Simulation of two dimensional OCDMA-PON system based on FBGs

Mingzhu Zheng¹, Qiwu Wu²*, Yang Zhou¹, Lingzhi Jiang¹ and Jiaqi Liu¹

¹College of Information Engineering, Engineering University of PAP, Shaanxi, 710086, China
²College of Equipment Management and Security, Engineering University of PAP, Shaanxi, 710086, China
*Corresponding author’s e-mail: cli@hunnu.edu.cn

Abstract. In order to study the effect of transmission distance on the performance of optical code division multiplexing passive optical network systems based on fiber Bragg Grating (FBG), a two-dimensional OCDMA-PON system based on cascaded FBGs is designed and constructed by using the VPI optical communication software. The spectrum, waveform and eye diagram of the output signal are analyzed by setting different fiber lengths in the system. The experimental results show that different fiber lengths have different effects on the system. Within a certain transmission distance, the longer the fiber length, the smaller the error generated by the output signal and the better the signal quality; beyond this certain distance, the quality of the output signal deteriorates sharply and the error generated becomes larger.

1. Introduction

Due to the rapid development of information technology, people's demand for data traffic of communication services has gradually climbed. Therefore, in order to fully develop and reasonably use the huge bandwidth resources of optical fiber, various multiplexing technologies have emerged, such as the most popular passive optical networks (PON) multiplexing technology. It mainly includes passive optical network technology based on time division multiplexing (TDM), orthogonal frequency division multiplexing (OFDM), wavelength division multiplexing (WDM) or optical code division multiplexing (OCDMA) technology. Among them, OCDMA-PON technology, which combines the advantages of both optical code division multiplexing and passive optical networks, becomes one of the best candidates for future high-bandwidth reliable optical communication systems and a research hotspot [1].

Chuanqi Li studied and analyzed the effect of signal power spectrum on the BER of FBG-based code-division multiplexing optical networks. Manghu Cao gave the maximum allowable error of FBG parameters based on the study of the effects of grating center wavelength and relative position and different number of users on BER performance in FFH-OCDMA systems. It provides a basis for reducing the production accuracy as well as the cost of codecs. The impact of the degree of FBG code mismatch on the OCDMA-PON system is analyzed by Chen Jiaming using VPI platform simulation. Yanyan Zhou studied the performance change of codecs when the data transmission rate in a two-dimensional OCDMA-PON system based on Bragg fiber grating exceeds the limiting condition and found that the system can still recover the original signal correctly even when the rate exceeds a certain limit. The relationship between multi-user interference and Bragg grating reflection bands in OCDMA-PON systems was investigated by Guimaraes.
It is clear from the above information that most of the studies related to OCDMA-PON systems based on FBGs have not analyzed the effect of fiber length on transmission performance. Therefore, in this paper, VPI is used to design and simulate a two-dimensional OCDMA-PON system based on cascade FBG. By changing the length of optical fiber, the frequency spectrum, waveform and eye image results of the output signal are observed and analyzed, and relevant conclusions are finally drawn.

2. Optical code division multiplexing passive optical network system
The OCDMA-PON system, as the name suggests, is a system that includes two key technologies, which are the optical code division multiplexing (OCDMA) and the passive optical network technology. Among them, the optical code division multiplexing (OCDMA) technology is combined with channel multiplexing and multiple access technologies in the optical domain. The user data source, laser source, optical coder/decoder, optical power combiner, transmission fiber and optical receiver are the basic components to realize this technology. In the optical code division multiplexing system, firstly, the address code of each channel is assigned to each signal, which is optically encoded by the encoder and then multiplexed by the coupler to become a one-way signal. Then the optical fiber is transmitted to the receiver by the decoder for matching optical decoding. Finally, the decoded signal is input to the receiver for processing and then output. It can be seen that the OCDMA technology’s signal multiplexing and exchanging are different from other multiplexing technologies, so it has the advantages of high-speed all-optical processing, flexible address allocation, full utilization of spectrum resources, high confidentiality and support for asynchronous transmission [2]. The passive optical network (PON), on the other hand, is a future-oriented broadband access technology with good service transparency, high economic value, and ease of management. It is characterized by passive components between optical line terminals and optical network units, thus providing huge transmission bandwidth and reducing the energy consumption of system operation. Because of its unique advantages, PON technology has become the most popular access network solution today.

Since the optical codec/decoder is one of the most core components in the OCDMA-PON system [3], its performance is one of the decisive factors for good or bad system performance. That’s why its design is also crucial to the overall performance of the system. In OCDMA systems, there are many devices that can be used as optical coder/decoder, including fiber Bragg grating (FBG), fiber delay line (FODL), array waveguide grating (AWG), spatial light modulator (SLM), etc [4-6]. Among these devices, FBG is the most suitable codec for use in commercialized OCDMA-PON systems due to its superior cost performance, unique filtering characteristics, and flexible codecs. Therefore, OCDMA-PON systems based on FBGs have become a more popular research content in the field of optical communication today.

3. Simulation experiments and results

3.1 Introduction to the simulation platform
In this paper, VPI, a professional optical communication software which commonly used in the field of optical network research, is used for simulation experiments. Since this simulation software has a large number and variety of optical network simulation modules, the user can build the system conceived by the user independently with any module according to the demand, thus realizing the efficient model construction of the optical transmission system. It is also possible to set or optimize the optical communication system by modifying the parameter settings of each device in the model. Using various types of analyzers, the simulation system can be operated with performance indicators such as spectrum, waveform, eye diagram and BER. Users can select the appropriate analyzer to study the system operation data according to the actual needs.

3.2 System model diagram
The experiments are based on the VPI simulation platform to build and simulate a two-dimensional single-user OCDMA-PON system based on cascaded FBGs. The structure is shown in Figure 1. The
transmitter side of the system includes a laser source, data sequence generator, pulse transmitter, Mach-Zehnder modulator, FBG encoder, optical power combiner, and SOA amplifier, while the transmission module is an ideal loss-free fiber. The receiver side includes SOA amplifier, FBG decoder, optical power combiner, direct receiver, and signal analyzer. The main optical encoder/decoder has 5 fiber Bragg gratings and 4 fiber delay lines in each, and its parameters are set according to the address code selection.

![Figure 1](image.png)

**Figure 1.** A two-dimensional single-user OCDMA-PON system based on cascaded FBGs.

### 3.3 Simulation parameter setting

The parameters of the center wavelength of each grating in the coder/decoder and the fiber delay line are set as in Table 1. And the basic parameter settings of the system are shown in Table 2.

**Table 1. Codec parameter setting.**

| Encoder/ nm | Decoder/ nm |
|-------------|-------------|
| FBG1 1548.8 | FBG2 1549.4 |
| FBG3 1550  | FBG4 1550.6 |
| FBG5 1551.2 | FBG6 1551.2 |
| FBG7 1550.6 | FBG8 1550   |
| FBG9 1549.4 | FBG10 1548.8 |

| Fiber delay line/ ns |
|----------------------|
| FODL1 0.24           |
| FODL2 0.24           |
| FODL3 0.24           |
| FODL4 0.24           |
| FODL5 0.24           |
| FODL6 0.24           |
| FODL7 0.24           |
| FODL8 0.24           |

**Table 2. System parameter setting.**

| Name                           | Value            |
|-------------------------------|------------------|
| Bitrate                       | 1e9bit/ s        |
| Light source center frequency | 1550nm           |
| Light source spectrum range   | 1548.8nm–1551.2nm|
| Light source power            | -115dBm          |
| Dispersion coefficient        | 0ps/ nm/ km      |
| Sampling rate                 | 128e9Hz          |
| Sampling center frequency     | 193.548e12Hz     |
| Time window                   | 16e-9s           |
3.4 Simulation results and analysis

3.4.1 Spectrum analysis of the output optical signal at different fiber lengths.

The results of the integrated spectrogram show that there is no significant change in the power of the signal as well as the spectrum within 10 km; the power of the signal decreases when it exceeds 100 km, while it decreases more obviously when it reaches 1000 km. But in general, no matter how the transmission distance changes, the frequency of the signal always remains at the center frequency of 193.548 THz, and no spectral shift occurs.
3.4.2 Waveform analysis of output electrical signal at different fiber lengths.

Analyzing these waveforms, we can know that within 100km, the decoded signal can still be restored to the original user signal despite partial distortion, while beyond 1000km, the waveform changes drastically and the signal distortion is larger. This indicates that the system cannot decode normally when the transmission distance exceeds a certain length, which makes the signal have a large error.
3.4.3 Eye diagram analysis of the output electrical signal at different fiber lengths.

![Eye diagram at a length of 10km](image1)

Figure 8. Eye diagram at a length of 10km

![Eye diagram at a length of 100km](image2)

Figure 9. Eye diagram at a length of 100km

![Eye diagram at a length of 1000km](image3)

Figure 10. Eye diagram at a length of 1000km

Analyzing the eye diagram results, we can know that within the transmission distance of 100km, the eye diagram of the output signal is still clear on the whole, and some messy lines gradually decrease with the increase of transmission distance, which indicates that the anti-noise performance and signal decoding ability of the system is relatively strong, and the reliability of transmission is high. After the fiber length exceeds 1000km, the regularity of the eye diagram decreases and the lines are messy, and the signal distortion is large, which indicates that the decoding ability and anti-noise performance of the system are weak and the transmission reliability is low.

4. Conclusion

In this paper, a two-dimensional single-user OCDMA-PON system based on cascaded FBGs is constructed by VPI, and the signal quality of the system output at various fiber lengths is simulated and analyzed. From the experiments, it is clear that the noise immunity and signal decoding ability of the system are relatively affected by the variation of fiber length. Within a certain range, the longer
transmission distance is, the better the quality of the output signal is instead; when the upper limit is exceeded, the signal quality decreases sharply and generates larger errors. This paper provides a certain reference value for the research of subsequent code division multiplexing type passive optical network 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), the basic research foundation project of Engineering University of PAP (No.WJY201920, No.WJY202019, No.WJY202144), the military theory research project of engineering university of PAP (No.JLY2020085), the education and teaching fund project of Engineering University of PAP (No.WJJ202039, No.WJX2021101), the research capacity improvement plan of engineering university of PAP (No.WKY202127), the PAP’s Military Scientific Research Mandatory Project (No.WJ2020A020048), the basic research foundation project of college of Information Engineering of Engineering University of PAP (No. XYJC202112).

References
[1] Ahn, B. G, Park, Y. L. (2002) A symmetric-structure CDMA-PON system and its implementation. IEEE Photonics Technology Letters, 14(9): 1381-1383.
[2] XU W. (2008) Recent Progresses in OCDMA. Piscataway, N. J.
[3] Yi, C. Q. (2009) Application study of OCDMA-PON technology. Optical Communication Technology, 33(4): 18-20.
[4] Wang, X. Wang, X. H. Sun, Y. B. Li, Q. J. (2007) Advances in OCDMA systems and related devices. Semiconductor Optoelectronics, 28(2), 451-457.
[5] Li, C. Q. Sun, X. H. Zhang, M. D. Ding, D. (2005) Analysis and research of OCDMA system networking technology and core components. Journal of Quantum Electronics, 22(3): 326-333.
[6] Li, C. Q. Zhu, Y. C. Zhou, W. (2008) Research on tunable coder/decoder for optical code division multiple access system. China Laser, 35(12): 1901-1905.