Faster return of investment in WDM networks when elastic transponders dynamically fit ageing of link margins

Jelena Pesic(1), Thierry Zami(2), Petros Ramantanis(1), Sébastien Bigo(1)
(1) Alcatel-Lucent Bell Labs France, (2) Alcatel-Lucent France, Route de Villejust, 91620 Nozay, France
Jelena.Pesic@alcatel-lucent.com

Abstract: We illustrate the cost reduction during 10-year life of a core WDM network enabled by elastic transponders when accounting directly for end-of-life OSNR detection margins, compared to margins progressively growing with network ageing.
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1. Introduction

In WDM networks, link margins (LM) [1] are necessary to maintain a satisfying quality of transmission even after several cable cuts, where each cut yields additional attenuation or if the network features are not known with enough accuracy. It is also helpful to better withstand the ageing of the network elements and the time varying impairments such as fast changes of polarization of light. However, when too large, LM can significantly shorten the transmission reach of the WDM channels. The recent advent of elastic optical transponders (EOT) [2] introduced a new paradigm, where EOTs dynamically change their modulation format to minimize LM with respect to the network ageing. Thus, operators like France Telecom and British Telecom have recently showed interest in EOT to reduce LM in their networks [1, 3]. In this study, we model the progressive ageing of the optical transmission link in a timely manner during 10 years and we quantify the benefits of dynamically fitting the EOT modulation to the physical network quality, assuming ideal LM monitoring. We report such a benchmarking with adaptive LM applied to the Kaleidon, Italian WDM network for different throughputs, traffic growing rates and yearly EOT cost erosions.

2. Network and physical assumptions

Kaleidon [4] is a 44-node Italian backbone network, not reported here, covering the whole Italian territory. It is equipped with WDM links carrying up to eighty 50 GHz-spaced channels and with optical cross connects (OXC) based on broadcast-and-select layout [5], so that each channel in transit goes through exactly one filtering function per traversed node. We investigate the planning of this network assuming only transparent signal transmission along the light paths (LP) without regeneration, connecting all pairs of nodes in the network and relying upon EOTs supporting 3 different modulation formats: 100 Gb/s PDM-QPSK, 150 Gb/s PDM-8QAM and 200 Gb/s PDM-16QAM modulated at 32 GBaud with SDFEC [6]. For each pair of nodes, we consider the 5 associated shortest paths, in terms of distance, bridging the 2 nodes. Hence, we handle 5x44x43/2=4730 distinct LPs. Each LP is a concatenation of spans composed of single-mode fiber with 16.7 ps/nm/km chromatic dispersion (CD) and 0.25 dB/km attenuation, followed by a line optical erbium doped fiber amplifier (EDFA) and without in-line compensation of cumulated CD. In our calculations, the losses for crossing OXC are assumed to be 20 dB. The received signal to noise ratio (SNR) after propagation along the LP, including both linear and nonlinear noise and directly derived from optical SNR (OSNR) in 0.1 nm, can be expressed as in [6]:

$$SNR = \frac{P}{P_{ASE} + \alpha_{NL} P^3} \qquad (1) \qquad\qquad P_{ASE} = h\,\nu \cdot NF \cdot G \cdot B \qquad (2)$$

where P is the channel power at the input of each transmission fiber section, P_{ASE} is the amplified spontaneous emission power from the optical amplifiers expressed as in (2), h is Planck's constant, ν is the optical carrier frequency, NF is the amplifier noise figure, G is the amplifier gain (equal to the span loss), B is 12.48 GHz (0.1nm) and α_{NL} is the nonlinear interference coefficient that depends on the Baud-rate, span length and fiber CD. Applying model from [6], for each LP we calculate the corresponding SNR given by (1). Each modulation format has its own associated SNR requirement for error free SDFEC decoding. Besides, in practice this decoding would also indicate the actual LM. Target OSNR required in 0.1 nm for 100 Gb/s PDM-QPSK is 11 dB [7] while for 150 Gb/s PDM-8QAM and 200 Gb/s PDM-16QAM OSNR values are 15 dB and 18 dB, respectively [6]. Therefore, 100 Gb/s PDM-QPSK carriers can propagate transparently along 3100 km whereas transmission reaches for 150 Gb/s PDM-8QAM and 200 Gb/s PDM-16QAM are 1300 km and 600 km, respectively. To each connection we assign the modulation format enabling sufficient performance along its LP while maximizing its spectral efficiency. When the transmission conditions change due to the equipment/network ageing, each EOT could adapt its modulation format to recover enough LM by lowering spectral efficiency and transporting less capacity. Any remaining capacity will be transported by means of new installed EOTs. For example, at some point, to a given connection would be assigned the PDM-16QAM format along its LP. Later on, this channel capacity could be scaled down to PDM-8QAM supporting 150 Gb/s due to ageing. Another EOT carrying 150 Gb/s should be then added to serve the residual 50 Gb/s along the same LP.

3. Model of ageing link margins (LM)

We consider four contributions to the ageing of LM: fiber ageing (fiber cuts), OXC ageing, EOT ageing, and EDFA ageing. Each one of these elements is explained with its contributions in Table 1. Value in column BoL (EoL) represents contribution of the network element to the begin-of-life (end-of-life, after 10 years) LM respectively, while value in the column "yearly ageing step" represents the corresponding step value added each year.

Fiber ageing is expressed in terms of fiber cuts. Each time the fiber is cut, additional attenuation is introduced caused by repairing splicing process. Starting from [8] that reports 4.39 cuts/year/1000 miles, we model the yearly additional fiber attenuation of 0.00163669 dB/km. This implies that fiber ageing will strongly depend on the fiber plant length. *OXC ageing* is reflected through the filtering ageing originating from the progressive possible relative detuning between the optical frequency of the carriers and the center frequencies of the filtering and blocking spectral transfer functions of the traversed OXCs. This is why we assume the OSNR penalty associated to passing through one filter degrades with time, as indicated in Table 1. This also means the contribution of the OXC ageing in our model depends on the number of OXCs crossed by the LP of the signal. *EOT ageing* is reflected through the need of higher OSNR target values at EoL after several years relatively to BoL in order to properly detect the signal. It comes in addition to a constant margin provision for the distribution of OSNR performances when the EOT comes out from the production line. We model this effect as an additional OSNR degradation of 1 dB (respectively 1.5 dB) at the BoL (respectively EoL). For *EDFA ageing* we suppose that the output power is not affected by ageing since any degradation (to a normal extend) can be compensated by an internal feedback control on the pump feeding the erbium fiber. Consequently, we only consider its NF ageing during a 10-year period, as shown in Table 1.

In terms of nonlinear effects of WDM transmission, we assume full loaded WDM links from the BoL until the EoL, making our model compliant with dynamic traffic. So, α_{NL} in (1) remains unchanged along the network life.

Table 1. Elements that contribute to LM ageing during 10 years

Ageing network elements:	**BoL:**	**EoL:**	**Yearly ageing step:**
Fiber (fiber cuts)	0	0.0163669 dB/km	0.00163669 dB/km
OXC (filtering through 1 WSS)	0.03 dB [5]	0.1 dB [9]	0.007 dB
EOT (changing of SNR target values)	1 dB	1.5 dB	0.05 dB
Amplifier (NF)	4.5 dB [10]	5.5 dB [10]	0.1 dB

4. Traffic and cost erosion model

In order to observe the difference of the network behavior in case of different starting traffic values we consider 2 types of traffic demands, both bidirectional with the yearly traffic increase of 20%. For the first traffic type we average the results for the starting traffic from 50 Gb/s to 100 Gb/s with the granularity of 5 Gb/s {50 Gb/s, 55 Gb/s,…, 100 Gb/s}, whereas for the second traffic type we average the results for the starting traffic from 100 Gb/s to 200 Gb/s with the same granularity of 5 Gb/s {100 Gb/s, 105 Gb/s,…, 200 Gb/s}. Moreover, in both traffic cases, we average the results on the previously mentioned 4730 LPs. We also consider the sensitivity of cost benefits on the EOT cost. Since the EOT supports 3 different formats realized by the same hardware, we consider its price to be unique (regardless of used modulation format) and normalized to the value of 1 at the BoL. With time, maturity of the new technologies is expected to lead to price reductions and therefore potential cost benefits for operators.

5. Simulation results and discussion

Fig. 1 presents the total number of deployed EOTs per LP per year in Kaleidon network in order to satisfy the yearly traffic increase of 20% for the set of traffics starting from 100 Gb/s, over the 10-year period for the two following design approaches. The first design accounts for EoL LM, while the second one accounts for LM progressively evolving according to the model described in section 3. In both cases, Fig. 1 shows the ramping up of the number of EOTs to accommodate the incremental traffic capacity. As expected, the design based on EoL LM needs more deployed EOTs than progressive LM, particularly during the first years. The number of deployed EOTs in the last year is the same for both designs since progressive LM become then equal to EoL LM. In the same context, Fig. 2 presents the percentage of cost savings for each year cumulated from the BoL of the network if the progressive LM ageing are taken into account compared to the standard EoL LM. First year savings reach 15% while by the end of the 10th year savings drop to 0%. The main part of the cost savings appears at the BoL of the network. Thus, progressive LM allow an operator to defer the capital expenditure in the future life of the network and to better master its return on investment during the first years of network life, when it is the most essential. Contrary to the expectations, we find that increasing EOT cost erosion from 5% up to 20% per year has only a moderate effect on

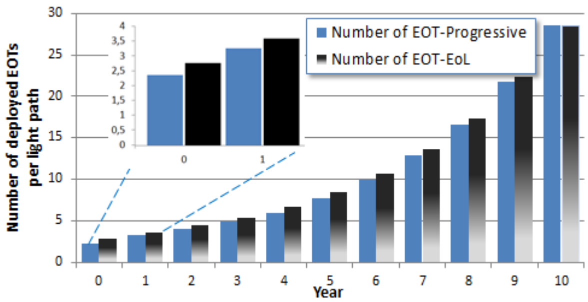

Fig. 1. Total number of deployed elastic optical transponders (EOT) per year, per LP

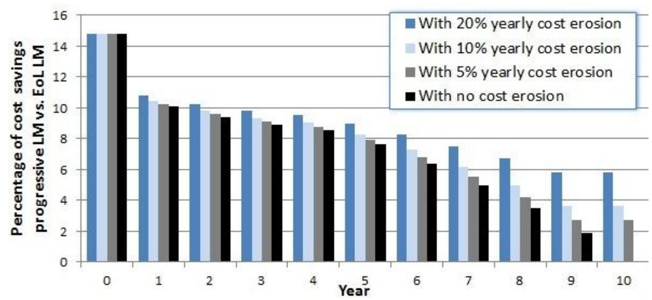

Fig. 2. Cost savings for 0%, 5%, 10% and 20% yearly elastic optical transponders (EOT) cost erosion

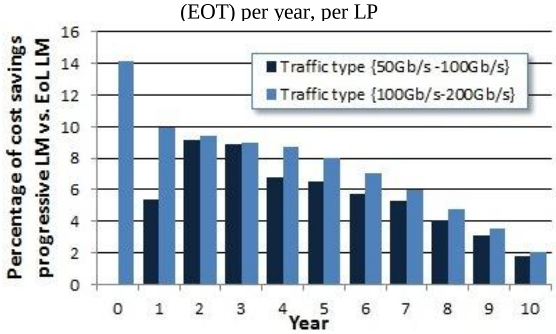

Fig. 3. Cost savings for two types of traffic with 10% of EOT cost reduction

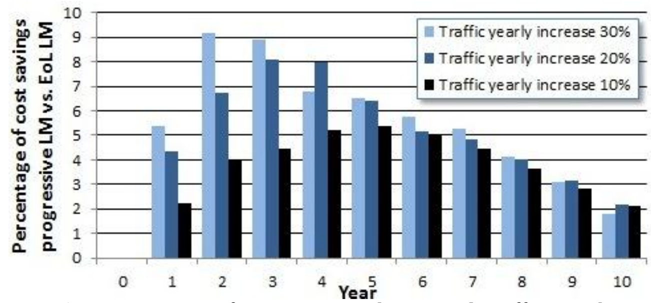

Fig. 4. Cost savings for 10%, 20% and 30% yearly traffic growth with 10% of EOT cost erosion

cost savings. Fig. 3 shows different time evolution of the gain for two types of traffic while accounting for 10% of EOT yearly cost reduction and for 30% yearly traffic growth. When serving higher volume traffic demands, starting from 100 Gb/s, cost savings appear earlier than when serving lower volume traffic demands. Because with the set of lower traffic demands from 50 Gb/s to 100 Gb/s, the time to reach the maximum capacity of each deployed EOT is longer than with the set of higher traffic demands starting from 100 Gb/s to 200 Gb/s. Actually in this latter case, new EOTs should be deployed earlier and can better benefit from larger LM difference between EoL and progressive designs during the first years of the network, enabling larger channel capacity and thus saving EOTs. Besides the sensitivity of cost savings on the EOT cost erosion (Fig. 2), this study also explores the impact of the yearly traffic increase on the cost savings in Fig. 4. It presents the cost savings during 10-year period with the 10% of EOT cost erosion, for the set of traffic starting from 50 Gb/s to 100 Gb/s with 10%, 20% and 30% yearly traffic growth. Similarly to the previous results, with the higher yearly traffic increase, existing connections are filled sooner, leading to earlier and therefore larger cost savings.

6. Conclusion

We have quantified in terms of cost savings along the life of the Kaleidon network, the benefit of using EOTs to dynamically fit the ageing of link margins. Our results showed that the main benefit of EOT appears at the BoL and strongly depends on the volume of the traffic in the network. We have also shown that when accounting for yearly traffic increase, changing the EOT cost erosion from 5% to 20% has only a moderate effect on global cost savings. We believe this paradigm of "progressive link margins" could be applied quite precisely with advanced monitoring, enabling the network to optimally serve connections and readjust as needed if physical conditions change.

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