Design and Operation Strategies for Optical Transport Networks with Reduced Margins Service-Provisioning

Daniela Moniz[1,2], João Pedro[1,2], João Pires[2]
1 - Infinera Portugal, R. da Garagem 1, 2790-078 Carnaxide, Portugal
2 - Instituto de Telecomunicações, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
dmoniz@infinera.com, jpedro@infinera.com, jpires@lx.it.pt

Abstract: This paper overviews the key architectures and network design and operation solutions to efficiently exploit low margin provisioning in optical transport networks.

1. Introduction

The constant pursuit of ways to extract more capacity at lower cost per bit from optical transport networks leads to the need to exploit automation capabilities to reduce operational expenditures as well as strategies to exploit detailed knowledge of the physical network infrastructure to maximize capacity and reduce capital expenditures [1]. This is empowered by recent advancements in the control plane, flexible transponders and enhanced performance monitoring capabilities. By accurately estimating optical performance, it is possible to leverage forecasting methods to predict its evolution throughout network operation. This enables to develop different design solutions to optimize the network resources adaptively to the current and forecasted network conditions [2,3]. Importantly, understanding the real-time state of optical performance and confidently estimating its evolution will allow to challenge the established practice of designing optical channels to be uninterrupted until the network end-of-life (EoL), which entails using high margins to accommodate the different effects that can degrade performance and/or limit the estimation accuracy (e.g. devices aging and model uncertainties). This static and conservative approach reduces the opportunity of exploiting advanced coherent interfaces to their fullest, preventing the efficient use of their fine-grained capacity, spectral efficiency and reach trade-off (e.g. via modulation format, symbol rate, FEC) to cost-effectively maximize capacity, reducing the capital expenditures (CapEx) [4]. Although there are clear benefits in shifting to provision optical channels with squeezed performance margins, operating transport networks with current-state-of-life (CoL) information will require a different level of network vigilance and automation, since a faster than expected degradation of performance can result in traffic disruption. In order to leverage this potential, innovative architectures and network design applications [5-8] have been proposed with the aim of provisioning channels with reduced margins, while minimizing the probability of traffic disruption due to any channel reaching the minimum acceptable quality-of-transmission (QoT).

This work overviews some of the key aspects to achieve a compromise between transforming margin into capacity while acting proactively to mitigate the risk of operating too close to the performance limit, highlighting the main provisioning strategies proposed in the context of networks operating with reduced margins. The comparative analysis reveals the benefits and drawbacks of each strategy in terms of CapEx savings, network resilience and complexity.

2. Network Planning & Operation with Reduced Margins

The optical channels' QoT can vary significantly along the network lifecycle, in view of different factors, such as long-term aging of network elements, interference from newly set up neighboring channels and sudden failures. In order to ensure the channels' error-free transmission throughout the network operation, additional margins are typically assigned at the beginning-of-life (BoL) to meet the required service level of agreement (SLA) until the network EoL. These safety boundaries are used to accommodate performance model inaccuracies (design margins), transmission channel degradation (transmission margins) and components aging (system margins). However, an overprovisioning of margins can prevent the use of the most cost-effective modulation format that is available when operating with the actual performance at each period of time, as shown in Fig. 1(a). In this example, the deployment of additional margins leads to using 16 quadrature amplitude modulation (QAM), whereas the use of optical channels with sufficient margins according to the CoL would enable to use instead the more spectral efficient 32 QAM.

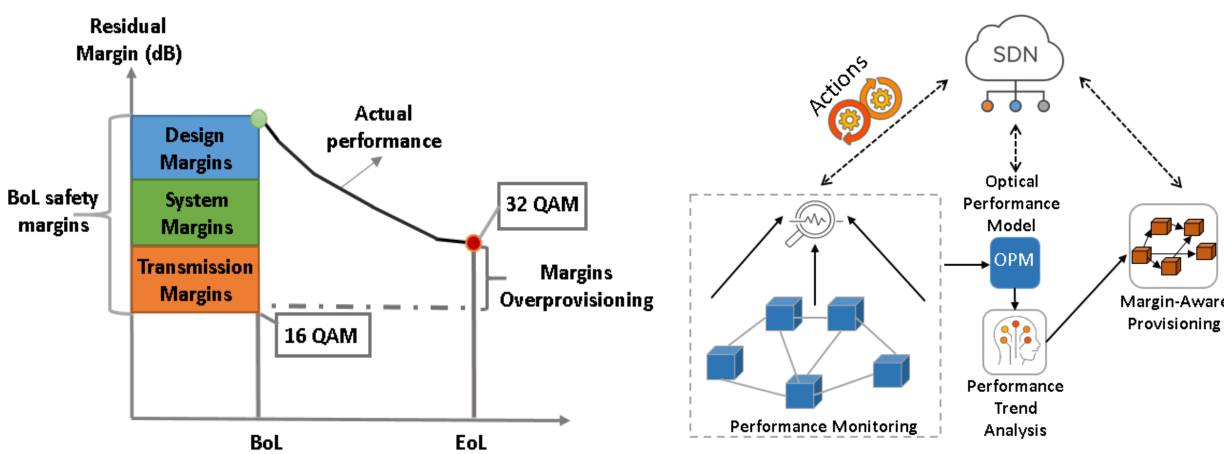
With the aim of reducing optical performance margins, new technologies have been developed exploiting the ability to have access to key physical parameters of the network in order to accurately estimate the current performance and forecast its evolution [2]. By combining this with recent advances in software-defined networking (SDN) and flexible line interfaces, it is possible to set up and operate optical channels with lower margins, thereby increasing the capacity per channel being provisioned and reduce the overall CapEx through minimizing the number of line interfaces that have to be acquired. Fig. 1(b) details the generic network architecture that has to be adopted to provision optical channels with reduced margins. Through constantly monitoring key parameters in the network it is possible not only to accurately assess the QoT of existing channels but also to combine it with an optical performance model (OPM) and trend analysis with the aim of better predicting the performance of future channels. This information is assumed to be accessible to a margin-aware provisioning framework, which optimizes the network resources to be allocated based on the actual and forecasted network conditions. Noteworthy, the deployment of optical channels with reduced margins increases the risk that as a result of evolving conditions (e.g. device or fiber aging) the channel reaches the performance threshold at which point traffic disruption can occur. Hence, it is paramount to enforce an operational model that is natively prepared to manage this risk. For example, the optical network can be fully automated in order to close the optimization loop and act before the performance degrades below an acceptable level. This action, when timely triggered, can avoid disruption of the traffic carried over degraded optical channels.

3. Reduced Margins Provisioning Strategies

In order to exploit the benefits from starting to deploy optical channels over the optical transport network with smaller margins, different provisioning strategies have been proposed [5-8] with the aim of balancing the risk of operating too close to the performance limit with the capacity increase from using more spectral efficient channel formats. The first strategy consists of simply provisioning optical channels with reduced margins and when their performance is reaching the minimum acceptable level using an already scheduled or a new maintenance window (CoL-P MW), where services running over the affected optical channels can be temporarily and safely disrupted while changes take place (e.g., torn down and set up new optical channels) [6]. The second scenario assumes that OTN switching (CoL-P OS) is present in the network nodes with the aim of being capable to reroute traffic demands whenever an optical channel becomes close to the performance limit and has to be torn down [7]. The OTN switches enable to execute the rerouting events in tens of milliseconds (assuming both the old and new optical channels are still active when the reconfiguration takes place), therefore guaranteeing almost hitless rerouting of traffic [9]. The third approach restricts the utilization of reduced margins to shared restoration paths, assuming a more conservative margin stacking for working paths. It exploits the fact that restoration paths are usually active only during the time strictly necessary to fix the source of failures and, consequently, margins such as the ones used to account for device or fiber plant aging are not required (CoL-P SR) [8]. With the aim of gaining insight on the main advantages and drawbacks of each provisioning strategy, Table I highlights the main characteristics of the different strategies considered in this study.

4. Results and Discussion

In order to compare the potential of the aforementioned strategies, this section introduces a detailed network simulation framework, intended to mimic the different characteristics of the provisioning methods through the development of Integer Linear Programming (ILP) models that are executed per planning period of the network operation. The formulation of the ILPs for CoL-P OS and CoL-P MW are based on the models applied in the context of the works described in [7,10], respectively. The ILP for CoL-P SR uses the model presented in [10] with the implementation of additional constraints to support shared restoration. Moreover, the framework also emulates performance degradation through the progressive aging of the network elements, as described in [7]. The study is conducted on a reference network and traffic scenario, defined by Telefónica in the FP7 IDEALIST project with SSMF fiber spans, route & select with colorless add/drop ROADMs, line interfaces operating at 64 Gbaud using 75 GHz frequency slots and supporting modulation formats from QPSK to 64 QAM. The simulation assumes a 10 year network lifecycle with 6

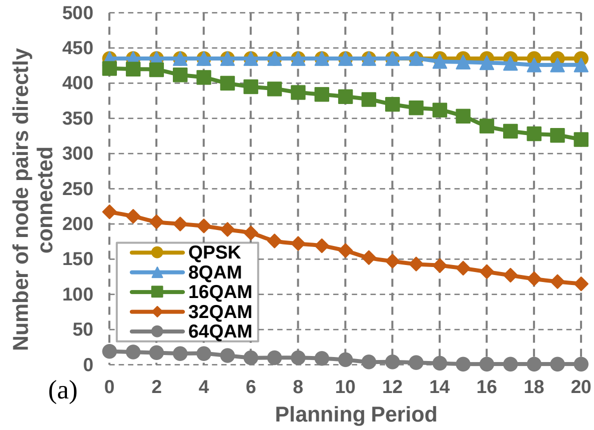


(a) (b)

Fig. .1 (a) Provisioning comparison between margin stacking at BoL and exploiting the actual performance margins and (b) Transport network architecture to provision optical channels with reduced margins.

Table I. Main chacteristics of the reduced margins service provisioning strategies.

Provisioning Strategy	CoL-P MW	CoL-P OS	CoL-P SR
Network Requirements	Any network architecture	With OTN switching	Any network architecture
Traffic Impact	Traffic affecting	Quasi-hitless	Hitless
Reduced Margin Channel Types	All channels	All channels	Restoration channels



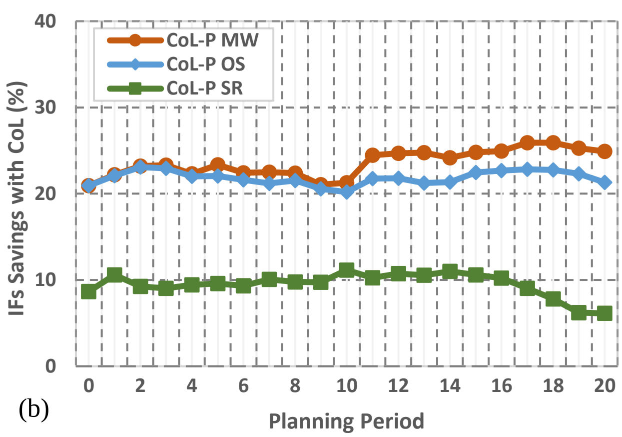


Table II. Impact on running traffic and number of rerouting events for each the provisioning strategy.

Provisioning Strategy	Total Traffic Affected (Tb/s)*	Number of Rerouting Events
CoL-P MW	16.7	0
CoL-P OS	0	82.8
CoL-P SR	0	27.5

* total traffic of 34.4 Tb/s

Fig.2 (a) Number of node pairs directly connected with each modulation format and (b) Evolution of the percentage of interfaces savings when using different provisioning strategies with the currrent-state-of-life performance throughout network operation.

months between planning periods, 100/200/400 Gb/s traffic demands randomly generated between 13% of node-pairs. Traffic demands are routed over one of the available grooming possibilities along the three shortest routing paths.

The first set of results, in Fig. 2(a), shows the impact of the aging model on the possible usage of each modulation format between the network node pairs. As can be seen, there is a gradual decrease in the number of node pairs directly connected, meaning there is room to increase network capacity via using higher order modulation formats at the BoL when using reduced margins. These benefits are quantified in Fig. 2 (b), which depicts the evolution of interface savings throughout the network lifecycle. As expected, it reveals that savings are much smaller with CoL-P SR due to the fact that the reduced margins are only exploited to save regenerators in the restoration channels. However, this is achieved without compromising the running traffic, as shown in Table II. On the other side, the differences between the CoL-P OS and MW strategies in interface savings are a consequence of the traffic reconfigurations via the OTN switches enforced in the former, which require that both the old and new optical channels are still active when the rerouting takes place, eventually imposing additional line interfaces. Despite being the strategy that can best leverage the provisioning of optical channels with reduced margins to increase savings in hardware resources, CoL-P MW is the only approach that demands to temporarily disrupt traffic in order to torn down existing/setup new optical channels, as highlighted in Table II. Moreover, this table also presents the number of rerouting events carried out during the network operation for both CoL-P SR/OS scenarios, emphasizing that the number of these events is smaller when reduced margins are only exploited to provision restoration channels.

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