ORCHESTRA – Optical Performance Monitoring Enabling Flexible Networking

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ABSTRACT

An optical network, like any system, has to be observable before it can become subject to optimization, and this is the main capability that ORCHESTRA project introduces. ORCHESTRA's high observability will rely on information provided by the coherent transceivers that can be extended, almost for free, to operate as software defined optical performance monitors (soft-OPM). Novel digital signal processing (DSP) OPM algorithms will be developed and combined with a novel hierarchical monitoring plane, cross-layer optimization algorithms and active-control functionalities. ORCHESTRA vision is to close the control loop, enabling true network dynamicity and unprecedented network capacity efficiency.

Keywords: coherent receivers, optical performance monitors (OPM), hierarchical monitoring plane, cross-layer optimization, transmission margins

1. INTRODUCTION

The continuous growth of IP traffic and the emerging of new services mostly hosted in the cloud are leading to a huge increase of traffic volume, with high unpredictability and dynamicity. This motivates the design of a new truly flexible and programmable networking environment. The Wavelength Switched Optical Networks (WSON) used today in core and metro networks are typically designed with a large capacity overprovisioning factor. Moreover, optical connections are established taking into account gross margins and worst case assumptions regarding aging effects and interference, further wasting network resources.

Elastic optical networks provide finer granularity and flexibility as a means to improve network capacity efficiency and scalability [1]. By trading off transmission rate, spectrum and reach, and having more reconfiguration options, the network can be better optimized, as well as adapted in response to traffic evolution. Optimization processes are therefore needed to avoid wasting resources and requiring new investments.

However, before an optical network can be subject to optimization, it first has to be observable. Current control and monitoring infrastructures cannot adequately support this in a cost-effective and scalable way. Coherent interfaces and reconfigurable optical photonic nodes have the possibility of reporting a huge amount of data related to the physical links; this data, however, are currently not fully exploited.

ORCHESTRA will rely on information provided by the coherent transceivers that can be extended, almost for free, to operate as software defined impairment optical performance monitors (soft-OPMs). Using and correlating such information from multiple soft-OPMs enables an accurate knowledge of the physical layer's status. This allows a fine, cross-layer optimization of connections, aiming to reduce capacity overprovisioning [2] and transmission performance margins [3],[4], and obtain savings in investment. Moreover, higher physical layer observability can also increase network availability. Apart from enabling prediction and avoidance of link outages [6], soft failures such as increased ASE noise due to aging of equipment, or some sort of malfunctioning not reported, or interference due to higher load, can be identified, isolated and solved with appropriate control actions.

ORCHESTRA will develop advanced DSP algorithms to add real-time multi-impairment reporting capability to coherent transceivers. A novel hierarchical monitoring plane handles monitoring information with an efficient and scalable approach. Information from multiple soft-OPMs deployed in the network is correlated, to provide an even better understanding of the physical layer. The advanced monitoring functions used in optimization procedures will enable true cross-layer optimization and unprecedented network capacity efficiency (Fig. 1).

2. THE ORCHESTRA CONCEPT

The future of optical networks is coherent and elastic: operators are deploying an all-coherent, multi-format transport layer, with even more functionality being shifted to the electronic domain, leveraging DSP in powerful ASICs. This allows operators to shed redundant optical hardware and simplify network design, while enabling opportunities for unprecedented functionality. ORCHESTRA will take advantage of the evolving telecom trends and aggressively pursue the development of advanced DSP algorithms that will add real-time impairment measurement-capability to flexible optical transceivers; potentially, every single transceiver in the optical network will be used as a soft-OPM. Moreover, a key point is that monitoring functions come almost for free. The receiver ASICs for DSP in coherent transponders are already deployed, thereby removing the need for additional hardware.

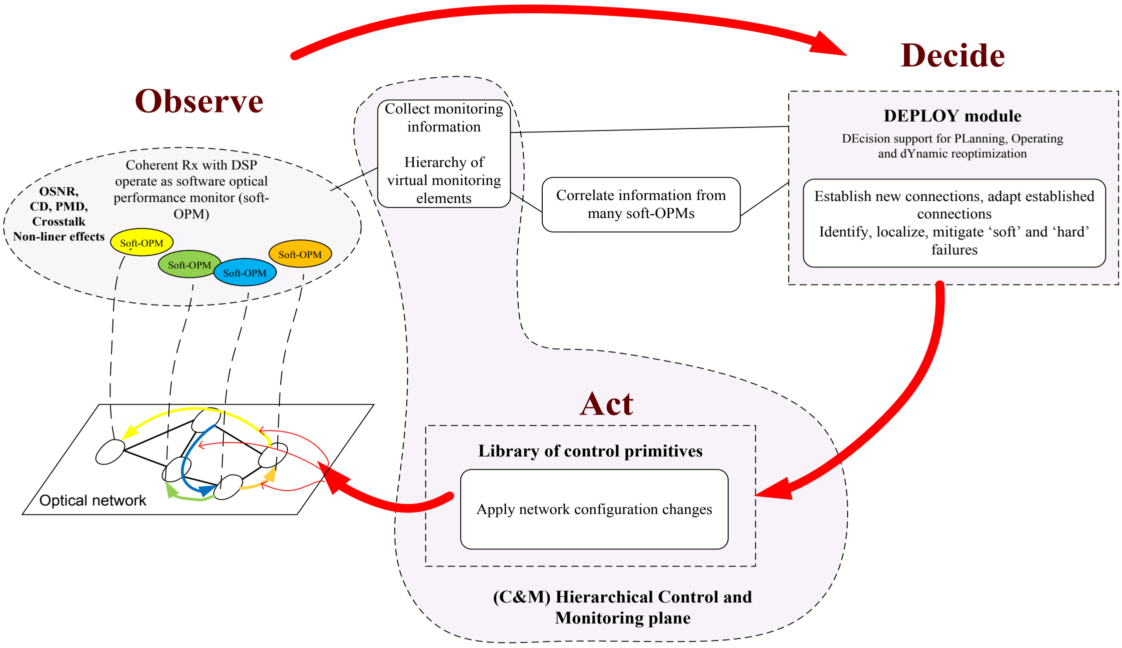

Figure 1. ORCHESTRA closes the loop between the physical and the control plane, yielding true cross-layer optimization, dynamicity and self-configurability, which will jointly provide unprecedented network efficiency.

2.1 Advanced DSP-based physical-layer multi-impairment monitoring algorithm suite

In addition to algorithms for measurement and mitigation of chromatic and polarization mode dispersion (CD, PMD), ORCHESTRA will work on optical signal to noise ratio (OSNR), and self-phase modulation (SPM) monitoring algorithms, and take on the challenge of estimating inter-channel effects such as cross-phase modulation (XPM) and crosstalk. Emphasis will be placed on developing DSP schemes that are hardware-efficient, to minimize power consumption. The latter will also be achieved using a modular implementation approach: the control and monitoring plane will be able to make optimal use by engaging and disengaging impairment monitoring and mitigation functional blocks of the transceivers, as dictated by changing conditions and network-wide operational goals (i.e., trading off estimation accuracy vs energy efficiency).

2.2 A holistic approach to Quality of Transmission (QoT) determination

In ORCHESTRA, the control and monitoring plane will have a plethora of soft-OPMs from which it can extract physical-layer information. But we can do even more: an optical performance monitor at a receiver provides aggregate performance measures over a path that usually spans multiple network links. ORCHESTRA's ambitious objective is to correlate information from multiple soft-OPMs deployed throughout a network, using methods such as network kriging and statistical estimation [8]. Correlation of information from multiple soft-OPMs opens up a multitude of possibilities for efficient network operation including, but not limited to: QoT prediction before actual establishment of a lightpath, accurate QoT measures to enable rapid and reliable Service Level Agreement (SLA) management within and across operator domains; detection, as well as anticipation, of both 'hard' (total link failure) and 'soft' (link degradation) failures. Moreover, such methods make the gradual deployment of the ORCHESTRA solution more appealing, since added value can be obtained even with a small set of soft-OPMs.

2.3 Scalable hierarchical control and monitoring infrastructure

ORCHESTRA will develop a hierarchical control and monitoring infrastructure (C&M) capable of transferring and manipulating monitoring information while going beyond passive-monitoring operations by adding active-control functionality (Fig. 2). The hierarchical monitoring infrastructure will consist of virtual entities and agents, with the Operation Administration and Maintenance (OAM) handler of the ABNO (Application-based Network Operations) controller [7] placed at the root of the hierarchy. The OAM handler will enable effective processing of monitoring information (filtering, correlation) and fault management, avoiding bottleneck issues related to centralized approaches. Active control plane functions will be organized in a library of control primitives: this will include the tuning of transmission parameters of a flexible transceiver (changing modulation format, FEC, bandwidth, transmission power, etc.), the shift of connections over unused spectrum (push-pull

[9]), rerouting, for a single or multiple lightpaths. A centralized and hierarchical control plane approach will be examined (with a main focus on the hierarchical solution). In the hierarchical approach, monitoring agents will be delegated to perform active control plane operations, so that proper actions will be evaluated at a local level where a single connection's parameters and properties are adjusted, and propagate to higher hierarchy layer, to include multi–connection actions at a global end-to-end level. In this way the complexity and the intervention to the network is minimized, therefore avoid overwhelming the central ABNO controller.

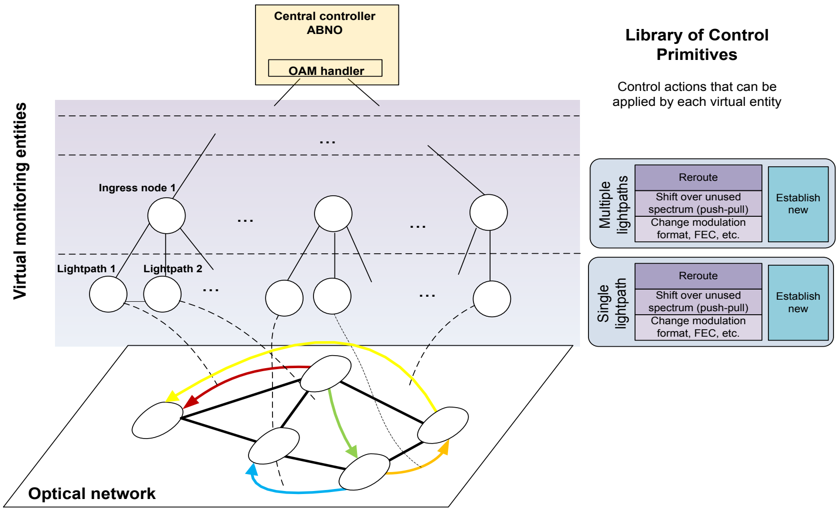

Figure 2. ORCHESTRA'S hierarchical control and monitoring plane.

2.4 Dynamic optimization procedures for fault management and network re-optimization

The introduction of optical flexible networking has vastly increased the optimization dimensions over a traditional WDM network. Moreover, new types of optimization problems are emerging, given the dynamicity and flexibility of the networking infrastructure and the support of sub-wavelength granularity and grooming at the optical domain (via multi-flow transceivers). However, state-of-the-art algorithms designed up until now are based on worst-case physical layer estimates and gross margins: interference effects and aging of equipment are two typical issues for which worst-case assumptions are applied.

Cross-layer optimization is the key to unleashing the full potential of flexible transceivers. ORCHESTRA's advanced cross-layer optimization functions will be compiled in a library module called the Decision support for PLanning, Operating and dYnamic reoptimization (DEPLOY). Previous studies in WDM networks demonstrate that cross-layer optimization can reduce the number of wavelengths required in a WDM network by 10% [5], while even higher spectrum savings of up to 60% were reported for flex-grid case [4]. ORCHESTRA aims to achieve true cross-layer optimization enabling the interaction with the physical layer to obtain any parameter of interest with high accuracy. True cross-layer optimization lowers the margins of the transceivers, enabling them to use their capabilities to the fullest extent, yielding a network with unprecedented capacity efficiency.

2.5 Efficient monitoring of alien lightpaths

Typically, optical domains are islands where all elements are managed and controlled by a single operator. Enabling the direct access of the domain to clients is not widely followed, since it opens a back door to the outside world. The friendly lightpaths (managed by the operator) can be affected by any sort of misalignment of the alien (coming from other domains) lightpaths' technology. It is also hard for the aliens to obtain good QoT over an unknown domain, and also for the operator to grant such guarantees unless it knows exactly the transmission parameters of the alien. And this gets worse with recent advancements, where connections can use different modulations formats, and where the spectrum gap between connections is getting smaller with the adoption of flex-grid technology. So dynamic provisioning of aliens looks like an unfavourable feature. However, alien wavelengths enable the sharing of equipment and resources among operators and in this sense can allow new business models similar to those present in wireless networks, increase revenues, reliability and service speed. ORCHESTRA with its advanced monitoring capabilities can provide efficient solutions to a number of QoT issues that arise from alien wavelengths deployment.

2.6 ORCHESTRA concept demonstration

ORCHESTRA's ultimate goal is to bridge the gap between the laboratory and real-world applications and operational environments. To achieve this, ORCHESTRA emphasizes experimental validation throughout its lifetime. Components, software and subsystems will first be proven individually in the lab, before final integration and demonstration in a real-world environment, comprising state-of-the-art commercial optical transport equipment and field-deployed fiber spans at the premises of Telecom Italia lab (TILAB). ORCHESTRA will therefore incorporate the developed blocks (advanced DSP library, impairment correlation algorithms, dynamic optimization procedures, control and monitoring infrastructure) in a series of networking experiments to demonstrate the potential of its solutions.

3. USE CASES

Traditional lightpath provisioning imposes the consideration of abundant margins: (i) unallocated margins when transponders' reach exceeds the transmission distance, (ii) design margins due to unknown parameters of the physical layer, and (iii) system margins to avoid interventions due to aging or particular events (e.g., high interference from latter added connections) [3]. These margins result in the use of more transponders and 3R regenerators that, at the time and under the conditions revealed during the set-up, are not strictly necessary. ORCHESTRA's accurate monitoring plane, together with an efficient and fast acting control mechanism permits to lower these margins, and dynamically identify problems and modify the connection parameters (e.g., modulation format, FEC, or even the path) to adopt and achieve the required signal QoT. If the adaptation cannot fully remedy the problem, additional equipment (e.g., 3R or new transponders) need to be deployed. Ultimately, the investment will be lowered or postponed until really needed (which also results in savings due to lower costs). To enable operation with lower margins, ORCHESTRA will develop a library of offline and online cross-layer optimization algorithms (DEPLOY) and use them in techno-economic studies.

Apart from increasing network capacity, ORCHESTRA targets to also increase the network availability. Continuous, multi-parametric and accurate knowledge of the physical layer can be used, (i) to predict hard failures, such as fiber-cuts [6], (ii) improve hard-failure localization, and (iii) identify certain soft-failures, such as abnormal ASE noise from a failing EDFA, increased OSNR due to aging of equipment, fiber bends and bad connectors, cross-talk and nonlinear interference [10]. On a similar tone, deterioration of the network performance after a failure is fixed, can be identified and circumvented. Alien wavelengths can be also considered in a similar manner, being able to identify and localize whether they are the cause of some soft-failure, e.g., use high launch power, are misaligned, create high crosstalk and nonlinear interference, etc.

4. CONCLUSIONS

ORCHESTRA relies on information provided by coherent transceivers that can be extended, almost for free, to operate as software defined optical performance monitors (soft-OPMs). Novel advanced DSP algorithms for real-time multi-impairment monitoring will be developed that will be combined with a novel hierarchical monitoring plane to handle monitoring information in an efficient and scalable manner. Impairment information from multiple soft-OPMs will be correlated, to provide an even better understanding of the physical layer. The advanced monitoring functions used in optimization procedures will enable true cross-layer optimization, yielding unprecedented network capacity efficiency and higher network availability.

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