Research on Rayleigh Scattering and Brillouin Scattering of Bidirectional Wavelength Division Multiplexing System

Qiwu Wu\textsuperscript{1a} and Yang Zhou\textsuperscript{2}

\textsuperscript{1}College of Information Engineering, Engineering University of PAP, Xi’an 710086, China
\textsuperscript{2}College of Equipment Management and Support, Engineering University of PAP, Xi’an 710086, China
\textsuperscript{a}cli@hunnu.edu.cn  *Corresponding author’s e-mail: wuqiwu700@163.com

Abstract. In order to study the influence of Rayleigh and Brillouin scattering on the performance of bidirectional Wavelength Division Multiplexing (WDM) system. On the VPI simulation platform, a two-way WDM simulation system was built. Rayleigh scattering and Brillouin scattering were generated by setting the parameters of the optical fiber module and system parameters such as Brillouin Scattering, Rayleigh scattering, Rayleigh Distortion, and Rayleigh Distortions. Then, the frequency spectrum of the received signal and the bit error rate were observed and analysed. Experimental results show that Rayleigh and Brillouin scattering will cause the performance of the two-way WDM system to degrade. By separating the back propagation channel, the impact of these two effects on the performance of the two-way WDM system can be reduced.

1. Introduction

Since the occurrence of new crown pneumonia in 2020, applications such as remote meetings and online education have ushered in unprecedented development [1]. These applications rely on the transmission of the backbone optical network, and the optical network using wavelength division multiplexing technology can greatly increase the overall network capacity [2]. However, WDM networks using single-fiber bidirectional structure transmission will produce severe Rayleigh scattering and Brillouin scattering [3]. When light waves propagate in an optical fiber, there is uniform scattering along the length of the optical fiber. A small part of the scattered signal will propagate backward along the incident direction and be captured by the optical fiber. This phenomenon of propagating optical signals in the opposite direction is called Rayleigh scattering [4]. Brillouin scattering refers to a kind of nonlinear light scattering caused by the interaction between the incident light field and the elastic acoustic field in the optical fiber [5].

VPI transmission maker (VPI) is a professional optical communication system simulation software developed by VPIphotonics in Germany [6]. It has a wealth of optical communication system simulation modules, including various types of information sources, transmitter and receiver modules, optical modulators, multiplexers and filters, optical fibers, optical amplifiers, analyzers. Researchers can freely call related modules to build corresponding experimental systems in the experimental area according to relevant rules, and can modify the parameters of each module in the system, even programming languages such as MATLAB/C++ can be used to design related modules, which greatly improves the work efficiency of researchers. Through various types of analyzers, the signal's eye
diagram, waveform diagram, spectrogram, bit error rate and other information can be obtained, which facilitates the research on the simulation of optical communication systems by researchers.

At present, there are many studies on the Rayleigh scattering and Brillouin backscattering effects in optical fibers and the factors that affect the performance of bidirectional WDM systems, but there are few studies on the effects of the two effects in a complete WDM system. Therefore, this article constructs a two-way WDM simulation system based on the VPI simulation platform. The impact of the two effects on the performance of the two-way WDM system through experiments were observed.

2. Two-way WDM System Based on VPI

This article uses the VPI platform to build a VPI-based two-way WDM system. As shown in Figure 1. The system includes Tx Laser Array module, WDM_MUX_N_1_Ideal module, Universal Fiber module, Filter Opt, Rx_OOK_BER, Const, Numerical Analyzer 2D. The functions of each module are as follows:

- **TxLaserArray_vtmg1**: The module represents a Laser array which consists of a user defined number of single externally modulated transmitters. This module is quite useful for generation of a WDM signal.

- **WDM_MUX_N_1_Ideal_vtms1**: The module multiplexes N optical WDM channels with an adjustable insertion losses.

- **UniversalFiber_vtms1**: The Universal Fiber model simulates a wideband nonlinear signal transmission in optical fibers with piecewise constant parameters specified for each fiber span individually, taking into account bidirectional signal flow, stimulated and spontaneous Raman and Brillouin scattering, multiple Rayleigh scattering, Kerr nonlinearity, dispersion, PMD effects, local insertion loss and reflectance at each joint between spans. It is ideal for modeling forward- or reverse-pumped Raman amplifiers, which often form part of the transmission fiber itself.

- **SignalAnalyzer_vtms1**: This module works as an interface to the VPIphotonicsAnalyzer tool that is used to display and analyze electrical and optical signals.

- **Rx_OOK_BER_vtms1**: Optical receiver with BER estimation. Estimates Bit Error Rate and Q factor for intensity modulated direct detection optical transmission systems. Calculates the increase in signal level (dB, optical) that is required to give a specified BER. Incorporates complete receiver model with polarizer, APD or PIN photodetector, arbitrary postdetection low-pass filter and clock recovery. Uses either deterministic or stochastic approach for BER estimation. In the stochastic mode Chi-square signal statistics is assumed. Intersymbol interference can be taken into account. In the deterministic mode module uses a Moment Generating Function approach to calculate the exact probability density function for the combined signal and noise. Gaussian approximation is available in both deterministic and stochastic regimes.

- **Const_vtms1**: Produces a float output that is constant for each simulation run. Often used as an X-input to a NumericalAnalyzer2D. Can be controlled by a sweep or a simulation script.

- **NumericalAnalyzer2D_vtms1**: This module works as an interface to the VPIphotonics Analyzer tool for two-dimensional numerical data.
3. Experiment and Performance Analysis

3.1. System default simulation settings and results

The system default setting parameters are shown in Table 1. The experiment changes the parameters of Brillouin Scattering, Rayleigh scattering, Rayleigh Distortion, Rayleigh Distortions, etc. to observe and analyse the frequency spectrum and bit error rate of the received signal.

| Default parameters         | Value            |
|----------------------------|------------------|
| Time Window                | 64/10e9          |
| Bit Rate Default           | 10e9 bit/s       |
| Sample Rate Default        | 160e9Hz          |
| Greatest Prime Factor Limit| 2                |
| Brillouin Scattering       | NO               |
| Rayleigh scattering        | NO               |
| In Band Noise Bins         | OFF              |
| Boundary Conditions        | Periodic         |
| Brillouin Distortions      | NO               |
| Brillouin Distortions      | NO               |

Under the condition of default parameter setting, the experimental diagram of the received signal spectrum and bit error rate is shown in Figure 2. The value of the bit error rate obtained by the experiment is 0.08122. It can be found from the experimental results that when there is no Rayleigh scattering and Brillouin scattering in the system, the frequency spectrum of the received signal is very regular and the signal quality is very good, which can fully meet the needs of normal communication.
3.2. The impact of Rayleigh scattering on the system
When the other values are all default values, set the Rayleigh scattering and Rayleigh Distortions parameter values to Yes, observe and analyse the frequency spectrum and eye diagram of the received signal. The experimental results are shown in Figure 3.

3.3. The impact of Brillouin Scattering on the system
When the other values are all default values, set the Brillouin Scattering and Brillouin Distortions parameter values to Yes, observe and analyse the frequency spectrum and eye diagram of the received signal, and the experimental results are shown in Figure 4.
The bit error rate obtained by the experiment is 0.08763. Comparing the experimental results with Figure 2, it can be found that the received signal spectrum shifts, the received signal is distorted, and the bit error rate increases. Therefore, Brillouin Scattering will seriously degrade the signal quality of the system, but by separating the back propagation channel, the effect of this effect on the performance of the two-way WDM system can be reduced, so that the system can communicate normally.

### 3.4 The impact of Brillouin Scattering and Rayleigh back-scattering on the system at the same time

When the other values are all default values, set the parameter values of Brillouin Scattering, Brillouin Distortions, Rayleigh scattering and Rayleigh Distortions to Yes. Observe and analyze the spectrum and eye diagram of the received signal. The experimental results are shown in Figure 5.
The bit error rate obtained by the experiment is 0.09358. It can be found that when both effects exist, compared with the experimental graph in Figure 2, the signal not only produces frequency components, but also produces signal frequency shifts, resulting in a decrease in signal quality and an increase in bit error rate. By separating the back propagation channel, the impact of these two effects on the performance of the two-way WDM system can be reduced, and the system can communicate normally.

4. Conclusion
Rayleigh scattering and Brillouin scattering are two important effects in optical fibers. This paper uses the VPI simulation platform to build a two-way WDM simulation system. From the experimental results, it can be seen that both Rayleigh scattering and Brillouin scattering will cause the performance of the system to decrease. By separating the back propagation channel, these two effects can be effectively reduced. The focus of the next study is to consider the influence of the third effect in fiber propagation-Raman effect on the system.

Acknowledgments
This work is supported by the Natural Science Basic Research Plan in Shanxi Province of China (No.2020JM-361), the Young and middle-aged scientific research backbone projects of Engineering University of PAP (No.KYGG201905) and the basic research foundation project of Engineering University of PAP (No.WJY201920, No.WJY202019).

References
[1] Li, M. et al. (2020) Single-Mode VCSEL Transmission Over Graded-index Single-Mode Fiber Around 850 nm. In: 2020 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA. pp. 1-3.
[2] Wang, D., Zhang, S. and Li, Q. (2019) WDM transmission system based on coherent optical OFDM and its performance analysis. In: 2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC), Chengdu, China. pp. 2157-2161.
[3] Shang, J. et al. (2019) Measurement of Temperature-Dependent Bulk Viscosities of Nitrogen. In: Oxygen and Air From Spontaneous Rayleigh-Brillouin Scattering. In: IEEE Access. pp. 136439-136451.
[4] Jackson, J., Kun, S., K. O. Agyekum, Oluwasanmi, A. and Suwansrikham P.(2020)A Fast Single-Image Dehazing Algorithm Based on Dark Channel Prior and Rayleigh Scattering. In: IEEE Access. pp. 73330-73339.
[5] Dechun, W., Zhihui, F. and Jie, T. (2016) The study of temperature measurement on optical fiber in OPGW based on stimulated Brillouin scattering. In:2016 IEEE International Conference on Information and Automation (ICIA).Ningbo. pp. 1753-1757.
[6] Cao, P. (2015) Development and Research of DAML Coherent Receiver Based on VPI. M.D. Thesis, Nanjing University of Posts and Telecommunication, Nanjing.