PERFORMANCE ESTIMATION OF LONG-HAUL OPTICAL TRANSMISSION SYSTEM OVER A COHERENT SYSTEM USING GAUSSIAN NOISE MODEL

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ABSTRACT

The demand for internet capacity is expected to increase exponentially owing to more implementation of the Internet of Things and 5G which requires high speed and data volume to be delivered to clients. To accommodate this internet demand in the future, fiber optics is the most viable alternative for delivering reliable high-speed Internet access with good quality of service. Optical Transmission systems (OTSs), however, suffer from signal impairments such as nonlinearities in optical fibre and Amplified Spontaneous Emission noise. Signal impairments due to fiber nonlinearities become more significant as the optical power, transmission distance, capacity and the number of channels in the fiber are increased. Hence, to maintain the quality of the transmission as the length of the transmission increases, the Gaussian Noise (GN) model, a reliable tool for performance prediction over a wide range of system scenarios, was used to check for signal distortion. Noise estimation and optical signal-to-noise ratio were used to measure the quality of transmission while the obtained results were also used to evaluate the performance of longer-distance OTS. This paper addresses the nonlinear issue and provides possible solutions to identified challenges.

Keywords: *Gaussian Noise (GN), Optical Transmission System (OTS), Quality of Transmission (QoT), Optical Communication System (OCS)*

INTRODUCTION

The demand for large-capacity networks, particularly large-capacity optical networks, is rising as internet traffic continues to grow at an exponential rate (Kamiyama et al., 2021). The optical communications sector today faces the problem of meeting the internet speed demands of the rapidly developing 5G and 6G networks, which call for a significant increase in internet data rate. Optical fiber connection is the foundation of the current internet and global communication networks (Naghshvarianjahromi et al., 2022).

However, because of the increased launched optical power, these needs are limited by fiber nonlinear impairments. Numerous methods of compensating for fiber nonlinearities have been put forth (Ming et al., 2022). The Gaussian Noise (GN) model has become a powerful tool for predicting the Quality of Transmission (QoT) in the physical environment. It is also used to predict long-distance transmission effects. The model is a reliable tool for performance prediction of uncompensated coherent systems, characterized by a favorable accuracy versus complexity trade-off over a wide range of system scenarios (Poggiolini et al., 2014; Abolade et al., 2021).

The GN-Model is a simplified algorithm used to simulate long-haul optical Dense Wavelength Division Multiplexing (DWDM) communication transmission systems that use advanced modulation formats. The GN-Model enables users to simulate very complicated advanced modulation DWDM multi-span transmission systems in an extremely short time (Ming et al., 2022). The choice of coherent optical communications is guided by its usage long haul deployments because of the increase in bandwidth demand, hence there is a need for better spectral efficiency and advances in high-speed digital signal processing for Optical Transmission System (OTS). In long-haul Optical Communication systems (OCS), nonlinear effects are unavoidable since they increase with an increase in transmission distance (Kamiyama et al., 2021).

A number of digital signal processing (DSP)-based performance enhancement algorithms have been presented to mitigate the effects of equalization-induced noise enhancement and transceiver nonlinearities (Dd et al., 2021). This was done to improve transmission performance in conventional IM/DD optical transmission systems without requiring any physical structure modifications.

The popularity of the GN model is undoubtedly due to its relative simplicity. However, as a result, it fails to predict certain properties of nonlinear interference (NLI) such as modulation format dependence (Semrau et al., 2019). In this paper, the performance of the GN model on a coherent optical communication system was investigated.

RELATED WORKS

This issue was addressed in, when the GN model for nonlinear interference (NLI) was used as a starting point to derive two minimum energy consumption points (Lundberg et al 2017). Moser (2012) carried out an investigation to model a channel for optical communication using intensity modulation. It was discovered in the work that the main distortion is caused by additive Gaussian noise. An alternative derivation of the GN model of the nonlinear interference (NLI) in strongly dispersive optical systems was proposed by (Serena & Bononi, 2013). Purnama (2021) worked on the validation of the GN model on a short-span optical fiber transmission system. It was observed that the process NLI in the system follows a Four-Wave Mixing (FWM) pattern where there are three frequency components, that contribute to the generation of the NLI noise at frequency. While Purnama (2021) worked on the validation of the GN model, this research, however, focused on the estimation of a long-haul optical transmission system over a coherent transmission system using the GN model.

METHODOLOGY

In this work, the performance of the GN model at predicting the signal quality in a 125 km optical transmission link at 25 km/span was investigated through simulation. The optical power launched into each transmission span was varied over a wide range to capture the nonlinear effects. GN model provides another approach in which the signal distortion due to nonlinear fiber effects is assumed to have additive Gaussian noise characteristics. This noise characteristic is then added incoherently to reduce the complexity of the computational process. OptiSystem software estimates the system's Optical Signal-to-Noise Ratio (OSNR) and Bit Error Rate (BER). Combining the GN model nonlinear noise estimation with the measured OSNR was used to determine the generalized OSNR, which is the generally acceptable metric for evaluating the Quality of Transmission of an OCS. The results obtained were used to evaluate the possibility of emulating longer-distance transmission with a reduced number of spans. Assuming linear propagation and additive Gaussian noise ASE are present, the relationship between BER and OSNR for the coherent system is expressed by equation (1)

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{OSNR}{2}}\right) \tag{1}$$

The GN model is based on the approximation that the nonlinear noise was modelled as additive Gaussian noise that is independent of ASE noise. The principle is to have a simple GN model to inspect the nonlinearity of the transmission system, therefore avoiding complex computational methods to solve the NLSE in fiber optic transmission. The GN model takes advantage of the fact that long-distance fiber transmission without group velocity dispersion compensation will disperse individual data bits over many bit periods. This effect results in nonlinear interactions between numerous data bits that can take on the characteristics of additive white Gaussian noise (Poggiolini *et al*, 2013).

RESULTS AND DISCUSSION

The results obtained were used in plotting the graph in Figures 1 and 2. These were obtained after the simulation.

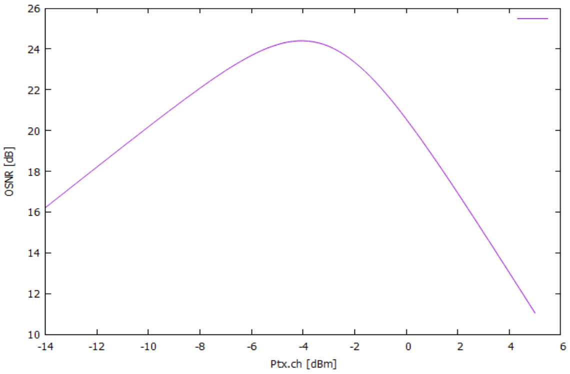

Fig. 1. Model Performance using Optical Signal-to-Noise Ratio

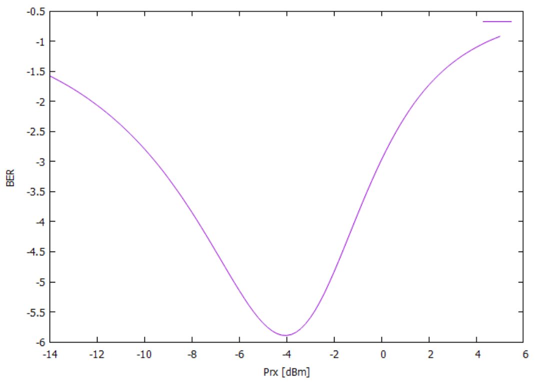

Fig. 2. GN Model performance using Bit Error Rate

Figure 1 shows the GN-model performance using OSNR while Figure 2 shows the evaluation of the GN-model using BER. It can be deduced from the results the importance and effectiveness of the GN model as a viable alternative for performance evaluation in a latency-sensitive network.

CONCLUSIONS

The application of the GN model for evaluating the performance of nonlinear effects in fiber transmission was established in this work. A viable method to analyze and estimate the performance of long-haul optical transmission over a coherent transmission system using the GN Model has been proposed. The system performance was optimized. The proposed model shows the superiority of the technique to significantly reduce the NLI variance.

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