Physical impairments
in all-optical networks

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Abstract. The feasibility of transparent lightpaths in all optical networks (AON) is conditioned by the wavelength continuity constraint and by Quality of Transmission (QoT) requirements. This paper proposes an original solution to this problem.

1 Introduction

In this paper, we propose an original approach aiming to minimize both CAPEX and OPEX inherent to electrical regenerator (ER) placement. Three linear transmission impairments are considered: ASE (amplified spontaneous emission), PMD (polarization mode dispersion) and intra-channel crosstalk (ICX). The impact of the gain profile of inline EDFAs is also investigated.

2 A new QoT-dependent ER placement strategy

Let us consider a network topology G(V, E) where V is a set of OXSs and E is a set of contra-directional fiber pairs. Up to W wavelengths are available per fiber. Given a binary static traffic matrix $T = t_{i,j}$, we assign to each traffic demand the shortest path $p_{i,j}$ in G(V, E). Let us index by increasing order the intermediate nodes along this path from 1 to $M_{i,j}$. In order to lighten our notations, we suppress in the following indices i and j. Our aim is to determine for each path p if the adopted route is admissible, both in terms of network capacity and of QoT. For that purpose, we introduce an iterative function $C(w, m, n)$ representing the cost for implementing an m-th ER along path p at node n in using wavelength w from node n. We have $m \leq n \leq M$, $1 \leq m \leq M$ and $1 \leq w \leq W$. Let $\rho(w, k, n)$ be the cost inherent to the placement of an ER at node k, considering then a transparent lightpath from k to n on wavelength w. We can then define iteratively the cost $C(w, m, n)$ as:

$$C(w, m, n) = \mathrm{Min}[C(w, m-1, k) + \rho(w, k, n)] \qquad \forall k, m-1 \leq k \leq n-1 \tag{1}$$

The cost from implementing a first ER at the source node is null. The cost for implementing this first ER at the other nodes along path p is infinite:

$$\begin{gathered} C(w,1,1)=0 \text{ and } C(w,1,k)=\infty \\ \forall w, 1 \leq w \leq W \text{ and } \forall k, 2 \leq k \leq M \end{gathered} \tag{2}$$

The cost $\rho(w,k,n)$ of the transparent segment $[k,n]$ is chosen as the product of three functions Θ, λ and φ that depend on the tuple (w,k,n). Θ characterizes the availability of an ER at nodes k and n. Let $\Delta(k)$ and $\Delta(n)$ be the total number of ERs installed at nodes k and n respectively (these numbers are related to the logical degree of these nodes). Let $\delta(k)$ and $\delta(n)$ be the number of available ERs at these same nodes. Θ for segment $[k,\ n]$ is then equal to $\mathrm{Min}[\delta(k)/\Delta(k), \delta(n)/\Delta(n)]$ if $\delta(k)$ and $\delta(n)$ are not null, else, Θ is infinite. λ characterizes the wavelength continuity constraint on segment $[k,n]$. It is equal to "1" if wavelength w is available on each hop of this segment, else it is infinite. φ refers to QoT and is itself the product of three other functions, α, β and γ depending on the tuple (w,k,n). It evaluates the penalty inherent to ASE, PMD and ICX. Assuming that inline EDFA optical amplifiers are used every L_0 kilometers and that $L_{k,n}$ is the distance from k to n, each optical signal transiting along the path p cumulates ASE noise power $P^{ASE}_{(w,k,n)}$ that must remain under P^{ASE}_{max} (see equation 3 from [1]). The parameters of this equation are: n_{sp}, the noise figure of an EDFA; h, the Planck's constant; C, the velocity of light in vacuum; B_o the optical bandwidth and $G(\lambda(w))$, the saturation gain of an EDFA.

$$P^{ASE}_{(w,k,n)} = \left[(n_{sp}.h.C.B_o) \times \frac{\{G(\lambda(w))-1\}}{\lambda(w)}\right] \times \left\lfloor \frac{L_{k,n}}{L_0} \right\rfloor \leq P^{ASE}_{max} \tag{3}$$

Assuming a common fiber dispersion parameter D^2_{PMD} on each hop, the cumulated PMD along segment $[k,n]$ is given by [1]:

$$PMD(k,n) = \sqrt{L_{k,n} \times D^2_{PMD}} \tag{4}$$

Let $\chi(w,k,n)$ be the number of optical channels on wavelength w that share the same switching fabric along segment $[k,n]$. Let χ_{max} the maximum admissible number of interferers per switching fabric. We have adopted for the cost inherent to α, β and γ the following definitions:

$$\alpha(w,k,n) = \begin{cases} \frac{2(P^{ASE}_{max} - P^{ASE}_{(w,k,n)})}{P^{ASE}_{max}}, \text{ if } P^{ASE}_{(w,k,n)} \in [\frac{P^{ASE}_{max}}{2}, P^{ASE}_{max}] \\ \infty, else \end{cases} \tag{5}$$

In equation 5, one one hand, we aim to maximize the path length by minimizing the cost α when $P^{ASE}_{(w,k,n)} = P^{ASE}_{max}$. Simultaneously, by imposing $P^{ASE}_{(w,k,n)} >$

$P_{max}^{ASE}/2$, one rejects systematically too short paths in order to reduce the number of ERs. The same rationale is used for equation 6.

$$\beta(w,k,n) = \begin{cases} \frac{2(PMD_{max}^2 - PMD_{(w,k,n)}^2)}{PMD_{max}^2}, & \text{if } PMD_{(w,k,n)}^2 \in [\frac{PMD_{max}^2}{2}, PMD_{max}^2] \\ \infty, else \end{cases} \tag{6}$$

$$\gamma(w,k,n) = \begin{cases} \frac{\mathrm{Max}\left[\chi_{(w,k',n)}\right]}{\chi_{max}}, \forall k', k < k' < n, & \text{if } \chi_{(w,k,n)} \in [0, \chi_{max}] \\ \infty, else \end{cases} \tag{7}$$

2.1 Numerical results

Let us consider the NSFNET North-American backbone with $|V| = 14$ nodes and $|E| = 21$ edges. The capacity of the system is $W = 6$ wavelengths per fiber in the C-and with a 5nm spacing. Three types of profile of EDFA amplifiers are considered: flat with a gain of 35 dBm, almost flat with oscillations gain between 30 dBm and 35 dBm and very fluctuant with oscillations between 25 dBm and 40 dBm, the average gain over the considered band being in each case equal to 35 dBm. The capacity of each optical channel is $D = 10$ Gbps. The other parameters are set to the following values: $B_o = 50$ GHz, $n_{sp} = 1.5$, $D_{PMD} = 0.1$ ps/$\sqrt{km}$ and $\chi_{max} = 3$. For different traffic load, we have compared the traffic demand acceptance rate under three network configurations: opaque, transparent and translucent. We have also investigated the impact of the EDFAs' gain profile. Performance curves will be discussed during oral presentation.

3 Conclusion

As expected, full transparency rejects a large fraction of the traffic demands. Translucent networks based on our strategy and assuming flat gain EDFAs enable almost the same acceptance rate as opaque networks. Under the same traffic scenarios, the acceptance rate decreases with the variability of the profile of the EDFAs.

References

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