CROSS-LAYER, DYNAMIC NETWORK ORCHESTRATION, LEVERAGING SOFTWARE-DEFINED OPTICAL PERFORMANCE MONITORS

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High rate optical transmission with coherent detection has emerged as the most promising approach toward addressing the challenges arising from the explosive and continuous growth of Internet traffic. Multi-rate, multi-flow optical interfaces are under development to overcome the capacity limit of fixed grid DWDM networks, allowing more efficient use of the optical spectrum. Elastic optical networks with configurable multi-carrier optical super-channels and flexible optical nodes are being proposed as a mean to improve network scalability, flexibility and end-to-end performance of optical connections [1].

Taking for example an optical network that serves as the backhaul to a number of access providers, fully dynamic networking technologies will be able to support the gradual expansion of end-user line-rates (or end-user coverage) by means of flexible connections whose line-rates increase in an adaptable manner, and with fine granularity. In such a scenario, the network may have to cope with the issue of overcoming a transmission-reach limit without introducing regeneration, or with the issue of a capacity crunch towards a particular destination that is already provisioned with several randomly allocated legacy channels.

Optimization processes are therefore needed to avoid waste of resources and deployment on new massive or unnecessary investment [2]. These optimization processes involve also traditional provisioning in legacy networks. Often deployed 3R regenerators or high performance systems are not strictly necessary at the time and under the conditions revealed during the set-up. These abundant margins are added beyond the optical reach in order to avoid to need interventions over data channels despite aging or particular events (e.g. maintenance operations during the channel lifetime).

A frequent and accurate monitoring, together with an efficient and fast mechanism of acting (control plane) permits to modify connection parameters (e.g. modulation format, FEC, or even the path) in order to adopt the strictly necessary quality of the signal in any moment, variable during the lifetime of the channel [3]. Of course, this allows the possibility of reducing the margins and, as a consequence, to postpone investments.

However, before an optical network can be subject to optimization, it first has to be observable. Current control and monitoring infrastructure 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; these data, however, are currently not fully exploited.

In this paper we propose a new control and monitoring architecture that relies on the information provided almost for free by the coherent transceivers, which are extended to operate as software defined multi-impairment optical performance monitors (soft-OPM).

General Concept and Vision: the ORCHESTRA Architecture

ORCHESTRA is a dynamically controlled and managed optical network that relies on information provided by coherent optical interfaces, operating in tandem as software defined optical performance monitors (soft-OPM).

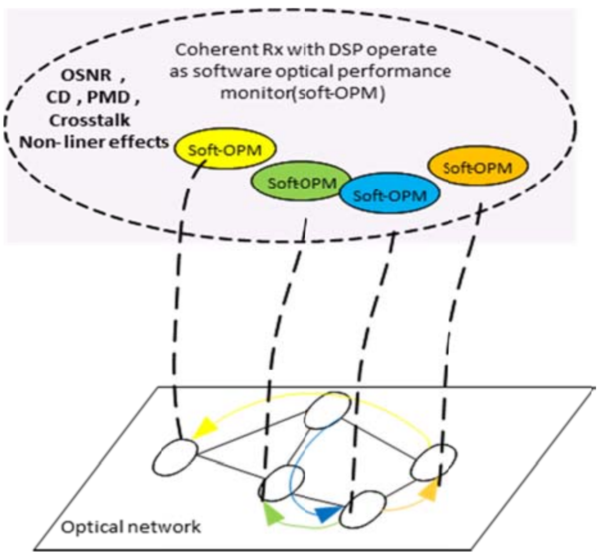

Figure 1: An example of a Soft-OPM architecture

ORCHESTRA network has its applicability in core and backbone optical networks, where high capacity DWDM systems are employed and coherent detection is adopted; however, exploitation of ORCHESTRA paradigm could also be found in future metro networks using sample coherent cards as soft optical monitors also for low rate and low cost direct detection interfaces [4].

Currently, hardware monitors (mainly providing power, CD, DGD and Q^2 values) are used in coherent WDM line-cards for failure and fault recovery purposes. Obtaining accurate, real-time physical layer monitoring information will facilitate correlation analysis between different measures.

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) algorithms, and will take on the challenge of estimating inter-channel linear and nonlinear effects such as cross-phase modulation (XPM) and crosstalk.

Emphasis will be placed on developing DSP schemes that are hardware-efficient, to minimize node controller computation load and 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).

It will also enable, through cross-layer optimization algorithms, the interaction among different entities, such as bandwidth variable transponders, optical amplifiers, and flex-grid colourless and directionless ROADMs. FEC coding gain, Raman pump power, super-channel spectral width, could all be adapted to network needs by predicting the quality of service of new connections (in case of new provisioning), and become self-reacting (self-adjusting, self-organizing and self-healing) in case of degradation, faults and congestion [5].

A hierarchical monitoring control and management plane

In ORCHESTRA scenario, the control plane is organized as a hierarchy of virtual monitoring entities (Figure 2). The virtual entities at the bottom of the hierarchy (leaves) correspond to individual lightpaths, while entities at higher levels include ingress nodes, nodes corresponding to regions, and others, which are related to several (subsets of) lightpaths.

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 that will be enforced at the different levels of the hierarchy by the virtual monitoring entities (Figure 3).

The hierarchy's root is the central ABNO network controller under which all lightpaths in the network reside [6]. Each monitoring virtual entity can take configuration decisions for all the light-paths under it in the hierarchy.

The decisions pertain to several control-dimensions, and in particular: (i) transmission configuration parameters, such as the modulation format, the baudrate, the FEC, filter guardbands, and also (ii) resource allocation parameters, such as the path, the spectrum and the regenerators used.

The hierarchical control plane will handle 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.

Depending on the specific task the control plane will follow certain procedures to solve the problem and optimize the network, procedures that involve in various ways interactions with the physical layer and the soft-OPMs.

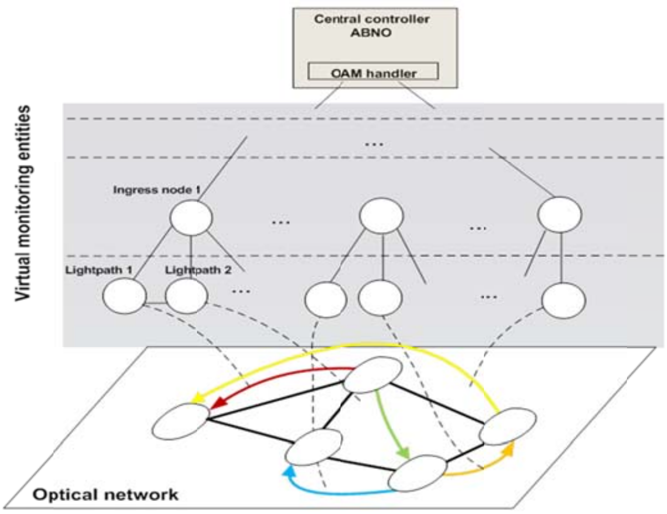

Figure 2: ORCHESTRA's hierarchical control and monitoring (C&M) infrastructure

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 a higher level where actions on more light-paths are allowed, with the network controller being the final level that can interact with all connections.

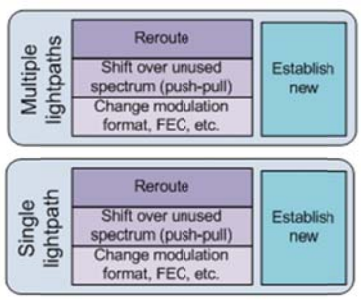

Figure 3: Library of Control Primitives: control actions that can be applied to each virtual entity.

Dynamic optimization procedures and use-cases

With the introduction of optical flexible networking 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, the algorithms designed up till now completely neglect the physical layer or, in the best case, are based on worst-case physical layer estimates and gross margins: interference effects, full load 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. 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 [6].
ORCHESTRA aims to achieve true cross-layer optimization enabling the interaction with the physical layer to obtain any parameter of interest with high accuracy. 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).
True cross-layer optimization lowers the margins of the transceivers, enabling them to use their capabilities to the fullest extent, from day one to end of life.
In fact, systems upgrade is not always a “all in one” process. This means that the upgrade touches single links/node and the upgrade progression can be deferred during particular events when a, even improbable, event of failure facilitated by the upgrade itself can cause huge damage in terms of data loss or brand value (typical events are Olympic games, Expo, …). The result is that during a period (longer than one night) is possible to have “hybrid” optical paths, i.e. composed by links adopting different technologies. Of course this intermediate and unusual situation can benefit of the monitoring and the possibility of fast network reaction assured by the ORCHESTRA mechanism.

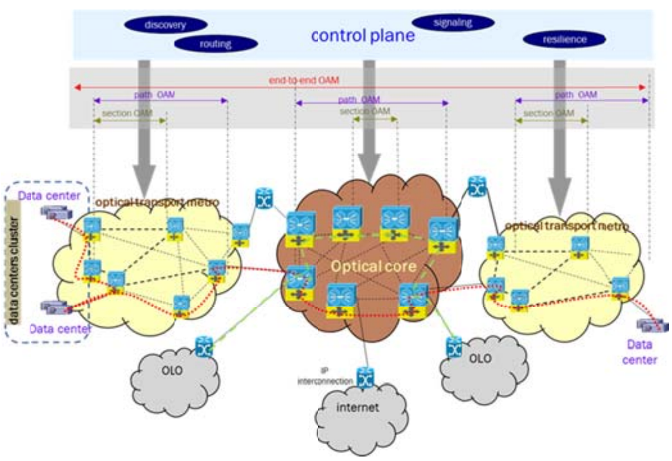

Figure 4: Hybrid optical path in a multi domain environment

“Hybrid” path are also the one crossing different networks domains.
It could be the case of a multi-vendor domain in a single operator network or the case of alien wavelengths in a multi-operator/multi-vendor domain.
Typically, optical domains are islands where everything is managed and controlled by a single operator. Enabling the direct access of the domain to clients is not widely followed, since it opens the back door to the outside world. The former case is usually dealt by OTN transparent framing. A slight digital performance monitoring is embedded in OTN but is not enough to cope with multi-vendor domains of different size as in the scenario shown in Figure 4.
The friendly light-paths (of the operator) can be affected by any sort of misalignment of the alien (coming from other domains) light-paths’ technology. It is also hard for the aliens to obtain good QoT/QoS over an unknown domain, and also for the operator to grand 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 allowing new business models similar to those present in wireless networks, increase revenues, increase reliability and service speed. ORCHESTRA with its advanced monitoring capabilities can provide efficient solutions to a number of quality of transmission issues that arise from alien wavelengths.

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 efficiency and higher network availability.

Acknowledgements

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