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Performance analysis of multiuser optical wireless network (IR, or UV light for signal carrying) under different environmental conditions

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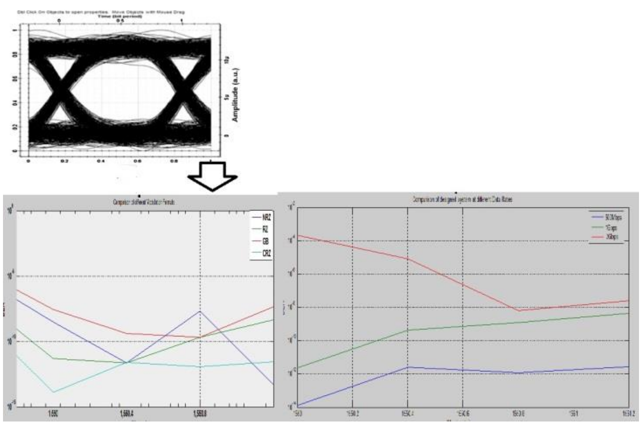
Graphical abstract



Abstract

The field of optics is flourishing day by day on account of the wide usage of the internet and its associated technologies. Free Space Optics (FSO) is a data transmission technique that employs light propagation to send data. This technology is very effective in those circumstances where fiber optic cables cannot be deployed. This paper provides a model and simulation of the Fiber Bragg Grating (FBG) based FSO network under different environmental conditions, such as modulation types and data rates. Also, investigation of the impact of Multiple Access Interference (MAI) on FSO under design parameters has been done. The designed system performance is analyzed under the multiuser optical wireless network by changing data rates and modulation types. The proposed model's security is achieved through the use of the FBG encoder/decoder and the FSO channel for transmission. It has been inferred that the CRZ modulation type provides the best BER and Q factor compared to other formats, and a data rate as high as 1Gbps can be achieved using the CRZ modulation format. It has been noticed that as the number of users grows, the BER value begins to deteriorate.

Keywords: FSO, BER, MAI, FBG, CRZ, UV and IR, optical wireless network

1. Introduction

Next-generation technology must be able to meet today's bandwidth demands as well as provide enough bandwidth for future growth due to network expansion and the development of novel applications. Owing to its high bandwidth capacity, optical wireless technology seems to be the best option for addressing the challenges of access networks (Wu *et al.*., 2014). Free Space Photonics (FSP) and Optical Wireless (OW) are other names for FSO communications (OW). A wide range of optical connections may benefit from FSO communication, including those between buildings, ships, planes, and satellites. As the need for high-speed communication systems grows, FSO systems have evolved to meet that demand. A high-bandwidth and cost-effective solution based on free-space laser communication for fulfilling the high bandwidth requirements of the customers is required.

One at a time to offer full duplex functionality, an FSO device has a laser transmitter and a receiver. There are two lenses in each FSO unit: one that sends light into the atmosphere, and another that receives it. A potential solution to the growing broadband access market is FSO technology. Aside from their optical nature, these systems have advantages including cheap operating costs, quick deployment, and high bandwidths comparable to those found in fiber. To efficiently deliver traffic to the optical fiber backbone, FSO offers a mix of characteristics such as limitless bandwidth, low cost, simplicity, and speed of implementation, among other things.

OCDMA (Optical Code Division Multiple Access) (Yin and Richardson, 2008) is a technique that uses optical coding to perform multiple transmissions and accesses in the same time slot and frequency. OCDMA is capable of implementing high-speed transmission by switching data via all-optical signal processing, and so efficiently allocating bandwidth. Regardless of the network architecture, data security is a major issue when it comes to data transfer. There's a widespread misconception that wireless connections are less secure than connected ones. However, for a variety of reasons, FSO is much more secure than RF or other wireless communication methods. Spectrum analyzers and RF meters have no way of detecting laser beams in this environment. Owing to the fact that the transmission is optical in nature, it follows a straight line and cannot be readily intercepted. As a result of these factors, it's difficult to locate and intercept the laser beams. FSO-based network transmissions benefit from the addition of encrypted data transfers (Abd El-Malek *et al.*., 2016).

The main outcomes of this research work will be:

1. A model and simulation of FBG based OCDMA-FSO network is presented.

2. The proposed system's performance is evaluated using various modulation formats and data sets.

3. The effect of MAI on the performance of a designed network has been studied using various parameters.

The following is how the paper is organized. Section 2 has highlighted the related work pertaining to FSO. Section 3 defines the proposed model, followed by Section 4 about the simulation of the proposed model. Section 5 discusses the results and their interpretations, and the conclusion is the final section of the paper.

2. Work done in India and abroad

The major work that has been done by the researchers in the field of FSO deployment, operational methods and security has been highlighted.

An optical CDMA implementation using spectral-coding of incoherent broadband optical sources has been proposed by the authors in (Kaler and Monga, 2016). It has been proposed to use FBG's spectrum properties to create an FBG encoder/decoder. This study uses Spectral-Amplitude Coding (SAC) from FBG for coding and decoding. According to the other research (Kumar and Singh, 2014) an optical CDMA communication system using FSO was proposed by the authors. NRZ modulation is used to create a 2.5 Gbps data stream. An MZM modulator modulates the 2.50 Gbps NRZ data stream before it is sent through FSO via four mode-lock lasers.

During the implementation of an FSO system, a system designer must address a number of problems. These concepts were discussed in (Henninger and Wilfert, 2013). In their research, they include conventional gains and losses that occur along the way from the transmitter to the receiver via the medium. It was demonstrated in (Sharma and Kaur, 2012) that an FSO system that is resistant to fading may be implemented using a simulated test bed that employs an FSO link having sufficient SNR and BER and the greatest stream rate of 2.5 Gb ps.

An Optical CDMA system based SAC is examined in FSO and OF situations, with an emphasis on different types of codes, in (Mostafa *et al.*., 2017). Attenuation and dispersion are the main factors to consider in this analysis. Different rain attenuation circumstances are also used to compare the performance of different codes. The work (Tseng *et al.*., 2020) has been reported based on the bipolar OCDMA method based on SCA for optical-polarized creation and transmission. The suggested system utilizes a dual electro-optical modulator architecture, which boosts transmission speed above existing methods.

The use of FSO communication in application networks is on the rise as a widespread technology. System (Talib *et al.*., 2016) is primarily designed to decrease the likelihood of a mistake occurring. There is an OCDMA code used in the FSO system called the Zero-Cross Correlation (ZCC). Incorporating Wavelength Division Multiplexing (WDM) and Orthogonal FDM methods, a new ultra-high capacity FSO connection has been created (Singh *et al.*., 2021). The influence of dynamic meteorological conditions, such as bit error rate, signal-to-noise ratio (SNR), and maximum transmission range, is considered.

FSO communication systems Non-Line of Sight (NLOS) security issues have been studied in some detail. We know that increased atmospheric concentration of scattering particles, an eavesdropper may be able to detect an increase in scattered optical power. The FSO communication system's performance is estimated using several channel models (Wilfert *et al.*., 2021). Meanwhile, several FSO communication enhancement mitigation strategies have been developed and studied throughout the years. Researchers have studied FSO channel models and have proposed hybrid modulation techniques to further improve FSO performances. Free space optical (FSO) communication be able to give high-bit-rate line-of-sight transmissions over lengthy distances of up to numerous Km over a wide range of spectrum. As such, FSO is a striking solution for terrestrial last-mile connectivity in communication networks, particularly wherever fiber connectivity is scarce. FSO is equally important for next generation technology of the future 6G era to scale down bandwidth challenges. IR and UV light in optical fiber plays a very important role for signal carrying. Stronger is the IR and UV, stronger will be the intensity of signal (Mittal *et al.*., 2016, 2020a,b; Pandey, 2016; Pandey and Nanda, 2015;Pandey and Ramontija, 2016).

Some other related work similar to the mentioned above has been done by many authors in their manuscripts (Bhanja *et al.*., 2017; Cheng *et al.*., 2020; Eid and Rashed, 2021; Magidi and Jabeena, 2021; Raddo *et al.*., 2020; Sarangal *et al.*., 2021; Singh and Malhotra, 2021; Upadhyay *et al.*., 2020; Wijanto and Huang, 2021). Working in the field of FSO is thus a very appealing option.

3. New grey forecasting model

The proposed model design and the components that are being used are mentioned in this section. A DM laser, a pre-amplifier, and an optical multiplexor are all part of the system's architecture, as illustrated in Figure 1. The pulses generated by a sine generator are rectangular in shape. Using the electrical generator, the discrete mode laser creates optical pulses with a tiny line width, and the preamplifier amplifies the boosted electrical pulses even more.

A pulse generator is a circuit or a piece of electrical equipment that generates square pulses. Pulse generators may produce output pulses with widths (durations) ranging from minutes to less than 1 picoseconds. Pseudo-random binary sequence (PRBS) generators are commercially applied in the area of electrical and electronic engineering. Their randomness is one of their most important properties, because they are very useful in producing white noise test patterns. The availability of this PRBS test equipment is frequently a limiting factor, because commercially available electronic PRBS test equipment covers data rates up to 15 Gbits/s.

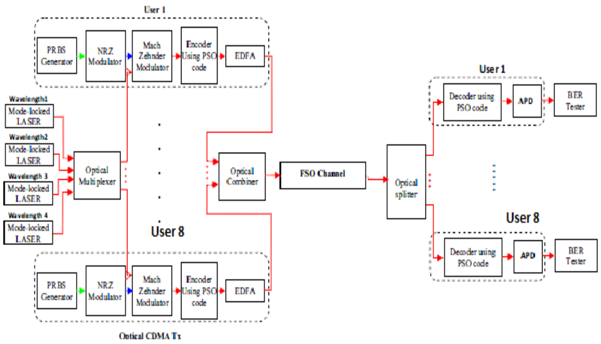


Figure 1. An OCDMA-FSO network block diagram.

Fabry-Perot (FP) laser diode limited to melt in a single mode of the FP chamber is utilized as the DM laser. At a bias of 55mA, it has a 3dB electrical bandwidth of about 10GHz. An optical transmitter's optical output is amplified by a booster amplifier immediately before it enters an optical fiber. As the optical signal goes through the optical cable, it is attenuated. To return the optical signal to its original strength, an inline amplifier is utilized. At improve the sensitivity of an optical receiver, an optical pre-amplifier is connected to the end of the optical fiber link. Praseodymium amplifiers are also used, although Erbium is the chosen rare earth for them. Long-distance optical communication makes use of EDFAs for amplification.

Optical filters, often implemented as flat glass or plastic structures, are used to selectively transmit distinct wavelengths of light. Long wavelengths, short wavelengths, or a range of wavelengths can all be passed through them. Filter design are primarily differentiated by their transfer function rather than their topology. Transfer functions used may be linear or nonlinear.

4. Simulation setup

Simulation Setup indicated that received power can be increased by increasing transmitted power up to limit to mitigate channel attenuation loss (Bhanja *et al.*, 2017). A 5 Gbps data signal is created using the Non-Return-to-Zero (NRZ) modulation type in the optical CDMA over FSO communication system presented in Figures 2 and 3. Using four mode-lock lasers to generate a 3 mW dense WDM multi-frequency light source operating at 1550.0–1551.2 nm, the 5 Gbps NRZ data stream is first modulated with a MZM modulator before being sent via FSO. Next, an optical CDMA signal is sent across FSO in order to make use of it. In this case, there are eight OC-48 users, each of whom needs a unique signature code. Because they preserve the correlation benefits of PSO linear sequences while requiring less bandwidth expansion, pseudo orthogonal (PSO) matrix codes are useful for OCDMA applications. The coding set generated by PSO matrix codes is slightly higher.

User 1 has a lengthy time-slot reuse sequence in this model. The chip has a period of 100 ps because of the four time slots employed without a protective band. A decoder at the base station retrieves PSO code, which is then, transformed to electrical via APD for successful recovery of 5 Gbps of optical CDMA data at the base station.

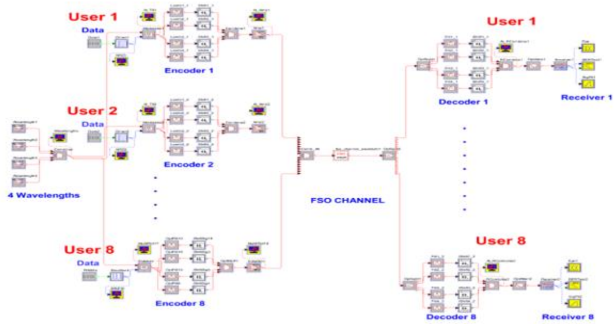


Figure 2. Simulation setup for 8 users OCDMA-FSO proposed network.

Due to MAI, even when using an FBG encoder, the total system's signal-to-noise ratio is limited due to interference from other users transmitting at the same time. The most prevalent cause of bit errors in an optical CDMA over FSO communication system is crosstalk between various users using the same common FSO channel, known as the MAI.

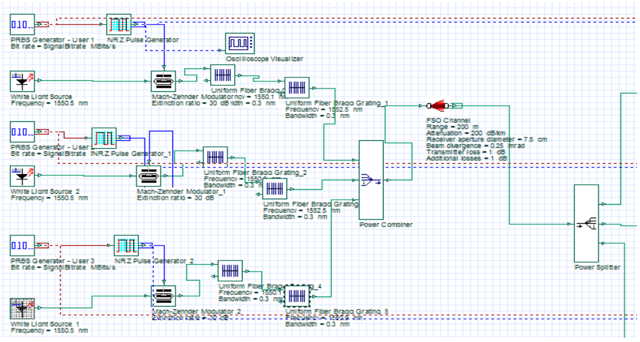


Figure 3. Simulation setup for transmission network.

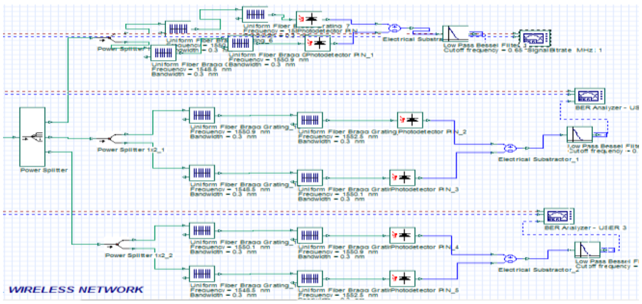


Figure 4. Simulation setup for receiver network.

Figure 3 depicts the FBG-based OCDMA communication system block diagram. An Optical External Modulator (OEM) is used at the transmitter to optically modulate data using a uni-polar digital signal. The Mach–Zehnder modulator is employed in this project. After that, the modulated code sequences are assembled and sent across the FSO connection. Optical splitters separate the modulated code sequences at the receiver.

An overlapping chip will not utilize on the receiver side since it might cause interference there. After that, the image detector picks up on the encoded signal. The incoming signal is filtered with a Low-Pass Filter (LPF) to retrieve the original sent data. Using FBG encodes and decodes data in this work. The OOK modulation format is employed here. FBGs are used inside the fiber to modulate the broadband coherent optical signal's amplitude spectra. Spectral frequency chips centered on the grating frequency are used to assign a unique signature sequence to each OCDMA system user using FBG.

5. Results and analysis

The major factors that are used for the analysis of performance of the proposed model are BER, Eye diagram etc. The eye diagram depicts the breadth and height of the eye in three dimensions: length, width, and height. The noise is only a margin of the signal, as seen by the height of the eye opening. By employing an optical splitter, we were able to expand the number of users. Figures 4 and 5 illustrates the simulation's outcome, which shows how users and BER interact. According to this idea, as the number of user's increases, data and voice quality will degrade and become unusable.

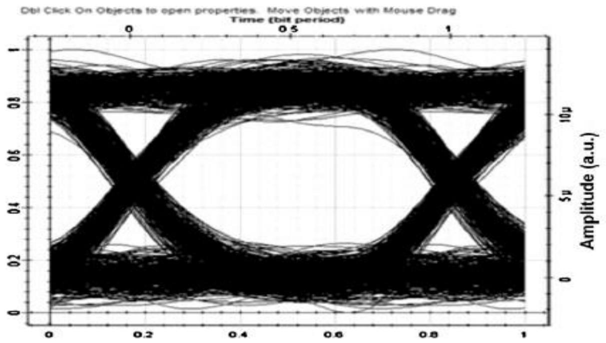


Figure 5. Eye diagram representation for BER with respect to users.

For the implementation of a planned transmission system, degradations owing to chromatic dispersion, Kerr nonlinearities, and the like are critical concerns to consider. One of the most effective ways to counteract these degradation sources is to create the optimal modulation format. The modulation formats are therefore examined and the optimal forms are then selected among NRZ, RZ, Gaussian Beam (GB), and Chirped RZ (CRZ).

Table 1. MAI effect on the various network parameters

Number of Users		Data Rate & Modulation Format	BER	Q Factor
1	U1	1Gbps & CRZ	1.28E-22	18
2	U1		4.46E-18	16
	U2		2.22E-16	15
3	U1		4.23E-16	15
	U2		5.45E-14	14
	U3		1.34E-12	13
4	U1		2.34E-12	13
	U2		4.34E-10	11
	U3		1.21E-09	10
	U4		4.22E-09	10

Table 2: Beam divergence effect on the various network parameters

Number of Users	Beam Divergence	BER	Q Factor
U4	0.25 mrad	1.28E-14	14
	0.50mrad	4.34E-12	13
	0.75mrad	4.22E-09	10
	1.0 mrad	2.52E-08	8

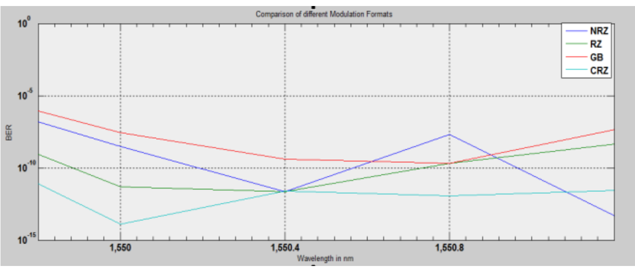


Figure 6. Comparative analysis of various modulation formats.

Figure 6 shows the modulation comparison on four users' secure OWC network. NRZ, RZ, CRZ, and GB modulation formats are compared on four different channels: 1550, 1550.4, 1550.8, and 1551.2. It has been observed from the results that if modulation formats RZ, NRZ, GB, and CRZ have been applied to the designed system, CRZ yields better results as compared to other formats, and BER as good as e-14 can be obtained using the CRZ format.

It has been observed from Figure 7 that the proposed OCDMA-FSO network can work satisfactorily at 1Gbps using CRZ modulation format and BER as good as e-12 and a Q factor as high as 13 can be obtained. It has been concluded that the designed multiuser OCDMA-FSO network yields better performance for the CRZ format as compared to NRZ, RZ, and GB formats, and a data rate of

1Gbps can be obtained for a 4 user network using the CRZ format.

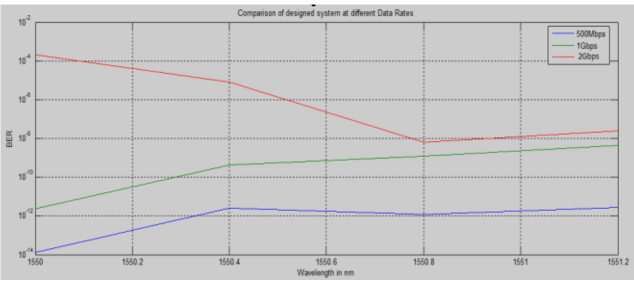


Figure 7. Comparative analysis between different data rates.

Despite the usage of the FBG encoder, interference from other users transmitting at the same time, known as MAI, is the primary factor limiting the entire system's effective signal-to-noise ratio.

BER and Q factors decrease when the number of users rises, as seen in Table 1. Table 1 illustrate that while there are only one user, the BER and Q factor are 1.28E-22 and 18 correspondingly; however when there are four users, the BER and Q factor degrade rapidly.

Table 2 shows beam divergence as a characteristic of optical electromagnetic beams. When the beam comes from an aperture that has a large wavelength relative to it. An antenna's aperture, often known as its effective area, is a measurement of how well it receives radio waves energy.

6. Conclusion

Fast and low-cost access to the fiber optic backbone is provided by FSO. Fibre-quality connections are provided by FSO technology as well as the industry's lowest-cost transmission capacity. This paper presents the design of a 5 Gbps optical CDMA over FSO communication system for 7000 m. NRZ modulation has been used to investigate the optical CDMA over FSO performance with and without MAI and with various NRZ parameter settings. It has been found that optical CDMA communication systems using NRZ outperform those using FSO when using NRZ. As transmitter power rises, so does broadcast range. Increasing the number of users has been found to reduce the system's efficiency. This means that in the optical CDMA over FSO communication system, MAI is a barrier. It has been concluded that the designed multiuser OCDMA-FSO network yields better performance for the CRZ format as compared to NRZ, RZ, and GB formats, and a data rate of 1Gbps can be obtained for a 4 user network using the CRZ format. It can be concluded that the designed multi-user secured optical-wireless network gives best performance for 1Gbps data rate using CRZ modulation format when beam divergence is 0.25mrad, receiver aperture diameter is 9.5cm and transmitter diameter is 5 cm. High bandwidth and cost are the major concerns for the deployment that will be done in the future pertaining to the proposed work.

This type of can lead to the improvement of the system in future. There are different techniques like OFDM-FSO, WDM-FSO based scheme are new technique to improve the future system performance with high speed and longer distance. This study also indicated that new techniques could be designed by combination of these and, by enhancing these techniques, system designing can be improved and the demerits of FSO system can be reduced to a minimum level.

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