ORCHESTRA

Optical peRformanCe monitoring enabling dynamic networks using a Holistic cross-layEr, Self-configurable Truly flexible appRoAch

H2020-ICT- 645360

D2.3 – Dynamic network control plane requirements and specifications

Document Information

Scheduled delivery	01.02.2016
Actual delivery	01.02.2016
Version	14
Responsible Partner	SSSA

Dissemination Level

PU	Public

Revision History

Date	Editor	Status	Version	Changes
27.10.2015	N. Sambo	draft	00	ToC
9.12.2015	N. Sambo	draft	01	ABNO databases; flexible operations and actions upon failure; hierarchical monitoring architecture; testbed; scalability analysis
10.12.2015	N. Sambo	draft	02	Introduction
21.12.2015	R. Morro	draft	03	Control plane specifications
23.12.2015	G. Bernini	draft	04	ABNO and reference control plane
07.01.2016	A. Pagano	draft	05	Alarm generation in Telecom Italia network
18.01.2016	N. Sambo	draft	06	Executive summary, Conclusions
26.01.2016	K. Christodoulopoulos	draft	07	Cost analysis
26.01.2016	N. Sambo	draft	08	Refinements
28.01.2016	K. Christodoulopoulos	draft	09	Refinements
28.01.2016	A. Pagano	draft	10	Refinements
29.01.2016	Y. Pointurier	draft	11	Refinements and internal revision
31.01.2016	K. Christodoulopoulos	draft	12	Refinements
01.02.2016	N. Argyris	draft	13	Internal revision
01.02.2016	N. Sambo	final	14	Final

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Internal Reviewers

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Acknowledgements

The research leading to these results has received funding from the EC HORIZON 2020 under grant agreement n° 645360.

Glossary of Acronyms

Acronym	Definition
ABNO	Application-Based Network Operations
AIS	Alarm Indication Signal
ALTO	Application-Layer Traffic Optimization
BER	Bit Error Ratio
BOL	Beginning Of Life
D	Deliverable
DoW	Description of Work
DSP	Digital Signal Processing
EC	European Commission
EOL	End Of Life
FDI	Forward Defect Indication
FEC	Forward Error Correction
FTFL	Fault Type and Fault Location
FWM	Four Wave Mixing
GMPLS	Generalized Multiprotocol Label Switching
I2RS	Interface to the Routing System
IETF	Internet Engineering Task Force
IGP	Interior Gateway Protocol
LP	Lightpath
LOF	Loss Of Frame
LOS	Loss Of Signal
LSP	Label Switched Path
LSP-DB	Label Switched Path DataBase
NMS	Network Management System
OAM	Operations, Administration, and Maintenance
OCh	Optical Channel
ODU	Optical Data Unit
OLA	Optical Line Amplifier
OMS	Optical Multiplexed Section
ONF	Open Networking Forum
OSNR	Optical Signal to Noise Ratio
OSPF	Open Shortest Path First
OTN	Optical Transport Network
OTS	Optical Transmission Section
OTU	Optical Transport Unit
PCE	Path Computation Element
PCEP	PCE Protocol
PL-DB	Physical Layer Database
PLM	Payload Mismatch
PM	Project Manager
PM-*m*QAM	Polarization multiplexing *m* quadrature amplitude modulation
PM-QPSK	Polarization multiplexing quadrature phase shift keying
PMI	Payload Missing Indication

PO	Project Officer
QoS	Quality of Service
QoT	Quality of transmission
REG	Regenerator
ROADM	Reconfigurable Optical Add&Drop Multiplexer
RSVP	Resource Reservation Protocol
SDN	Software Defined Networking
SLA	Service Level Agreement
SSF	Server Signal Fail
SSS	Spectrum Selective Switch
TCM	Tandem Connection Monitoring
TE	Traffic Engineering
TED	Traffic Engineering Database
TR	Transponders
VNTM	Virtual Network Topology Manager
WP	Work Package

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1. Executive Summary

Optical networks for core and metro segments are evolving toward more dynamicity and flexibility. Each network resource is set depending on the current requests and network status with the aim of optimizing the service while guaranteeing an efficient use of the network (e.g., minimizing the occupied spectrum). In such a vision, networks are going to operate close to their physical limits, as an example, trying to increase the optical reach of connectivity or packing channels in the spectrum. A particular case is the reduction of worst-case margins. Typically, network operators adopt worst-case margins to account for aging of network devices, model inaccuracy and so on. The adoption of margins in quality of transmission estimation is a conservative approach when setting up connections and guarantee to operators to satisfy the proper quality of transmission level. However, it results in the underestimation of the optical reach, thus, to the overestimation of the number of opto-electronic regenerators. Reducing worst-case margins permits to increase the optical reach but requires a proper monitoring of network performance, as well as a proper management of monitoring information to verify the quality of transmission against soft failures[1] (e.g., due to aged devices). More generally, the flexibility of next generation optical networks require an efficient handling of monitoring information permitting to optimize transmission and network parameters based on the service and on the current status of the network considering the physical layer. Thus, an observation of the network and a control and management plane able to efficiently manage and set network devices is mandatory to react to possible degradations, or worse, to failures. Transmission parameters re-optimization may be mandatory to avoid outages in case of soft failures. Thus, an orchestration of monitoring and control functionalities is essential in future networks. First, monitoring information has to be efficiently handled – accounting for scalability issues – to localize possible problems and identifying the causes. Then, the control plane should be able to remotely set network devices based on the failure and the status of the network and services with the aim of optimizing network resources, while guaranteeing high reliability.

This deliverable discusses the main requirements and specifications, intended both as functionalities and control/management performance (e.g., scalability). The ORCHESTRA consortium has identified the IETF Application-based Network Operation (ABNO) architecture as the candidate model for the control and management plane. Indeed, ABNO integrates the main functionalities to control and manage a network: e.g., path computation, provisioning, and management of monitoring information. Provisioning can be implemented with Software Defined Networking protocols such as the OpenFlow, while the emerging SDN NETCONF protocol can be used to exchange monitoring information. In this deliverable, the ABNO architecture is illustrated with its functional elements and control plane protocols that can be used in the ORCHESTRA network are presented. A relevant ABNO element is the Operation Administration and Maintenance (OAM) Handler responsible for the interpretation of monitoring information and for triggering reactions to counteract failures or degradations. By building on the OAM Handler functionalities, a hierarchical monitoring architecture is proposed. The OAM functionalities of interpretation and reaction are supported at each layer of the hierarchy and are integrated into “monitoring managers”, each one responsible to collect and

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[1] Failures/degradations are classified in two typologies: hard and soft failures. Hard failures imply the inability to use a given network devices (e.g., due to a link cut) and cause the lost of connectivity. Soft failures imply the degradation of the quality of transmission and do not necessary imply the lost of connectivity.

interpret monitoring information related to a sub-set of network devices or connections. Such division of responsibility provides high scalability of the management plane, which is an important requirement. Indeed, the observation of commercial systems (e.g., installed in Telecom Italia networks) highlights the complex management and suppression of alarms, showing that providing a scalable management of alarms and monitoring information is mandatory. Considering such problems, the hierarchical monitoring architecture is proposed and simulations show the high scalability achieved by such architecture in case of link failure.

Moreover, this deliverable summarizes the main causes of hard and soft failures and implications on the services: loss of connectivity or bit error ratio increase. Actions can be taken based on a list of control primitives: switch to a disjoint path, change of transmission parameters (modulation format, forward error correction – FEC) to provide more robustness to the transmission, or shift in frequency. The selection of the item included in the list of primitives is driven by the type of the failure and the involved service. Particular attention is given to the re-optimization of transmission parameters, thus to the change of modulation format or FEC since they can be fast operations and they may not involve the use of several ABNO functionalities such as for path computation. However, re-optimization of transmission parameters is not trivial since it can imply the reduction of the supported bit rate and such event could be not permitted for specific service classes. For this reasons, the selection of the reaction upon soft/hard failure has to be performed based on the service class and accounting for the service level agreement. This deliverable presents a table, organized per failure and service classes, showing the actions that the control plane can take to guarantee the proper reliability. Considering this table, reaction time is discussed. In particular, in case of soft-failures, a fast reaction is not strictly required since a proper selection of the threshold for alarm generation prevents service outage and gives to the control/management plane the chance to reconfigure the involved network devices on time before the outage. Thus, in case of soft failures, specific reaction time requirements for the control and management plane are not essential. In case of hard failure, the real bottleneck for a fast recovery is mainly driven by the time needed to reconfigure the switches at the data plane, while the time required to exchange messages in the control plane is much lower.

Finally, we revisit the preliminary cost analysis that was presented in Section 7 of Deliverable D2.1, taking equipment depreciation into account. This is an attempt to give some preliminary results on the cost savings that the ORCHESTRA concept can achieve, while more detailed techno-economic studies are carried out in WP7 and will be reported in D7.4. The savings at the end of the examined periods were observed to be 14% without assuming money revaluation at intermediate periods.

2. Introduction

Core and metro networks are evolving to support ultra-high rate communication systems enabling elastic adaptation and optimization of transmission parameters while guaranteeing high reliability [1]. Emerging data plane technologies are going to support the increasing traffic demand with transponders enabling high bit rates such as 1 Tb/s, possibly looking at downscaling power consumption and costs per bit, and offering high spectral efficiency, thus increasing network life [2]-[6]. At the control plane layer, Software Define Networking (SDN) is emerging as an architecture to remotely set network devices, thus programming transmission characteristics (such as offered bit rate) and switching [7]-[9]. However, a more efficient orchestration of the transmission characteristics could be achieved by an observation of the network in general, the physical layer, and the services (through the management of monitoring information) so that transmission parameters could be optimized and efficiently controlled depending on the actual observed status of the network and services’ performance. In this sense, the management plane has still to experience relevant advances. Network management includes the Operation, Administration, Maintenance (OAM) functions required to monitor and interpret the measurements on services and devices, and to recover from faults or degradations [10].

Recently, the Application-Based Network Operations (ABNO) architecture [11] has been proposed within the IETF as a solution integrating control (e.g., path computation) and management (e.g., OAM) functionalities and orchestrating both applications and service provisioning at the client layer. Such architecture may have the prospects to offer to the operators an agreed way to properly control and manage networks and applications. ABNO includes the OAM Handler, a key functional block to verify the actual quality of transmission (QoT) at the data plane and the service level according to specific agreements (SLAs) at the application layer. The OAM Handler is responsible for: i) receiving alerts about potential problems; ii) correlating them (e.g., for fault localization); iii) triggering other components of the ABNO, such as the Path Computation Element (PCE), to take actions to preserve the services that are interested by the fault or the degradation. In such a scenario, monitoring techniques are also fundamental. The data plane may offer new ways of monitoring: as developed within the ORCHESTRA project, coherent systems permit direct monitoring of the optical connections through the digital signal processing (DSP) into the receiver itself. Based on such monitored information, if needed, the OAM Handler has to trigger proper actions (e.g., adaptation of transmission parameters, re-routing) to react against soft or hard failures (e.g., link degradations or faults, respectively) which degrade QoT and, in turn, service level. Currently, the OAM Handler still requires to be deeply investigated, also considering scalability issues, e.g. given that the amount of alarms generated by an optical network may be huge. Moreover, alarms may also become much more frequent because of system margin reduction. Indeed, besides the ORCHESTRA consortium, other vendors and operators are now oriented to reduce system margins that account for aging, model inaccuracies, inter-channel interference and other degradations [12]-[15]. Such margins cause the underestimation of the optical reach, thus, increase the number of regenerators in a network and in turn the costs. A reduction of system margins can decrease the number of installed regenerators, but, on the other hand, a more frequent generation of alarms may occur. Indeed, as described in [14], more conservative thresholds should be adopted to trigger alarm generation and, in this case, the number of alarms can become even much higher than in current networks.

This deliverable defines the general control and management architecture of the ORCHESTRA network considering the main specifications and requirements to guarantee reliable services, as well as efficient provisioning. Such considerations feed, in particular, WP5 where the control and management plane is designed and implemented. Requirements are intended both as functionalities and performance (e.g., scalability).

First, the ABNO architecture is defined as the reference control and management architecture (Sec. 3), highlighting control and management functionalities required by the ORCHESTRA network. Then, operations to react to hard- and soft-failures are summarized (Sec. 4) by referring to the list of primitives defined in D2.1 and considering different classes of traffic. Then, the hierarchical monitoring architecture proposed within the framework of the ORCHESTRA project is presented (Sec. 5). Such monitoring architecture has the OAM Handler at the root. Then, an overview of the alarm management and their suppression in current networks is reported (Sec. 6) highlighting the complexity of such a management. Finally, a performance analysis is reported, highlighting the scalability of the hierarchical monitoring architecture (Sec. 7) and the cost reduction (Sec. 8) provided by the ORCHESTRA network.

3. Reference control and management plane: ABNO

ORCHESTRA targets to close the loop between the optical layer and the network control and management functions. This is one of the main objectives set to provide more flexibility, dynamicity and efficiency in the optical network operation and service provisioning. This translates into challenging requirements for the control and management architecture, that in turn has to provide reactive and proactive control and monitoring functions in order to efficiently implement and support the ORCHESTRA key concept of observe, decide, act loop.

With this in mind, the reference control and management approach chosen in ORCHESTRA is the ABNO architecture since it includes the main functions to control and manage both network and services.

3.1. ABNO Functionalities

The ABNO architecture [11] provides an SDN-based framework for on-demand and application-specific control and management of network resources in a wide range of network applications (e.g. point-to-point and point-to-multipoint connectivity in transport networks, optimization of traffic flows, network virtualization, mobile back-haul, etc.) and in a range of network technologies from packet (IP/MPLS) to optical.

The ABNO approach is disruptive with respect to traditional network control and management model, where services are delivered and operated in response to management requests basically driven by a human user. ABNO tries to address the challenges of today’s networks that integrate multiple technologies and need to provide a wide variety of services in response of direct requests from the application layer, trying to meet heterogeneous characteristics and traffic demands.

The main idea in the ABNO architecture is to bring together several existing control and management technologies for gathering and manipulating information about the resources available in a given network, in terms of topologies and their mapping to network resources, their operational status, mostly to provision and monitor network services.

In practice, ABNO can be seen as a composition and integration of existing components enhanced with a few new elements. This is the core idea behind the ABNO approach: provide an architectural concept for SDN based control and management of heterogeneous networks by leveraging on existing control technologies, tools and frameworks, properly integrated and coordinated. Therefore, ABNO does not provide a software design, neither it is intended to provide implementation constraints. Each implementation of the ABNO architecture may provide interpretations and customizations concerning the functional components. As an example, multiple functional components could be grouped together into one software component to have all the given control and management functions grouped with a single external interface exposed.

The full ABNO architecture, as defined by IETF in [11], is depicted in Figure 1. Key ABNO functional components to be adopted and enhanced in ORCHESTRA are briefly described hereunder.

The ABNO controller is the main gateway to the network for the Network Management System for the provisioning of network coordination and functions. The ABNO Controller is basically a bridge across all the internal components. ABNO governs the behavior of the network in response to changing network conditions and in accordance with application network requirements.

PCE is a key element in the ABNO architecture and is devoted to path computation across a network graph (in some cases it also performs wavelength or spectrum assignment). The PCE may receive these requests from the ABNO Controller or from network elements themselves. The PCE operates on a view of the network topology stored in the Traffic Engineering Database (TED). A more complex computation can be provided by a Stateful PCE that enhances the TED with a database (the LSP-DB) containing information about the LSPs that are provisioned within the network. Additional functionality in an active PCE allows to make provisioning requests to set up new services or to modify in-place services. These proactive PCE functions are relevant in ORCHESTRA and refer to the integration of the algorithms provided by WP4 for network re-optimization and to react to soft- and hard-failures.

Operations, Administration, and Maintenance (OAM) Handler is the ABNO building block most relevant to the ORCHESTRA control and management approach. It is responsible for gathering monitoring information to keep the ABNO aware of how a network is operating, thus detecting faults and taking the necessary actions to react to problems in the network. This latter function is typically just a trigger to the PCE or the ABNO controller to notify degradations and failures to be recovered. Therefore, the OAM Handler receives notifications from the network about potential problems, and can also take an active role to explicitly request monitoring information from the underlying network devices. In this direction, ORCHESTRA extends the OAM handler functions and scope towards a hierarchical monitoring infrastructure. The core idea is to spread the main OAM Handler functionalities, such as receiving alerts, correlating them and take actions, in a hierarchical monitoring system composed by dedicated coordinated and cooperative agents providing high reliability and scalability.

The Provisioning Manager is the component responsible for the provisioning of the underlying network resources. Thus, it takes care of all the interactions and communications with the control plane(s) deployed on top of the network under the ownership of the ABNO. It requests the provisioning of new lightpaths as well as their dynamic modification and reconfiguration according to decisions taken by the PCE. In the context of ORCHESTRA, the Provisioning Manager has to be flexible and support different control plane technologies and approaches that may adopt to operate and provision the optical network. Sec. 3.3 provides an overview of control plane alternatives envisaged for ORCHESTRA.

Other functional components are part of the ABNO architecture depicted in Figure 1, like the VNTM, the ALTO server and the I2RS client, are envisaged to take a minor role in the ORCHESTRA control and monitoring plane due to their specific scope that is mostly out of the scope of this project.

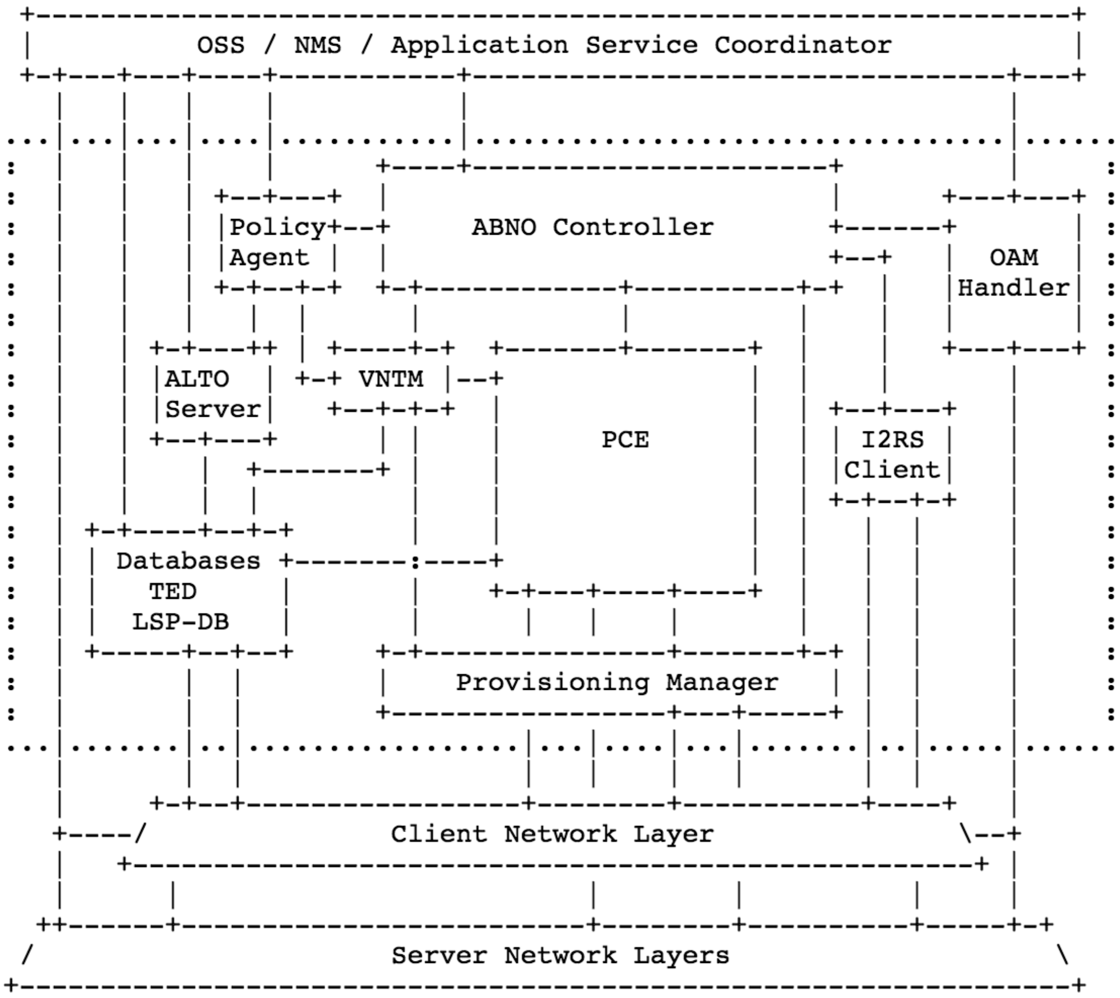

Figure 1: ABNO architecture defined by RFC 7491

3.2. ABNO Databases

The databases considered in the ABNO architecture are the TED storing traffic engineering information (such as the range of spectrum occupied per link) and the LSP-DB containing information on the state of LSPs such as traversed interfaces, bit-rate, occupied frequency slot [16]. Besides these two databases included by the IETF RFC 7491, we also consider in ORCHESTRA a database storing physical layer information, named Physical Layer DataBase (PL-DB). Such database stores all the accessible information related to the physical layer, which are known from the devices' data sheets or accessible through monitoring. PL-DB entry may refer to an LSP or to a network device like a fiber. PL-DB may include BER of lightpaths, amplifiers' information (e.g., noise figure), fiber information (e.g., attenuation, chromatic dispersion, average differential group delay, and effective area), and so on.

3.3. Control plane technologies

The adoption of the ABNO architecture enables a straightforward integration of control and monitoring functions that is crucial for the ORCHESTRA vision and concepts. Indeed, ABNO offers the opportunity to leverage and enhance the OAM handler and the Provisioning Manager functionalities towards a control and monitoring architecture that allows to close the loop between the optical layer and the network management functions.

In particular, the Provisioning Manager is the ABNO component responsible to interact with the underlying network resources, in terms of provisioning of new connectivity services and dynamic modification of existing ones according to information about physical layer retrieved by the OAM Handler through the monitored parameters.

Within ABNO, the Provisioning Manager operations to provision the network resources can take place at two different levels: i) by directly programming and configuring network devices in the data plane, following a pure SDN approach within ABNO, ii) by triggering a set of actions to be programmed with the assistance of a separated control plane instance running outside ABNO. A number of reference control plane technologies already exist for both options and they have been reviewed in D2.1 [14].

As said, in the case of direct provisioning of network resources, the Provisioning Manager would act as an SDN controller, thus following a pure SDN control approach. SDN is standardized in the context of the Open Networking Forum (ONF) and can be defined as a control framework that provides programmability of network functions and protocols by decoupling the data plane and the control plane [17]. With SDN, network intelligence and state information is logically centralized within a controller, while an abstracted and vendor independent view of network resources is exposed to upper layers by means of open Application Programming Interfaces (APIs). SDN provides a software abstraction of the physical network that allows the network itself to be programmable and therefore closely tied to application and service needs. OpenFlow [18] is the de-facto SDN standard protocol driving the integration of SDN controllers and network devices. It is based on flow switching and is capable to provide software and user-defined flow based routing, control and management functions, in support of both electrical packet and optical circuit technologies.

Another option, relevant in the context of ORCHESTRA, is to use NETCONF as an alternative to OpenFlow to provision network resources and implement the needed control actions. NETCONF [19] provides a more active configuration protocol that could be suitable for bulk programming of network resources. Its use as a provisioning protocol is dependent on suitable YANG models being defined for the given network technologies to be controlled. Moreover, NETCONF enables a system of Notification messages that can be easily and efficiently adopted to implement alarms related to soft or hard failure. Such mechanisms are under investigation in WP5 and are firstly detailed in D5.1.

In the case of interaction with an external control plane, ORCHESTRA assumes that it is a Generalized Multi-Protocol Label Switching (GMPLS) instance running on top the optical network under the ownership of ABNO. GMPLS [20] is defined within IETF and provides network control plane procedures for automated provisioning of network connectivity services with functions for Traffic Engineering, network resource management, and service recovery. The GMPLS architecture as defined in related standards is conceived to operate over multiple switching technologies (packet, Layer-2, Time Division Multiplexing –TDM-, fibre and wavelength switching). A wide set of extensions are defined for GMPLS signalling (e.g. RSVP-TE) and routing (e.g. OSPF-TE) protocols to support specific technologies like Wavelength Switched Optical Networks (WSON), G.709 Optical Transport Networks (OTN) and Flexi-Grid.

When a GMPLS control plane is deployed, the PCE Communication Protocol (PCEP) [21] can be used at the Provisioning Manager as the protocol to interact with GMPLS nodes for requesting the establishment of LSPs, following the active PCE concepts defined in [22]. In this case, the Provisioning Manager is basically used to isolate the twin ABNO PCE functions of computing and requesting paths from the active provisioning mechanisms.

4. Flexible operations and control/management plane requirements and specifications

The control and management planes, ABNO in general, have to be responsible for reacting upon degradation or faults based on the current status of the network and the physical layer. Such reaction procedures should satisfy requirements that are driven by the service (e.g., restoration within 50ms). Thus, a proper discussion on the requirements of the control and management planes is required. First, this section aims at identifying the actions that could be taken depending on the service and the failure. Then, control/management requirements are discussed.

4.1. Actions upon failure

A relevant requirement for the ORCHESTRA ABNO is to handle two types of failures:

1. *hard:* they consist in the damage of a link or a node so that the connectivity is lost. As an example, they can be due to a fiber cut.
2. *soft:* they imply a transmission performance degradation, not necessary causing a service outage. As an example, if the pre-FEC BER threshold of a transponder is 2×10^{-3} and the soft failure only causes an increase on the BER up to 10^{-3}, no outage is experienced. Instead, an outage is experienced if the pre-FEC BER passes above the threshold. A soft failure may be due to a malfunction or aging of network devices like amplifiers, equalizers, fibers and so on. It can also be due to an excessive cross-talk with other channels. Such failures may be relevant when margins against aging or crosstalk or cross-phase modulation are under dimensioned [12]-[15].

Thus, soft or hard failures impact services in a different way and it must be also considered that services may belong to different classes of traffic, thus requiring different actions for preservation. A requirement for ABNO is to handle different classes of services. Some classes of traffic are here considered:

1) Gold: protected lightpath
2) Silver: not protected lightpath and bit-rate reduction is not admitted after failure recovery (i.e., 100% bit rate recovery)
3) Bronze: not protected lightpath and bit-rate reduction is admitted after failure recovery (i.e., ≤ 100% bit rate recovery)

A discussion is here provided on how a bit rate reduction could be experienced and why it can be an important issue in elastic optical networks. A soft failure affecting a service can be overcome by switching to a more robust modulation format. This operation implies a reduction of the bit rate. As an example, with PM-16QAM at 28 Gbaud and 12% FEC, 200 Gb/s net rate is obtained; with PM-QPSK at 28 Gbaud and 12% FEC, 100 Gb/s net rate is obtained. Thus, if a reconfiguration from PM-16QAM to PM-QPSK is required, to keep the same information rate, the introduction of a new sub-carrier or the set up of a new lightpath must be performed. Similarly, a soft failure could be overcome by adapting the overhead (FEC) [23], thus increasing code redundancy. Also this operation may imply a reduction of the bit rate. Indeed, if a transponder works at the maximum baud rate and code bits are increased upon soft failure, net rate decreases.

Table 1 Failure detected by the OAM system and required actions

Failure ID	Failure	Impact	Impacted class	Actions
1	Hard: link or node	Loss of connection	Gold	• switch to protection path • notify the upper layer in the hierarchy
2	Hard: link or node	Loss of connection	Silver or Bronze	• notify the upper layer in the hierarchy • ABNO controller orders re-routing
3	Soft: e.g., amplifier, equalizer, fiber aging	BER increase	Gold	• switch to protection path • notify the upper layer in the hierarchy
4	Soft: e.g., amplifier, equalizer, fiber aging	BER increase	Silver	Possibilities: 1) FEC adaptation is expected to successfully recover from failure A. not implying slot width increase: • FEC is adapted • notify the upper layer in the hierarchy B. implying slot width increase: • notify the upper layer in the hierarchy • ABNO controller orders re-routing 2) FEC adaptation is NOT expected to successfully recover from failure • notify the upper layer in the hierarchy • ABNO controller orders re-routing
5	Soft: e.g., amplifier, equalizer, fiber aging	BER increase	Bronze	Possibilities: 1) FEC adaptation is expected to successfully recover from failure • FEC is adapted • notify the upper layer: if bit rate is lost ABNO could take actions on lost bit rate 2) Change of modulation format is expected to successfully recover from failure • Change of modulation format • notify the upper layer in the hierarchy: ABNO could take action on lost bit rate 3) Change of modulation format or FEC is NOT expected to successfully recover from failure • notify the upper layer in the hierarchy • ABNO controller orders re-routing
6	Soft: inter-channel interference	BER increase	Gold	• switch to protection path • notify the upper layer in the hierarchy
7	Soft: inter-channel interference	BER increase	Silver or Bronze	• notify the upper layer in the hierarchy • Depending on resource availability, ABNO controller orders one of the following actions: – shift in frequency – power re-equalization – re-routing

Table 1 aims at summarizing possible actions required once the monitoring architecture reveals a hard or a soft failure, depending on the class of traffic. Actions belong to the library of primitives presented in D2.1 [14]. Such library includes: re-routing (including protection or dynamic restoration), spectrum shift, change of modulation format or FEC. Besides such actions, further procedures could be taken into account: e.g., power re-equalization.

In case of hard failure and protected lightpath (gold class), a switch to the protection path should be performed to recover the traffic (Failure ID 1). Thus, the monitoring layer identifying an affected lightpath triggers the switching to the protection path. Such event should be notified up to the OAM Handler to take records about possible loss of traffic taking care that SLAs are satisfied. In case of unprotected lightpath (silver and bronze), the monitoring plane informs the OAM Handler, which interacts with the ABNO controller (Failure ID 2). Thus, dynamic restoration can be triggered.

In case of soft failure such as amplifier multifunction, a BER increase above the pre-FEC threshold may be experienced. If the affected lightpath is protected (Failure ID 3), switching to the protection lightpath can be triggered. If the affected lightpath is silver class (Failure ID 4), FEC adaptation is taken into consideration, evaluating if the increase of the redundancy implies or not an increase of the ITU-T frequency slot width (i.e., the passband of traversed filters). If not, FEC adaptation is triggered by the monitoring layer identifying the affected service and then OAM Handler is notified. If the FEC adaptation implies a slot width increase, the OAM Handler has to be notified and the TED has to be consulted to check spectrum resource availability and, eventually, re-routing has to be ordered to preserve the whole traffic. In this case, the OAM Handler notifies the ABNO controller which requests the PCE to compute the recovery path. This also happens if FEC adaptation is not enough to provide transmission robustness and re-routing has to be performed. If the affected service is a bronze class (Failure ID 5), actions that imply a bit rate reduction could be taken. Thus, if FEC adaptation is expected to successfully recover from failure, this action is taken. Then, the ABNO controller will take or not actions related to the lost bit rate. Also the change to a more robust modulation format could be applied. Again, the ABNO controller will take or not actions related to the lost bit rate. If no modulation format or FEC adaptation is expected to recover from failure, the ABNO controller will trigger rerouting. Note that actions not involving the consultation of ABNO TED, LP-DB, and PL-DB or the invocation of PCE for re-routing – such as the switch to a protection path, modulation format adaptation, and, in many cases, FEC adaptation – are triggered by the layer detecting the failure (e.g., *level 0*, see next Section) before notifying the upper layers in the monitoring hierarchy. Modulation format or FEC adaptation may imply a communication between the controller of the transmitter and receiver to pass information such as the target modulation format or code rate and notifications. Different actions can be taken if the soft failure is due to inter-channel interference (XPM and FWM). In this case, for silver and bronze classes (Failure ID 7), ABNO controller could order to shift lightpath in frequency, or power re-equalization, or re-routing. Indeed, channel interferences such as XPM/FWM typically depend on the distance in frequency of the interfering channels (the close the channels the largest the impact of XPM/FWM) and on the optical power (the highest the power of the interfering channel the largest the impact of XPM/FWM).

4.2. Control/management plane requirements and specifications for reaction

Control and management plane are required to be extended to support the aforementioned operations/reactions detailed in Table 1. Moreover, hereafter a discussion on performance requirements of the control/management plane, in terms of reaction time, is provided. As stated before, ORCHESTRA analyzes two types of failure: soft and hard.

Soft failures encompass slow events such fibers and amplifiers degradation (e.g., due to aging). More details can be found in D2.1 [14] and D2.2 [15]. Thus, given their nature, soft failures are not expected to cause service outage. Indeed, we can assume that thresholds to trigger alarms are properly set to values with the scope of preventing a service outage. On the other hand, hard failures require quick responses due to the fact that connectivity is lost. For gold class of service, protection is performed at the lower layers, not requiring, therefore, any control plane action except for notifications to the OAM Handler or to the ABNO controller, e.g. to inform about re-routing. Instead, silver and bronze class of services may require ABNO operations to reroute the affected traffic. Control plane performance may affect recovery time: notifications and path calculation times, message delivery latencies and so on influence directly the time needed to restore the affected services. However, data plane latencies (SSS reconfiguration, power equalization, transponder settings – FEC and/or modulation changes, etc.) are some order of magnitude higher than control plane ones. Thus, strict requirements for control plane performance in terms of response time are not essential.

A different issue is what concerns scalability: for example, routing in an optical network is critical due to the "analog" features of the process that must take into account many parameters and execute complex and usually non-linear algorithms that may lead to unacceptable convergence times. Such complexity suggests to keep under a reasonable value the number of nodes per domain and to restrict the IGP routing area dimensions to the same limit. The actual number of network nodes heavily depends on the algorithm complexity and on the number and type of the involved parameters; however, the routing process should be able to support a value of some dozens of nodes (30-50). Deploying an external PCE that can be run on a high-performance computing platform is surely a key factor with respect to the case where the source node (with limited computing power) is in charge of performing path calculation; gain in path computation time highly compensates PCEP message delivery time. It is therefore clear that hierarchical control architecture[2] is needed to coordinate all the different domains. This approach has many other advantages; among them it is worth mentioning:

- Every domain can deploy its own control technology as far as a common element (SDN controller, child active-stateful PCE, classical NMS with appropriate NorthBound Interface, etc.) is employed as single interface element towards higher elements in the hierarchy;

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[2] Note that, in this case, the term "hierarchical" is referred to the responsibility of a PCE on a specific network domain for path computation purposes; thus, it is not referred to the hierarchical monitoring architecture.

- It is possible to separate the domains from different vendors that usually have optimization and routing algorithms relying on proprietary features;
- Topology details of the domain can be hidden to the higher controllers that, in turn, may not need to know such information and can therefore operate on a summarized topology, reducing thereby complexity and computation times;
- The position of control plane elements can be confined within restricted geographical limits reducing message delivery latencies;
- The control architecture can be aligned with the monitoring one, discussed in Sec. 5.

5. Hierarchical monitoring architecture

A hierarchical architecture presented in [24] [25] has been proposed within the framework of the ORCHESTRA project. The monitoring infrastructure consists of virtual monitoring entities and agents with the OAM Handler at the root of the hierarchical infrastructure. OAM functionalities are spread into the several layers with the aim of meeting the requirement of scalability.

An optical network (with fixed- or flexible-grid) is considered to be equipped with monitors, that are assumed for lightpaths (LPs), links, and nodes, as in Figure 2. LP monitors are assumed to be integrated in the DSP unit of each lightpath coherent receiver (e.g., pre-FEC BER monitors), while, as an example, power monitors can be assumed for links and nodes.

The proposed hierarchical monitoring architecture is presented in Figure 3. Each entity provides the same OAM functions: i.e., collecting and correlating alerts and triggering actions to preserve services. Each one is responsible for a specific set of LPs or for a sub-set of nodes or links (e.g., nodes belonging to a given network area). Exchange of monitored information can be triggered due to physical layer degradations or faults and, in this case, information flows towards the upper layers. Each layer correlates and filters the received information efficiently sending less amount of monitoring information to an upper layer toward the OAM Handler. Alternatively, the OAM Handler on behalf of the ABNO controller can ask the monitoring plane to get specific monitoring information (e.g., OSNR) that can be used to have a more updated PL-DB or to perform advanced path computations for new requests, as proposed within the ORCHESTRA project [26] and investigated in WP4.

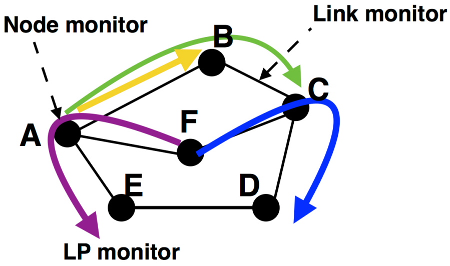


Figure 2 Example of network and monitors

The monitoring architecture is divided in three parts, one per monitored type of element: thus, it includes monitoring elements responsible for LPs, for links, and for nodes. Regarding LP monitoring architecture, the *level 0* is responsible for OAM of single LPs. Similarly, regarding link and node, the *level 0* is responsible for OAM of single links or nodes, respectively. Upper layers are responsible for a set of LPs (e.g., LPs starting from the same ingress node), links, or nodes. While the level in the hierarchy increases, the monitoring entities are responsible for a larger set of LPs or links and nodes, up to being able to correlate information of all LPs, links, and nodes.

More details on the architecture and a possible implementation will be presented in D5.1. In this deliverable, in particular in Sec. 6, a preliminary assessment of this architecture is provided. Further assessment is reported in D5.1 together with an analysis of the amount of traffic to be re-routed in case of failure.

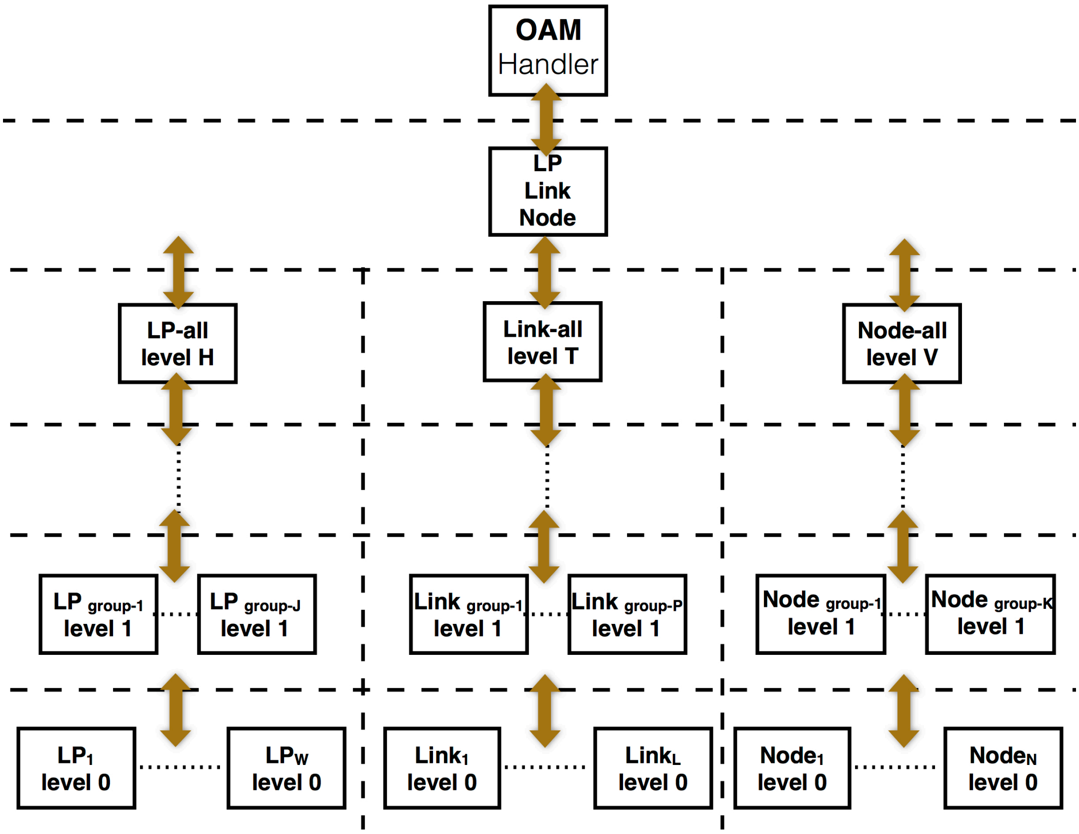


Figure 3 Hierarchical monitoring architecture

6. Analysis of alarms in Telecom Italia network

This section shows how the generation of alarms is currently handled in Telecom Italia networks. Such section aims at categorizing the type of alarms, their level of danger, and how alarms are inhibited or not according to the standard ITU-T G798 [27]. The section highlights that a scalable management of alarms is mandatory. Furthermore, we also have to consider that alarms in next generation optical networks may also become much more frequent because of system margin reduction, as explained in the Introduction of this deliverable; additionally notifications of degradations, that are usually reported as warnings, are not filtered as alarms. Finally, some indications about how performance data are handled in Telecom Italia optical networks are presented. Performance data reports about circuits' QoS. Acquired Performance data is compared to specific threshold and could raise specific alarms to warn on performance degradation of transmission process. Performance data reports about digital parameters (e.g., pre-FEC BER) or analogue ones (e.g., transmitted and received optical power).

6.1. Alarm taxonomy

Alarms can be raised by different management elements with a customizable severity level. Alarms are usually categorized as in the following:

- Equipment alarms
- Communication alarms
- Transmission alarms
- Environmental alarms

Equipment alarms report failures that are raised by specific hardware components. They warn of:

- internal fiber cable connection problem
- internal fiber break
- hardware failure

Communication alarms report communication failures, such as LAN connection or node control lost.

Transmission alarms report failures between the equipment node and the remote network equipment, for example:

- fiber cable break
- line problems within the network
- bad transmission quality
- problems on remote network equipment

Transmission alarms are reported by management entities issued from the information model. These management entities represent the functional elements and operations that can be performed on the optical signal during transmission process.

Finally, environmental alarms can be raised by each control or environmental point of cards and shelves.

According to the severity level, alarm indicators display different colors. Alarm severity levels are defined as in the following:

- Critical/Red: A service-affecting condition has occurred and immediate corrective action is required.
- Major/Orange: A service-affecting condition has developed and urgent corrective action is required.
- Minor/Yellow: A non-service-affecting fault condition has occurred and corrective actions are needed to prevent a more serious fault (for example, one affecting the service).
- Not Reported/Blue: Detection of a potential or impending service-affecting fault which is not reported but logged. As a consequence a Not Reported fault can be retrieved.
- Not Alarmed/Gray: Detection of an event which does not require operator action. The event can be permanent or transient. Neither visual nor audible signals are triggered.

Each managed entity (hardware component, communication port, transmission entity/facility) is associated with a set of alarms and related severity levels via one or several profiles. Optical thresholds are the triggering factors for power alarms like Power Loss and Power Degraded alarms (Figure 4). Optical threshold value at port level can be set via an optical threshold profile that has been created before.

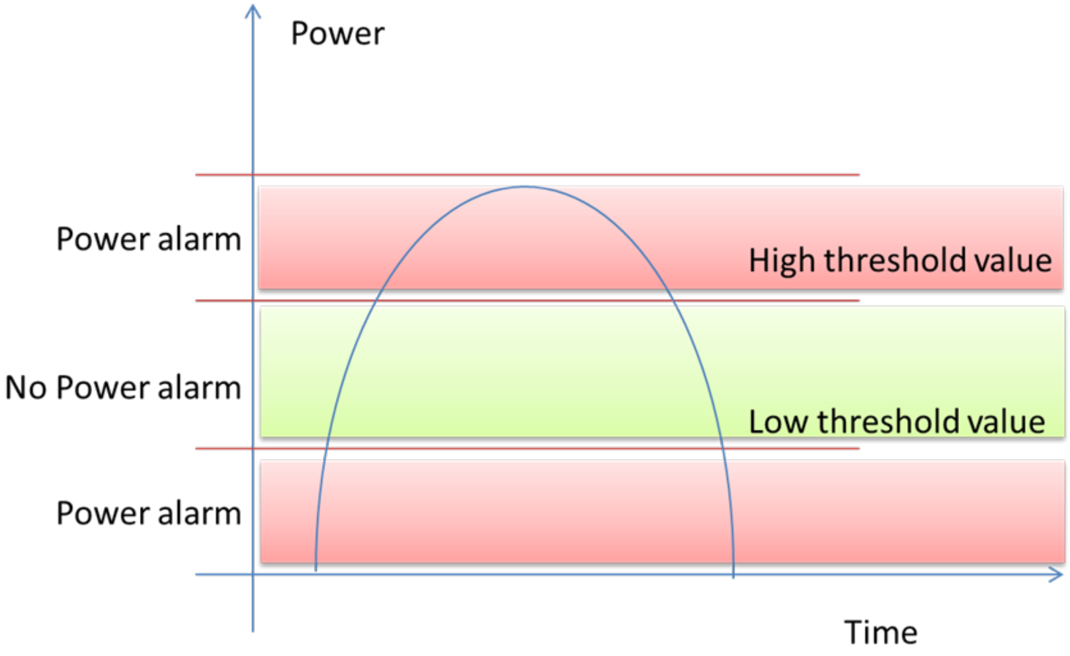


Figure 4 Power alarm raise against crossing of threshold values

6.2. Alarms reporting and correlation

Alarm notification follows specific rules about alarm reporting and inhibition processes that take place to reduce the amount of alarm information to the relevant bare minimum. Figure 5 illustrates the main steps of the alarm notification process, which comes to equipment and transmission alarms. In particular, the following rules are currently taken into account:

- Equipment alarms can be generated only when traffic services are not impacted;
- Transmission alarms can be generated only when the problem is just about transmission issues (i.e. fiber misconnection);
- Transmission and equipment alarms can be both generated when the problem needs to be reported from an equipment and a transmission perspective to enable a complete operation view to the network management system.

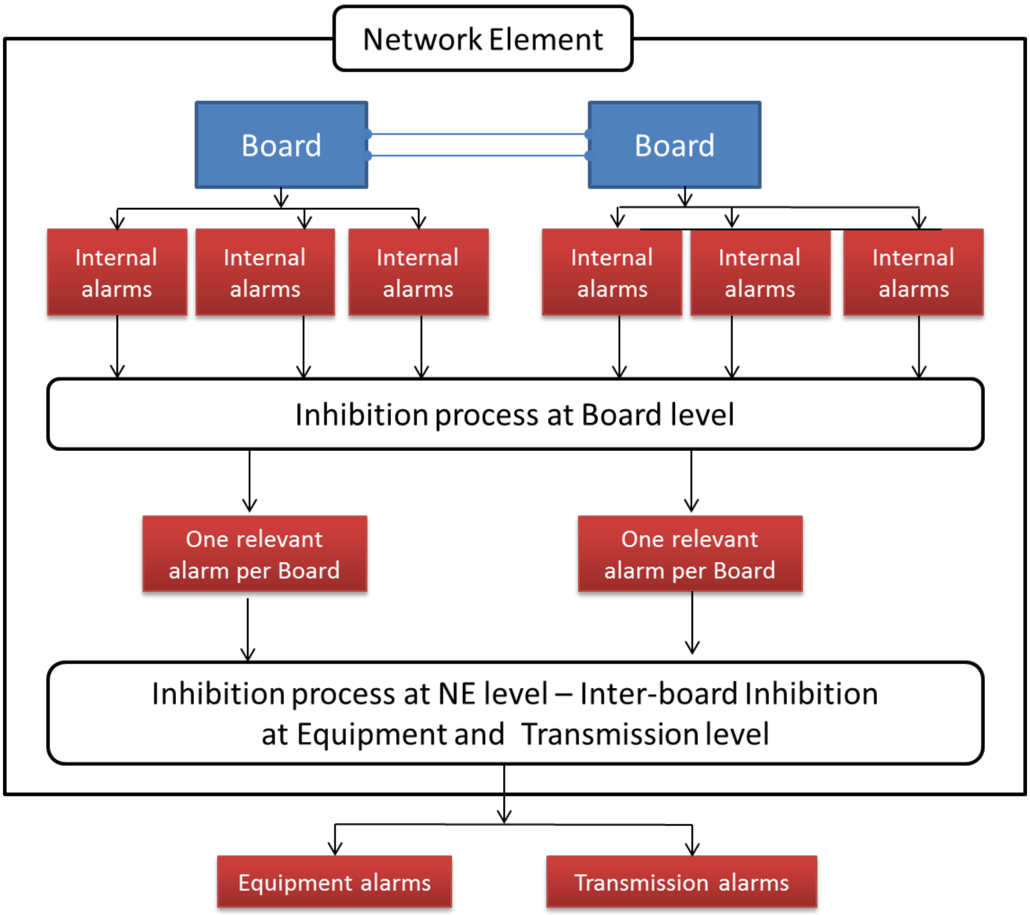


Figure 5 Simplified alarm notification process

According to what is specified in ITU-T Recommendation G.7710/Y.1701 [28], inhibition mechanism hides all the downstream equipment alarms, which result from a source alarm.
Equipment alarm inhibition mechanism is a two-step process:

1. Equipment alarms are analyzed at board level first. The objective of this first step is to keep only one relevant alarm per board.
2. Equipment alarms are then analyzed at NE level where inhibition rules at board level are extended to the relation between boards.

The sequence of equipment alarms raised by a defect will be filtered to keep the source alarm as the relevant one to be taken into account by the alarm management system. Inhibition mechanism is continuously performed to scan alarm relevance each time a new defect is detected or cleared.

Hardware defect alarms (hardware failure, equipment missing or mismatch) inhibit all the other alarms raised by a board (Figure 6).

- A hardware failure alarm is never inhibited.
- A hardware failure alarm inhibits downstream failure alarms. This is not the case of hardware degradation, which does not inhibit downstream alarms.

A signal alarm inhibits other downstream signal alarms. A client alarm inhibits optical signal alarm on the relative carrier, if a one-to-one relationship is deployed (Figure 7). For boards which handle several input ports and one output port, if at least one cabled input port does not raise any alarm, downstream alarms are not inhibited as shown in Figure 8, while if all cabled input ports raise alarms, downstream alarms are inhibited.

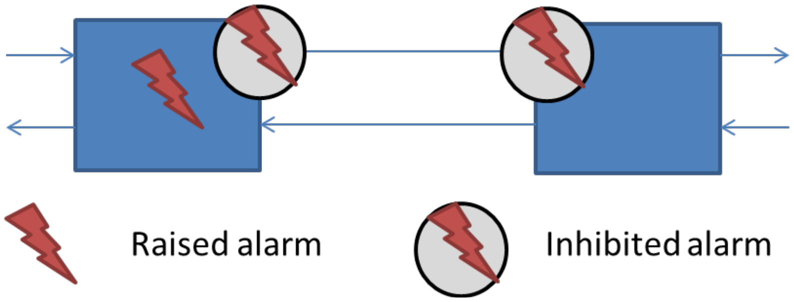


Figure 6 Signal Versus Hardware Alarm Inhibition

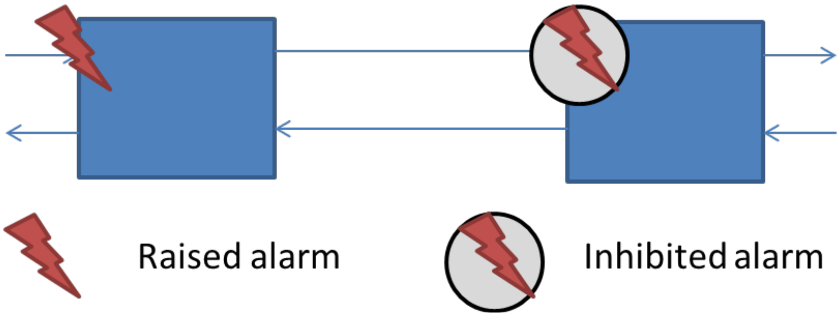


Figure 7 Client side Signal alarm inhibition

Figure 8 Single/Multiport Signal alarm inhibition

When several transmission layers as defined in ITU-T G709 are impacted by alarms, the alarm of a given layer inhibits the alarm(s) of the upper levels (**Figure 9**) [29].

The cascading inhibition process is summarized:

- OCH alarms inhibit OTU, ODU and Client alarms,
- OTU alarms inhibit ODU and client alarms,

- ODU alarms inhibit Client alarms.

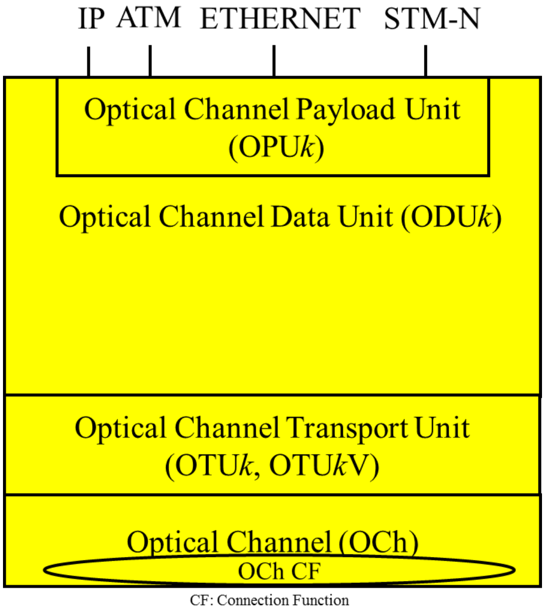


Figure 9 OTN stack

When alarms monitor the same transmission layer, the inhibition rules follow the ITU-T G798 standard. Alarm correlation and inhibition process are controlled at the board level by raising, propagating, and detecting maintenance signals such as SSF (Server Signal Fail) and AIS (Alarm Indication Signal). SSF transmission alarm is generated for network management purposes on OMS, ODU and Client layers. It indicates that a service is down because a server layer is down (Server/Client relationships are defined according to the functional model of the NE). The root cause is given by the primary alarm on the server layer.

The AIS alarm indicates that:

- the service is down and the downstream alarms such as LOS (Loss Of Signal), LOF (Loss Of Frame), PLM (Payload Mismatch) have to be inhibited according to the above rules,
- the source problem is located upstream.

Using OTN maintenance signals FDI (Forward Defect Indication), AIS (Alarm Indication Signal) and PMI (Payload Missing Indication), the number of alarms in case of a broken fiber and a full loaded optical spectrum will be reduced from 1k to few ones. As an example, Figure 10 shows how the use of maintenance signal OTS-PMI (and OMS-PMI) will prevent OMS (OCH) LOS alarms when none of the wavelength is present [30]. Furthermore detection of defect indication generates backward maintenance signals according to what is indicated in Figure 11.

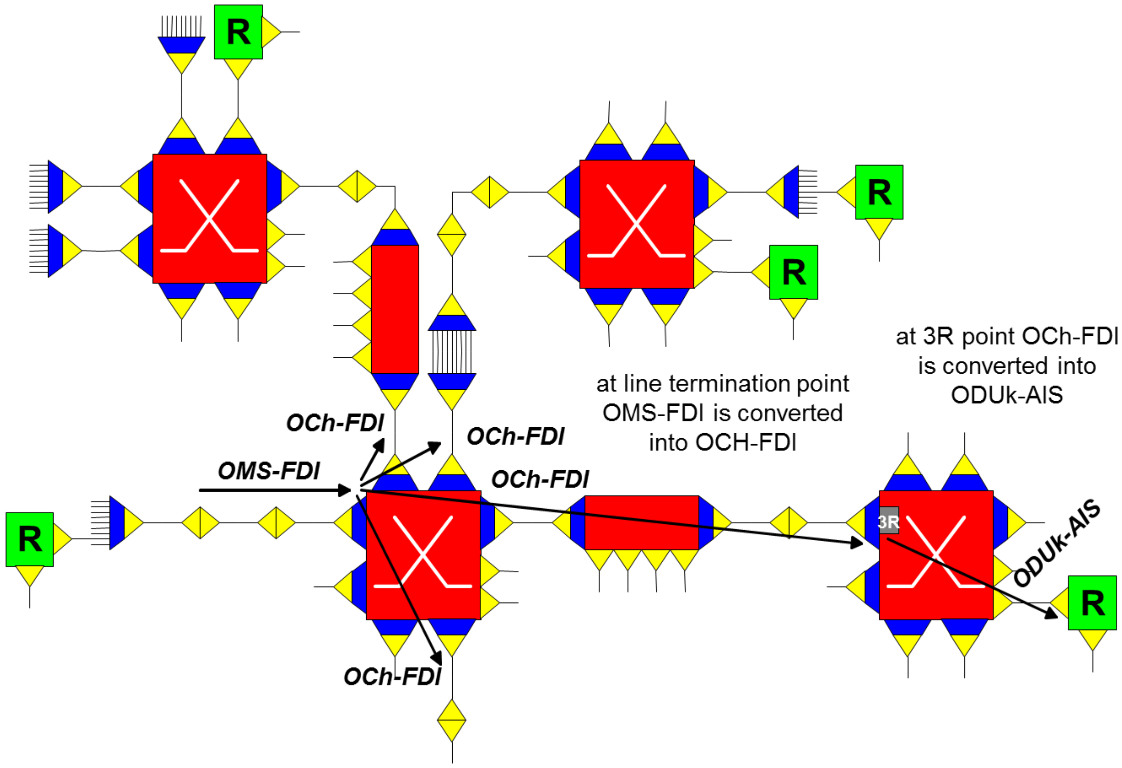


Figure 10 Alarm suppression in OTN [30]

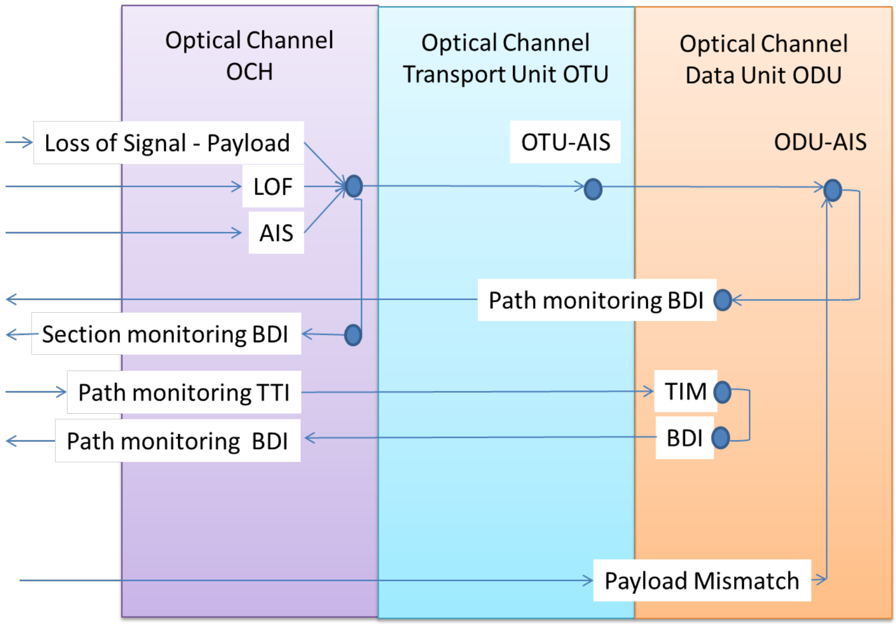
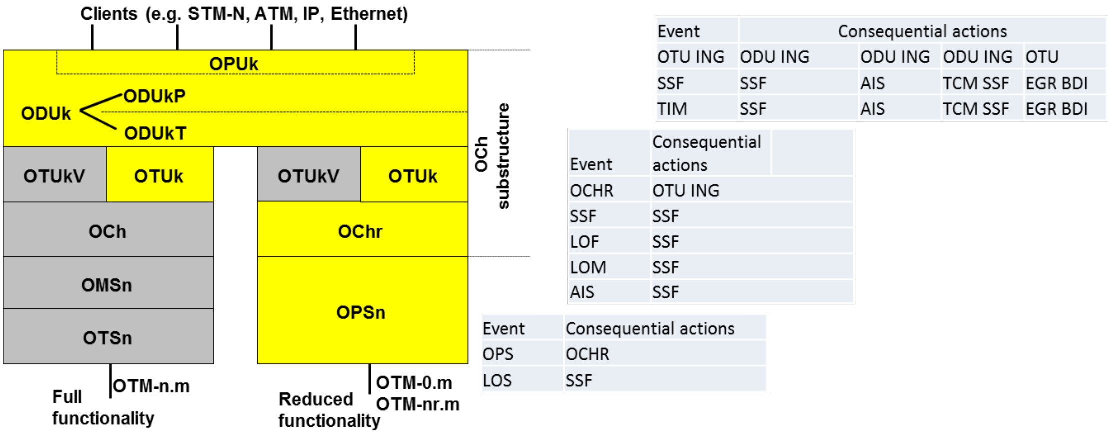


Figure 11 OTN Maintenance Signals Interaction

Alarm correlation on a commercial DWDM system is implemented according to what is previously described.

On the client side, alarm correlation is done according to a simple rule: client LOS generates OCHr SSF (Server Signal Fail), that generates OTU ingress (client) SSF and consequently ODU client SSF and AIS (Figure 12). On WDM side, any relation to client loss is lost and only ODU payload AIS is reported forward.



Event	Consequential actions			
OTU ING	ODU ING	ODU ING	ODU ING	OTU
SSF	SSF	AIS	TCM SSF	EGR BDI
TIM	SSF	AIS	TCM SSF	EGR BDI

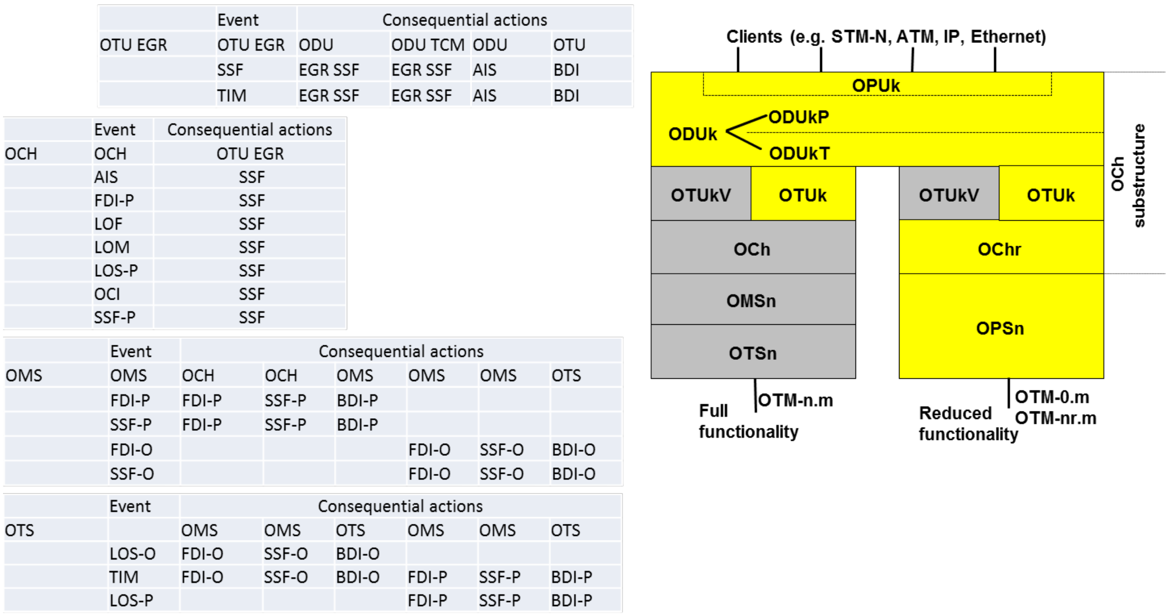
Event	Consequential actions	
OCHR	OTU ING	
SSF	SSF	
LOF	SSF	
LOM	SSF	
AIS	SSF	

Event	Consequential actions
OPS	OCHR
LOS	SSF

Figure 12 Defect Indication propagation for a commercial DWDM system (client side)

On the WDM side, in case of a OTS LOS, OMS FDI and SSF are generated, payload or overhead accordingly. The same happens in case of a OMS loss: OCH FDI and SSF are generated and propagated, masking alarms from upper layers. OCH loss generates WDM OTU SSF and consequently ODU AIS (Figure 13).

For each trails, alarms are reported without masking only at ODU termination point or in non-intrusive monitoring points along the link.



	Event	Consequential actions			
OTU EGR	OTU EGR	ODU	ODU TCM	ODU	OTU
	SSF	EGR SSF	EGR SSF	AIS	BDI
	TIM	EGR SSF	EGR SSF	AIS	BDI

	Event	Consequential actions
OCH	OCH	OTU EGR
	AIS	SSF
	FDI-P	SSF
	LOF	SSF
	LOM	SSF
	LOS-P	SSF
	OCI	SSF
	SSF-P	SSF

	Event	Consequential actions					
OMS	OMS	OCH	OCH	OMS	OMS	OMS	OTS
	FDI-P	FDI-P	SSF-P	BDI-P			
	SSF-P	FDI-P	SSF-P	BDI-P			
	FDI-O				FDI-O	SSF-O	BDI-O
	SSF-O				FDI-O	SSF-O	BDI-O

	Event	Consequential actions					
OTS		OMS	OMS	OTS	OMS	OMS	OTS
	LOS-O	FDI-O	SSF-O	BDI-O			
	TIM	FDI-O	SSF-O	BDI-O	FDI-P	SSF-P	BDI-P
	LOS-P				FDI-P	SSF-P	BDI-P

Figure 13 Defect Indication propagation for a commercial DWDM system (WDM side)

6.3. Multi level, multi vendor connection monitoring

Multi-level connection monitoring is essentially used for interoperability between sub-networks and islands of transparency. Six levels of Tandem Connection Monitoring (TCM) Bytes are used to tag and transport monitoring information at the border between sub-networks.

The TCM assignments provide the means for monitoring various connection levels to determine connection quality, to detect connection failure, and to drive protection switching operations. These monitors also support the process of defect and fault localization by being able to determine the domain or link in which the defect or failure has occurred.

Considering a multi-vendor and multi-operator show-case, cascaded and nested monitoring data should be provided to efficiently report event log and detect faults' causes (Figure 14). TCM fields report alarms such as AIS. One byte is allocated in the ODUk overhead to transport a 256-byte fault type and fault location (FTFL) message. The forward and backward fields are further divided into three subfields: a fault type indication field, an operator identifier field, and an operator-specific field.

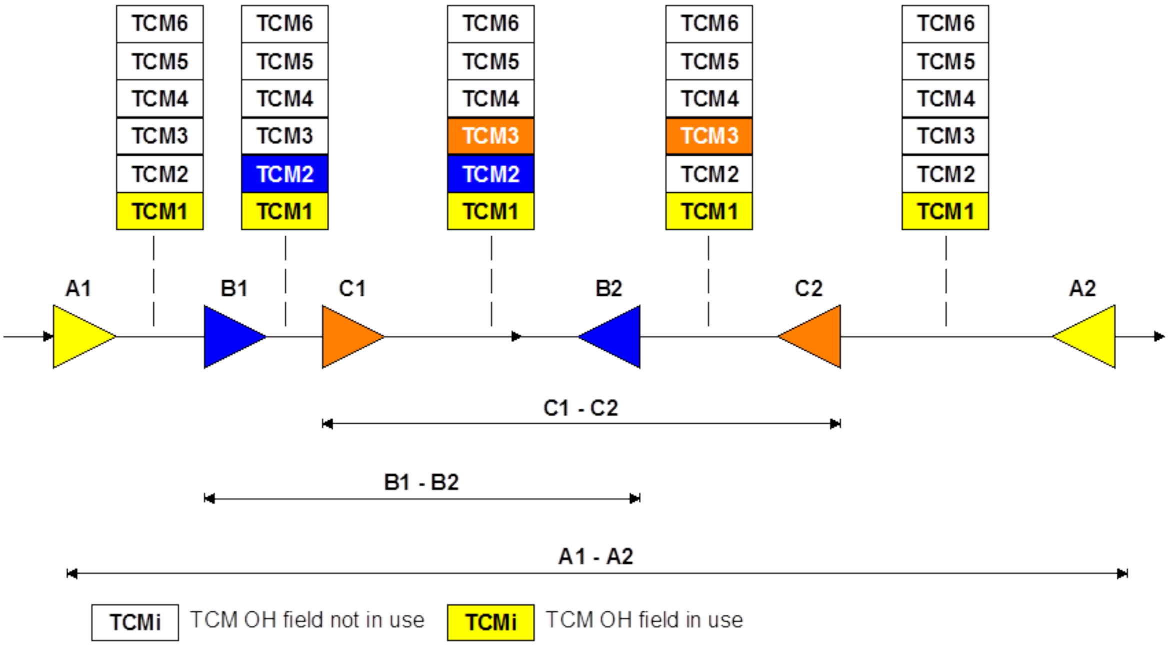


Figure 14 Cascaded and nested TCM

6.4. Analysis of performance in Telecom Italia network

Quality of service delivered is directly related to the capacity to respond to performance issues of a system. In addition to equipment and transmission alarms, specific alarms to warn the network operator on performance degradation of the transmission process are available.

There are three types of performance counters:

- Time counters: they count the elapsed time (in seconds) during which an error is present in the system, within a given period
- Digital counters: for example, related to error counters. Error counters count the number of errors reported for a given period
- Analog counters: they report about analog data such as power, temperature, current

Performance counters collection is reported with either 15-minutes or 24-hour granularity; important parameters to be displayed are:

- the Rack# of the board
- the Shelf# of the board
- the Board type and Port#
- the Port type (Client or Line).

Performance monitoring is based on counter value collection process, which triggers every 15 minutes for a 24 hours period. Every 24 hours, counter values are saved into a history file, then reset to 0, to increment again for a new period of 24 hours. The collection is also done once a day for 24-hour performance monitoring data.

Monitoring management is available from Network Management suite, which offers a graphical user interface to generate different types of reports for performance monitoring data. It allows also the storage of historic performance data of managed Network Elements, reporting long-term trend analysis of the stored performance data.

7. Scalability analysis

The performance of the proposed hierarchical monitoring architecture is evaluated in terms of scalability. First, measurements are carried out on a commercial system to identify the generated alarms in case of link degradation. Then, such alarms are used as input for simulations in a national topology composed of 30 nodes and 55 bi-directional links [31]. Scalability is evaluated, as it is a relevant requirement for the architecture.

7.1. Generated alarms on measurements

To identify the alarm generated upon link degradation considering commercial cards, we performed measurements on the testbed in Figure 15. A lightpath was activated at frequency 195.30THz. A variable optical attenuator (VOA) has been placed on the line interconnecting the two nodes and has been used to emulate link hard failure. When we started attenuating the power over the optical link, the power at the receiver decreased: at -28 dBm several alarms appeared (as a link cut occurred). From the receiver, 8 alarms were generated due to the link loss. They were mainly related to the OTU2/ODU2/ODU0 (4 alarms), while others related to OCh layer (2 alarms), OMS (1 alarm), OTS (1 alarm). From the transmitter, 5 alarms appeared: 1 for OTS layer, 1 for OMS and the remaining 3 alarms were OTU2/ODU2/ODU0. Thus, a single link degradation generated 13 alarms related to a single lightpath. In the experiment, no hierarchical monitoring architecture has been implemented.

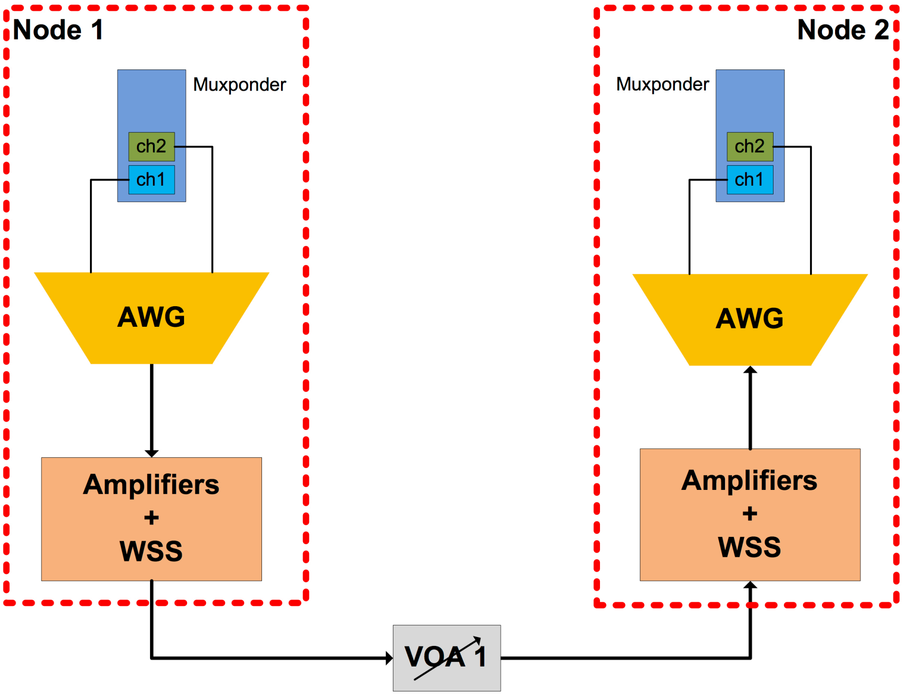


Figure 15 Testbed for alarm generation.

7.2. Simulations to evaluate scalability of the hierarchical architecture

Simulations were carried out to evaluate performance of hierarchical architecture in terms of scalability (measured as the number of alarms processed by each monitoring entity). We considered two management architectures: i) the proposed hierarchical monitoring architecture; ii) a centralized OAM receiving all monitoring information and correlating them. Link hard-failure is considered (i.e., all lightpaths traversing the failed link are disrupted and each one is source of alarms). Failure locations are generated on random links (at most one link fails at a given time) and the generated number of alarms is counted. Results are recorded until the confidence interval of 5% at 95% confidence level is achieved. The network operates with Poisson traffic. The holding time of each connection is exponentially distributed. 100Gb/s lightpaths occupying a frequency slot of 37.5 GHz are assumed [16]. The hierarchical monitoring architecture consists of *level 0* , *1*, *2*, and OAM Handler. *Level 0* is composed of monitors. *Level 1* is composed of functional entities, each one correlating monitoring information of LPs starting from the same ingress node. Thus, at *level 1*, there is a monitoring entity for each network node. *Level 2* is composed by a single entity which gathers all the info coming from *Level 1*. The root is the OAM Handler. In both centralized and hierarchical scenarios, the number of affected lightpaths generating the alarms is the same, but in the centralized scenario, 13 alarms per affected lightpath are sent to the OAM Handler while, in the hierarchical scenario, 13 alarms per affected lightpath are sent to the *level 1* and each entity at *level 1* is responsible for a subset of lightpaths (thus, providing higher scalability).

Simulations are reported in Table 2 that shows the average number of alarms received by the OAM Handler in the centralized scenario or by each monitoring entity at each level in the hierarchical scenario. In the centralized scenario, an average of 420 alarms reaches the OAM Handler which has to process all the information, identify the degraded network element, and take actions for the lightpaths interested by the degradation. On the contrary, with the hierarchical architecture, 48 alarms in average are received by each monitoring entity at *level 1*. At *level 2*, around 9 alarms are received, while 1 reaches the OAM Handler. Number confirms the high scalability provided by the proposed architecture.

Table 2 Number of received alarms per monitoring entity at each Level in case of hard link failure

	Level 1	**Level 2**	**OAM Handler**
Centralized OAM Handler	Not present	Not present	420.03
Hierarchical architecture	47.97	9.2	1

8. Network planning with reduced margins – Cost benefits

The results presented in the following are outcomes of the multi-period planning study reported in Section 7 of D2.1 in an attempt to give some initial results on the cost savings that the ORCHESTRA concept can yield by postponing the purchase of equipment.

The goal of the study presented in D2.1 was to explain the concept of postponing investment, when provisioning lightpaths with reduced margins (ORCHESTRA approach) as opposed to provisioning with End-of-Life (EOL) margins (the traditional approach). The studied scenario assumed constant traffic over 5 periods to put the focus on the upgrades required at intermediate periods due to the reduced margins, and decouple that from upgrades that would be required due to traffic increase. In the traditional approach, the EOL margins planning scenario, and assuming no traffic increase, all equipment is purchased at the initial period, while the high margins used ensure that the quality of transmission (QoT) of the provisioned lightpaths is adequate even at the end of the last period. On the other hand, provisioning with reduced margins results in an incremental multi-period network planning scenario, even without assuming traffic increases; the QoT of lightpaths falls over time as equipment ages and more connections are added to the network causing interference. Since lightpaths are provisioned with reduced margins at a given time, some of them can fall below the acceptable QoT threshold at some later time. In this case new regenerators need to be provisioned.

Reducing the margins increases the efficiency of the network and can avoid the purchase of equipment, or postpone it until they are actually needed, resulting in both cases in reduced network cost. The savings realized by avoiding the purchase of equipment are easy to see, but even postponing it can yield significant savings. These come from the fact that equipment prices decrease as time progresses (depreciate), while saved money can be also invested with interest. These factors were captured in the cost model that is described in Section 7 of Deliverable D2.1.

The results presented in Section 7 of D2.1 did not take into account the depreciation of equipment and as so the cost of the two examined scenarios (planning with EOL margins and planning with reduced margins) was almost the same at the end of the examined periods. The cost of the reduced margins scenario was slightly higher, assuming an extra cost for the deployment of ORCHESTRA's monitors to support the provisioning with reduced margins.

In the following we revisit the results of the study reported in D2.1, taking this time into account the depreciation of equipment to translate the results of the study so as to give initial results on the cost savings that the ORCHESTRA concept can achieve. Note that this study is a preliminary study and is an initial step towards the more detailed techno-economic studies that will be carried out in the framework of WP7 and will be reported in D7.4 in M18. In Section 8.2 we discuss in some details the direction that we have taken in WP7 to extend this preliminary study.

8.1. Cost savings

In Section 7 of Deliverable D2.1, we studied and compared the cost of a network over five periods for two cases of lightpath provisioning: (i) with End-of-life (EOL) margins, and (ii) with reduced margins, which is the ORCHESTRA approach. In the study the SPARKLE Pan-European topology was assumed, while the details for the assumed physical layer, traffic and transponder specifications are reported in Deliverable D2.1.

To calculate the total cost of a period we add the cost of the transponders (TR), regenerators (REG), optical line amplifiers (OLA), optical switches (ROADM add/drop terminals and lines) that are deployed in the start of that period. We also assume that regenerators can be displaced and transferred to a different location from the one in the previous period, and this adds extra expenses. Moreover, we assume that the fiber is rented and we add the rental cost in the calculations. The cost of the network equipment, the cost of regenerators displacement and the rental cost at the first period are given in Section 7 of D2.1 and are repeated here in Table 3 for quick reference. Note that the prices are relative to the price of the 100 Gb/s transponder (which corresponds to 1 Cost Unit – C.U.) and were taken from IDEALIST project [32]. The accumulated cost is the sum of the costs of the previous periods up to the current one.

Network element	Unitary price (C.U.*)	Annual cost (C.U.)
TR 100G (1 or 2 carriers, DP-QPSK or DP-BPSK)**	1	-
REG 100G (1 or 2 carriers, DP-QPSK or DP-BPSK)**	2	-
cost of a REG displacement	0.1	-
OLA EDFA	0.15	-
WSS 1x20 line 96 ch 50 GHz fix grid (incl. OA)	0.3	-
WSS CD A/D sub module with 24 ports fix grid (incl. OA)	0.4	-
fiber rental (SSMF per km per period)	-	0.004

Table 3 Parameter values used in the Cost analysis

Figure 16 presents the accumulated cost, also analyzed in a per element contribution, for the EOL provisioning scenario. As discussed the cost of all equipment is paid upfront, at period 1, and does not change, since no new equipment is added at latter periods. Regenerators are not displaced, so there is not additional cost for this operation. The only cost that is added in each period is that of renting the fiber. Thus, the accumulated cost is high in the first period and rises slowly over the 5 examined periods.

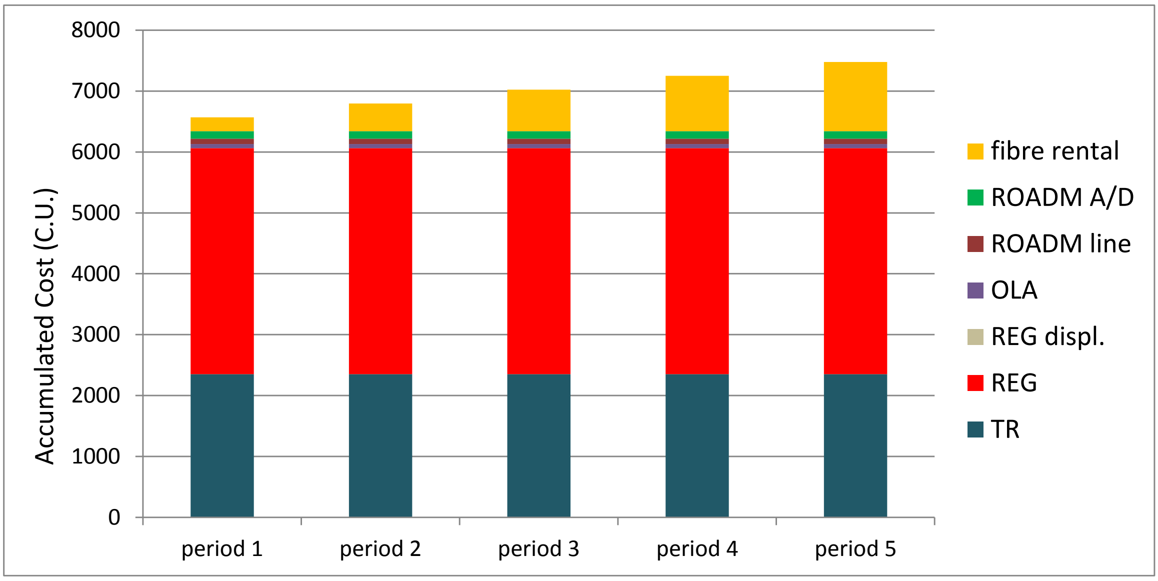


Figure 16 Accumulated cost (in C.U.) and contribution per element for provisioning with EOL margins

Figure 17 presents the related accumulated cost, also analyzed in a per element cost, for provisioning with reduced margins, assuming 10% depreciation of equipment every half period. Note we did not assume depreciation of the rental cost, since the price is typically agreed to be fixed for many periods. Note that a typical value for the duration between beginning of life (BOL) and EOL (considering the drop in the reach that is assumed here) would be 10 years but typically each optical technology is used for 5-7 years and then it is gradually replaced by new technology to support increasing demands and higher client rates. Thus each examined period in the study would correspond to about 1.5-2 years in reality. So the assumption that the equipment depreciates about 10% every year seems relatively reasonable for the equipment at hand.

As seen in the related results in D2.1, in the first period when provisioning with reduced margins there is substantially lower number of regenerators that are deployed, since the reduced margins result in longer transmissions. The regenerators are added over the 5 examined periods, ending up to be the same number with the case of provisioning with EOL margins in the last period. However, due to depreciation the accumulated cost is lower. In particular, we calculate the percentage savings at the end of a period as:

$$\frac{C^{\mathrm{A}}(\tau_n) - C^{b}(\tau_n)}{C^{\mathrm{A}}(\tau_n)} \cdot 100\%,$$

where $C^{\mathrm{A}}(\tau_n)$ and $C^{B}(\tau_n)$ is the cost of *End-of-Life margins* case and the cost of *reduced margins* case at period τ_n. We are mainly interested in the savings at the end of the last examined period, that is *n*=5.

The savings that were obtained vary with time and at the end of the examined periods were observed to be 13.69%. Note that the savings can be increased by investing the reserved money at intermediate periods, a factor that was not considered in the above calculations.

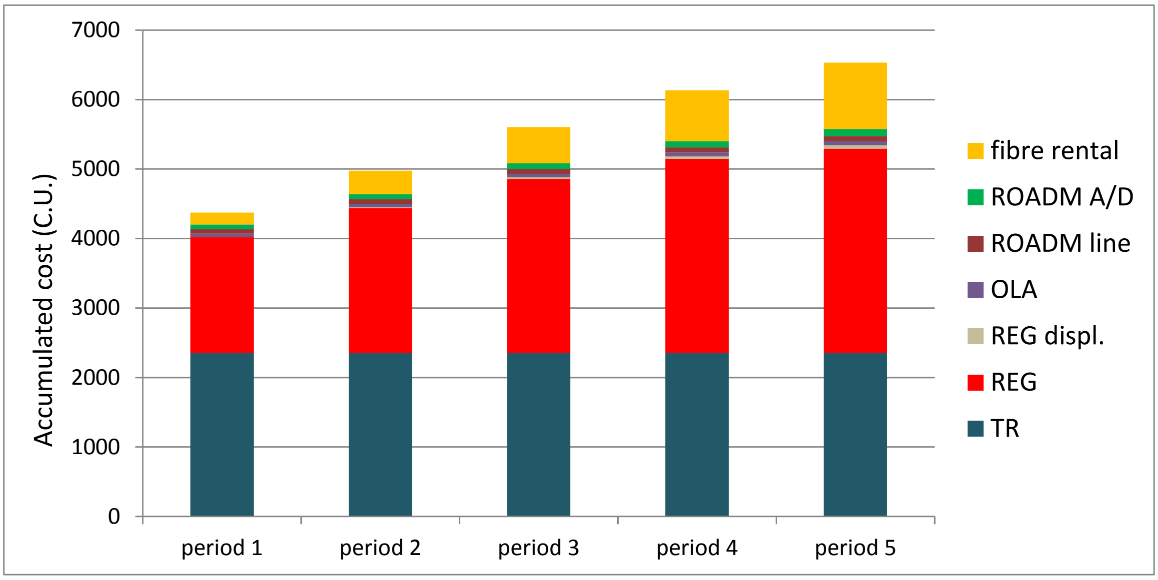


Figure 17 Accumulated cost (in C.U.) and contribution per element for provisioning with reduced margins

Figure 18 presents the accumulated cost for provisioning with EOL margins and with reduced margins assuming three different depreciation scenarios: (i) 5% depreciation, (ii) 10% depreciation and (iii) 20% depreciation per 0.5 periods. As expected, the higher the depreciation the higher the cost savings. We observed savings at the last period of 7.76% for 5% depreciation, of 13.69% for 10% depreciation, and 30.35% for 20% depreciation. Note that 10% depreciation is more reasonable, while the other two depreciation scenarios can be considered a sort of sensitivity analysis. Again, note that in these calculations we did not consider the revaluation of saved money in the intermediate periods.

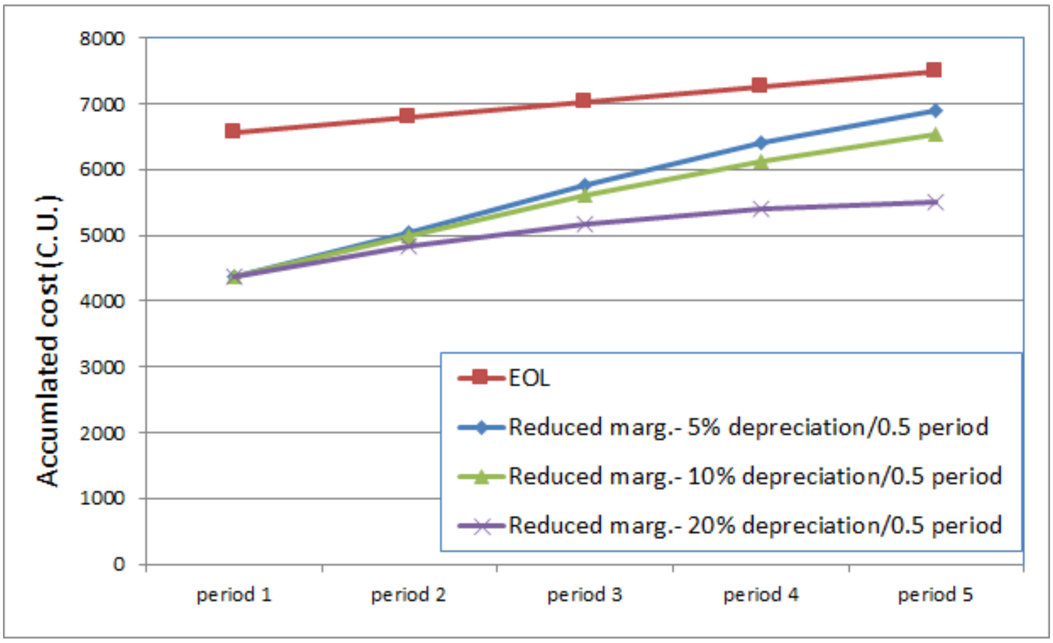


Figure 18 Accumulated cost for provisioning with EOL margins and with reduced margins, for 5%, 10% and 20% depreciation/0.5 period.

8.2. Future directions

As discussed in the introduction of this section, the results here reported are a translation of the results of the preliminary study that was reported in Section 7 of Deliverable D2.1 into cost savings, by taking into account the depreciation of equipment.

This preliminary study paves the way to more detailed studies that are currently performed in the framework of WP7 and will be reported in Deliverable D7.4. In particular, re-visiting the assumptions made in this study we are working on a number of different directions.

Firstly, the preliminary study used a physical layer model that took into account the ageing effects, but assumed worst-case interference present even at the beginning of life of the network. By considering the actual interference for each lightpath, we can further reduce the margins. So, in future studies we plan to also consider interference margins reductions, separately in an attempt to understand the contribution and significance of each margin, and jointly to achieve even higher network efficiency and cost savings.

To perform the more detailed techno-economic studies we have developed an RSA heuristic algorithm that provisions lightpaths with reduced ageing and interference margins, which is reported in Deliverable D4.1. More algorithms are currently developed: e.g., one is based on an integer linear programming (ILP) targeting to achieve the optimum planning for each period. Note that in the preliminary study we used shortest path routing and first-fit wavelength assignment with relaxed spectrum continuity constraints, while the developed RSA algorithms enable more sophisticated and accurate solutions.

Finally, the studies that are planned for WP7 will consider more advanced network scenarios, where traffic increases with time, and will also examine the use of higher-rate transponders and various depreciation models (e.g. based on learning curves [33]), to name some of the extensions.

9. Conclusions

ABNO has been identified as the reference control/management architecture for the ORCHESTRA network integrating in a standard way the main functionalities to control and manage network and services. ABNO includes the OAM Handler responsible for processing monitoring information. In the framework of the ORCHESTRA project, OAM functionalities are supported by a monitoring plane organized per hierarchical layers. Each single monitoring entity at a given layer has the responsibility of a sub-set of network devices or connections such that high scalability is achieved. Simulations have shown the high scalability provided by the proposed hierarchical monitoring architecture in managing alarms when a hard failure occurs.

Then, after alarms are generated, the control plane has to take actions to react to soft or hard failures. A wide range of failures was discussed considering different classes of service. The main actions to react to a hard failure have been identified as: i) switch to a protection path; ii) dynamic restoration. The main actions to react to a soft failure have been identified as: i) switch to a protection path; ii) change of modulation format; iii) change of FEC; iv) carrier frequency shift; v) power re-equalization; vi) dynamic restoration. Dynamic restoration is an intrusive reaction because it involves the interaction between several ABNO elements from the top of the monitoring hierarchy: at least the OAM Handler, the ABNO controller, the PCE, the databases (at least TED), and the Provisioning Manager. The time required by the control/management plane for reaction has been also discussed assessing that the control and management planes do not represent a bottleneck for a fast recovery: the time is not a problem in case of soft failure, and, in case of hard failure, data plane reconfiguration is the bottleneck for a fast recovery.

NETCONF has been identified as the protocol to implement the exchange of monitoring information, especially thanks to the presence of the NETCONF Notification message, which can be efficiently used to implement alarms in case of soft or hard failures.

Such conclusions feed WP5 for the design and the implementation of the control/management plane. D5.1 presents a preliminary version of the control and management planes, which are designed and extended for the ORCHESTRA network.

We also extended the case study reported in Section 7 of D2.1, taking into account the depreciation of equipment, in an attempt to give some initial results on the cost savings that the ORCHESTRA concept can achieve. The savings at the end of the examined periods were observed to be 14% without assuming money revaluation. This study is a first step towards the more detailed techno-economic studies that are carried out in the framework of WP7 and will be reported in D7.4 in M18.

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