LSP.

8. Use cases

8.1. Service Optimization and Restoration in Multi-layer networks

Multi-layer networks are a reality today, and they are operated by different groups of people, following different operational procedures. This requires an independent optimization of the client and server layer networks. Such independence may cause a situation, where the re-routing of a client layer LSP fails, because some of resources on the selected alternate path share fate with some of resources on the LSP’s failed path. This usually happens due to lack of knowledge of the server layer network by a client layer path computation function at the time when the alternative path is selected.

The high volume and importance of IP traffic in provider networks today requires the client and server layer networks to share sufficient information in order to enable an optimized transport for IP/MPLS services and address existing inefficiencies. From the carrier perspective it is very important that the SRLG information is provided by the server layer TE application and is used by the client layer path computation.

In a typical multi-layer network, where IP/MPLS is the client layer network and WDM/OTN is the server layer network, the client layer network is responsible for the protection of the IP/MPLS traffic from networks failures. This is normally achieved via using

protection schemes, such as FRR and/or LFA. Regardless of the used mechanism, the SRLG information, provided by the server layer network, helps to optimize the client layer network with respect to reduced link utilization and reliable and efficient protection of the user traffic.

Today the SRLGs information is used mainly when calculating diverse alternative paths for the IP/MPLS LSPs. Therefore, the following procedures are performed periodically:

- Building traffic matrix for the server layer network (based on IP links)
- Solving traffic engineering problems in the server layer network
- (Re-)Calculating SRLGs to be propagated into the client layer network
- Simulating failure scenarios
- Making sure that the affected IP/MPLS LSPs function properly after they are replaced onto SRLG diverse alternative paths

GMPLS ENNI reduces the OPEX costs of performing these procedures via the automation as follows:

- server layer network automatically discovers and advertises the SRLG information into client layer network via a common routing protocol;

- client layer network path computer uses the SRLG information when selecting diverse paths.

8.2. IP/MPLS Offloading with ENNI automation

A typical application in multi-layer (IP/MPLS over optical) networks is termed ‘IP Offloading’, in which the network responds to the increase in traffic of a particular service or across a segment in the IP network by dynamically creating additional IP/MPLS links served by GMPLS LSPs provisioned in the server layer network, and placing the extra IP/MPLS traffic onto said links. Likewise, when the IP/MPLS traffic decreases to a normal pattern, the said GMPLS LSPs are torn down, and the extra IP/MPLS links are removed from the client layer network TE domain. The increase in traffic is typically caused by an elevated number of high traffic flows/services traversing an IP network segment.

The decision process driving IP offloading is complex, and is governed by a set of rules. These rules reduce the cost of running the multi-layer network, while ensuring that it remains stable.

Automation of IP Offloading poses a number of challenges. It includes dynamic provisioning, release and maintenance of GMPLS LSPs in the server layer (e.g. WDM) network as well as automatic advertising/withdrawing them as (numbered or/and unnumbered) TE links into/from the client layer network. In order to pre-plan and manage properly the said dynamic IP/MPLS TE links, it is important to know in advance (and also in real time) the capabilities and resource availability of server layer network. The network domain/layer virtualization procedures described in this document helps to solve this complex operational issue.

8.3. Use of PCE and VNTM in Multi-layer Network Operation

Two key elements have been proposed to help in the management and coordination of multi-layer networks: the Path Computation Element (PCE) and the Virtual Network Topology Manager (VNTM). PCE is responsible for the calculation of paths between endpoints, particularly in complex scenarios involving, for example, WDM layer physical impairments. VNTM is in charge of maintaining the topology of the client layer network by instantiating virtual links, in the server layer network. I.e., it can be used to provide TE links to the client layer network dynamically.

Several cooperation modes between PCE, VNTM and the NMS have been proposed in [RFC5623]. For instance, the operator can request a new MPLS tunnel via the NMS, which communicates with a PCE with information of the multi-layer network. The PCE, in case there are enough resources in the IP/MPLS layer, normally returns a path for the tunnel made of real TE links. On the other hand, if there is a lack of resources in the IP/MPLS layer, the response may contain a path with one or more Virtual TE Links. In this case, the NMS can cooperate with the VNTM to suggest the set-up of a GMPLS LSP(s) in the server layer network. The VNTM, based on the local policies, can accept the suggestion and cause the set-up of the GMPLS LSPs in the server layer network.

In order for the computation to be effective, the PCE needs knowledge of the overlay topology (SRLGs, MELGs, TE metrics of the Virtual TE links), which can be provided via GMPLS ENNI.

9. Security Considerations

TBD

10. IANA Considerations

TBD.

11. References

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12. Acknowledgments

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