Robustness of Quality of Transmission Estimators for IC-RWA to Uneven Channel Powers in Core Optical Networks

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ABSTRACT
The Quality of Transmission (QoT) estimators, envisaged to optimize the Impairment Constraint Routing and Wavelength Assignment (IC-RWA) in optical transparent networks, are often assessed in a steady configuration by means of re-circulation loops and/or transmissions simulations. In such context the powers of the WDM channels are regularly fixed to a given set of values related to a given point of the periodical transmission.

But in installed systems these powers may become uneven, for instance because of the imperfect flatness of optical amplifiers gains over the band occupied by the transmitted WDM comb. In such a frame of a most realistic channel power evolution, this paper investigates the predictions accuracy of a QoT estimator in terms of non-linear effects impact. Hence, we achieved transmission simulations of 50 GHz-spaced channels over several network sections featuring optical amplifiers with no perfectly flat gain. Despite such feature, it appears that the non-linear phase remains a well suited parameter to characterize the penalties induced by the non-linear effects provided that the channel powers excursion remains in the range [-1 dB, 1 dB].
Keywords: All-optical networks, Nonlinear effects in fibers, Quality of Transmission, WDM channel power.

1. INTRODUCTION

The current evolution of the traffic demands and the maturity of flexible optical devices make a reality the deployment of reconfigurable transparent networks. In such a context, the optical WDM channels are no more always regenerated in the network nodes unlike in an opaque network. Hence, the routing process should be upgraded with a Quality of Transmission (QoT) estimator as accurate as possible and compliant to the control plane real-time operating mode. The elaboration of this estimator has received a lot of attention by means of experiments and/or simulations [1]. Previous publications addressed the impact of some engineering rules [2](knowledge or not of the exact chromatic dispersion map) or the impact of the optical routing on the accuracy of the QoT predictions [3]. However, most of them are based on even channel power assumptions. Hence in optical re-circulation loops the WDM channel powers are periodically reset to the same values. But, in real networks, the imperfect flatness of the optical amplifiers gains over the band of the WDM comb may yield a discrepancy between the real channel powers and the nominal ones assumed by the QoT estimator. Such divergence may challenge the precision of the QoT estimator. This paper quantifies the potential error prediction due to these power shifts and identifies the domain of power excursion where the accuracy of the QoT estimator is not degraded.

2. GENERAL FEATURES OF THE QoT ESTIMATORS

To be rapid, the QoT estimator should be based on simple parameters, easy to accumulate along the light-path. Among them, the Non-Linear Phase (NLP) is often considered to account for the non-linear impairments because of its additive property [4]. For the longer connections when the physical feasibility is a real issue, the NLP is a key parameter. Basically it is related to the power of the channel under test. Actually, as the QoT estimator is validated in a WDM context [1][2], the relation between the transmission penalties and the NLP value also depends on the power of the adjacent channels because of the Cross-Phase Modulation (XPM) and the Four-Wave Mixing. But in a real network we do not think that the complete knowledge of all the channel powers on all the spans in the network will be available to the control plane. Then, the channel powers will likely be assumed around a given average value. It is the reason why, as compared to this assumption, the power unevenness of the main channel but also of its adjacent channels can make the non-linear effects influence different from the expectation.

3. DESCRIPTION OF THE SIMULATION SET-UP

We simulate an optical transmission traversing fibers and transparent nodes of a core network. The performance of the channel under test is measured at each node. It emulates the propagation of a WDM comb comprising twenty one 10.7 Gb/s NRZ channels spaced by 50 GHz. The center wavelength of this comb is 1550.12 nm that is also the wavelength of the detected channel. We assume that each node performs optical routing and also carries out a perfect channel power equalization. The inter-node WDM transmissions are achieved on 80km-length SMF spans of which chromatic dispersion is under-compensated to +100 ps/nm by means of dispersion compensating fibers. N_S is the number of spans between each node. The residual chromatic dispersion is reset to 0 ps/nm at each node in order to maintain it limited whatever the ingress and egress node. The nominal channel

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power at the fibers input after each node is 1 dBm for the SMF and -6 dBm for the chromatic dispersion compensating fibers. Each span has an optical amplifier that may induce WDM channel power unbalance. Each amplifier exhibits a specific random gain excursion driven by an uniform law on the interval [-δ*G*, δ*G*]. This statistical distribution of the gain is applied on 7 wavelengths regularly spaced as shown in Figure 1. The higher δ*G* is, the less regular the gain over the band of the WDM comb is.

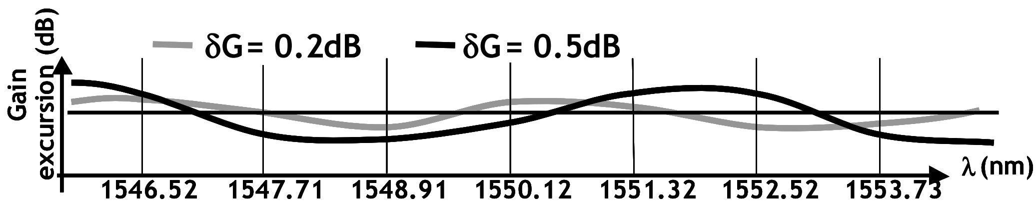

Figure 1. Illustration of gain excursions on the transmission band for different standard deviations.

A convenient way to illustrate the impact of the non-linearities consists in establishing the Optical Signal to Noise Ratio (OSNR) required to achieve a given Bit-Error-Rate (BER) as function of NLP that increases with the distance. But, in a Dense-WDM context (50 GHz frequency spacing), the XPM impact strongly depends on the synchronization of the binary information carried by the channels interplaying along the transmission. Hence, to establish the precision of a QoT estimator, one needs to run numerous simulations with various initial time synchronization cases to identify the worst case and the average one in terms of OSNR penalty. In that respect, we performed 300 simulations with different random time synchronizations between the WDM channels carrying a 256 pseudo-random bits sequence. The leftmost part of Figure 2 illustrates the resulting OSNR excursion. For each NLP, one point stands for one simulation with perfectly equalized WDM combs at the input of all the fiber spans. Therefore along a given simulated light-path, each transmission section between each pair of nodes corresponds to a given NLP. It explains the discrete NLP values appearing in this figure. The rightmost part of Figure 2 shows the evolution of the standard deviation of the set of required OSNRs for each NLP. These standard deviations should remain as small as possible to allow a good prediction of the QoT estimator. But we see that the higher the NLP is (equivalent in our case to “the longer is the light-path”), the larger the standard deviation is and so the less accurate the estimator would be. The added value of our study is to observe how this standard deviation points degrade when the channel powers get less uniform along the transmission.

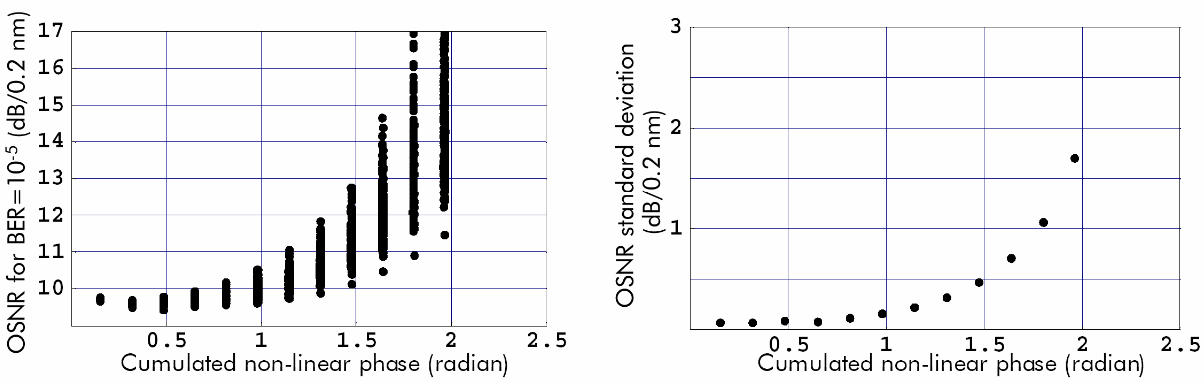

Figure 2. Illustrations of the excursion of OSNR penalty due to the various channel synchronizations. The chromatic dispersion is reset to 0 ps/nm at each node and with 4 x 80km-SMF spans between nodes.

4. SIMULATION RESULTS

We have considered 4 values for δG: 0 dB, 0.5 dB, 1 dB and 1.5 dB. We also simulated several transmission configurations with different number of spans between nodes which means different propagation lengths between each channel power equalization: 320 km (N_S = 4), 480 km (N_S = 6), 640 km (N_S = 8). The corresponding standard deviation curves appear in Figure 3. Firstly it shows the precision degrades when N_S increases. This feature is normal since the chromatic dispersion is reset to 0 ps/nm more often with N_S = 4 as compared to the cases with N_S = 6 or 8. The more regularly resetting to 0 ps/nm of the chromatic dispersion implies that the transmission will suffer from more XPM impairments because of the periodical re-synchronization of the bits carried by the adjacent channels. Consequently, the OSNR penalties raising slope is higher and the related accuracy degrades quicker with respect to the cumulated NLP. It is important to notice that for the three N_S cases simulated, the precision on the required OSNR only significantly degrades when δ*G* = 1.5 dB as compared to δ*G* = 0 dB. For the 3 other δ*G*s, the curves are nearly identical. It means the relevance of the QoT estimator validated in a regular context (δ*G* = 0 dB) will not be impacted by the unevenness of a WDM comb provided that the channel power excursion remains in the range [-1 dB, 1 dB]. Indeed, in that case the variance of the required OSNR induced by the uneven channel powers remains small as compared the one only due to the XPM effect that appears in Figure 2. When $N_S = 8$, we see that the standard deviation is slightly degraded when $\delta G = 1$ dB, on the contrary of when $N_S = 4$ or 6. Actually, the distance between each channel power equalizer is slightly too large to prevent the channel powers irregularities from enlarging the penalties due to the non linear effects. In practise it means that the inter-channel power equalizer distance should not exceed about 500 km when $\delta G = 1$ dB. In case of larger δG, this distance should be smaller than 300 km or the control plane should account for the worst case curve (the one with $\delta G = 1.5$ dB in figure 3). These statements are valid in the frame of our hypothesis: the spectral gain of the optical amplifiers considered should be flat in average.

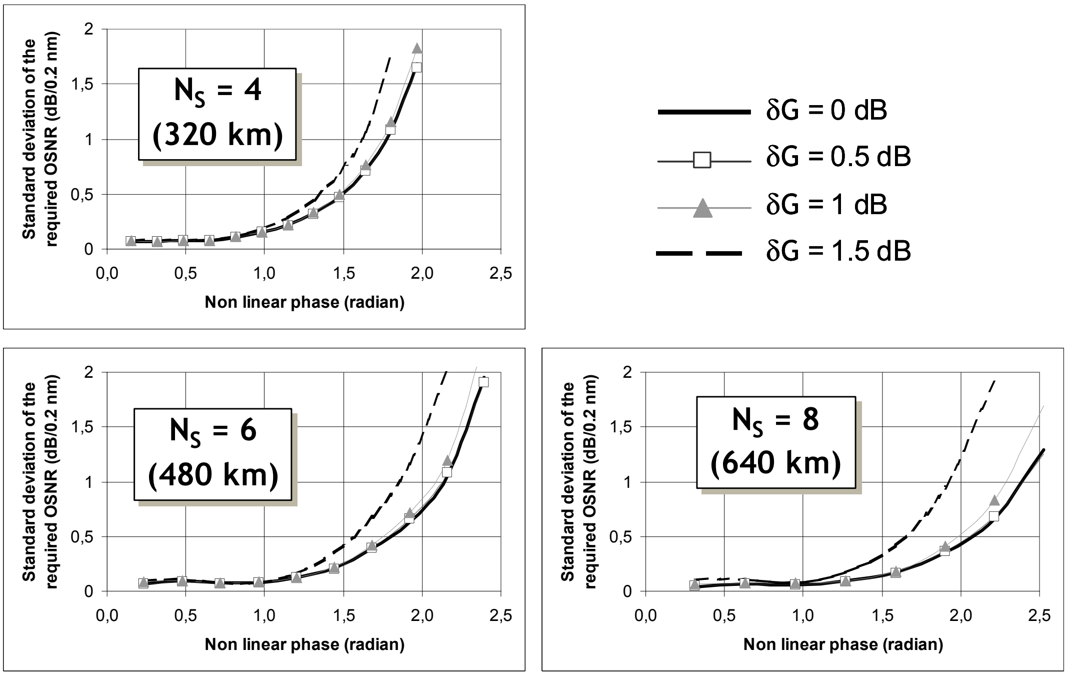

Figure 3. Comparison on the standard deviation of the required OSNR to achieve BER=10^{-5} as function of the channel NLP for various N_S and various spectral unbalances of the amplifier gain.

5. CONCLUSIONS

This study focused on the degradation of the QoT estimator accuracy due to the non-linear effects in the optical fiber in case of transmitted WDM comb with irregular channel powers. In that respect, we simulated the transmission on SMF fibers of a WDM comb of which channels were spaced by 50 GHz. Each traversed fiber span featured an optical amplifier with flat spectral gain in average over the band of the WDM signal transmitted. In that frame, it appeared that, if the distance between the channel power equalizers in smaller than 500 km, the accuracy of the QoT estimator is not challenged by the discrepancy that exists between the uniform channel powers assumptions and the real channel powers when the amplifier gain excursion remains in the interval [-1dB, 1 dB]. The channel power discrepancies may also induce errors on the Optical Signal to Noise Ratio and the in-band crosstalk assumed by the QoT estimator. Their impact are not addressed in this paper. However one can say that they are easier to figure out than the prediction errors due to the non-linear effects by means of the channel power monitoring that will likely occur in the network nodes. The other main goal of this paper is also to illustrate the importance of establishing the domain of validity of the QoT estimator, which may be seen as much important as its accuracy.

REFERENCES

[1] B. Lavigne, *et al.*, ”Method for the Determination of a Quality-of-Transmission Estimator along the Lightpaths of Partially Transparent Networks”, *ECOC'07*, vol. 3, pp. 287-288.
[2] F. Leplingard, *et al.*, ”Determination of the Impact of a Quality of Transmission Estimator Margin on the Dimensioning of an Optical Network”, *OFC'08*, Paper OWA6.
[3] T. Zami, *et al.*, ”Impact of Routing on the Transmission Performance in a Partially Transparent Optical Network”, *OFC'08*, Paper JThA50.
[4] J.C. Antona, *et al.*, ”Nonlinear criteria phase as a criterion to assess performance of terrestrial WDM systems”, *OFC'02*, Paper WX5 .