International Journal of Computer Engineering in Research Trends
Multidisciplinary, Open Access, Peer-Reviewed and fully refereed
Research Paper Volume-7, Issue-10, 2020 Regular Edition E-ISSN: 2349-7084

Performance Analysis of Free Space Optical Communication Network with Different Modulation Techniques

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Available online at: http://www.ijcert.org

Received: 17/10/2020, Revised: 22/10/2020, Accepted: 26/10/2020, Published: 31/10/2020

Abstract:- Free space optics is one of the emerging technology of optical wireless communication which refers to propagation of light beams through atmosphere for broadband communication. It is a promising alternative solution for RF network, as it provides stable data transmission and highest data rates. However performance of this system could be prominently degraded due to various atmospheric conditions that may lead to increase in bit error rate and affect link sustainability. In order to increase its reliability for all weather conditions, data modulation scheme is employed so as to make the communication link feasible. This paper presents analysis of proposed FSO system with comparative study of different modulation techniques under weak turbulence at 1550 nm wavelength in terms of BER and Q factor so as to mitigate adverse effects and improve efficiency. The findings are based on which modulation format provides better means of communication among OOK, ASK, FSK, BPSK, DPSK, QPSK for different link ranges and attenuation. Finally the simulation results are obtained, analyzed and further discussed.

Keywords: Free space optics, Modulation techniques, Bit error rate, Q Factor, Turbulence.

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1. Introduction

In recent years, there is tremendous growth and advancement has been observed in information and telecommunication domain with increase in the demand for higher bandwidth, long distance communication and high speed internet. Free space optical communication is a line of sight technology that uses light as carrier and free space as medium to transfer information such as data, voice, images, video etc. between transmitter and receiver separated by certain distance through a wireless link [4]. Easy and quick deployability, license free operation, insensitivity to electromagnetic interference, excellent data security, cost effectiveness and less power are some unique features which makes this technology much interesting. It operates on 2.5 Gbps bandwidth and communication can be achieved up to several kilometers with maximum 10 Gbps data rate by full duplex connectivity in THz frequency spectrum. The optical source utilized is LASER. It is preferred over LED due to its high pointedness, directivity and coherence that it's beam exists [2]. Also it is useful where physical connections are impractical. It has numerous applications in last mile access, remote sensing, disaster recovery, radio astronomy, military, satellite communication and many more.

Despite of great advantages of FSO, its performance is limited by the factors like absorption, scattering, rain, snow, scintillation, fog, geometric losses that affects signal strength and also greatly reduces the receiver

 https://doi.org/10.22362/ijcert/2020/v7/i10/v7i1001

sensitivity as well as detection efficiency which results in the signal degradation. However to overcome all the above drawbacks we use several types of modulation techniques at the transmitter end that help us to modulate intensity of the transmitted signal which carry the information [3]. The overall objective of the paper is to focus on review of the FSO communication system with different modulation formats in order to have high link availability and reliability. Rest of the paper is organized as follows, Section II presents an overview on FSO communication system. Section III describes various digital modulation schemes. Different optimization factors are given in Section IV. Then Section V explains system designing in brief along with design parameters and FSO link layout. Section VI contains simulation framework. Afterwards Section VII involves result analysis. Finally, Section VIII concludes the research work.

2. FSO Communication System

Conventional free space optics system has a transmitter and a receiver and in between them an atmospheric channel [2]. The transmitter is configured to deliver optical signals in free space. FSO channel is most proper pathway for showing free space natural connections [1]. The main function of receiver is to estimate the transmitted data from received optical beam. As long as there is a clear LOS between the source and destination, FSO communication is possible.

For this system the performance can be determined directly from the power flow.

$$Pr = Pt+GTx+GRx-\text{total loss} \quad (1)$$

Where, Pr = Power received [W]
Pt = Power transmitted [W]
GTx = Transmit antenna gain
GRx = Receive antenna gain

3. Digital Modulation Schemes

Since the information cannot be directly sent without an error at the receiver, thus several modulation techniques are employed in FSO so that message is less affected by noise and it will reach to destination without distortion [2]. The selection of modulation scheme for optical signal transmission plays an important role in reduction of atmospheric effects [10]. Various techniques are listed below,

1. On-Off Keying (OOK): It is a direct detection technique that requires adaptive threshold in which when bit 0 is transmitted it remains in off state and when bit 1 is transmitted it remains in on state.

2. Aptitude Shift Keying (ASK): The amplitude of the carrier signal varies in discrete levels in accordance with the input digital signal, keeping frequency and phase constant where each amplitude encodes an equal number of bits.

3. Frequency Shift Keying (FSK): It is changing the frequency characteristics of an input binary signal according to the carrier signal, where binary information can be transmitted with frequency changes.

4. Binary Phase Shift Keying (BPSK): It is coherent detection technique that conveys data by modulating two different phases of a reference signal 0° and 180° where change in phase takes place with respect to the reference signal.

5. Differential Phase Shift Keying (DPSK): It is a direct detection technique in which we change phase of the signal without considering reference signal where information that is transmitted is the result of phase difference between current and previous symbol.

6. Quadrature Phase Shift Keying (QPSK): Four phases used to represent data bits which help to encode two bits per symbol while representing the data, where two successive bits in a bit stream are combined together to form a message.

4. Optimization Factors

Bit error rate characterizes the quality of data link in digital domain. It can be given as number of bits in error divided by total number of bits transferred during a specified time interval [7]. Quality factor describes the quality of transmission in analog domain. Thus it is stated as signal to noise ratio or SNR.

The performance of each modulation technique is measured by calculating BER and Q-factor in presence of atmospheric destruction as well as noise [7].

5. System Design

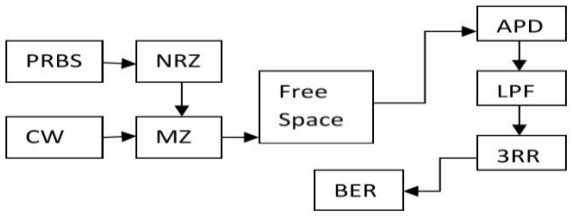

Figure 5.1 System Model of FSO Communication

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To generate necessary information signals for transmitting from transmitter side to receiver through atmospheric channel, Pseudo Random Bit Sequence (PRBS) generator is used which creates data bits in binary form as 1's and 0's that is converted into electrical form by NRZ pulse generator. As the medium of propagation is free space, it throws a lots of challenges for transmitted signal such as atmospheric turbulence results in intensity fluctuation and degradation of optical beam. Thus there is necessity of modulator to modulate the data for transmission that depends upon various modulation schemes. Mech Zhender modulator used here for same. CW Laser with frequency 1550 nm and power 20-70 dBm is chosen for converting the signal into optical form. FSO channel is designed with different link ranges and specific attenuation values for various atmospheric conditions. In receiver section Avalanche Photo Diode (APD) is used for optical to electrical conversion. Then received signal recovered after amplification and filtering used for boosting strength of signal as signal that is received is very weak. Low Pass Bessel Filter is used for this purpose. 3R regenerator is used for reamplification and also reshaping of signal. To analyze the signal BER analyzer is used for estimating bit error rate, quality factor and eye pattern in order to evaluate performance of the link.

Table 5.1 Parameters used for designing of FSO link

Parameters	Values
Transmitting Wavelength (nm)	1550
Transmitting Power (dBm)	20, 30, 40, 70
Link Range (km)	0.5, 1, 1.5, 2
Attenuation (dB/km)	0.1, 4.2, 8.68, 25.5
Data Rate (Gbps)	10

Table 5.1 shows different parameters that are used for designing and simulating a free space optical link for several modulation techniques used in this paper as discussed earlier such as OOK, ASK, FSK, BPSK, DPSK and QPSK. For each of these modulation schemes, FSO channel is constructed with link ranges 0.5km, 1 km, 1.5 km and 2 km with typical attenuation values set to 0.1 dB/Km, 4.2 dB/km, 8.68 dB/km and 25.5 dB/km for clear sky, haze, rain and fog scenario respectively. As attenuation increases under different atmospheric conditions, there is also necessity for adjusting the transmitting power in accordance with receiver sensitivity in order to obtain less distorted signal and minimum BER.

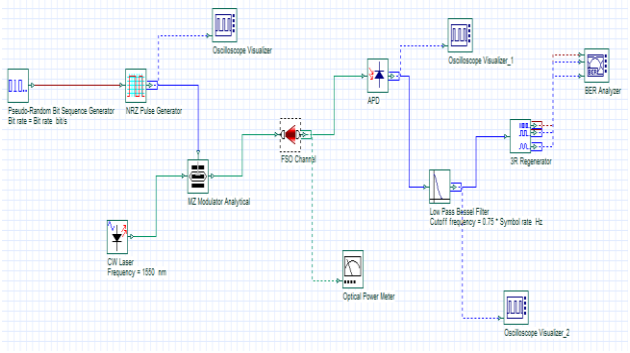

Figure 5.2 Optimized 1550 nm FSO Link Design

After extensive analysis and design of different modulation techniques using free space optical communication, it is expected that the best modulation technique for FSO will be obtained in terms of quality factor, signal to noise ratio and bit error rate. Furthermore, atmospheric effects in the FSO link should be as minimum as possible for long range operation.

6. Simulation Framework

Eye diagram analyzer is used to quickly visualized and determine the quality of signals in high speed digital transmissions. This tool helps in analysis of Q factor, eye opening, eye closure, extinction ratio, eye height, jitter etc. with their respective graphs. Here, eye pattern is obtained for OOK modulation technique for four different atmospheric conditions at four link distances.

Firstly for clear sky condition at a distance of 0.5 km, the transmitter power requirement is 20 dBm. The Q factor is 487.90 as shown in figure below.

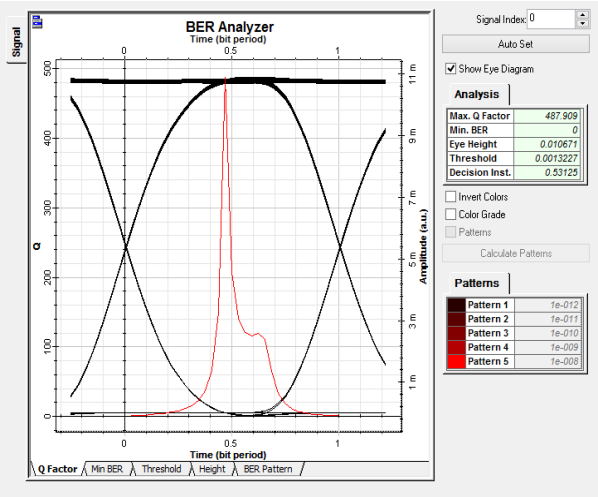

Figure 6.1 Simulation Result for Clear Sky at 0.5 km

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Now for haze condition at a distance of 1km, the required transmitter power is 30 dBm. Its Q factor is 464.44 as indicated in following figure.

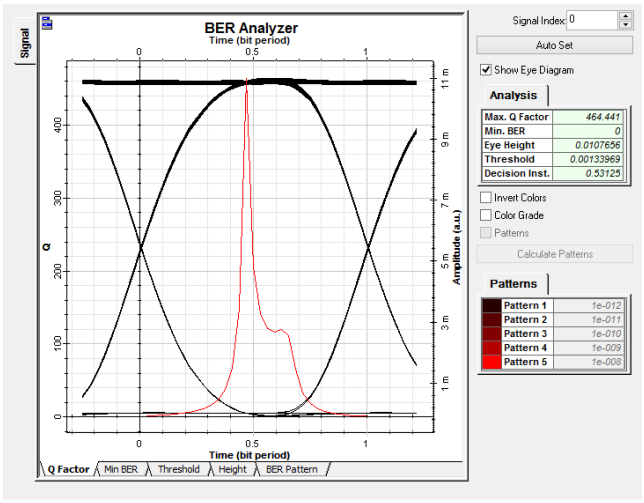

Figure 6.2 Simulation Result for Haze at 1 km

Then for rain condition at a distance of 1.5 km, there is power requirement of 40 dBm. As illustrated in the following figure the Q factor is 372.3.

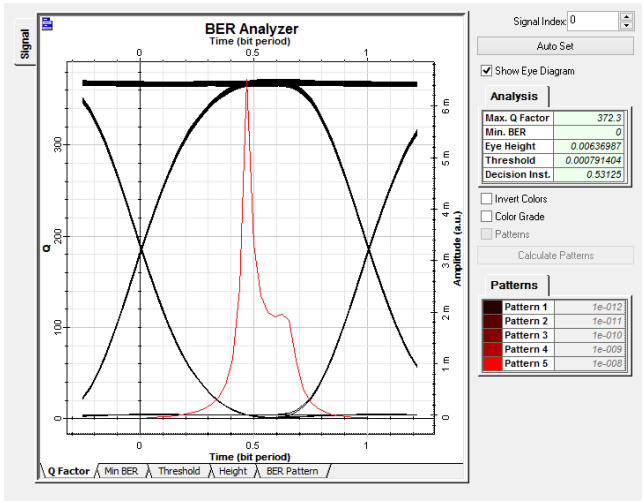

Figure 6.3 Simulation Result for Rain at 1.5 km

Lastly for fog condition at a distance of 2 km, there is requirement of power upto 70 dBm. Q factor is 94.22 as given in figure below.

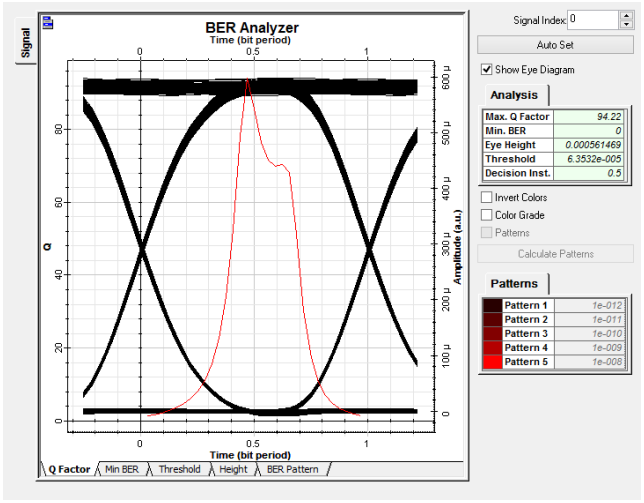

Figure 6.4 Simulation Result for Fog at 2 km

The wide eye opening indicates that the received signal is less distorted. As the link distance goes on increasing it results in more eye closure. Negligible bit error rate shows that the quality of signal proves to be high. Maximum Q factor and minimum BER represents that performance of FSO system is satisfactory.

7. Result Analysis

After execution of simulating various modulation formats with their respective transmitting power, link range, attenuation constant and weather condition, we get the following results as shown in table 7.1 The choice of best modulation technique depends upon maximum quality factor and minimum bit error rate. So in this paper, it has been concluded that OOK proves to be most efficient and robust scheme.

Table 7.1 Comparison of Typical Modulation Techniques

Modulation Type	Q Factor	BER
OOK	487.90	0
ASK	461.89	0
FSK	0	1
BPSK	0	1
DPSK	26.10	1.12×10^-15
QPSK	12.42	6.76×10^-03

8. Conclusion

Free space optics is a promising wireless technology which has proved to be very efficient means of communication that has gained much more popularity and demand in-spite of facing atmospheric disturbances. In this work, a comprehensive survey of communication through FSO system with main focus on the study of various

 https://doi.org/10.22362/ijcert/2020/v7/i09/v7i0902

turbulent conditions of atmosphere has been presented. The comparative analysis of performance evaluation of several modulation techniques shows that which scheme performs superior among others in terms of maximum Q factor, better SNR and minimum BER. Furthermore, it has been concluded that maximum quality factor is inversely proportional to minimum bit error rate, thus with decrease in BER, there is increase in Q factor. Hence the performance of free space optics link enhances.

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