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Observing the generalized SNR statistics induced by gain/loss uncertainties / Ferrari, A.; Borraccini, G.; Curri, V.. - ELETTRONICO. - 45th European Conference on Optical Communication (ECOC 2019):(2019), pp. 343 (4 pp.)-343 (4 pp.). (Intervento presentato al convegno 45th European Conference on Optical Communication (ECOC 2019) tenutosi a Dublin (IR) nel 22-26 Sept. 2019) [10.1049/cp.2019.1077].

*Availability:*

This version is available at: 11583/2837112 since: 2020-06-23T15:04:58Z

*Publisher:*

IET

*Published*

DOI:10.1049/cp.2019.1077

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# OBSERVING THE GENERALIZED SNR STATISTICS INDUCED BY GAIN/LOSS UNCERTAINTIES

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**Keywords:** Optical fiber networks, WDM networks, Optical fiber communication

## Abstract

We performed a Monte-Carlo analysis to observe how the linear and nonlinear contributions to the generalized SNR vary with the uncertainties of gains and losses in line systems. We show variations up to 2.5 dB with spectrally dependent uncertainties of the two components.

## 1 Introduction

Operators are interested in maintaining the best performance of their optical networks by reducing margins and identifying potential performance bottlenecks. Thus, it is fundamental a reliable estimation of the generalized signal to noise ratio (GSNR) since it has been extensively proven as unique merit parameter for quality of transmission (QoT) [2]. The GSNR is defined as the ratio between signal power ( $P_S$ ) and amplifier ASE noise ( $P_{ASE}$ ) plus nonlinear interference disturbance ( $P_{NLI}$ ) generated by fiber propagation:

$$\text{GSNR} = \frac{P_S}{P_{ASE} + P_{NLI}} = (\text{OSNR}^{-1} + \text{SNR}_{NL}^{-1})^{-1}, \quad (1)$$

Where OSNR is the optical signal to noise ratio that can be obtained from the optical spectrum analyzer (OSA) and  $\text{SNR}_{NL}$  is the signal-to-NLI ratio. As shown in [3,4], parameters' uncertainty plays a key role in the QoT estimation accuracy. Critical points are represented by the accuracy in the knowledge of these parameters. Specifically, the connector loss, determining an uncertainty in the evaluation of the NLI, and the ripples in the amplifier gain and noise figure, introducing a non-flat frequency response of the line. In a green field scenario, the proper characterization of each network element allows a QoT estimator to get GSNR values with good accuracy [2,3]. While, in a

brown field, the line system is deployed and in-service, thus, getting an accurate while detailed characterization of the device is quite challenging. Design parameters, datasheets and measurements got from telemetry are the main source of information and play a key role in the proper estimation of the GSNR. Photodiodes within network elements represent one of the main sources of information about the actual working point of a line system, measuring the total optical power on the probed point of the network. Unfortunately, photodiodes themselves cannot provide any information about the frequency response of the line, giving only spectrally aggregated values. For this reason, a QoT estimator relying just on these data can only provide an aggregated flat estimation and cannot consider fluctuations given by frequency ripples or insertion losses. In this analysis, we set values supposedly coming from telemetry and datasheets. Then, values of ripples and connector losses are varied statistically and it is observed how the QoT figure statistically fluctuates. For this reason, the total power levels before and after each amplifier, design parameters and the datasheet values are fixed: fiber propagation parameters and amplifier noise figure.

Successively, a Monte Carlo analysis is carried out, randomizing the connector loss and amplifier gain ripple of each span in the line system. Using a

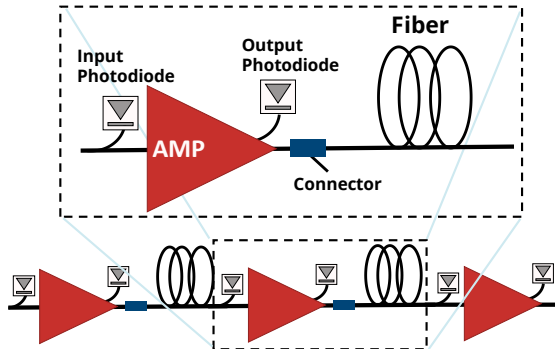


Figure 1. Line system scheme

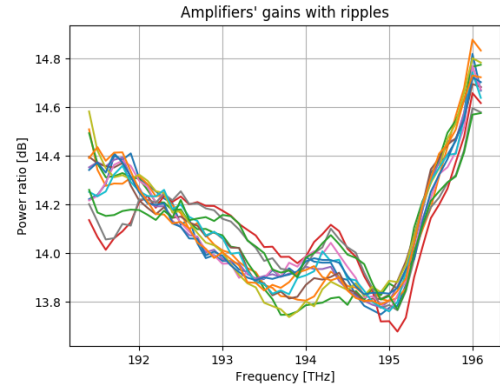


Figure 2. Amplifiers' gains with ripples.

frequency flat approach, the GSNR oscillates within a 2.5 dB gap after a 20-span line system. We identified a large source of inaccuracy in the frequency variation of the GSNR showing that a QoT estimator capable to follow variation can reduce the oscillations within 1.5 dB. To reach such a gain, information retrieved from WSSs and transceivers could be used.

## 2. Methodology

A ~1500 km line system made by 20 spans is emulated and analysed. Fig. 1 shows the line system abstraction. Each span is modelled as the cascade of a connector, a spool of standard single mode fiber (SSMF) and an erbium-doped fiber amplifier (EDFA). In each span, two photodiodes are considered: one before and one after each amplifier. Therefore, the measured quantities are the total input and output power of each EDFA. From these measurements, it is possible to deduce the average EDFA gain and the total span loss between two consecutive amplifiers. Amplifiers are set in transparency mode, i.e., the average gain is set to compensate for the loss of the previous span. The overall fiber plus connector loss ( $A_S$ ) is assumed constant and set to 14 dB, therefore, the average amplifier gain is 14 dB. Fiber is supposed a SSMF with a loss of 0.18 dB/km, a dispersion coefficient equal to 16.7 ps/nm/km ( $\beta_2=21.27$  ps<sup>2</sup>/km) and an effective area of 80  $\mu\text{m}^2$ . EDFAs are affected by gain ripples (Fig. 2) obtained from a measured dataset. EDFA noise figure is assumed flat in frequency and equal to 4.3 dB. We assume 91 PM-MQAM coherent channels in the 50

GHz fix WDM grid. Each channel is root raised cosine shaped with a gross symbol rate of 32 GBaud. The NLI is estimated using the GN-model [5] and the transmitted power is computed according to a local-optimization global-optimization (LOGO) strategy [6].

We investigate the line system performance on a Monte Carlo basis. Each Monte Carlo run creates a 20-span line system where each span has a random realization of connector loss and amplifier ripple. Connector losses are randomly selected using the probability distribution reported in [7] with a mean connector loss equal to 0.75 dB. The ripples are randomly extracted from the measured dataset reported in Fig. 2. For the given  $A_S$  and for each Monte Carlo realization, for each span, the connector loss has been extracted and the actual fiber length is computed to satisfy the loss constraints. At each Monte Carlo run, the propagation is emulated and GSNR, OSNR and SNR<sub>NL</sub> are evaluated. Thus, histograms in function of the span count are reported as heatmaps.

## 3 Results

In Fig. 3, we evaluate the histogram of SNR<sub>NL</sub> (Fig. 3a), OSNR (Fig. 3b) and GSNR (Fig. 3c) by considering together values of all the channels and all the Monte Carlo runs in each fiber span. In this way, we observe how the line performances fluctuates with respect a QoT estimator, providing a single worst-case value for all the channels. In general, the OSNR is lower than the SNR<sub>NL</sub>, because of the power launch strategy. Indeed, NLI power is half of the ASE noise power [6] in case

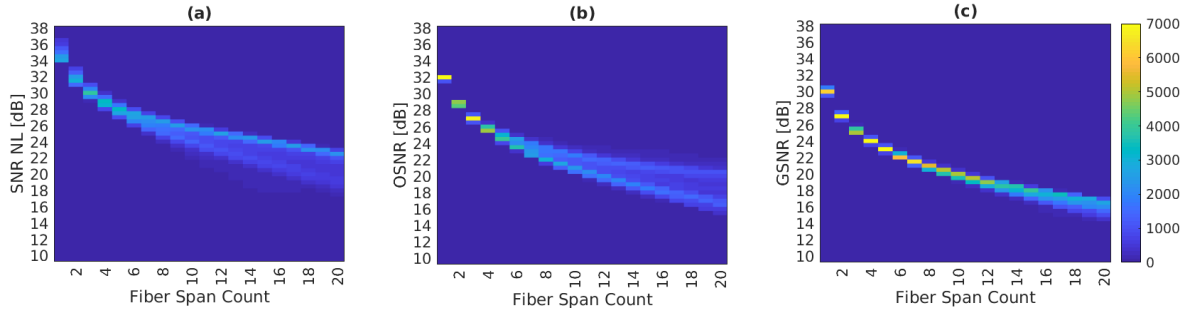


Figure 3: distribution of SNR<sub>NL</sub> (a), OSNR (b) and GSNR (c) along the line.

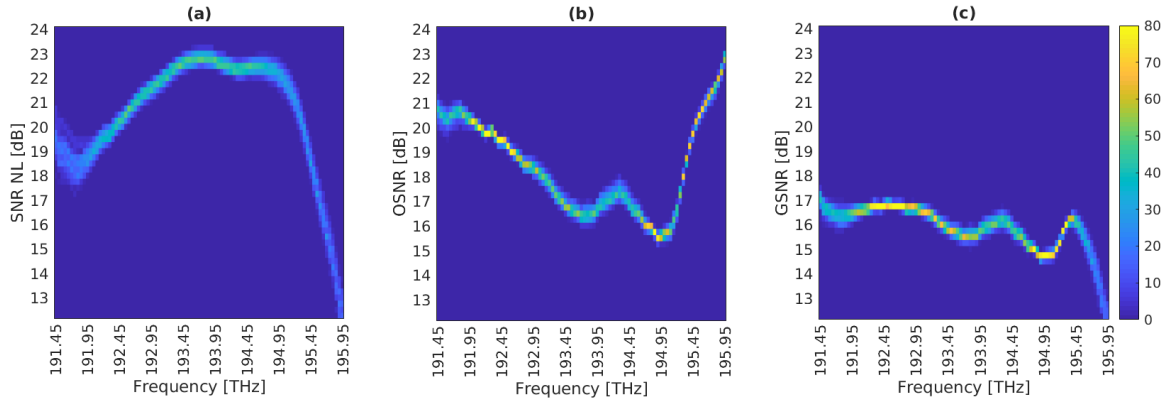


Figure 4. distribution of SNR<sub>NL</sub> (a), OSNR (b) and GSNR (c) vs frequency at the end of the line (after the 20<sup>th</sup> span).

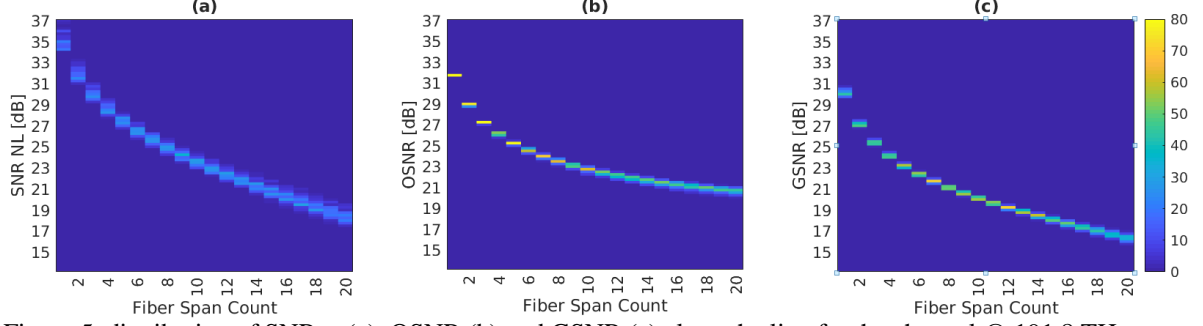


Figure 5. distribution of  $\text{SNR}_{\text{NL}}$  (a), OSNR (b) and GSNR (c) along the line for the channel @ 191.8 THz.

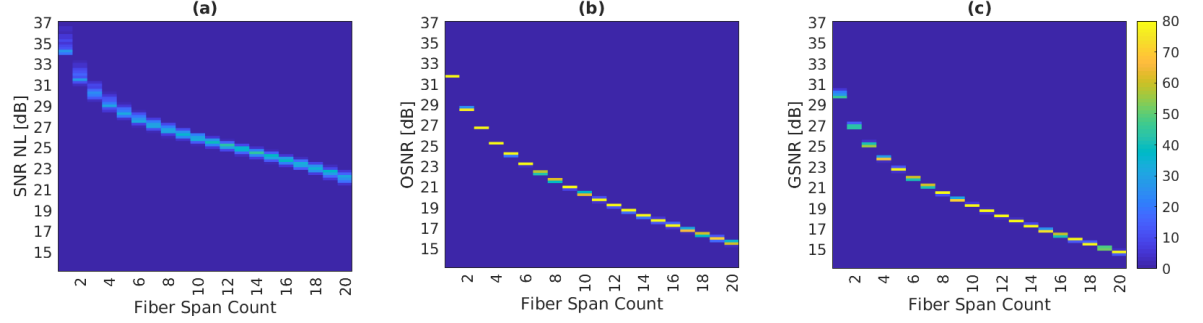


Figure 6. distribution of  $\text{SNR}_{\text{NL}}$  (a), OSNR (b) and GSNR (c) along the line for the channel @ 194.95 THz.

of optimum LOGO transmitted power [6]. This leads to an OSNR lower than the  $\text{SNR}_{\text{NL}}$ . As expected, the gain ripple and the connector loss variation make the  $\text{SNR}_{\text{NL}}$  and OSNR spread along the line. Then, at the end of the line,  $\text{SNR}_{\text{NL}}$  roughly oscillates between 18 dB and 23 dB giving an opening of 5 dB, while OSNR stands between 15.5 and 21 dB giving a 5.5 dB aperture. Combining the two, we get a GSNR oscillating between 14.5 and 17, thus, the gap is only 2.5 dB large. This reduction in the GSNR aperture with respect to OSNR and  $\text{SNR}_{\text{NL}}$  is due to the correlation between  $\text{SNR}_{\text{NL}}$  and OSNR. For the NLI-dominated channels, signal power is higher than the optimum, thus, they present very poor  $\text{SNR}_{\text{NL}}$ , and high OSNR. On the contrary, channels working below the optimum power are less affected by NLI, but OSNR is poorer. Fig. 4 shows the histogram of performances at the end of the line for each channel, by reporting the  $\text{SNR}_{\text{NL}}$  (Fig. 4a), the OSNR (Fig. 4b) and the GSNR (Fig. 4c). By referring to Eq. (1) on how  $\text{SNR}_{\text{NL}}$  and OSNR contribute to the GSNR, it can be observed that on central channels, ASE noise is dominant, while, on the edges, NLI is the performance-limiting disturbance. This is due to the amplifier gain ripple statistics since, on average, amplifier gain is larger at the edges than in the middle of the band, because of the physical effects, mainly to spectral hole burning [8]. The larger variation in the  $\text{SNR}_{\text{NL}}$  can be observed around 191.75 THz channels and it is equal to 2 dB, while, the largest oscillations in the OSNR are around 194.3 THz with a maximum extension of about 1.25 dB.

Finally, observing the GSNR, fluctuations are mitigated being within 1 dB amplitude. Two channels are selected: one dominated by NLI - @191.8 THz (Fig 5) - and one other dominated by ASE noise - @194.95

THz (Fig.6) -. The 191.8 THz channel presents an OSNR (Fig. 5b) degradation very small after the 10<sup>th</sup> span, while  $\text{SNR}_{\text{NL}}$  (Fig. 5a) becomes very steep. Therefore, the GSNR (Fig. 5c) becomes dominated by  $\text{SNR}_{\text{NL}}$ . While the 194.95 THz channel shows a very slow decrease in the  $\text{SNR}_{\text{NL}}$  (Fig. 6a) after the 8<sup>th</sup> span while the OSNR (Fig. 6b) decreases faster and faster. Then GSNR (Fig. 6c) is almost a copy of the OSNR being dominant. It can be noted that, in general, the  $\text{SNR}_{\text{NL}}$  presents higher oscillations than OSNR. This is due to the fact, that, while OSNR is just affected by gain ripple, the NLI power is also affected by randomness of the connector loss. It can also be noted that, with a frequency flat QoT estimator, the performance variation is large (Fig 3), but, since the variation, frequency by frequency is very small (Fig 4), a QoT estimator properly feed with frequency resolved data can significantly reduce the uncertainty improving accuracy and thus reducing margins.

## 4 Conclusion

The Monte Carlo analysis on the line system performances shows large oscillations if GSNR is taken just as a unique value, while the potentialities of a frequency resolved QoT estimator are large reducing the inaccuracy from 2.5 dB down to less than 2 dB at the end of the 20-span line system. State of the art networks cannot provide the information needed get this advantage, but smarter techniques such as machine learning properly feeded with power measurements coming from WSSes and parameters coming from transceivers can be used to aid a QoT estimator in this direction.

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