Actual Margins Algorithm for Multi-Period Planning

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Abstract: We present an algorithm that provisions lightpaths considering the actual physical performance and use it in a multi-period planning scenario to postpone equipment deployment. This, yields savings compared to current provisioning practice with End-Of-Life margins.

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1. Introduction

The Quality of Transmission (QoT) of the lightpaths (optical connections) is affected by the so-called physical layer impairments (PLIs). To achieve feasible communication over a lightpath, the QoT has to be acceptable (above a specific threshold). However, the PLIs and the QoT are not constant and vary with time, due to short, mid and long-term phenomena. Equipment ageing and maintenance operations (e.g., reparation of fiber cuts) accumulate additional and sometimes irregular deteriorations. Moreover, the existence and the characteristics of neighboring lightpaths [interference PLIs, such as crosstalk (XT), cross-phase modulation (XPM), and four-wave-mixing (FWM)] affect the lightpaths [1]. Interference typically becomes worse with time, as the load increases and new lightpaths are established.

To account for these anticipated deteriorations of the QoT, operators provision lightpaths for what is called the End-Of-Life (EOL) performance, that is, with high margins guaranteeing error-free communication under worst-case interference and ageing. EOL margins are typically calculated with the assumption of a fully loaded network and with equipment performance as expected to be after several (say, 10) years. Extra margins (design margins) are put to cope with inaccuracies in the QoT estimation methods.

In reality, however, the network operates most of the time far away from the EOL conditions and the ageing/interference effects play a major role only during the latest years. The high EOL margins result in reduced optical reach, requiring the deployment of more robust transceivers and a higher number of regenerators than is necessary at the time of installation (Begin of Life – BOL). ORCHESTRA [2] envisions a network that observes (through optical performance monitors -OPM) the physical layer and adapts/optimizes itself accordingly. In such an environment, operators can provision the lightpaths with reduced/actual margins. This yields increased efficiency and postpones the deployment of equipment until they are actually needed [3],[4],[5]. Provisioning with reduced margins becomes more relevant with the deployment of coherent receivers and the arrival of elastic optical networks (EON). Flexible transceivers, also referred to as bandwidth variable transceivers (BVTs) [2], allow multiple transmission options chosen to fit traffic requirements [3]. Operators can tune such transceivers, as the network evolves, to account for deterioration due to ageing or interference.

In this paper, we present an ageing model and a cost model appropriate for evaluating the benefits of postponing the purchase of equipment through network state observation. We then present an algorithm to provision lightpaths accounting for the actual physical layer conditions (reduced margins). This algorithm is suitable for incrementally planning a network over multiple periods, postponing the deployment of equipment. This, along with equipment depreciation, yields substantial cost savings compared to provisioning with EOL margins.

2. Ageing Model

A key factor affecting the lightpaths' QoT is the degradation caused by equipment ageing. The main components whose performance deteriorates with time are the transceivers, the fibers and the EDFAs. We assume that ageing affects the fiber attenuation parameter $a_{loss}(\tau)$, modeled as a (linear or non-linear) function of time τ. The attenuation depends also on the traversed number of connectors and splices. Typically, connectors are placed at both ends of the link, while the number of splices depends on the type of network, the failures, etc. Connector's loss $c_{loss}(\tau)$, splice loss $s_{loss}(\tau)$ and number of splices $z_e(\tau)$ in a span e are modelled as functions of time. We assume that the span loss is completely compensated by the EDFA at the end of the span, whose noise figure $N(\tau)$ deteriorates with time. In a similar approach, we model the ageing effect of an optical switch (ROADM) as noise power. In particular, we assumed that passing, dropping, and adding traffic requires 3 WSSs (instead of 2, 3, 3 WSSs, respectively) and 2 EDFAs (instead of 1, 2, 2 EDFAs, respectively). In Table 1 we report the noise contribution of a switch A_n, assuming standard conditions and a noise figure of 5 dB for the EDFAs. We also model the ageing of the transceiver with a margin $M_T(\tau)$. Finally, when calculating the QoT of each lightpath, we also assume a design margin $M_d(\tau)$ to account for QoT calculation uncertainties (effects that are not considered due to inaccurate knowledge of the physical layer) and to also avoid operating right at the limit. Table 1 shows reference BOL and EOL values for the aforementioned parameters, while Table 3 presents the acceptable reaches for a flexible transponder. The reaches are calculated for BOL and EOL ageing parameters and without interference or with worst case interference.

To decide whether a lightpath is feasible we take into account the above parameters for the given time instant and the actual utilization of links, and we use the GN model [6] to calculate the SNR and compare it to the related threshold (defined by the used FEC).

3. Cost model

Provisioning lightpaths with reduced margins allows the utilization of less network equipment at the starting and at intermediate instants of the network's lifetime. We examine the incremental multi-period network planning problem [7], where we install new equipment at each period, depending on the new traffic and on the feasibility of the established lightpaths. We compare two scenarios, provisioning with (i) EOL margins and (ii) reduced margins. In the former, we add equipment at intermediate periods only to serve the new traffic itself, since increased interference and ageing do not affect the established lightpaths. On the other hand, in the latter scenario, we add equipment to account also for QoT problems that appear with the evolution of the network. Note that the latter scenario can also require an extra initial cost for monitoring the QoT (OPMs) [2] to estimate the actual network conditions.

Deterioration	**BOL**	**EOL**
α_{loss} (dB/Km)	0.22	0.24
c_{loss} (dB)	0.20	0.30
s_{loss} (dB)	0.60	0.60
N_e (dB)	4.50	5.50
A_n(dB)	20.00	23.00
M_d (dB/lightpath)	2.00	2.00
M_T (dB)	0.00	0.50

Table 1. Parameters BOL and EOL values**.**

.Network element	**Unitary price (C.U.)**
40 Gbps fixed transceiver/ regenerator	0.60
100 Gbps fixed transceiver/ regenerator	1.00
200 Gbps fixed transceiver/ regenerator	1.20
400 Gbps fixed transceiver/ regenerator	1.36
Flexible transceiver/ regenerator	1.75
EDFA	0.15
WSS (1x20)	0.30
WSS (1x9)	0.20

Table 2. Relative prices of equipment values at time τ_0.

The incremental cost of the devices that are required in the reduced margins scenario allows savings with respect to EOL margins scenario, because these devices may never need to be placed, or their cost may have decreased by the time they are used. Finally, we can also take into account the revaluation (interest) of saved money.

Regarding the price evolution of equipment $c(\tau)$ (transceivers, regenerators, switches, etc.) at time instant τ, we have assumed Wright's Cumulative Average Model [7] based on learning curve:

$$c(\tau) = c(\tau_0)\cdot(u(\tau))^{\log_2 R}, \tag{1}$$

where $c(\tau_0)$ is the initial price, $u(\tau)$ the cumulative number of units produced until time τ, and R the learning rate expressed as decimal. Table 4 shows the calculations for the price of a 100G transceiver based on units projection according to [8].

Datarate (Gbps)	Spectrum Slots	BaudRate (symbols/s)	Bit rate	Modulation Format	BOL ageing -no interference reach (Km)	BOL ageing - worst case interference reach (Km)	EOL ageing - no interference reach (km)	EOL ageing - worst case interference reach(Km)
100	2	16	128	DP-16QAM	1900	1200	700	600
100	3	32	128	DP-QPSK	5900	4500	1800	1700
100	6	64	128	DP-BPSK	6900	6100	1900	1900
200	3	32	256	DP-16QAM	1300	1000	400	300
200	6	64	256	DP-QPSK	3400	3000	900	900
400	5	51	510	DP-32QAM	400	400	100	100
400	6	64	512	DP-16QAM	700	600	200	200

Table 3. Transmission tuples of the 400 Gbps BVT, and the corresponding best and worst case reaches assuming 1dBm launch power and LDPC FEC.

Year	**Units (K)**	**Price (C.U.)**
τ_0	8	1
τ_2	10	0.61
τ_4	12	0.51
τ_6	12	0.45
τ_8	10	0.42
τ_{10}	8	0.40

Table 4. Forecasted number of 100Gbps units and resulting price for R=0.85.

4. Lightpaths provisioning algorithm

To provision lightpaths with reduced margins we developed a heuristic algorithm. The algorithm consists of a pre-processing phase, which calculates the set $Q_{s,d}$ of candidate (path p, transmission tuple t, regeneration points r) triples that can be used to serve a demand from s to d. Since the transmission reach depends on the current network state (including ageing and interference, Table 3), we create different triples for the possible set of nodes where regenerators may be placed, taking into account only the ageing effects. Then, the algorithm serves the demands one-by-one in a particular order. For each demand, it considers the pre-calculated (p,t,r) triples, and for a given triple, considering the related regeneration points, the algorithm allocates spectrum to the sub-paths (transparent lightpaths). Then it uses the Q-Tool (e.g. GN model) with input the current utilization of the links to account for actual interference, in order to determine (i) if this sub-path has unacceptable QoT or (ii) if it turns infeasible some previously established lightpath. If the answer to any of the two questions is yes, the algorithm searches for a different spectrum allocation, examining also cases with spectrum guardband between the lightpaths, to reduce interference. We repeat the above process for all sub-paths, and when it is successful, the algorithm considers the triple as feasible. If not successful, it continues with the next triple. After examining all the triples for that demand, we select the one whose spectrum allocation minimizes the objective:

$$\underset{(p,t,r)\in Q_{s,d}}{\text{Min}} \left(w\cdot S_{p,r,t}(\tau) + \ (1\text{-}w)\cdot C_{p,r,t}(\tau)\right), \tag{2}$$

where $C_{p,t,r}(\tau_i)$ is the cost of triple (p,t,r) calculated by adding the prices $c(\tau)$ of equipment added in this period (the cost of equipment in this period is given by Eq (1)), $S_{p,t,r}(\tau_i)$ is the total spectrum required by this triple, and w is a weight used to give the desired relative importance to the two optimization parameters.

5. Performance Results

We considered two network scenarios: an Elastic Optical Network (EON) and a fixed-grid (WDM) mixed-line rate (MLR). The transceivers assumed in each case are: (i) BVT and (ii) MLR fixed transceivers with 0 dBm launch power and LDPC SD-FEC, with 21.2% overhead and net coding gain 11.27dB at an output BER of 10^{-13}. The width of the spectrum slot (wavelength) was taken to be 12.5 GHz (50 GHz) and 320 (80) slots (wavelengths)/fiber for the EON (WDM) network setting. For our study we used a topology inspired by the Telecom Italia European backbone with fixed or flex-grid ROADM and uncompensated SMF links. In EON, we assumed that filters are tuned to 1.2xbaud-rate of the lightpath.

For all spans, we assumed length equal to 100 km, with an EDFA following each span to compensate the losses. We also assumed total traffic varying from 20 to 186.3Gbps in 10 periods with 25% compound growth rate per period. The supported client rates vary between (100, 200, 400) Gbps and each one is matched with an equal line rate transceiver. We carried out a multi-period incremental analysis for 10 periods and we present the results with a step of 2 periods. To model the physical layer we assumed the GN model with an extension to consider the ageing effect as described above. The prices of equipment at τ_0 are shown in Table 4, relative to the price at τ_0 of a 100 Gbps fixed transceiver (taken to be 1 C.U.). These were taken as reference (τ_0) in the cost model to calculate the depreciation (Eq. 1) as a function of time.

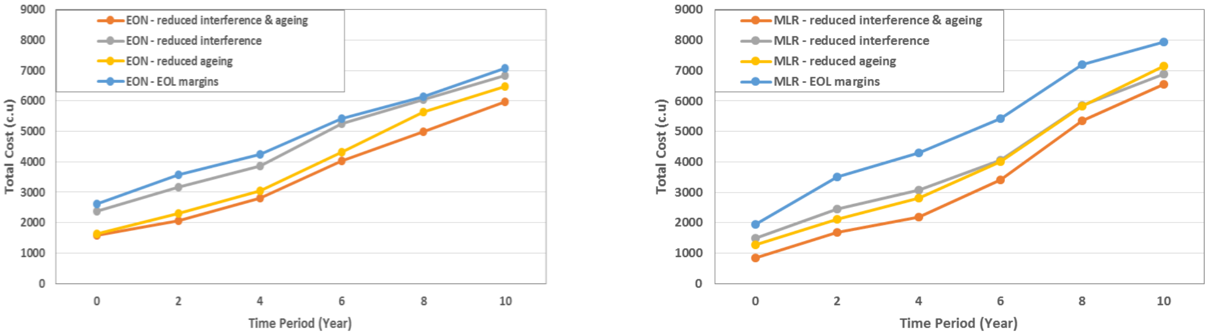

Figure 1. The accumulated total cost (in C.U.) for the (a) Elastic, (b) MLR network for the different planning scenarios.

We compare planning with (i) End-of-Life (EOL) margins and (ii)reduced margins with the following options: (ii.a) reduced interference margins and worst case ageing, (ii.b) reduced ageing margins and worst case interference, and (ii.c) reduced interference and ageing margins (the proposed solution). Fig. 1 shows the related results. As expected, when planning with EOL margins, the network uses expensive transceivers and regenerators from the first day of operation due to the worst case assumptions. After that, the cost increases with lower rate compared to the reduced margins planning cases, but remains higher at the end. We observe that for both network types (MLR and EON) the reduced interference and ageing margins case outperforms the others. Thereafter the interference degradation does not affect significantly the network at the early periods. As time passes, the difference from the reduced interference margins case decreases, implying that the network degradation due to ageing is more significant than the transmission reach degradation that is due to interference effects, at the latter periods. The worst performance is exhibited by planning with EOL margins, since the transmission capabilities of the transponders correspond to those presented in the EOL ageing and interference column of Table 1 from the first time period. So, when planning with EOL margins, the network uses more expensive transponders and regenerators from the first day of operation. Although the cost increases with lower rate as time passes, at the end of the examined period the accumulated cost is higher. Note that we assumed a design margin (2dB) that does not change as time advances, while a network employing OPMs can also reduce this margin [5], and thus the improvements can be even higher.

6. Conclusions

Planning with reduced margins requires optical performance monitors and an appropriate algorithm that accounts for the actual (ageing and interference) conditions of the network. We presented such an algorithm and used it in a multi-period planning scenario. For realistic network and price projections, we observed savings up to 16% for an EON and 24% for an MLR network, over the case of planning with End-of-Life margins.

Acknowledgments

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