A Monitoring Architecture for Self-Configurable Optical Networks

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ABSTRACT
This paper presents the hierarchical monitoring architecture and the Operation Administration and Maintenance (OAM) Handler proposed within the framework of the ORCHESTRA project. The architecture enables to confine sets of monitored physical parameters within specific levels in the hierarchy, with the aim of limiting the overload of the management plane. Monitored information is efficiently exploited for self-configuration in the optical layer.
Keywords: OAM Handler, ABNO, monitoring, optical network, EON.

1. INTRODUCTION

Core and metro optical networks are evolving to support ultra-high rate communication systems enabling elastic adaptation, optimization of transmission parameters while guaranteeing high reliability. In this context, the operation, administration, and maintenance are fundamental functionalities of networks [1]. Monitoring is crucial to verify the actual matching of quality of transmission (QoT) requirements and Service Level Agreements (SLAs). In case, the monitoring and the management plane have to trigger proper actions (e.g., adaptation of transmission parameters, re-routing) to react against link degradations/fault which degrade QoT and, in turn, SLA. An emerging candidate for the control and orchestration of next generation optical networks is the Application-Based Network Operations (ABNO) architecture [2] which includes the management of monitoring functionalities. In particular, the ABNO architecture encompasses a specific functional module called Operation Administration and Maintenance (OAM) Handler. 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 or recover the network services that are interested by the fault or the degradation. The OAM Handler interacts with devices devoted to monitoring and testing. It is important to notice that the amount of alarms generated by an optical network may be very large, even when no particularly relevant events occur, so that the number of false positive or redundant alarms can be very high. This may generate an overload of the OAM Handler that has to correlate the several received alarms and detect the possible affected services.

In this paper, we present the *hierarchical monitoring architecture* proposed within the framework of the EU project ORCHESTRA [3]. The monitoring infrastructure consists of virtual monitoring entities and agents with the OAM Handler at the root of the hierarchical monitoring infrastructure. Instead of a fully centralized OAM approach, improved scalability can be achieved through a hierarchical organization of monitoring/control actions. The hierarchical monitoring infrastructure enables effective fault management and dynamic network re-optimization based on the feedback from the monitors/physical layer. This hierarchical approach keeps the complexity and the intervention to the network as low as possible, avoiding to overwhelm the central network controller.

2. HIERARCHICAL MONITORING CONTROL AND MANAGEMENT PLANE

With the solution proposed in this paper, optical networks are monitored through the digital signal processing (DSP) of lightpath coherent receivers and/or other monitors (e.g., power monitors) [4]-[6]. The monitoring plane is organized as a hierarchy of virtual monitoring entities (Fig. 1). The virtual entities at the bottom of the hierarchy (leafs) correspond to individual lightpaths, while entities at higher levels may include ingress nodes, nodes corresponding to network regions, and others, which are related to several subgroups of lightpaths, links, or nodes. The hierarchy's root is the OAM Handler [6][7]. Each monitoring virtual entity can take decisions for all lightpaths under its responsibility in the hierarchy. The decisions pertain to several control-dimensions, and in particular: (i) transmission parameters configuration, such as the modulation format, the baud rate, the FEC, and also (ii) resource allocation parameters, such as the path, the spectrum and the regenerators used. Then, monitoring entities can pass "filtered" monitored information to the upper-layers monitoring entities. As an example, an amplifier degradation may generate tens of alarms in the *lightpath monitoring* layer. Higher layers can filter and correlate this information so as to localize the problem, avoiding forwarding all the alarms and overloading the OAM handler, increasing in this way the scalability of the system.

The OAM Handler interacts with the hierarchical control/monitoring plane which handles various types of tasks, such as establishing a new connection, adjusting the transmission rate, or resolving performance deterioration alarms, handling failures of links or nodes, to just name the basic ones. According to the hierarchal structure, the control plane starts by running procedures at a leaf node, i.e., taking local decisions about the transmission configuration of the connection that is involved. Then, as long as the problem is not resolved or the network is not effectively optimized, the problem passes to the higher level where actions on more network elements and lightpaths are allowed, with the ABNO network controller being the final level that can interact with all connections.

The available control actions form a library of control primitives (shown in Fig. 2) that include:

- Re-configuration of the transmission parameters such as the modulation format, the baud-rate, the FEC, the spectrum (without affecting neighbors) used by an established connection
- Shifting an established connection in the spectrum domain
- Rerouting an established connection (over a protection path)
- Establishing of new lightpaths (*Establish New* in Fig. 2) that also will leverage information of OAM (e.g., avoiding failed links).

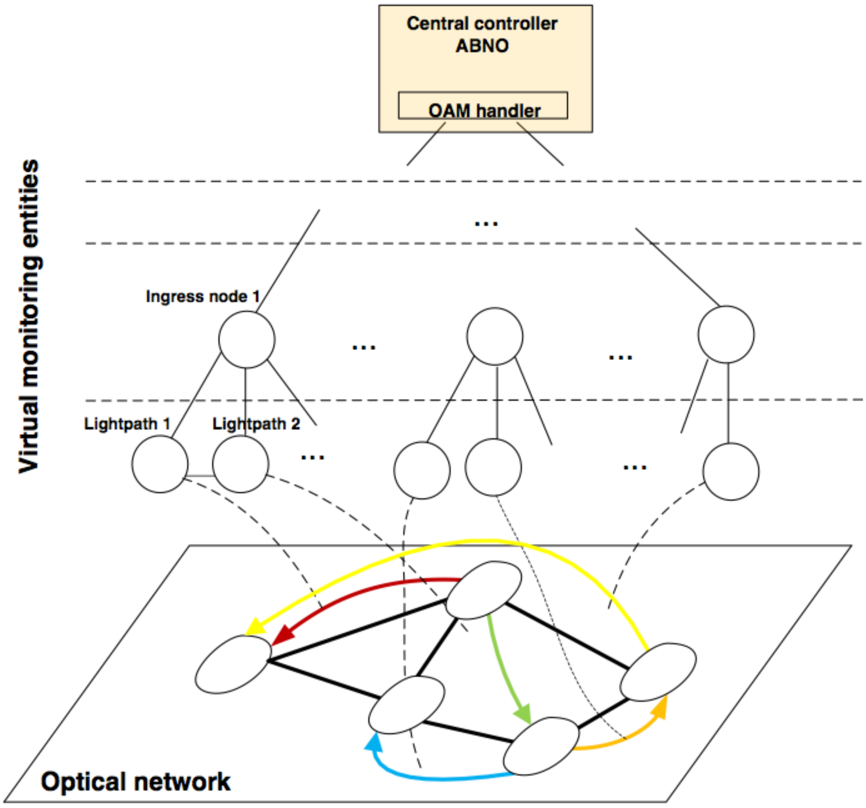

Figure 1. Hierarchical monitoring architecture.

The above primitives are ordered according to the criterion of increasing cost and complexity. It is worth noting that all these operations must be hitless. Moreover, as outlined above, each virtual monitoring entity can take decisions only about the network elements under its responsibility, with these decisions being applied using the appropriate primitives from the above list. Thus, starting from a single lightpath and local actions involving that lightpath, and going towards the root of the hierarchy, the cost and complexity of the actions increase, and so does the number of lightpaths that are involved in each case. The overall goal is to select the control primitive(s) that is (are) least expensive still acting as a remedy to the abnormal situation, such that the complexity is kept small and the problems are kept local, in order to avoid overwhelming the root (central network controller) and disrupting the network as a whole. Note that, even though the related control actions can be taken/applied by the virtual entities in a distributed manner, the central OAM Handler needs to be notified about the changes made so as to have an up to date view. In this sense, the OAM Handler can also be used to keep coherence and avoid conflicts (race problems).

The special case of local actions is of particular interest. This, actually, involves just the transmitter and the receiver and can be viewed as a sort of automatic self-tuning. Assuming that the underlying network is quite complicated, having transceivers with self-tuning capabilities can be very beneficial. These transceivers can be used in different networks with totally different characteristics, from the type of fibers to the amplifiers and optical switches that are used. Note that even a network that belongs to the same operator may be heterogeneous.

The transceivers envisioned in ORCHESTRA packed with self-adjusting capabilities enabled by their enhanced impairment estimation-monitoring capabilities can yield superior performance and operate close to their maximum capabilities in any type of network under any capacity requirement. On the other hand, once that information on monitoring is passed to the upper layers (e.g., network island), more information coming from different parts of the network can be correlated (e.g., through Network Kriging technique [5]) uniquely identifying the failed/degraded network devices.

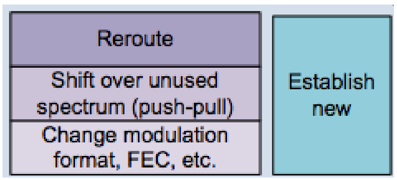

Figure 2. Library of control primitives.

3. USE CASE

This section presents some possible use cases for the proposed architecture. A first sub-section discusses use cases for information correlation: when correlation solves fault localization or not. In the latter case, fault localization is given in charge to higher hierarchical layers. Then, a second subsection summarizes some fault use cases and the possible actions that can be taken.

3.1 Information correlation enabled at different layers

Figure 3 shows some possible use cases of the proposed hierarchical monitoring architecture where alarm correlation is enabled at different levels. In Fig. 3a, two lightpaths are active and common link A-B is degraded. As an example, Q-factor monitors can be assumed in the DSP of receivers placed at node B and C, respectively, for LP_2 and LP_1. Such monitors are related to the leaf level of the monitoring hierarchy. After some processing of the monitored information, a degradation is detected. A reaction can be locally taken, such as Forward Error Correction (FEC) adaptation. Indeed, if FEC does not require an increase of the occupied ITU-T *frequency slot* [8] (i.e., the portion of spectrum associated with the LP that is switched), such operation can be immediately performed at the lightpath level. Moreover, the monitoring entities (of LP_1 and LP_2) at the lightpath level send alarm to the upper monitoring layer, i.e. the one associated with the Ingress node (in this case A). Such level identifies link A-B as degraded link, so that such "filtered" monitored information is sent to the OAM Handler, that, in collaboration with PCE, identifies all the involved lightpaths, thus updating their related information (e.g., *availability* information).

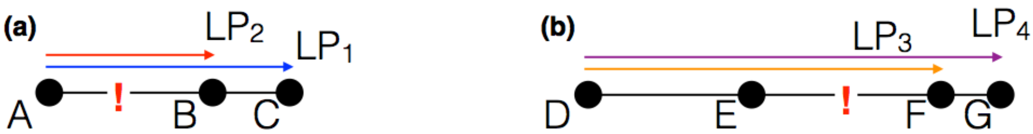

Figure 3. Examples of use cases.

In Fig. 3b, two lightpaths are active and common link E-F is degraded. Again, the monitors at the lightpath levels reveal a degradation and send alarm to the Ingress node monitoring layer (in this case D). Monitoring entity associated with node D is not able to identify the degraded link, being unable to discern between links D-E and E-F. Thus, this monitoring layer communicates with an upper layer (e.g., associated with a group of ingress nodes) that becomes in charge of fault localization. This layer can correlate more alarm information coming from different ingress nodes, thus having more chances to identify the degraded link.

It has to be noticed that such an architecture increases the scalability of next generation optical networks while guaranteeing reliability. Indeed, a single link degradation (such as introduced attenuation through a variable optical attenuator) may produce a huge amount of alarms associated to a single connection. Assuming that each network link carries tens of channels, a centralized OAM Handler is not a scalable solution. Such hierarchical architecture limits the number of alarms sent towards the root of the hierarchy. Correlation of information can be enabled at each layer.

3.2 Triggered reactions

By referring to the library shown in Fig. 2, that possible actions can be associated to the following use cases:

- *Failure*: such event typically does not permit the connectivity if a lightpath traverses a failed network element (e.g., link). The action required to react to such an event is re-routing (e.g., either on the protection path or on a new established on the fly according to the recovery scheme implemented).

- *Network element degradation/aging*: such events are not intrusive such as failures but cause service performance degradation. Transmission parameter adaptation can be enough to provide more robustness (usually at the expense of more required spectrum) to the service. As an example, more robustness can be achieved by adapting to a lower-order modulation format or introducing more redundancy through FEC adaptation.
- *Undesired degradations on specific frequencies*: this typically occurs due to interference between channels. In particular, when margins due to cross-talk or cross-phase modulation (thus, impairments involving channel interference) are kept low and new channels are established in the network, negative effects can happen on native channels. In these cases, a shift of lightpath in the spectrum [9] may be enough to reduce the interference and properly react to such degradation.

4. CONCLUSIONS

This paper presented the hierarchical monitoring architecture the OAM Handler proposed within the EU ORCHESTRA project. OAM Handler functionalities are spread into several layers following a hierarchical approach, enabling to confine sets of monitored physical parameters within specific levels in the hierarchy. This results in the limitation of the management plane overload. Monitored information can be correlated at each level of the hierarchy in an efficient way, and adaptation of transmission parameters (e.g., FEC) or re-routing are automatically triggered in case of physical layer degradations or faults.

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