The relevant impact of the physical parameters uncertainties when dimensioning an optical core transparent network

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Abstract We illustrate the importance to consider physical uncertainties in the Quality of Transmission estimators used for Impairment Constrained Based Routing. Power uncertainties of 1dB yield 80% of further regenerators.

Introduction

The introduction of transparent functions in core networks provides flexibility in terms of data bit-rates and modulation schemes for the WDM channels. But, unlike the opaque networks, the absence of unconditional regeneration implies that the physical impairments accumulate in each traversed Network Element (NE). So, to optimize the network utilization, the control plane should estimate the Quality of Transmission (QoT) to route a connection demand. Numerous studies have been published on that field called “Physical Impairments Constrained Based Routing” [1]. The present paper uses our proprietary routing tool [1] and QoT estimator [2]. In [3], we illustrated how the precision of the chromatic dispersion map knowledge impacts on the required regenerative resources in a core network. This paper goes further as we quantify the amount of extra regeneration resources needed with respect to the precision of the knowledge of all the physical parameters, and more particularly of the powers. From such study we can derive the required precision of the power estimations so that the dimensioning results are meaningful in a more realistic context.

Description of the optical network model

Fig. 1 shows the U.S. backbone network we consider. It comprises 46 nodes and 61 links. The traffic matrix has 650 distinct demands so that the mean connection length is 2150 km with a standard deviation of 1230 km. The dimensioning results reported hereafter correspond to the averaging of 100 routings of this matrix with different demand orders. The network is composed of standard single-mode fibers, erbium doped fiber amplifiers featuring chromatic dispersion compensation modules, and optical nodes based on wavelength selective switch. More detailed information about physical characteristics of each device is given in [1].

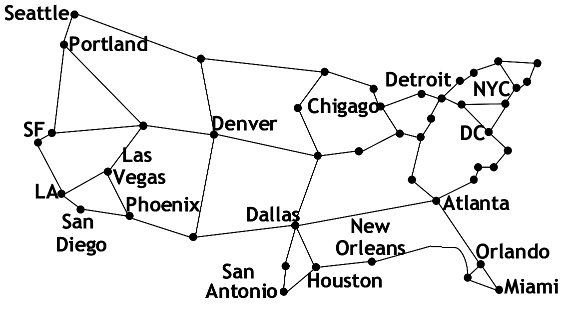

Figure 1: *U.S core network under study (see [4]).*

Description of the QoT estimator

The employed QoT estimator interpolates the Q factor in dB corresponding to the following additive physical parameters (***QoT param.***) cumulated along the light-path: the Amplified Spontaneous Emission power (P_{ASE}, in dBm) used to calculate the Optical Signal to Noise Ratio at the receiver, the residual Chromatic Dispersion (CD, in ps/nm), the non linear phase (ϕ_{NL}, in radian) [5], the Polarization Mode Dispersion (PMD, in ps) and the power of in-band crosstalk signal (P_{Xt}, in dBm) considered to calculate the final signal to crosstalk ratio. If we call Q_{ref} the threshold Q-factor determining the light-path feasibility and Q_e the Q-factor obtained from its QoT parameters, then this light-path is feasible if:

$$Q_e(\textit{QoT param.}) - m > Q_{ref} \qquad \text{(Eq. 1)}$$

m is a margin compensating for the uncertainties of our QoT estimator. *m* allows to balance the number of over-estimations and under-estimations [3]. It is convenient to establish *m* as a constant calculated in advance on a set of representative light-paths. But, to be more relevant, we propose to consider m as the standard deviation of the distribution of the Q_e factors induced by the parameter uncertainties. Furthermore, we consider *m* as a function of the QoT parameters uncertainties (***ΔQoT param.***) added along the light-path. *m* should as well integrate the inaccuracy induced by the interpolation of the QoT function [3]. Hence the “feasibility” equation becomes:

$$Q_e(\textit{QoT param.}) - \beta.m(\Delta \textit{QoT param.}) > Q_{ref} \qquad \text{(Eq. 2)}$$

we introduce a new factor β that stands for the aimed accuracy of the QoT prediction. Hence, because of the property of the Q_e factor Gaussian distribution, β=1 induces 68% accuracy on the feasibility prediction while it is 95% with β=2. We consider 6 standard deviations: on the PMD (ΔPMD), on the CD (ΔCD), on the ASE power (ΔP_{ASE}), on the power of in-band crosstalk (ΔP_{Xt}), on the detected signal power (ΔP_S) and on the non-linear phase ($\Delta\phi_{NL}$). ΔPMD and ΔCD, considered for each NE, are the precisions of the measurement equipments: +/- 7% for ΔPMD in operational condition and +/- 2% for ΔCD on a span compensated in chromatic dispersion. For each NE, we express ΔP_{ASE}, ΔP_{Xt} and ΔP_S in dB as they are

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related to an optical power knowledge that depends on the estimation method (theoretical calculation or prediction partially based on real-time monitoring measurements). Several sources of uncertainties may impact $\Delta\phi_{NL}$ but for simplicity purpose we gather them into a single uncertainty also expressed in dB as ϕ_{NL} is proportional to the channel power [5]. In the following for simplicity purpose ΔP_{ASE}, ΔP_{Xt}, ΔP_S and $\Delta\phi_{NL}$ are equal to a single power uncertainty noted ΔP the value of which ranges in the interval [0dB, 1.2dB]. As these uncertainties are independent from NE to NE (span, amplifiers or optical node) and as they add in each traversed NE, their associated final variance is the sum of the corresponding variances due to each NE.

The last step consists in translating the so-obtained variances of the cumulated QoT parameters into the variance of the estimated Q-factor. We suppose that the final established standard deviations are small enough to maintain the final QoT parameters in the domain where the QoT estimator interpolation is still valid [2]. In fact, the variation slopes of the Q factor with PMD or ASE or Xt or Ps are monotonous and independent in first approximation. Consequently, we also assume that for each of them the corresponding Q-factor standard deviation (ΔQ_{PMD}, ΔQ_{ASE}, ΔQ_{Xtk}, ΔQ_P) is the absolute value of the difference between the nominal value of Q_e (without uncertainty) and the value of Q_e obtained by accounting for the standard deviation of the considered parameter. Such approximation ensures an effective calculation speed. On the contrary, as the impacts of CD and ϕ_{NL} are not independent, their related standard deviation, $\Delta Q_{CD,\phi NL}$, should be established simultaneously. Therefore we sample a set of Q-factors by applying our QoT function on the following parameters: ($ASE_{nominal}$, $PMD_{nominal}$, $Xt_{nominal}$, $CD_{nominal}+i.\Delta CD/5$, $\phi_{NLnominal}+j.\Delta\phi_{NL}/5$) where i and j range from -10 to 10 with a step of 2 so that we get 121 samples. Thus, $\Delta Q_{CD,\phi NL}^2$ is the variance of this set with the weight of each point corresponding to the Gaussian probability of each couple (i, j) that is:

$$\mathbf{(2.\pi.\Delta CD.\Delta\phi_{NL})^{-1}.Exp[-\ ((i/5)^2 + (j/5)^2)/2]} \qquad \text{(Eq. 3)}$$

Then $m^2=\Delta Q_{PMD}^2+\Delta Q_{ASE}^2+\Delta Q_{Xtk}^2+\Delta Q_P^2+\Delta Q_{CD,\phi NL}^2$

Network dimensioning results

Figure 2 shows the numerical application of our model through the dimensioning results in terms of total number of regenerators for various ΔP values. When only the function uncertainty is considered (ΔP=0dB), at least 11% additional regenerators are needed (β=1). For all the other points of the curves, the uncertainties on all the physical parameters are considered as previously described. Two areas appear on *Figure 2*. In the *A* area the slope of the curve remains relatively small. On the contrary, The *B* area shows the quick evolution of the regenerators number when ΔP exceeds 0.5 dB. Hence, if this uncertainty reaches 1 dB, one needs up to 80% further regenerators to guarantee a reliable dimensioning result (β=2) as compared to the case with no uncertainty. To limit this increase, a power uncertainty as small as possible is necessary. But, since the curve slopes are reduced in the *A* area, the difficult effort to get it smaller than 0.5 dB will not provide valuable gain in terms of extra regenerators. Therefore power accuracy about 0.5 dB seems a good trade-off.

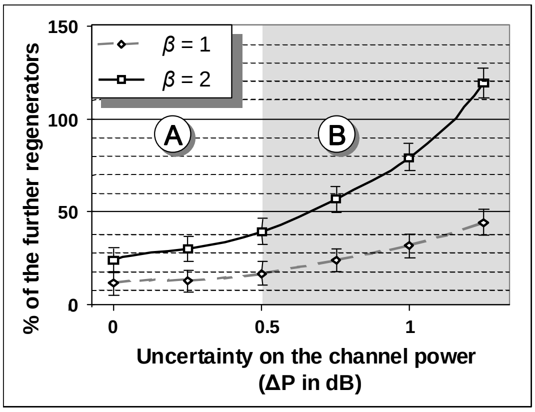

Figure 2: *Percentage of extra regenerators compared to the case without uncertainty; vertical bars show the standard deviation of the 100 simulations.*

Conclusions

This paper quantifies the importance of considering parameters and function uncertainties for a QoT estimator. It presents a model of uncertainty accumulation along a light-path. Actually, this study shows that, when dimensioning a U.S core network with a 95% reliability level (β=2), a more realistic accounting for physical parameters uncertainties, and more particularly for powers uncertainties (ΔP=1dB), results in 80% of extra regenerators needed. We conclude that these uncertainties should always be considered when planning resources for a network or when estimating the feasibility of new demands in an operating network. Such consideration is also crucial when comparing various dimensioning tools based on different QoT estimators to avoid misleading resource counting. Despite this resource increase, the transparency remains an interesting feature for the core network because of the further flexibility that it provides.

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