Network Design Framework Exploiting Low-Margin Provisioning of Optical Shared Restoration Resources

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Abstract: This paper proposes a network design framework tailored to support optical restoration with low-margins by exploiting real-time performance monitoring. Simulation results highlight that it enables resource savings without additional risks of traffic disruption.

1. Introduction

The optical transport landscape is changing due to the bandwidth growth and increasingly dynamic traffic flows [1]. In addition to the aim of operating the optical infrastructure at the highest possible capacity per channel being deployed (e.g. 800 Gbit/s per channel), it is also paramount to evolve towards a more autonomous network in order to cope with the operational challenges resulting from the support of emerging services (e.g. 5G) [2]. The embedding of further automation within the network operation coupled with improved monitoring of key physical parameters provides the opportunity to manage the network and provision resources in a more cost-effective and adaptive way. Particularly, the awareness of current optical performance enables to accurately estimate the quality-of-transmission (QoT) of optical channels, allowing to confidently provision them with margins smaller than the ones typically used, which rely on conservative/worst case figures for the different effects that degrade performance (e.g., fiber plant and components aging, model uncertainties) until the service end-of-life (EoL). The shrinking of performance margins will eventually increase the capacity per channel being deployed, leading to a reduction in the capital expenditures (CAPEX), as shown in several recent studies [3-5]. However, since optical channels usually have a long time-to-live, operating the network closer to the performance limit may require sophisticated procedures to quickly detect and react to a faster than expected degradation of performance in order to avoid traffic disruption [5]. This may entail traffic rerouting, down-grade of modulation format or manual interventions through scheduling a maintenance window. In each case, these actions could evolve additional operational and equipment costs which may not be desirable, or even acceptable, by the network operator, limiting the prospects of adopting service provisioning strategies exploiting reduced margins.

Unlike working (and protection) optical channels, which are active during the entire duration of the services they carry, restoration channels are idle the vast majority of time, only being active for the time required to fix eventual failures. Therefore, a more aggressive reduction of performance margins can be adopted for these channels. This paper proposes a service provisioning framework that exploits the availability of real-time performance data to provision optical restoration paths with low-margins, while assuming a conservative margin stacking for working paths. Simulation results over two reference transport networks highlight the benefits in terms of reducing the number of regenerators required to provision the optical restoration paths, which enable to reduce the overall network CAPEX without increasing the risk of traffic disruption or having to support sophisticated reconfiguration mechanisms.

2. Service Provisioning Framework & Operation with Reduced Margins

Advanced performance monitoring and automation procedures are underpinning the evolution towards a more dynamic optical transport network capable of efficiently supporting the demanding applications of tomorrow. The availability of current state-of-life (CoL) performance data is key to mitigate the uncertainty associated to the state of components, aging effects and optical performance model inaccuracies [4]. Hence, optical channels can be set up with smaller performance margins while still ensuring error-free operation until EoL. However, the extent of margin reduction depends on the risk the network operator is willing to accept with respect to faster than expected performance degradation. For traditional working and protection channels, given their long time-to-live, larger margin reductions are only acceptable if an advanced, and more expensive, network architecture and management/control system is prepared to proactively handle rapid deterioration of performance [5]. Otherwise, fairly large margins still need to be considered. Conversely, low-margin

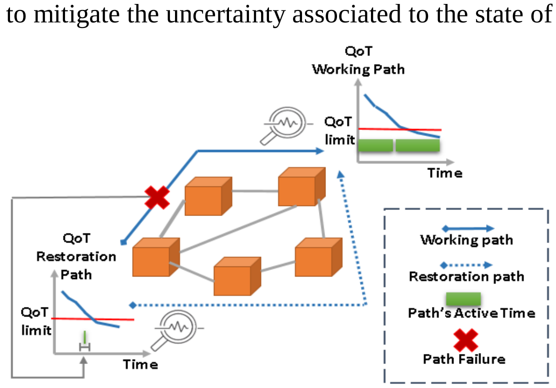

Fig. 1. Optical restoration with reduced performance margins.

provisioning can easily be exploited for restoration channels since: (i) they are active for very short periods of time and, as a result, long-term effects such as aging do not need to be considered in this time span; and (ii) they are idle most of the time, enabling to constantly monitor performance and, when needed, add extra 3R regenerators for restoration without disrupting the (active) working and protection channels [6]. Adopting smaller margins allows to deploy fewer shared regenerators over the typically longer restoration paths, minimization the overall CAPEX.

In this context, the proposed service provisioning framework provisions working paths with conventional EoL margins (including a 3 dB system margin) and restoration paths with CoL margins. It assumes optical restoration constrains both working and restoration paths to use the same modulation format, since they share the line interfaces deployed at the end nodes. Additional shared 3R regenerators are added to the restoration path in order to guarantee sufficiently high QoT. The multi-period framework is run at the start of each planning period and considers all new traffic demands to be routed within the current planning period and also the already routed traffic demands traversing optical channels whose restoration path QoT is near the limit. Particularly, a novel Integer Linear Programming (ILP) model is executed to route the new traffic demands such that the available capacity of deployed optical channels is utilized and the number of line interfaces and regenerators that have to be acquired are minimized. Simultaneously, the algorithm also reroutes the traffic demands running out of margin in their restoration paths and gives priority to obtain a solution occupying the minimum number of frequency slots. In order to reduce the complexity of the ILP model, spectrum assignment is performed afterwards, using the first-fit algorithm and taking into account the shared spectrum in the restoration paths. The ILP model is defined as:

Variables

$\boldsymbol{x}_{\boldsymbol{d}_{(s,t)}}^{\boldsymbol{l}_{(i,j)}} \in \mathbb{N}^{\mathbf{0}}$- number of traffic demands from type $d \in D$ between source node s and destination node t using the optical channel $l \in L$ with source node i and destination node j.
$\boldsymbol{\theta}_{\boldsymbol{l}} \in \mathbb{N}^{\mathbf{0}}$- number of optical channels required from type $l \in L$.
$\boldsymbol{\sigma}_{\boldsymbol{v}}^{\boldsymbol{e}} \in \mathbb{N}^{\mathbf{0}}$- total number of restoration channels with end-node $v \in V$ affected when the network link $e \in E$ fails.
$\boldsymbol{\varphi}_{\boldsymbol{v}} \in \mathbb{N}^{\mathbf{0}}$- total number of line interfaces for shared regeneration required per network node $v \in V$.
$\boldsymbol{\beta} \in \mathbb{N}^{\mathbf{0}}$- total number of network resources required.
$\boldsymbol{\alpha} \in \mathbb{N}^{\mathbf{0}}$- amount of spectrum occupied.

Parameters

$\boldsymbol{D}$ - set of traffic demands, where $\boldsymbol{D_i}$ are the demands already assigned in previous periods, $\boldsymbol{D_n}$ represents the set of new demands and $\boldsymbol{D_r}$ represents the set of demands that are carried by an optical channel running out of margin in restoration path.
$\boldsymbol{L}$ - set of optical channels, where $\boldsymbol{L_i}$ represents the set of optical channels already assigned in previous periods and $\boldsymbol{L_e}$ is the set of optical channels that traverse the network link $e \in E$.

$\boldsymbol{W_{d,l}}$ – total number of traffic demands from type $d \in D_i$ that use the optical channel $l \in L_i$ in the previous planning periods.
$\boldsymbol{F_l}$ - total number of frequency slots used to deploy the optical channel $l \in L$. $\boldsymbol{F}$- number of frequency slots available per network link. $\boldsymbol{S_d}$ -number of ODU slots to groom $d \in D$.

Service-Provisioning ILP Model

$$\min \boldsymbol{\beta} + \frac{\boldsymbol{\alpha}}{|\boldsymbol{E}| \times \boldsymbol{F}} \tag{1}$$

$$x_d^l = W_{d,l} \qquad \forall d \in D_i, \forall l \in L_i \tag{2}$$

$$\sum_{l \in L_{i,j=v}} x_{d_{(s,t)}}^{l_{(i,j)}} - \sum_{l \in L_{i=v,j}} x_{d_{(s,t)}}^{l_{(i,j)}} = \begin{cases} -N_d, & v = s \\ N_d, & v = d \\ 0, \forall v \in V \backslash \{s, d\} \end{cases} \quad \forall d \in D_n, D_r \tag{3}$$

$$\sum_{d \in D} S_d \times x_d^l \leq S_l \times \theta_l \qquad \forall l \in L \tag{4}$$

$$\sum_{l \in L_e} \boldsymbol{F_l} \times \theta_l \leq F \qquad \forall e \in E \tag{5}$$

$$\sum_{l \in L_v^e} \theta_l = \sigma_v^e \qquad \forall e \in E, \forall v \in V \tag{6}$$

$$\varphi_v \geq \sigma_v^e \qquad \forall e \in E, \forall v \in V \tag{7}$$

$$\sum_{l \in L} 2 \times \theta_l + \sum_{v \in V} \varphi_v = \beta \tag{8}$$

$$\sum_{e \in E} \sum_{l \in L_e} \boldsymbol{F_l} \times \theta_l = \alpha \tag{9}$$

$\boldsymbol{S_l}$ - number of ODU slots supported by optical channel $l \in L$.
$\boldsymbol{L_v^e}$- set of optical channels $l \in L$ that require a regenerator at network node $v \in V$ in their restoration path using the network link $e \in E$.
$\boldsymbol{N_d}$ - total number of traffic demands from type $d \in D$.
$\boldsymbol{V}$ - set of nodes; $\boldsymbol{E}$ - set of network links.

(1) consists of minimizing the hardware resources (line interfaces and regenerators) that have to be acquired and also has a secondary objective to minimize the number of frequency slots used.
(2) enforce that the traffic demands already deployed in previous planning periods and that do not need to be re-optimized are kept in the same optical channels.
(3) guarantee the general flow conservation for the new set of traffic demands and the ones that need to change the restoration path due to performance limitations.
(4) ensure the optical channel capacity restrictions.
(5) guarantee that total number of frequency slots used does not exceed the link capacity.
(6) compute the number of shared regenerators required at each network node in case that a specific network link fails.
(7) calculate the maximum number of regenerators that have to be deployed per network node.
(8) and **(9)** compute the total number of interfaces required and the total amount of spectrum utilized, respectively.

4. Network Scenario, Results & Discussion

In order to gain insight into the potential benefits of adopting the proposed framework, performance degradation was emulated based on the (fiber, ROADM and line interface) aging model presented in [5]. The study assumes three design scenarios: (i) the proposed framework with provisioning of EoL and CoL margins for working and restoration paths, respectively (SR-CoL); (ii) the conventional provisioning with EoL margins for both working and restoration paths (SR-EoL); and (iii) also assumes EoL margins but dedicated protection instead of shared restoration (DP-EoL). The study is conducted over the 30- and 44- node transport networks covering Spain (SBN) and Italy (IBN), as defined in the FP7 IDEALIST project, using line interfaces operating at 64 Gbaud and supporting modulation formats from

QPSK to 64 QAM and 75 GHz of frequency slots. The simulation assumes 10 year network lifecycle with 6 months between planning periods, 100/200/400 traffic demands randomly generated between 20% of the node pairs and a 20% traffic increase and 10% traffic churn per planning period.

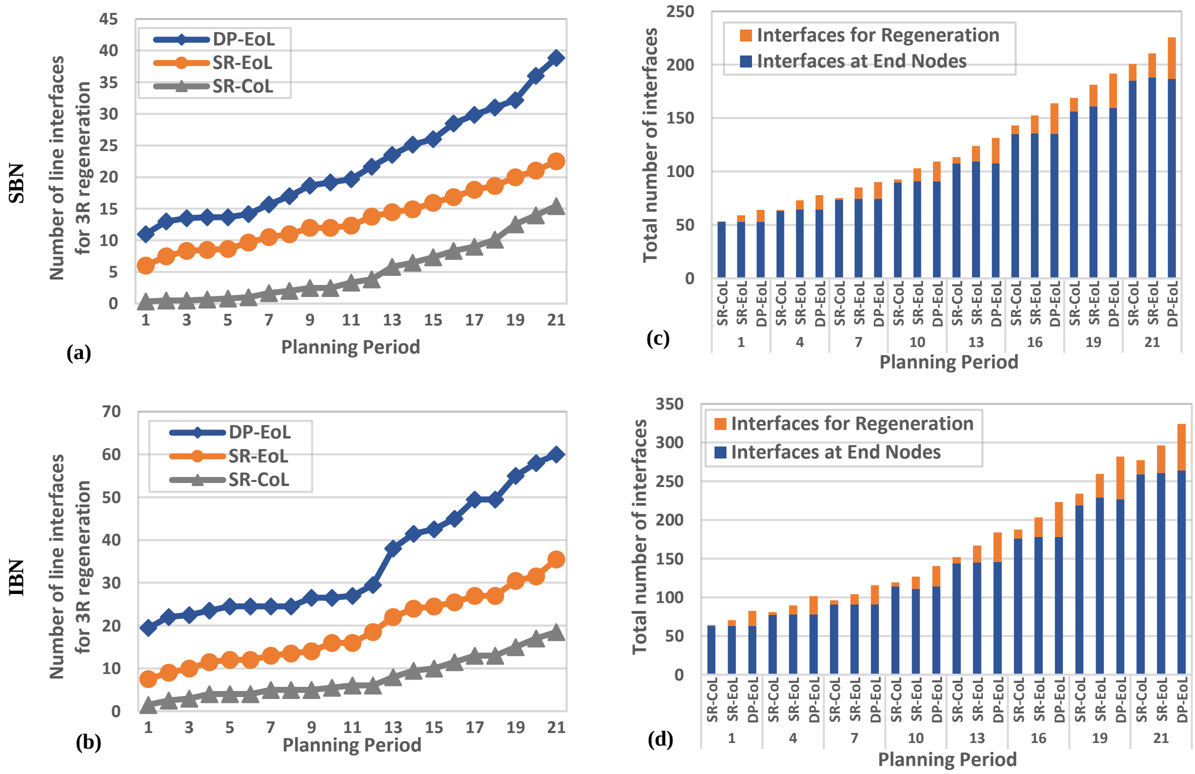

Fig. 2. (a-b) Evolution of the number of line interfaces that have to be deployed for regeneration in the backup paths and (c-d) evolution of the total number of line interfaces that have to be acquired throughout network operation for both network topologies.

The cumulative number of line interfaces for 3R regeneration deployed in the backup paths are plotted in Fig. 2 (a-b) for both network topologies. Firstly, it can be seen that there is a clear benefit from using shared restoration instead of dedicated protection, since for the same provisioning margins it allows to reduce the number of regenerator resources by up to 42% in both network topologies. Secondly, using CoL instead of EoL margins in the restoration paths results in additional savings in the number of regenerators deployed of around 31% for SBN and 48% for IBN in the last planning period. The larger savings obtained with IBN, when compared to SBN, are a consequence of the fact that paths are on average longer in IBN, impacting not only the number of regenerators but also the margins, which are usually a function of the path fiber length and the number of network elements traversed. Importantly, the reported savings in both networks are attained while also reducing the total number of line interfaces required to transport all traffic demands. As shown in Fig. 2 (c-d), the SR-CoL strategy always leads to the lowest total line interface count. Interestingly, it can be observed that in some cases there is a slight increase in the number of line interfaces used at the end nodes of the working/backup paths. This is due to the fact that the provisioning algorithm enforces a global optimization, minimizing the total number of line interfaces irrespective of whether they are deployed at the paths' end nodes or used for regeneration at intermediate nodes of the backup paths.

5. Conclusions

This paper presented a network design framework to exploit the real-time performance monitoring to cost-effectively operate shared restoration paths with reduced margins. Simulation results over two reference transport networks highlight the significant reduction in the number of network resources deployed to ensure network survivability.

Acknowledgments

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6. References

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