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# The impact of parameter uncertainty on QoT estimation using GN-based analytical model

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**Abstract:** We study the impact of parameter uncertainty induced by inaccurate α, β, γ, fiber length (L) and noise figure on QoT estimation using the GN-based analytical model. We find γ and L have the relatively large influence in most system structure cases. © 2021 The Author(s)

## 1. Introduction

With the development of coherent communication systems, previous fixed configuration of links and signals is gradually diversified, enabling elastic optical networks (EON). EON allows a dynamic network operation according to the link condition. Hence, the network control layer can make more flexible and efficient allocation of spectrum resources [1]. In conventional optical networks, accurate quality of transmission (QoT) of an unallocated optical transmission is not adopted. In order to ensure the robust network operation, a high margin is usually set including unallocated margin, system margin and design margin [1]. However, the high margin will lead to the underutilization of system, thus wasting a part of the transmission capacity. Through accurate QoT estimation, reasonable margin can be reserved to maximize the spectrum efficiency and balance the trade-off between cost and stability.

Currently there exist several QoT estimation methods. The traditional split-step Fourier method (SSFM) simulates the whole process of optical signal transmitting from the generator to the receiver side (Rx) where a large number of FFT and IFFT calculation is required, resulting in a high computation complexity. An alternative QoT estimation method is analytical model. Gaussian noise (GN) model has been proposed to calculate the amount of nonlinearity interference (NLI) based on the assumption that both signal and NLI follow Gaussian distribution [2]. The speed of GN model is at the ms level (depends on computational platform, need to specify), which can quickly estimate the QoT of a specific link. For amplified spontaneous emission (ASE) noise, well-known ASE noise accumulation model can be employed [3]. However, the main drawback of analytical model is that there are usually uncertainties in link parameters, such as fiber length (L), loss, dispersion, and nonlinear coefficients (α, β and γ) and amplifier noise figure (NF), which greatly affecting the accuracy [3].

In this paper, we study the impact of parameter uncertainty induced by inaccurate α, β, γ, L and noise figure on QoT estimation using the GN-based analytical model. A closed-form GN model is used to calculate the amount of NLI [4]. We scale L, α, β, γ and NF by 0.7-1.3 times and study the corresponding error of estimated signal-to-noise ratio (SNR). Different system structure and channel arrangement are considered. Both conditions of pure NLI and combined NLI and ASE are discussed.

## 2. Simulation setup

We conduct simulation to study the influence of the parameter uncertainties on the SNR estimation of GN-based analytical model. As shown in Fig. 1, we build a 28 GBaud K-channel wavelength-division-multiplexing (WDM) system with channel spacing of 50 GHz where Nyquist rectangular shaping is assumed. The optical link consists of N span of 80 km standard single mode fiber (SSMF) and erbium-doped fiber amplifier (EDFA) which compensates the fiber loss. At the Rx, the signal is coherently detected by an ideal local oscillator (LO).

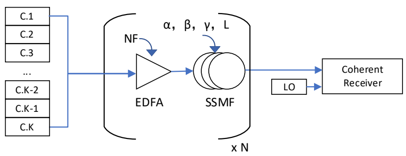


Fig. 1 The 28 GBaud K-channel WDM system with channel spacing of 50 GHz where Nyquist rectangular shaping is assumed.

## 3. Simulation results and discussion

Parameters α, β, γ, L, NF are scaled by 0.7 to 1.3 times to study how their uncertainties influence the QoT estimation value. Note that for a given case, only one designated parameter is with uncertainty and others are accurate. We show two cases. The first consider only NLI while the second consider both linear and nonlinear noise with results shown in Fig. 2 and Fig. 3 respectively. The X-axis is the parameter scaling ratio and the Y-axis is the SNR value. Launch power (LP) is set at 0 dBm.

We define ΔSNR-γ as the SNR absolute difference induced by scaling of γ. In the case of considering pure NLI as shown in Figs. 2(a)-2(d), taking 7-channel condition as example, with the increase of γ from 0.7 to 1.3 times, the SNR decreases from 24.22 dB to 18.98 dB and the ΔSNR-γ is as high as 5.24 dB. On the other hand, the SNR increases with the α, β and *L*. Within the scaling range, ΔSNR-α, ΔSNR-β and ΔSNR-*L* is 3.79 dB, 2 dB and 0.55 dB, respectively. From the view of comparison between scenarios with different channel number of 1 to 31 as in Figs. 2(a)-2(d), ΔSNR-γ does not change with the channel number while ΔSNR-α and ΔSNR-*L* reduce from 4.7 dB to 3.47 dB and from 1 dB to 0.39 dB, respectively. On the contrary, ΔSNR-β increases from 1.5 dB to 2.16 dB. It can be concluded that γ has the largest influence on SNR estimation in pure NLI condition.

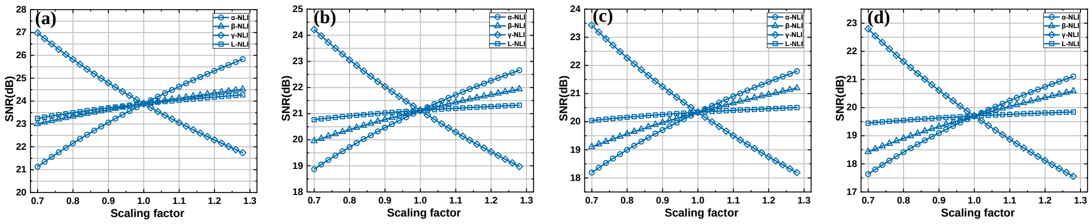


Fig. 2 SNR value calculated by the GN-based analytical model with corresponding scaled parameter in the condition of pure NLI with (a) 1-, (b) 7-, (c) 15-, (d) 31-channel WDM condition.

In the case of considering both NLI and ASE as shown in Figs. 3(a)-3(d), taking 7-channel condition as example, with the increase of L from 0.7 to 1.3 times, the SNR degreases from 19.95 dB to 16.35 dB and the ΔSNR-L is 3.6 dB. Similarly, within the scaling range, ΔSNR-γ and ΔSNR-NF is 2.9 dB and 1.5 dB, respectively. On the other hand, the SNR increases with α and β. ΔSNR-α and ΔSNR-β is 2.28 dB and 1.18 dB, respectively. From the view of comparison between scenarios with different channel number of 1 to 31 as in Figs. 3(a)-3(d), ΔSNR-γ, ΔSNR-α, and ΔSNR-β increase from 2.1 dB to 3.3 dB by 1.2 dB, 2.11 dB to 2.34 dB by 0.23 dB, and 0.65 dB to 1.44 dB by 0.79 dB. ΔSNR-L, ΔSNR-NF reduce from 4.8 dB to 3 dB by 1.8 dB, and 1.99 dB to 1.18 dB by 0.83 dB. Obviously, L has the largest influence in Fig. 3(a). Because in 1-channel WDM system ASE is the dominate proportion of the total noise, while NLI is less. Hence, L directly linked with linear noise has largest influence. On the other hand, γ has the largest influence while the proportion of NLI increases in 31-channel system.

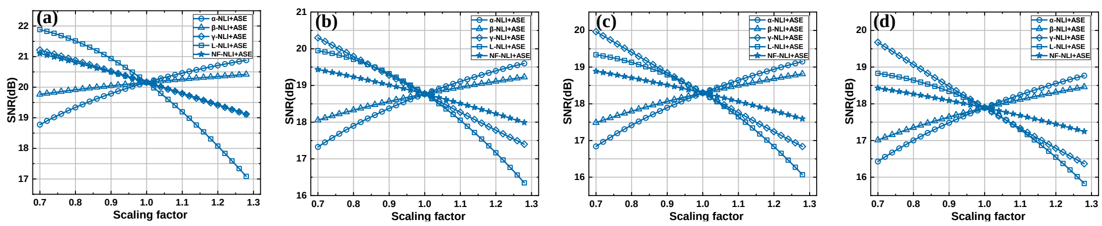


Fig. 3 SNR value calculated by the GN-based analytical model with corresponding scaled parameter in the condition including both NLI and ASE with (a) 1-, (b) 7-, (c) 15-, (d) 31-channel WDM condition.

Figures 4(a)-4(c) show how the channel number influences the ΔSNR of specific parameter with LP of -3dBm, 0dBm and 3dBm, respectively. In the case of considering pure NLI, taking Fig. 4(a) as example, with the increase of channel number from 1 to 31, ΔSNR-γ reaches 5.24 dB without changing. ΔSNR-α reduces from 4.7dB to 3.47dB. ΔSNR-L reduces from 1.03 dB to 0.4 dB, while ΔSNR-β is increasing from 1.51 dB to 2.16 dB. From the view of comparison between scenarios with different LP as in Figs. 4(a)-4(c), the ΔSNR of each parameter basically does not change for the pure NLI conditions.

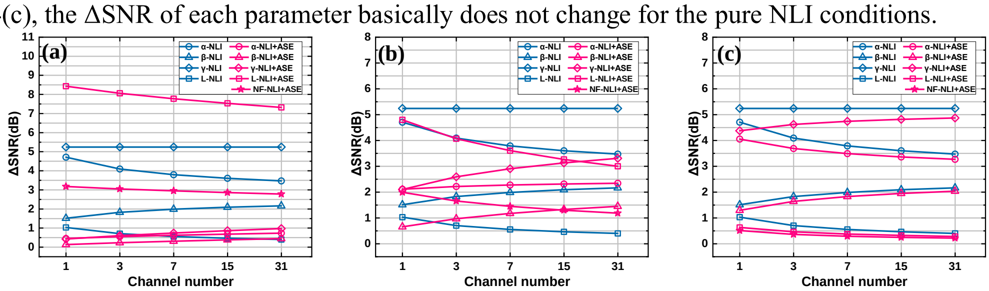


Fig. 4 The relationship between channel number and ΔSNR of specific parameter in both pure NLI conditions and NLI combined with ASE conditions with LP of (a) -3 dBm, (b) 0 dBm, and (c) 3 dBm.

In the case of considering both NLI and ASE, taking Fig. 4(a) as an example, with the increase of channel number from 1 to 31, ΔSNR-*L* reduces from 8.43 dB to 7.31 dB. ΔSNR-NF reduces from 3.17 dB to 2.78 dB. On contrary, ΔSNR-α, ΔSNR-β, and ΔSNR-γ increase from 0.45 dB to 0.73 dB, 0.13 dB to 0.44 dB and 0.42 dB to 0.97 dB respectively. These trends can be explained that with more channels, the proportion of nonlinear noise increases, while that of linear noise decreases. From the view of comparison between scenarios with different LP as shown in Figs. 4(a)-4(c), when the LP is 3dBm, ΔSNR-*L* is only 0.45 dB which is 7.97 dB less than that in -3 dBm case. ΔSNR-NF also decreases by 2.81 dB to 0.36 dB. On the other hand, ΔSNR-α increases from 0.45 dB to 4.05 dB by 3.6 dB and ΔSNR-γ increases from 0.13 dB to 4.37 dB by 4.25 dB. It can be found that with higher LP, the influence of the linear noise gradually decreases, and the NLI becomes dominant. Hence, the ΔSNR-*L* and ΔSNR-NF decrease with LP while ΔSNR-α and ΔSNR-γ increase.

Figures 5(a)-5(c) show how the symbol rate influences the ΔSNR of specific parameter in 7-channel, 15-channel and 31-channel WDM condition, respectively. Here, only NLI is considered. Taking Fig. 5 (a) as example, with the increase of symbol rate from 28 Gbaud to 46 Gbaud, ΔSNR-γ is 5.24 dB and does not change. ΔSNR-α reduces from 3.79 dB to 3.44 dB by 0.35 dB. ΔSNR-*L* reduces from 0.55 dB to 0.39 dB by 0.16 dB. On the contrary, ΔSNR-β increases from 1.99 dB to 2.17 dB by 0.18 dB. The fluctuation of ΔSNR is small, hence ΔSNR can be considered relatively stable with symbol rate in pure NLI conditions. From the view of comparison between scenarios with different channel number as in Fig. 5 (a)-(c), we can find that ΔSNR-α, ΔSNR-γ, ΔSNR-β, and ΔSNR-*L* are also relatively stable with the channel number in this scenario.

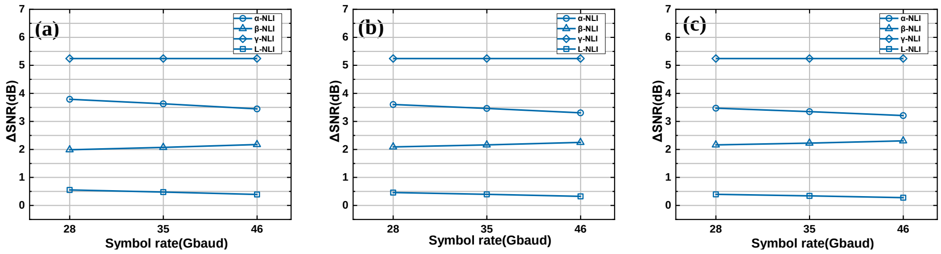


Fig. 5 The relationship between symbol rate and ΔSNR of specific parameter in NLI conditions with channel number of (a) 7, (b) 15, and (c) 31.

Figures 6(a)-6(c) show how the transmission length influences the ΔSNR of specific parameter in 7-channel, 15-channel and 31-channel WDM condition, respectively. Here, only the NLI is considered. Taking Fig. 6 (a) as example, with the increase of transmission length from 160 km to 1600 km, ΔSNR-γ is 5.24 dB and does not change. ΔSNR-α, ΔSNR-β, and ΔSNR-*L* increase from 3.48 dB to 4 dB, 1.88 dB to 2.08 dB and 0.13 dB to 1.83 dB. Besides the ΔSNR-*L*, the fluctuation of ΔSNR is small. Hence ΔSNR can be considered relatively stable with transmission length in pure NLI conditions. From the view of comparison between scenarios with different channel number as shown in Figs. 6 (a)-6(c), we can find that ΔSNR-α, ΔSNR-γ, ΔSNR-β, and ΔSNR-*L* are relatively stable with the channel number.

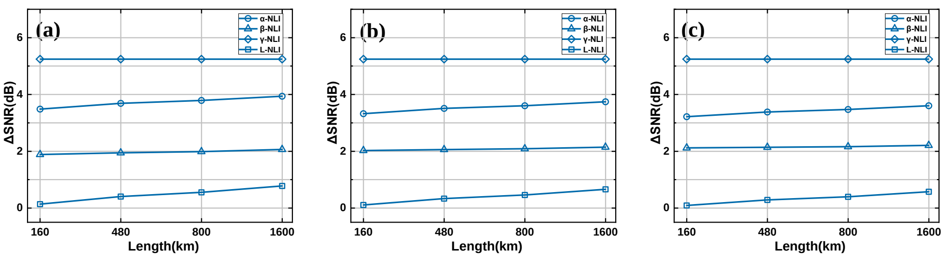


Fig. 6 The relationship between transmission length and ΔSNR of specific parameter in NLI conditions with channel number of (a) 7, (b) 15, and (c) 31.

## 4. Conclusions

Considering pure NLI condition, γ is the parameter that has the largest influence on the SNR estimation using GN-based analytical model. In the case of considering both NLI and ASE noise, γ and *L* have the relatively large influence. Meanwhile, SNR estimation error is different for system structure with various channel number and LPs, while the symbol rate and transmission length have little impact.

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