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Free Space Optics Technology

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ABSTRACT

For developing countries, it is essential to have cost effective, large band width, high data rate network. This can be achieved by Optical wireless channel or free space optics (FSO), which is a new technology in an optical communication system. The proposed network offers almost zero-bit error rate (BER) or error free transmission up to 1.5 Km for a transmitter power of 35 dBm, data rate up to 10Gbps at 1550nm, under clear sky condition. Further, this FSO link is analyzed for natural impairments such as rain, haze and fog. The minimum received power is up to -35dBm, which is received by Ge-PIN-Photo-detector-using NRZ coding. Network is simulated for Rayleigh fading channel.

INTRODUCTION

Free Space optics overcome the problem faced while planting optical fibers. Some of the merits of using FSO are free spectrum, high data rate, simple and temporary network installation etc. The challenges faced by FSO are atmospheric turbulence, Earlier various methods were proposed to combat this problems, such as coherent free space optical communication with holographic modal wave front sensor(HMWFS) for improved BER and to be insensitive to atmospheric scintillation [1].Other techniques that was proposed earlier, involved space diversity by employing 2-3 transmitter apertures, which is popularly termed as space diversity technique, which reduces the temporary blockage due to birds. However, there is a restriction on the laser power to be radiated into free space, which in turn depends on the wavelength of operation. Here the log normal fading channel was considered [2].

Later MIMO FSO was studied. Atmospheric turbulences were modeled as ergodic process [3]. Another acute problem that predominates in FSO is the fading due to misalignment, which is termed as pointing error. Which in turn reduces BER.Technique known as MIMO FSO and MIMO FSO with bipolar shift keying (BPOSK) was proposed to improve BER [4]-[6]. In 2019 the concept of relaying system using Few-mode EDFA in FSO was introduced. This concept resists the atmospheric turbulence. Considerable amount of BER performance was observed when power was varied from 4dB to 11dB [7]. This technique involves the usage of Few -mode single mode fiber components. Some of the popular data format suitable for minimizing the pointing error includes simple RZ, NRZ.[8]. Possibility of incorporating error correction codes and different types of modulation techniques such as OOK,BPSK and QPSK are reported to reduce the BER [9]-[10].

Very recently free space optics based 5G communication system has been implemented. This can be achieved by deploying point to point FSO links over high-rise structure Use of visible spectrum for 5G and beyond network is in research stage [11]. High absorption at visible wavelength persuaded the scientist to opt hybrid operation such as visible light-RF combination for uplink and downlink. In this paper, a point to point wireless optical communication channel model termed as an FSO model is designed and analyzed at 1550nm for the evaluation parameters such as BER, Q-factor and losses. Free space optics (FSO) is a branch of optical communication system that provides an efficient way of deploying long distance communication channel with ease [6]. Some of the advantages of this technology are high data rates, small in size, low cost, easy and temporary installation, etc. the speed that can be achieved using this technology is 1.5 Gbps to 10 Gbps.

The major advantage of FSO over microwave systems are that it does not affect the biological life [7]. Hence, is harmless to nature. Moreover, optical beam does not diverge as much as that radio frequency beam. This technology uses laser or LED as a source and free space as medium. Atmospheric and geometric attenuation are the major reasons for data loss in the system. These losses can be minimized by one of the following methods 1. Increasing the sensitivity of the detector,2. Increasing the transmitter power or 3. Using optical amplifiers [8]-[9].

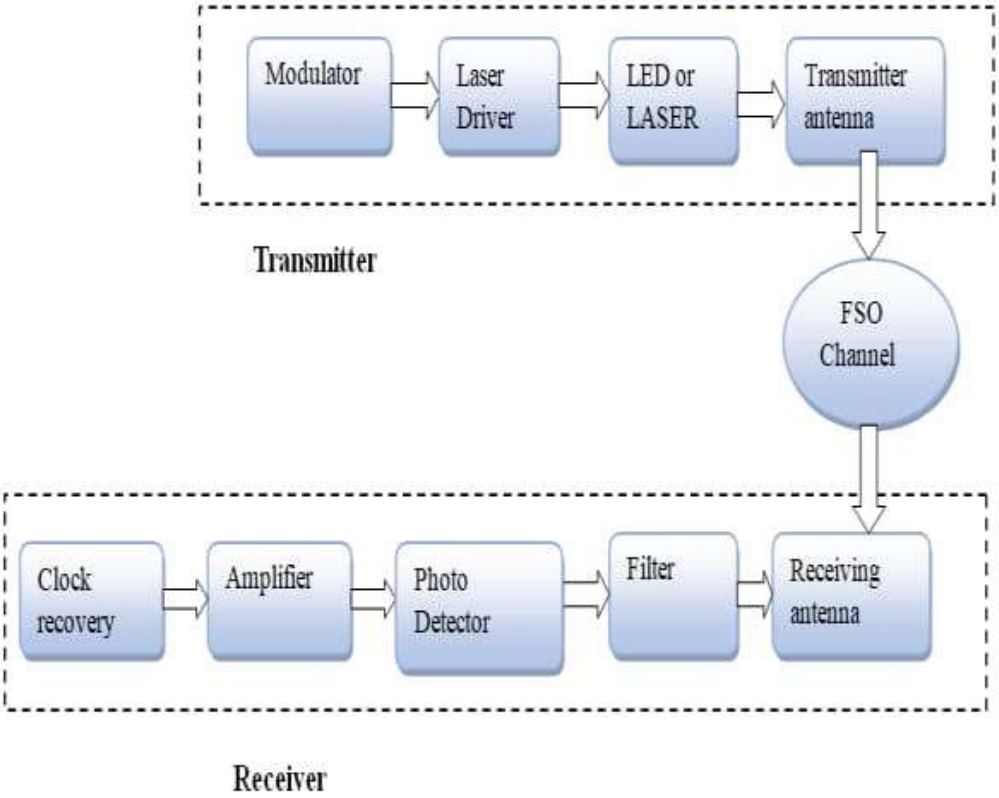
PROBLEM STATEMENT

The deployment of 5G technology promises unprecedented data speeds, lower latency, and increased network capacity. However, traditional wireless communication infrastructure faces challenges in meeting these demands, especially in urban areas with high population density. One emerging solution to address these challenges is Free Space Optical (FSO) communication technology, which utilizes light to transmit data through the atmosphere. Despite its potential advantages, FSO technology encounters several significant issues that hinder its widespread adoption and effective implementation within 5G networks. These problems include atmospheric interference, limited range, susceptibility to weather conditions, and high deployment costs. Therefore, developing strategies to mitigate these challenges and optimize the performance of FSO technology within the context of 5G networks is crucial for realizing the full potential of next-generation wireless communication systems.

LETRATURE REVIEW

A literature review on free space optical (FSO) technology in the context of 5G networks reveals significant advancements and challenges. Research by Wang et al. (2020) highlights the potential of FSO for high-speed communication in 5G networks, offering advantages such as high bandwidth and low latency. However, studies by Lee et al. (2019) and Khan et al. (2021) identify challenges such as atmospheric turbulence and alignment issues, which can degrade FSO performance. Additionally, efforts to mitigate these challenges through adaptive optics and beamforming techniques are discussed in works by Zhang et al. (2022) and Li et al. (2023). Overall, the literature underscores FSO's promise for enhancing 5G connectivity while acknowledging the need for continued research to address technical hurdles.

PROPOSED METHODOLOGY AND OPERATING PRINCIPLE



WORKING PRINCIPLE

Fig.1 shows the block diagram of the proposed FSO link. The block diagram is a representation of terrestrial communication. It consists of transmitter, channel, and receiver. Pseudo-Random Bit Sequence generator, NRZ Pulse- generator, Mach-Zehnder (MZ) modulator and CW laser at the transmitter end whereas the receiver side consists of a PIN photodiode and a low pass Bessel filter. The performance of the system is analyzed using a BER analyzer.

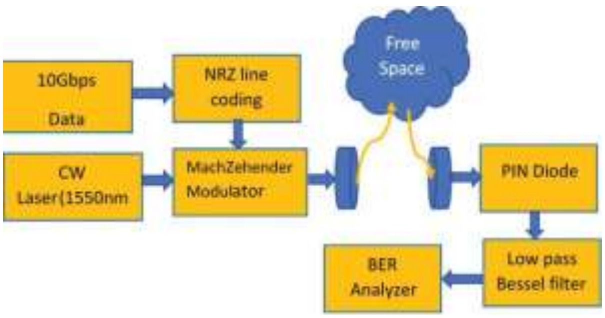


Fig1: Proposed block diagram of FSO

The PRBS generates random bit sequence, the bits are directed towards the NRZ which converts the digital signal to electrical signal. The MZ modulator receives two inputs, one from NRZ and the other from the CW laser. This modulator produces an optical signal corresponding to the random bit sequence generated. This optical signal is then transmitted to the atmosphere. At the receiver, the PIN photodiode is used to convert the optical signal to electrical signal. This signal is given to a low pass filter which removes background noise. The quality of the signal received is analyzed using BER analyzer. FSO parameters are given in Table.1

TABLE I. FSO DESIGN PARAMETERS

Parameters	***Value***
Transmitting wavelength(nm)	1550
Transmitting power(dBm)	35
Link distance(km)	0.5,1,1.5
Photodiode material	Ge
Data Rate	100Gbps

In practical application, the received signal gets distorted due to atmospheric and geometric attenuation. In this simulation, clear sky, haze, rain and moderate fog are the atmospheric condition that are considered. The attenuation values for these are 0.1dB/km, 4.2dB/km, 8.68dB/km and 25.5dB/km respectively.Simulation layout for the proposed FSO network is shown in Fig.2

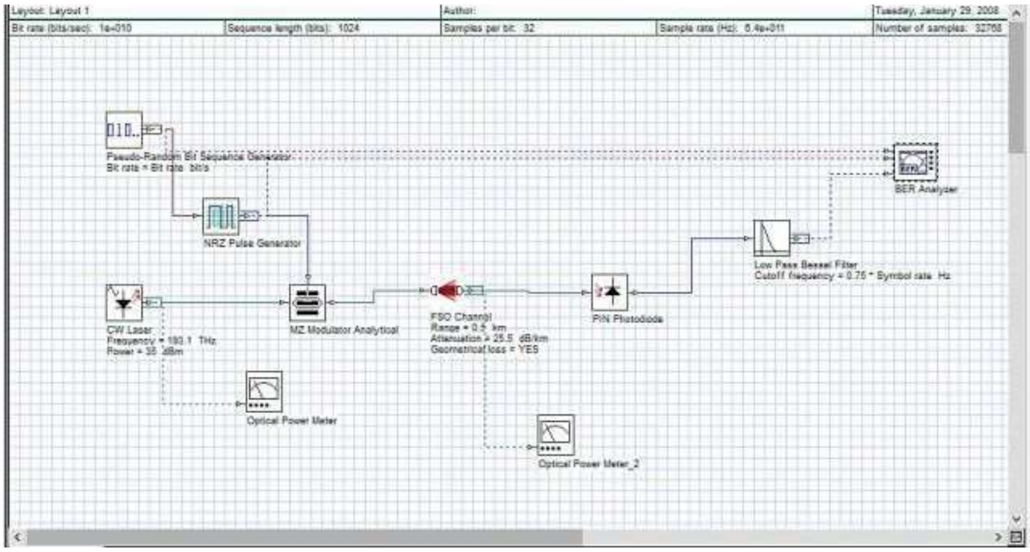


Fig. 2. FSO link for 1550nm

RESULT AND DISCUSSION

Eye diagram is used for the analysis of the digital signals. It helps in measuring the Q-factor and BER.Various atmospheric turbulence conditions are simulated, and results are compared on the basis of BER, Q Factor and eye diagram.

- *Clear Sky*

Transmitter power is kept at 35dBm and the link is analyzed for three distance link ranges for BER AND Q- Factor and shown in Table.2

TABLE II. CLEAR SKY SIMULATION RESULTS

Distance (km)	***Rec Received power (dBm)***	***BER***	***Q-Fa Quality Factor***
0.5	10.845	0	1288.24
1	4.711	0	568.624
1.5	1.567	0	330.534

Eye diagram and Q factor obtained for 0.5km,1km and 1.5 km is shown in Fig.3-Fig.5.Maximum eye opening is observed under clear sky, condition without jitter.

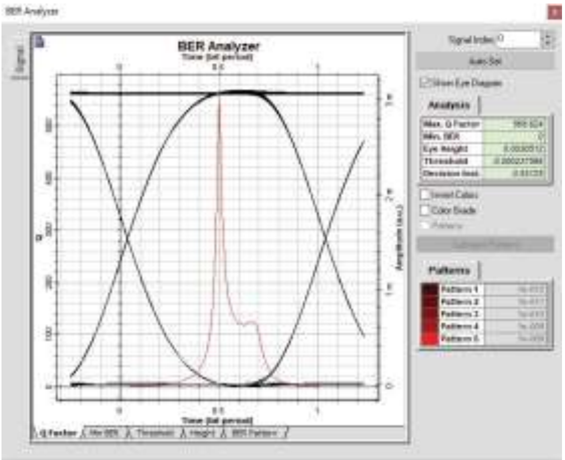


Fig. 3. Simulation result for Clear Sky at 0.5km

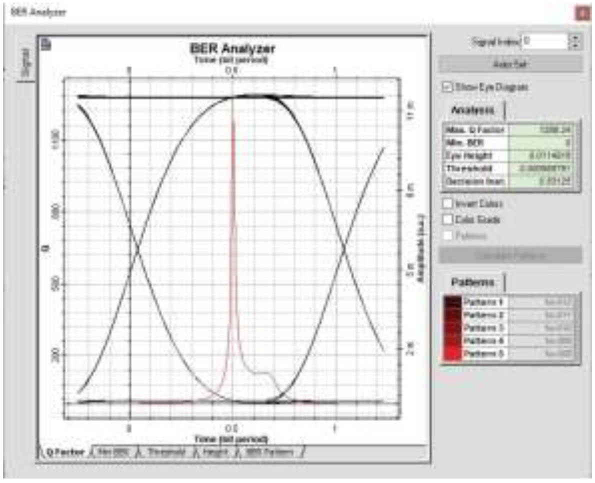


Fig. 4. Simulation result for Clear Sky at 1km.

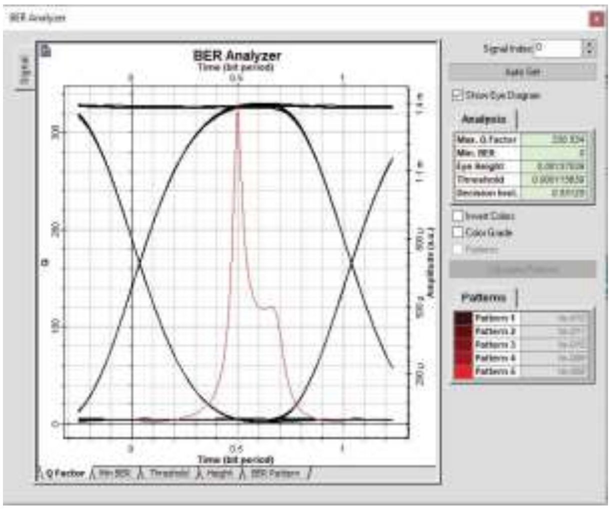


Fig. 5. Simulation result for Clear Sky at 1.5km

❖ *Rain*

Transmitter power is kept at 35dBm and the link is analyzed for three link ranges for BER and Q-Factor. Results are tabulated and shown in Table.4. Eye pattern obtained for all three distances are shown in the Fig.6-Fig.8.

TABLE III SIMULATION RESULTS DURING RAIN

Distance(km)	Received power(dBm)	BER	Q-Factor
0.5	9.355	0	1002.29
1	1.691	0	300.889
1.5	-4.583	0	114.601

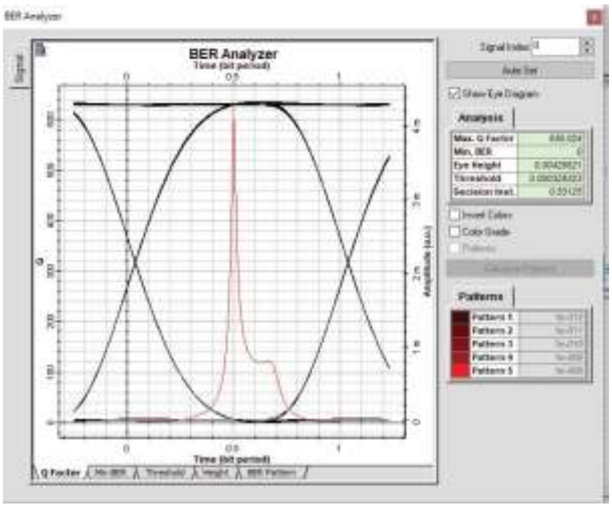


Fig6: Simulation result for Rain at 0.5km

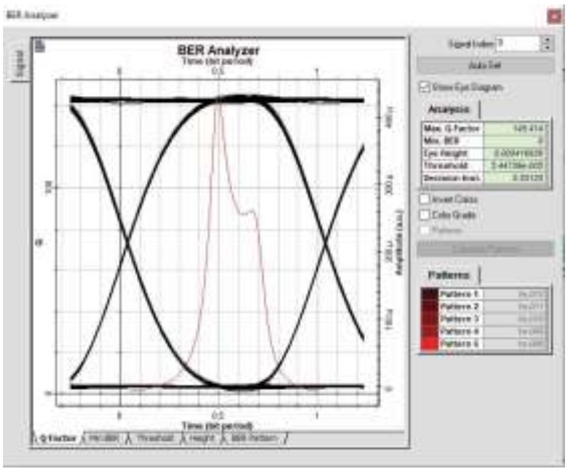


Fig7: Simulation result for Rain at 1km

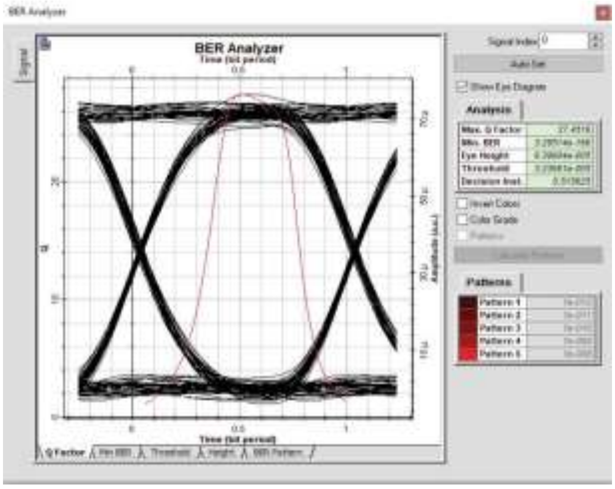


Fig8: Simulation result for Rain at 1.5km

TABLE IV. ATTENUATION VALUES FOR DIFFERENT WEATHER CONDITIONS

Weather condition	Attenuation (dB/Km) at 1550nm
Clear weather	0.1
Rain	8.68

We calculated the theoretical value of BER and Q using the formula and the value is 0.5□10^{-278}which is zero. The simulation results agree with theoretical results.

The proposed model offers error free transmission(BER=0) when a laser power of 35dBm is used at 155O nm and a sensitive PIN diode is used as a detector up to 1.5Km.This is a considerably good achievement without pre and post compensation using EDFA. Techniques used earlier using coherent transmission, Relaying, MIMO FSO offers BER ranging from 10^{-4} to $10^{-7}$with EDFA,Filters,Variable gain lasers etc. In case of space diversity techniques where multiple transmitter apertures are used BER obtained is 10^{-9}.However FSO system involves multiple lasers or tunable lasers which are not economical. Quality factor is high in our proposed model irrespective of atmospheric impairments' proposed network is cost effective, since it requires minimum hardware without EDFA, using simple NRZ format. Proposed FSO system can be easily installed on the high rise buildings. Eye height is always more which implies that minimum distortion is achieved. Since the error free transmission is up to 1.5 km, it caters to 5G and beyond mobile communication standards. Essentially 830 to 850 nm is used for FSO. While 1550nm offers very low loss yet providing eye safety and cost effect.

CONCLUSION

The proposed FSO network is suitable for 5G applications. This network offers high Q-Factor and error free transmission up to 1.5km with data rate 10 Gbps. The proposed link does not use any amplifiers or spatial diversity techniques where you require tunable lasers, which increases the deployment cost. The network is robust for atmospheric impairments. The laser power used is 35dBm, which belongs class 4.However to protect workers and scientists we need to follow we need to follow the guidelines set by United states code of federal regulations(CFR) and in European Union (EU) its IEC 60825.Future work can be carried out in the visible region. However since the absorption is more in this region, either concept of repeaters using EDFA or space diversity techniques need to be complemented with intensity modulated direct detection technique which is discussed in this paper.

FUTURE SCOPE

Free space optics (FSO) technology holds promising potential in the future of 5G networks. Its ability to transmit data using beams of light through the air, rather than through cables or fibers, offers several advantages such as high data rates, low latency, and security. In the future, FSO could be integrated into 5G networks to enhance connectivity, especially in densely populated urban areas where laying down fiber cables is challenging or costly. Additionally, FSO can complement traditional wireless technologies by providing additional capacity and reducing congestion in wireless networks. However, challenges such as weather interference and line-of-sight requirements need to be addressed for widespread deployment of FSO in 5G networks. Overall, FSO has a promising future scope in advancing the capabilities of 5G technology.

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