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E2E-OAM in Convergent Sub-Wavelength-MPLS Environments

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Abstract: This paper presents an End-to-End (E2E) Operations, Administration, and Maintenance (OAM) architecture for Telco networks including a Sub-wavelength domain. It addresses two main issues: compatibility between MPLS networks and different Sub-wavelength technologies, and scalability of the OAM flows across the whole network. The case for OPST Sub-wavelength technology in the data plane has been studied extensively, however this is the first study on a methodology to scale the number of OAM flows in an E2E scenario combing both subwavelength and MPLS switching domains. Finally the inter-carrier issue in E2E OAM is also explored.

Keywords: Sub-wavelength, MPLS-TP, OAM, OPST, Metro Networks.

1. Introduction

Photonic sub-wavelength technologies are being developed by multiple vendors [1][4 as a suitable solution for Metro Area Networks (MAN) . Many Optical packet switching (OPS) and optical burst switching (OBS) technologies and architectures have been proposed to support sub-wavelength services [8][12]. However, OAM aspects for photonic sub-wavelength technologies have not been analyzed in detail yet. In this paper, a novel OAM architecture enabling subwavelength and MPLS interoperability and scalable E2E performance monitoring is proposed. This architecture is based on three key innovative aspects on OAM sub-wavelength:

- A new E2E architecture enabling MPLS and subwavelength OAM interworking. MPLS and subwavelength interoperability is a key aspect to enable a smooth migration towards subwavelength based MAN architectures. Telco networks are commonly based on multi-domain MPLS solutions. In order to incorporate a Sub-wavelength domain within its network, a Telco will need the OAM of the Sub-wavelength technology to be capable of interoperating with the OAM of the rest of the network.
- OAM architecture within a single OPST subwalength domain so that each sub-wavelength domain can be seen as a single layer 2 switch (e.g MPLS-TP) in terms of OAM by the rest of the network
- A novel performance monitoring mechanism enabling scalable OAM flows in E2E network architectures. Performance measurement is accomplished by the injection of a

series of packet flows into the network. Therefore, E2E performance monitoring between any pair of border node (e.g OLT, DSLAM, BRAS, Cloud Datacenter...) connected to the multi-domain network might present scalability problems if the amount of extra traffic injected by OAM mechanisms into the network is too high.

2. The E2E OAM layered architecture

Operations, Administration, and Maintenance (OAM) is a general term that refers to a toolset that can be used for fault detection and localization, and for performance measurement. These tools are conceived for monitoring nodes, paths, physical and or logical links.

For E2E OAM of a network with fault detection and performance monitoring including a Sub-wavelength domain, interworking between the particular sub-wavelength technology and already existing MPLS networks is a key concern to be addressed.

With regards to a state of the art OAM, industry interest in MPLS-TP OAM places it as the enabler technology for an E2E OAM solution in multi-domain MPLS based networks. In this context, a layered OAM architecture is defined as integrating the Sub-wavelength technologies' OAMs with the standard MPLS-TP OAM as a necessary step to enable the desired E2E OAM in our reference scenario (network including Sub-wavelength domain).

The proposed E2E OAM architecture for the reference scenario is shown in Figure 1:

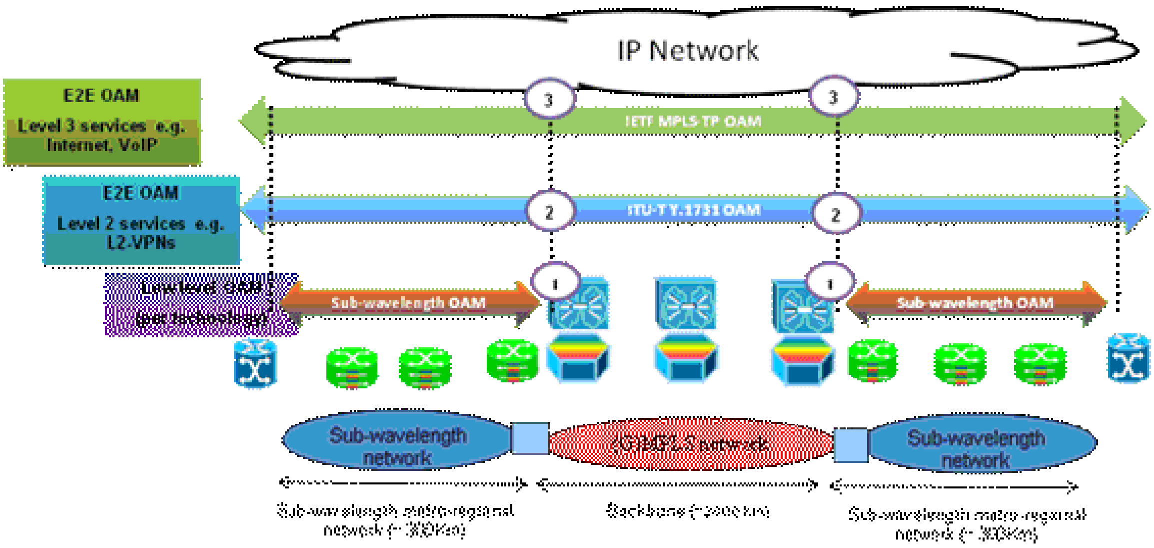

Figure 1: The E2E layered architecture

The main challenge addressed by this architecture is the interoperability between the two ITU-T and IETF MPLS-TP OAM paradigms and the proprietary OAM processes of the sub-wavelength technologies, to ensure the continuity of end to end OAM mechanisms. Bottom-up, it is possible to enable a seamless E2E OAM for services between any two nodes of the network having taken into account the following considerations:

1. Each sub-wavelength technology will implement its own OAM mechanisms (referred to here as a "Low-level OAM"). In this case, OAM functions are restricted to a single technology domain. When multi-technology domains are part of an E2E OAM service, one of the two referred OAM standards need to be used. In this case coordination between the Low level OAM and the standard OAM is compulsory to avoid duplicity of response to the same alarms. This coordination may include OAM messages encapsulation and interfaces definition.

2. ITU-T Y.1731 OAM [3] will enable end to end OAM between any two nodes of the network for L2 services e.g. L2VPNs.
3. IETF MPLS-TP OAM [4] will enable end to end OAM between any two nodes of the network for L3 services, e.g. Internet, VoIP.

The rationale behind this proposed distribution is the feasibility of an E2E OAM in scenarios where the size and complexity of the network can impact the scalability of another solution.

Assuming a configuration similar to Figure 2, the OAM traffic can significantly increase as the E2E service includes different technology domains. Applying a layered OAM architecture, intra OAM traffic remains within its domain, while the measure points for the E2E OAM are reduced to the domain borders. From an E2E perspective, the whole domain can be seen as a single node, drastically reducing the OAM load.

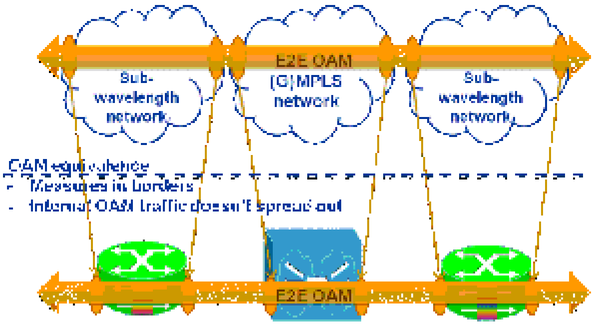

Figure 2: E2E OAM in the reference scenario

As mentioned before, the support of this layered architecture is based on the coordination between the native OAM of the sub-wavelength technology and the standard OAMs.With regards to the reference scenario presented in Figure 1, the workflow for a Loss of Connectivity (LoC) failure is the following:

1. When a connectivity failure is detected by the intra domain OAM, internal recovery mechanisms are launched. In this case, the E2E OAM is not notified of the failure.
2. Whenever internal recovery mechanisms are unable to recover from connectivity failure E2E OAM will identify the fault. It will localize the effected domain and launch appropriate recovery mechanisms.

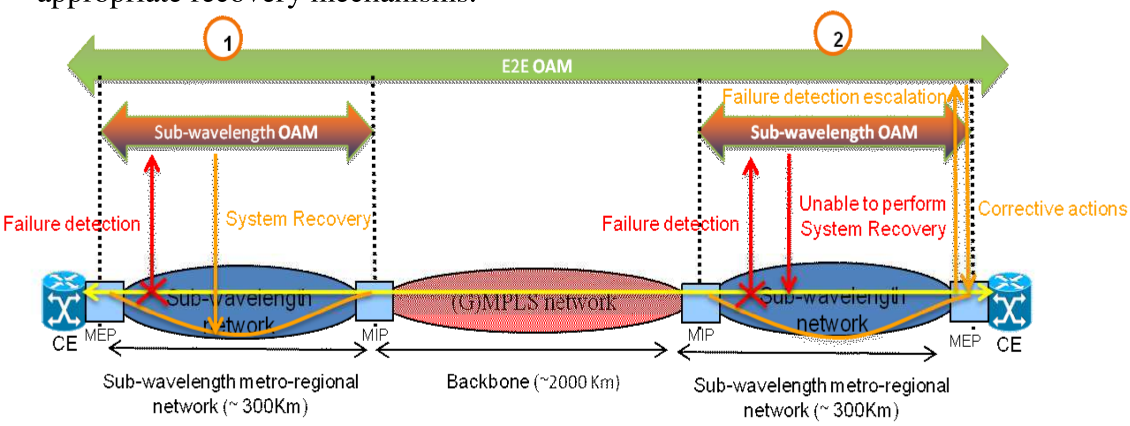

Figure 3: Intra-domain solved connectivity failure (left) and connectivity failure detection escalation (right)

The workflow for QoS degradation will be similar to the previous cases where internal OAM mechanisms support QoS degradation detection. In cases where internal OAM mechanisms do not support a QoS degradation detection mechanism or it fails, the workflow will start from a QoS degradation detected by E2E OAM:

1. When a QoS degradation is detected by the MPLS-TP OAM, localization mechanism is launched identifying the defective domain (Coarse-grain location).
2. The internal domain OAM mechanisms are contacted to solve the issue identifying the source of the degradation (Fine-grain location) when possible and acting accordingly.

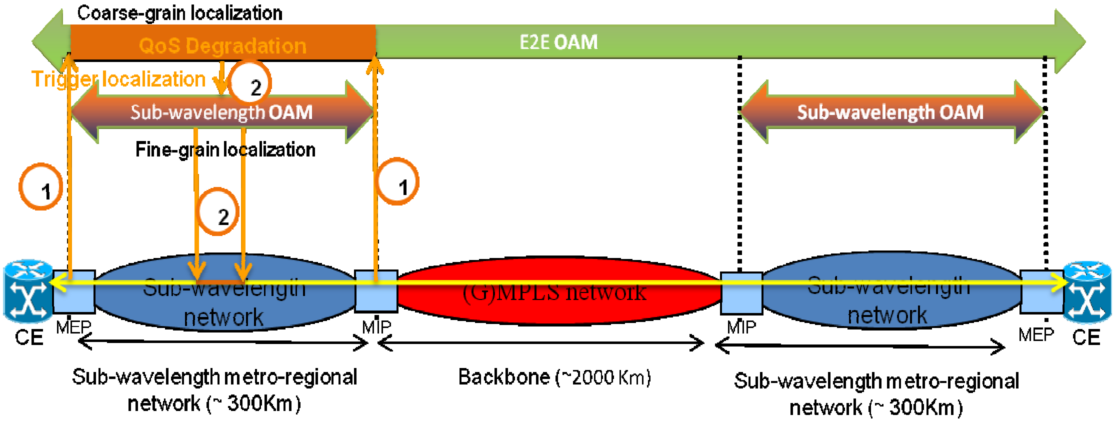

Figure 4: Coarse-grain (2) and Fine-grain (2) QoS degradation localization

3. OPST- enabling E2E OAM with sub wavelength technology

OPST provides an automated N2 mesh of sub wavelength paths between all end points. The OPST layer has been 'pre-engineered' to operate within specific boundaries optimised for metro/backhaul networks reducing the requirement for complex manual intervention to bring up, maintain and operate the system as a multi node ring network. According to it, and OPST network is operated as a single L2 switch (E.G Ethernet or MPLS).

The system supports a distributed L2 switching capability and can operate as either an LER (Label Edge Router) or LSR (Label Switched Router). In its CE (Carrier Ethernet) mode the system switches EVCs (Ethernet Virtual Connection) based on the VLAN identifiers (S-Tag/C-Tag) and class of service defined by the Priority Code Point (PCP). Operating as an LSR OPST nodes can be configured to support MPLS-TP switching based on LSPs operating over Pseudo wires.

The OAM capability follows the three horizontal layers that are implemented within the system, these being the following,

- Optical Line Control layer
- OPST laver
- Client layer

Each node deployed within the ring incorporates a component of each of these layers to form a fully distributed system where peering points are established at each of the layers between each of the distributed subsystems.

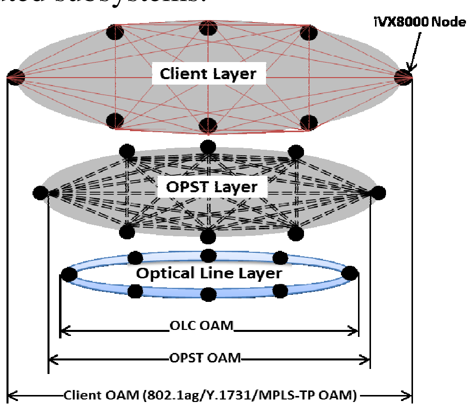

Figure 5: iVX8000 Multi-layer OAM

The Optical Line layer and OPST layer OAM operate as a closed system with OAM flows accessed by the client layer via a North Bound Interface (NBI).

The client layer OAM provide OAM functionality from edge port to edge port at a service flow granularity. The edge ports incorporate a NPC (Network Personality Card). The NPC provides the client interface characteristics required, e.g. Carrier Ethernet UNI, or MPLS-TP. Incorporated as part of the network personality interface is the data plane OAM target such as 802.1ag CFM, Y.1731 and MPLS-TP OAM.According to this architecture, a whole OPST domain can be seen as a single L2 switch (e.g MPLS-TP) node in terms of multidomain OAM interworking. At the client layer service OAM flows are exchanged / processed with upstream and downstream systems to provide an E2E service OAM capability. All client layer OAM events and management functions are also exposed via the NBI to carrier network management and OS (Operational Support) systems.

Client interface OAM is primarily homed in the NPC (Network Personality Card). The client layer OAM is determined primarily by the service standards and the network deployment on a per network basis. For the MPLS-TP OAM stack is included as part of the MPLS-TP client facing load.

The OPST on board OAM features are exposed and remotely accessible via the NBI (North Bound Interface) which is defined as an Application Programming Interface. The OPST NBI implements REST*ful* web services as its method of machine to machine interworking.

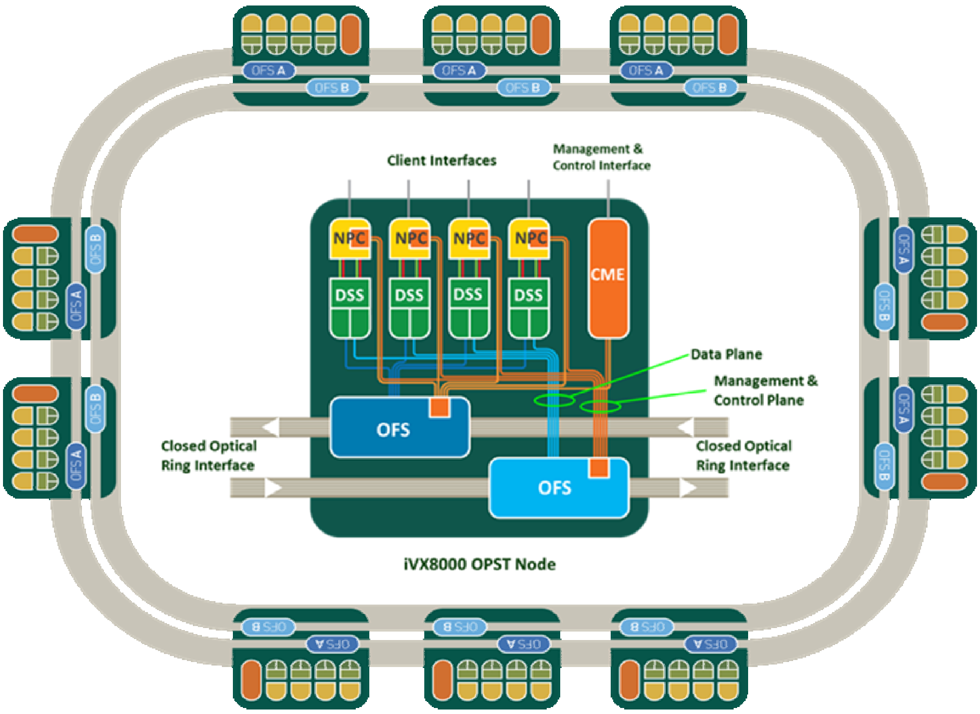

Figure 6: OPST nodes and ring network

The OPST system consists of a ring of subwavelength nodes creating a closed optical fabric formed by the fibre interconnect between the system's physical components. No external client interfaces are provided to this fibre layer.

The CME card provides an aggregation and access point for external control and management of the system via the XML based NBI. OPST nodes have interfaces on the control and management plane, on the data plane, where the client traffic ports are provided, on the OAM layer and on the synchronisation layer.

4. E2E OAM scalability analysis

OAM comprises a set of functions for i) Continuity check and Connectivity Verification and ii) performance and quality of service measurement. This section focuses on the scalability of both functions over the end-to-end OAM architecture proposed in this paper.

4.1 Continuity check and Connectivity Verification (CC-V)

When monitoring critical traffic requiring sub-50 ms restoration time, the CC-V rate in pps rises to 300pps. For small bandwidth LSPs the OAM rate in pps is substantial as the mentioned CC-V may reach up to a 15% of the channel. We note that current optical networks are limited by processing capacity in the electronic layer and not raw bandwidth. Thus, it is the rate in pps what matters and the sub-50 ms restoration time requirement poses significant scalability problems for LSPs in the range 1-10 Mbps.
However, these scalability problems could be solved by applying Label stacking in our E2E OAM architecture.

Assuming that label stacking is performed in the hierarchical level right after the LSP endpoint the OAM impact may be relevant only if tunnelling from the outermost network edge is performed -below 2,5%-. CCV traffic impact largely depends on the tunnel capacity. We consider 1 Gbps and 10 Gbps as suitable rates for LSPs and obtain the values in the following table. As it turns out, the OAM impact is very small. Furthermore, we have considered a packet size of 1500 bytes for the calculation, which is a worst case.

Table 4.1: OAM Impact for 1 and 10 Gbps tunnels (worst case)

Min mux level [Gbps]	Worst case [Mpps]	% OAM
1	0,083333333	0,0036
10	0,833333333	0,00036

Considering that, according to the proposed E2E OAM architecture, the whole Sub-wavelength domain will be equivalent to a single optical device we can conclude that the proposed OAM architecture provides a scalable solution with no extensions required to current OAM standards.

4.2 Performance and delay measurement

Performance measurement is accomplished by the injection of a series of packet flows that are utilized by different "in-service" or "on-demand" mechanisms namely: Packet Loss Measurement (LM), Packet Delay Measurement (DM), Client Failure Identification (CFI), Throughput Estimation and Route Tracing. Opposite to the CC-V, any standard mentions how many packets should be sent, nor the packet inter-arrival time for these flows. In the following, we provide an estimation of the number of packets to be sent in order to have a reasonable commitment between accuracy and scalability.

4.3 Delay Measurement (DM)

The absolute delay can be estimated with a single value in absence of packet loss. However, one normally accounts for the delay distribution. Typically, the delay distribution is Gaussian and the maximum likelihood estimators for mean and variance are

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$$

$$s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \mu)^2$$

where the $X_i s$ are the delay samples, out of N DM packets. As it turns out, the confidence interval for the mean, at a significance level α is equal to

$$\left(\overline{X} - Z_{\alpha/2}\frac{s}{\sqrt{N}}, \overline{X} + Z_{\alpha/2}\frac{s}{\sqrt{N}}\right)$$

if N is larger than 30, where $Z_{\alpha/2}$ is the corresponding percentile of the standard Gaussian distribution, which is equal to 1,96 for a 5% typical value of the significance level. The previous equation allows to obtain the number of packets N for a given confidence interval, the more the variance (jitter) the more the number of packets. Let us assume a typical case whereby the coefficient of variation (variance divided by squared mean) is equal to 0,3. Then

$$s = \sqrt{0,3}\,\overline{X}$$

and the relative error, expressed as a ratio between the length of the confidence interval and the estimated delay value is equal to

$$\frac{2Z_{\alpha/2}\sqrt{0,3}}{\sqrt{N}}$$

The above equation provides the value of the number of packets in terms of the relative error in the estimation of the average delay. The following table shows the number of packets versus the estimation error

Table 4.2: Number of packets versus relative error

Relative error	Number of packets
0,05	1881,6
0,1	470,4
0,2	117,6

As for the arrival pattern of the DM packets we note that a delay measurement which is performed by a packet train will be subject to correlation between the successive delay estimates. Alternatively, a Poisson sampling of the channel provides a better estimate due to the “Poisson Arrivals See Time Averages” property. The DM mean packet inter-arrival time must be larger than the average busy period of the largest PHB queuing backlog. For typical values, this is smaller than 10 ms.
Overall, we note that a number of 120 packets seems reasonable and the Poisson sampling suggested before will make the packet rate relatively small in comparison to the LSP traffic.

The proposed train of packet will on the one hand provide enough accuracy (i.e relative error below 0,2) for E2E jitter estimations and on the other hand will minimize the amount of OAM traffic injected in the network.

4.4 Loss Measurement (LM)

For the loss measurement, we basically estimate the number of packets which are lost out of a train of packets of size N. In order to estimate the value of N we choose an adequate value of the expected number of loss in the LM packet train and derive the packet train length accordingly. Assuming losses are independent with probability p, the expected number of losses out of train of length N are Np. If we set the latter to a value of 10, as a reasonable value to have a sufficient number of loss events, then the number N takes on values 100, 1000 and 10000 for loss probabilities of 10^{-1}, 10^{-2} and 10^{-3}. Accordingly, we have the following measurement routine:

- For "low frequency" background loss probability estimation one could send a single LM packet every 10 seconds, which yields 8640 packets per day. This running estimate may be reset at night time in order to have a point estimate of the loss probability per day.

- For on-demand LM due to noticeable packet drop at the user level a packet train of length 100 should suffice.

The same considerations about the randomness of the packet train arrivals apply here. In case of on-demand LM the packet trains runs back-to-back, as we wish to evaluate instantaneous loss.

4.5 Throughput measurement

The throughput measurement is performed by means of a packet train which is sent back-to-back. Then, the minimum inter-arrival time is calculated. This is known as a "packet-pair" technique. In order not to interfere with the rest of the LSP traffic, the packet train must be short. In order to accurately estimate the throughput the packet train must be long, because the larger the packet train the larger the number of inter-arrival samples.
This trade-off is usually balanced with the queue size of the most restrictive PHB. Clearly, the throughput measurement packet train must fit into the most restrictive queue along the path from source to destination. The bare minimum of a policer is around 66 packets, but this is a very conservative value. Therefore, we choose 100 packets as a good balance between measurement accuracy and isolation of the rest of the traffic in the LSP.

4.6 Route tracing

The route tracing OAM flow provides route verification functionality, like for instance the *traceroute* utility. A few packets suffice to verify the route (5 packets for example). Therefore, the offered load is negligible.

4.7 Loss Mesurement (LM)

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is accomplished by the injection of a series of packet flows that are utilized by different "in-service" or "on-demand" mechanisms namely: Continuity check and Connectivity Verification (CC-V), Remote Defect Indication (RDI), Alarm Reporting (AIS), Lock Reporting (LKR), Packet Loss Measurement (LM), Packet Delay Measurement (DM), Client Failure Identification (CFI), Throughput Estimation and Route Tracing.

Due to the scarce specification on the number of packets sent by OAM flow we propose the dimensioning of these flows based on our own experience in measuring packet loss, delay and throughput for a wide variety of systems:

- For Delay Measurement (DM), Packet Loss Measurement (PLM), Route Tracing and Throughput Estimation we assume that the on-demand mode will be normally used. Opposite to the CC-V, the IETF does not mention how many packets should be sent, nor the packet inter-arrival time for these flows. In the following, we provide an estimation of the number of packets to be sent in a single run of the estimates:
    - For DM we assume the delay distribution is Gaussian. Even though the estimation of its value is valid with the measure of 30 packets we propose a number of 120 packets to estimate the delay with a relative error below 0,2.
    - For PLM, we basically estimate the number of packets which are lost out of a train of packets of size N. For "low frequency" background loss probability estimation one could send a single LM packet every 10 seconds, which yields 8640 packets per day. This running estimate may be reset at night time in order to have a point estimate of the loss probability per day. For on-demand LM due to noticeable packet drop at the user level a packet train of length 100 should suffice.
    - The Throughput Estimation is performed by means of a packet train which is sent back-to-back. We choose a 100 packets train as a good balance between measurement accuracy and isolation of the rest of the traffic in the LSP.
- The rest of OAM flows have are comparatively negligible or are spurious alarms which do not contribute to the sustained offered load significantly.

As a result, we estimate the offered load of the overall OAM flow in a rough 120 pps sustained plus the on-demand OAM flow rate which depends on the OAM demand.

Aqui hay que poner la propuesta de tren de paquetes.

5. End-to-end Network OAM interoperability versus Service OAM

It is worth noting that, until now no clear distinction has been made between inter-carrier services OAM versus inter-carrier network transport OAM requirements. The first case could be underlying technology agnostic where as the latter will need to consider interoperability issues for end-to-end OAM delivery. MAINS [6] has provided the opportunity to investigate end-to-end OAM across heterogeneous optical technologies versus the option of using transport technology agnostic Service OAM.

Requirements for Operational, Administration and Maintenance have already been defined in detail by ITU-T, IETF and MEF, regarding the single-domain (single-technology) scenario. OAM Requirements considered so far depend mainly on the data transport network technology they aim to support. RFC 5860 for example has defined OAM requirements for OAM functionality for MPLS networks. Similarly Y.1730 defined requirements for OAM functions in Ethernet-based networks. Different OAM protocols have hence been developed and used for different data transport technologies.

A single network operator may want to monitor different technological domains, different topologies or even multiple heterogeneous domains and hence OAM at a different plane or OSI stack level. Moreover a Network Service Provider may want to achieve service OAM provisioning for reserved resources across multiple-carriers, more associated to the service. This gives rise to several considerations when dealing with interconnected heterogeneous networks and inter-NSP scenarios particularly in cases where the end-to-end OAM control information is of interest e.g. for ensuring end-to-end network support for a particular service, as the bottleneck could be technology independent. Hence inter-working between OAM for different technologies may not be sufficient to achieve inter-carrier OAM cooperation.

The End-to-End OAM approach taken by MAINS supports rise towards making a distinction between two sets of requirements: 1) network-to-network interoperability requirements between OAM mechanisms proposed for different transport technology domains versus 2) inter-carrier requirements which are technology agnostic but relate more to the services and service agreements between the different carriers (operators) involved. The End-to-End OAM layered approach adapted in MAINS supports the idea of handling these two sets of requirements separately and associated standardisation activities for this.

6. Conclusions

This document provides an analysis of the mechanisms and interactions needed to provide a Telco network including a Sub-wavelength domain with an E2E OAM granting compatibility with MPLS domains and assuring scalability in terms of OAM offered load.

A layered OAM architecture is defined integrating the Sub-wavelength OAM with the standard MPLS-TP OAM. This integration enables an E2E OAM in the presented reference scenario.

Sub-wavelength OAM will operate within its particular technology domain, performing fault management, performance monitoring and restoration always bounded to the limits of its domain. For connections concerning several domains MPLS-TP OAM is used (the ITU-T standard or the IETF standard in IP environments). Escalation from the intra-domain OAM to the E2E OAM or invocations from the E2E OAM to the intra-domain OAM are used accordingly to the issue to solve. The OPST case has been presented.

MPLS-TP OAM flows are dimensioned and its scalability is evaluated based on our own experience in measuring packet loss, delay and throughput for a wide variety of systems. The study reflects the dependency of the impact of the OAM traffic on the starting point of the LSP tunnelling (i.e. level of traffic aggregation) as well as on the tunnel capacity ranging from the 2,5% in the very worst case to negligible with tunnels beyond 10Gbps of capacity.

Finally, the inter-carrier issue consideration in E2E OAM has been presented.

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