STM JOURNALS

International Journal of
Solid State Innovations & Research

Volume 2, Issue 1, 2024
January–June
DOI (Journal): 10.37591/IJSSIR

https://journals.stmjournals.com/ijssir

Research IJSSIR

Performance Evaluation of Adverse Atmospheric Effects on Free Space Optical Communication

Ganesh N. Gaikwad[1, *], Ishwar Nivasrao Mundhe[2], Khushi Gopaldutt Nagaich[2], Nidhi Mishra[2]

Abstract

There is an increasing need for communication systems that can accommodate high bandwidth and quick data transfer rates in today's fast-paced technological environment. Free Space Optical (FSO) communication has become a very attractive technology to address these changing needs. FSO systems, which use license-free infrared beams, have a number of benefits, including strong bandwidth, immunity to interference, improved security, and small, light designs. FSO is used in many different applications, such as voice, video, and data transmission. It allows laser beams to be transferred between transceivers to enable point-to-point connectivity. Despite all of its advantages, climatic circumstances can affect the efficacy of FSO, especially when it comes to keeping connections in line of sight during bad weather. Free Space Optical Communication (FSOC) is a promising technology that uses optical signals to transmit data through the atmosphere, which can provide high bandwidth, low latency, and high security compared to other wireless communication technologies. However, atmospheric conditions such as fog, rain, and turbulence can cause attenuation, scattering, and beam wander, which can degrade the quality and reliability of data transmission. To overcome this major problem, several techniques like resending the data, sending through other route, or using Multiple in Multiple Out (MIMO) systems are used.

Keywords: FSOC, MIMO, high bandwidth, high security, low latency

INTRODUCTION

In today's fast-paced technological landscape, there is a growing demand for communication systems capable of supporting high bandwidth and rapid data transmission rates. To meet these evolving needs, Free Space Optical (FSO) communication has emerged as a highly appealing technology. Leveraging infrared beams in a license-free spectrum, FSO systems offer significant advantages such as robust bandwidth, immunity to interference, enhanced security, and compact, lightweight designs. FSO is employed across various applications including data, voice, and video transmission, facilitating point-to-point connectivity through laser beams exchanged between transceivers [1]. Despite its numerous benefits, FSO's effectiveness may be compromised by atmospheric conditions, particularly in maintaining line-of-sight connections amidst adverse weather. Issues such as atmospheric attenuation can lead to link failures, reduced throughput, or diminished link availability, underscoring the importance of implementing adequate measures to mitigate such challenges. Techniques used in FSOC are firstly, Error Correction Techniques: Error correction techniques in communication refer to methods for detecting and correcting errors that occur during the transmission of digital data over a communication channel. Repeat Code is a basic Forward Error

***Author for Correspondence**
Ganesh N. Gaikwad
E-mail: gaikwadtejas802@gmail.com

[1]Professor, Department of Electronics and Telecommunication Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India
[2]Student, Department of Electronics and Telecommunication Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India

Received Date: May 02, 2024
Accepted Date: June 04, 2024
Published Date: June 20, 2024

Citation: Ganesh N. Gaikwad, Ishwar Nivasrao Mundhe, Khushi Gopaldutt Nagaich, Nidhi Mishra. Performance Evaluation of Adverse Atmospheric Effects on Free Space Optical Communication. International Journal of Solid State Innovations & Research. 2024; 2(1): 21–29p.

Correction (FEC) technique where each message bit is duplicated multiple times before transmission. Hamming Code is a widely used Forward Error Correction (FEC) method in communication systems. It is primary function is to detect and correct potential transmission erroring Code. Bose-Chaudhuri-Hocquenghem (BCH) codes are a class of powerful error-correcting codes widely employed in various applications, particularly in the realm of data storage and digital communication [2–5].

Reed-Solomon codes are a class of error-correcting codes that play a crucial role in ensuring data integrity and reliability. Repeat Code is the repetition code which is one of the most basic linear error-correcting codes. To transmit a message over a noisy channel that may corrupt the transmission in a few places, the idea of the repetition code is to just repeat the message several times [6].

METHODOLOGY

Free-Space Optical (FSO) communication systems rely heavily on a comprehensive design analysis to ensure their success. This analysis requires a holistic approach, considering both the internal and external factors that influence the system's performance. The primary objective is to maximize the efficiency of light transmission, leading to a robust and reliable communication link. Internal system parameters, controllable during the design phase, determine the system's inherent capabilities. Careful selection and optimization of the parameters allows for maximizing the signal strength reaching the receiver. However, external factors like atmospheric attenuation, scintillation, and visibility further influence the system's performance. These uncontrollable environmental factors can significantly degrade the transmitted signal. A complete understanding of these limitations is crucial for developing mitigation strategies. This may involve incorporating adaptive optics to counteract atmospheric turbulence or integrating weather prediction systems to adjust operational parameters dynamically. By adopting this holistic approach, FSO system design can be optimized to achieve reliable data transmission even in challenging environments. This ensures successful implementation and the establishment of robust communication links.

This block-diagram in Figure 1 provides an overview of transceiver design and key components used in the system.

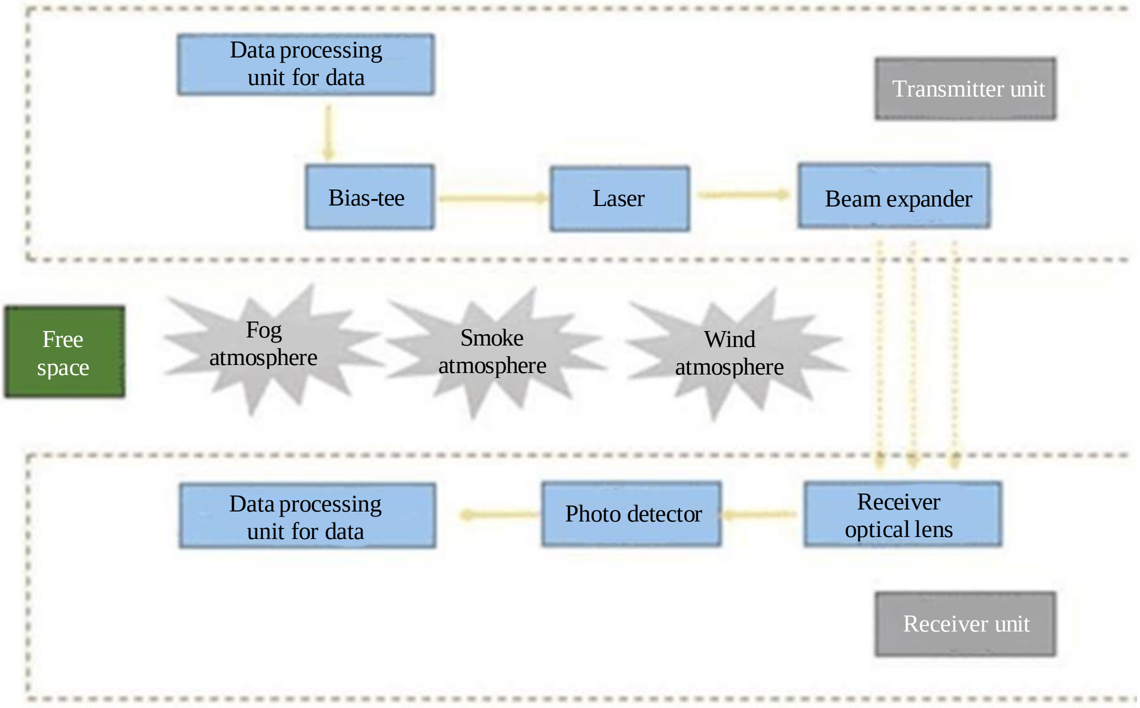

Figure 1. FSO communication block diagram.

Transmitter

A laser system operating at a single frequency of 635 nm is composed of a seed laser and an amplifier, both meticulously designed for minimal noise during operation. The primary light source utilized in this setup is a laser diode, emitting a unified beam ideal for transmitting data coherently. The selection of this laser diode is carefully tailored to meet specific criteria, including wavelength, power output, and modulation necessities. The transmitter configuration for the Free Space Optical (FSO) link adheres to the specifications outlined in Table 1 [7, 8].

Modulators are used to vary optical signal intensity or phase in response to data. Common modulators are electro-optic and acousto-optic, chosen based on data rate and modulation needs. Collimator is used to arrange shapes and focus the optical beam before transmission, using lenses or optical systems based on divergence and spot size requirements.

Receiver

The receiver system captures incoming optical radiation through a lens, directing it towards the photo detector for processing. Optimal performance is achieved with a larger aperture on the receiver lens, facilitating the collection of multiple independent radiation sources. This design ensures that the received signals are effectively focused and averaged onto the photo detector for analysis. Photodetector detects the focused signal. Common types are APDs for long range and PIN diodes for short-range communication due to their characteristics. Signal-Processing Electronics converts the electrical signal into a usable form. It comprises an amplifier, filter, and demodulator. The amplifier boosts the signal, the filter removes unwanted noise, and the demodulator extracts the information from the optical carrier [9, 4]. Receiver optics specifications are shown in Table 2.

As the optical beam travels through the atmosphere, it undergoes diffraction, causing it to spread out. This dispersion phenomenon can lead to scenarios where the receiver aperture fails to capture a portion of the transmitted beam, resulting in losses due to beam divergence, as illustrated in Figure 2 [10, 7].

EXPERIMENT DESCRIPTION

The setup used in the laboratory based FSO experiment consists of an optical transmitter laser Tx, Optical lense, Photodetector as receiver Rx separated by the atmospheric chamber; on the other side of chamber is a mirror that reflects laser beam reflected on optical lens that focused beam on photodector, as seen in Figure 3.

- *Fog chamber:* Uses Ultrasonic Humidifiers and high-rpm fans for fog generation, with temperature control for humidity regulation.

Table 1. Transmitter optics specifications.

No.	Parameter	Value
1	Wavelength	632±15 nm (Red)
2	Class	Class Illa
3	Operating voltage	3–6 VDC
4	Modulation frequency	10 kHz
5	Dimensions	$10 40 mm

Table 2. Receiver optics specifications.

No.	Parameter	Value
1	Material	Glass
2	Diameter	25 mm
3	Focal length	50 mm
4	Edge thickness	2 mm

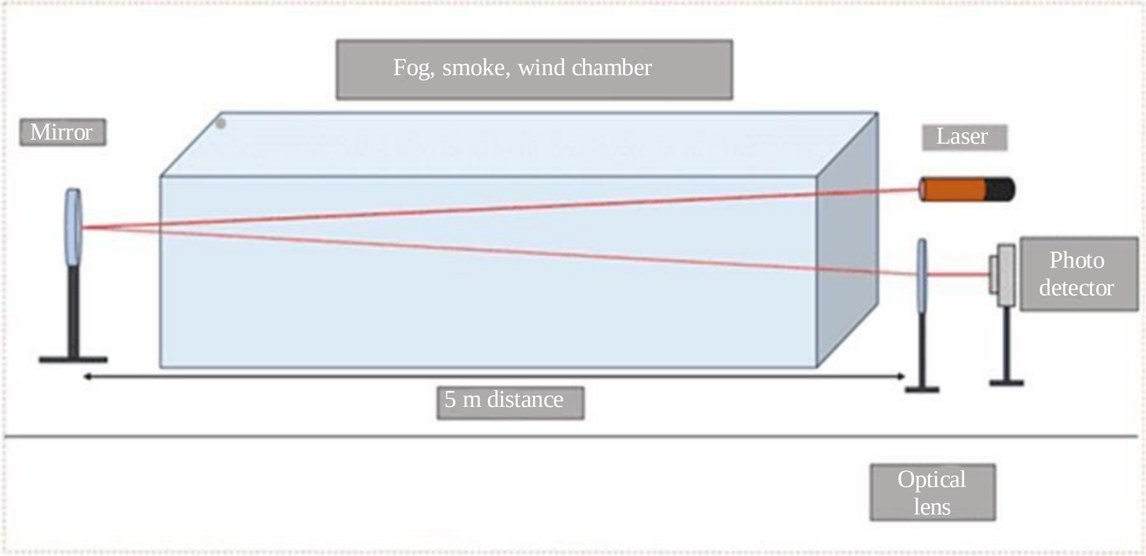

Figure 2. FSO experimental chamber.

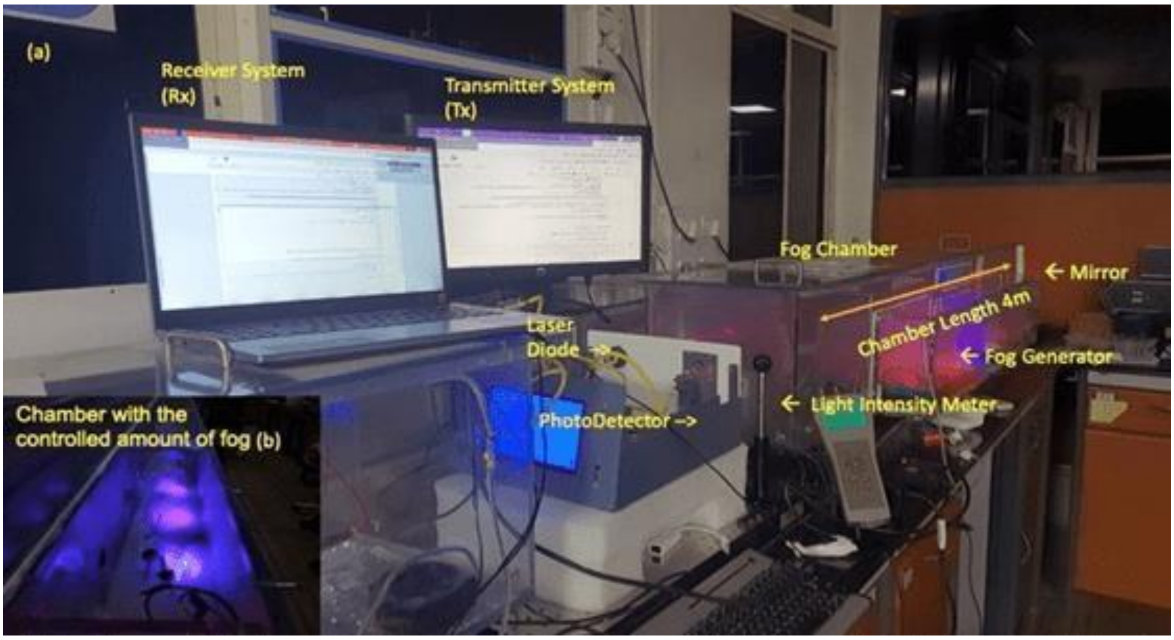

Figure 3. (a) The experimental set up to measure the fog attenuation and visibility, and laboratory controlled atmospheric chamber and FSO link setup, and (b) Smoke generator with controller.

- *Communication chamber:* Features a clear passage for laser beam transmission, temperature control, and high-speed fan for uniform fog distribution.
- *Smoke/dust chamber:* Utilizes high-speed fan to scatter smoke particles, simulating light attenuation for research purposes.
- *Wind tunnel:* Investigates turbulence effects on optical communication using high-speed fans to create chaotic airflow.

RESULT

An experiment for chamber analysis is carried out using a 5 mW red laser with a wavelength of 632±10 nm. Approximately 4 m are covered as you move through the chamber. The laser emits 5.728 mW of direct power. The detector's fixed wavelength is 635 nm. 3.303 mW of power is measured across a 4-m distance in the fog chamber when there is no fog. After the chamber has been filled with fog for a predetermined amount of time, the generator must be turned off. Until the experiment is finished, the fan should continue operating to keep the fog moving throughout the room. We measure the light intensity in (uW) by light intensity meter, as shown in Figure 3.

Fog

Fog Chamber: Four types of readings are taken as No Fog, Light Fog, Moderate Fog and Dense Fog. The conditions are based on light intensity at receiver end (Rx): as for No Fog (3.303 mW), Light Fog (100 mW), Moderate Fog (50 mW), Dense Fog (20 mW). The optimal BER rate provided by the FEC techniques—Repeat Code 0.3, Repeat Code 0.5, Hamming Code, BCH Code, and Reed-Solomon Code technique—is displayed in Figure 4. As observed in Figure 4, it shows that for No Fog and Light Fog Hamming Code technique gives the lowest BER rate, but for Moderate Fog and Dense Fog, BCH code technique gives the lowest BER rate.

Smoke

Smoke chamber's main use is probably to research how smoke and dust affect the amount of light that can pass through it. The powerful airflow that is produced by the high-speed fan is probably what moves the smoke particles about the chamber. To create a realistic testing environment, it is crucial to make sure the smoke particles are scattered equally. 90% of the power attenuation of light passing through the smoke chamber most likely pertains to the light's intensity being diminished as it travels through the smoke particles. Smoke particles could scatter and absorb light, reducing the visibility and power of the light entering the chamber. The chamber can imitate the effects of smoke on the transmission of light by reducing the power of the light travelling through it and offering insightful data for a variety of applications. In conclusion, a smoke chamber equipped with a high-speed fan and power attenuation features can be a helpful instrument for researching how smoke affects light transmission.

For Smoke Chamber, three types of readings are taken as No Smoke, Light Smoke and Dense Smoke. The conditions are based on light intensity at receiver end (Rx): as for No Smoke (3.303 mW), Light Smoke (100 mW), and Dense Smoke (20 mW).

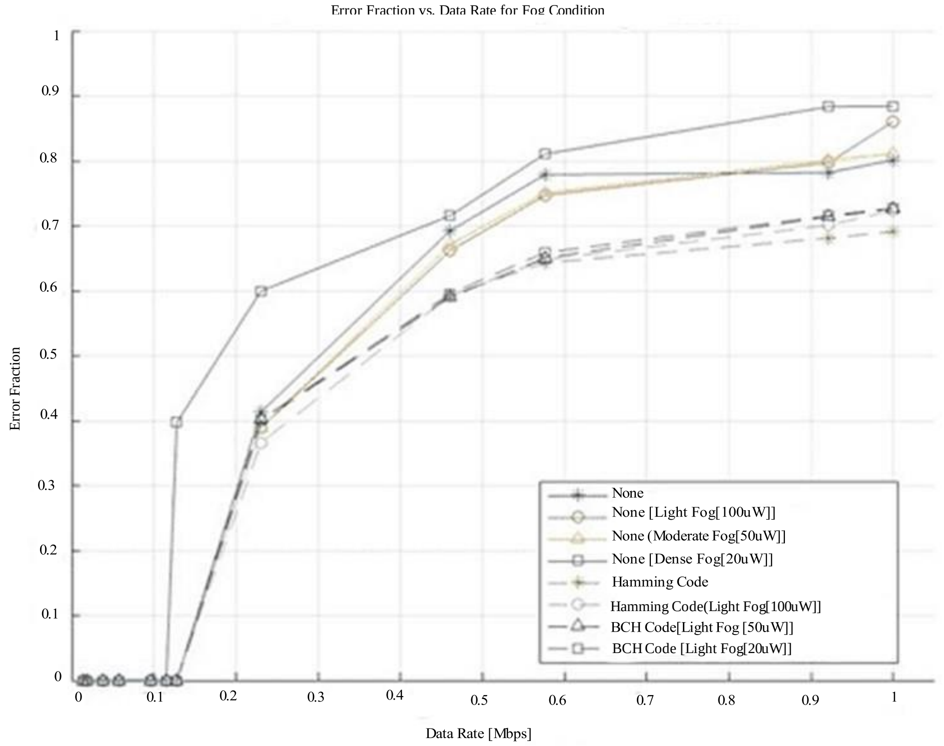

Figure 4. BER vs. Data rate fog chamber.

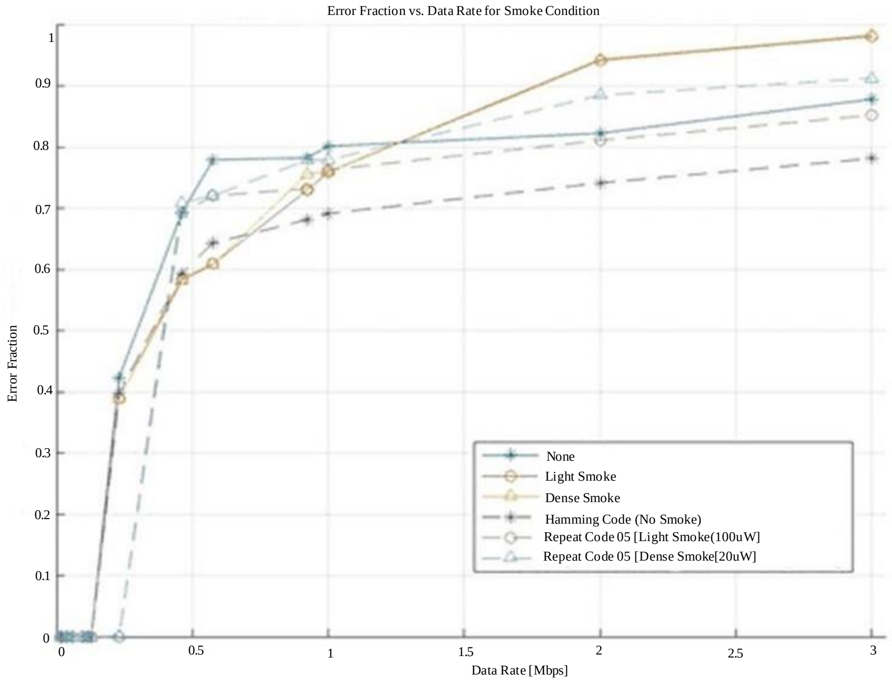

Figure 5. BER vs. Data rate smoke chamber.

As observed in Figure 5, it shows that for No Fog, Hamming Code technique gives the lowest BER rate, but for Light Smoke and Dense Smoke, Repeat code 05 technique gives the lowest BER rate.

Turbulence

Wind/Turbulence chamber's main objective will probably be to investigate how turbulence affects optical communication in free space. In order to create a turbulent flow pattern inside the chamber, the high-speed fans are probably set up to blow air in perpendicular directions. This may produce a chaotic setting that mimics turbulence's impacts in actual-world situations. The Turbulence Chamber does not have a power attenuation, in contrast to the Smoke Chamber. Instead, it is intended to give the light travelling through the chamber a jitter. The air's turbulent flow, which can change the air's refractive index, is the cause of the jitter. As a result, there may be distortions in the light entering the chamber, which can be utilized to explore how turbulence affects the light transmission. The erratic atmosphere the fans produce can mimic actual environmental circumstances, and the lack of power attenuation and addition of a jitter can offer novel insights into the impact of turbulence on light transmission.

For Turbulence Chamber, three types of readings are taken, as No Wind, Low Wind and High Wind. The conditions are based on Wind speed in chamber, as for No Wind (0 m/sec), Low Wind (7.6 m/sec), and High Wind (28.20 m/sec). As observed in Figure 6, it shows that for No Wind, Hamming Code technique gives the lowest BER rate, but for Low Wind and High Wind, BCH code technique gives the lowest BER rate.

Long Distance

In long distance experiment, we measure transfer of the data up to 100 m as Tx. Rx is on one side and the other side is mirror that reflects the laser onto the Photodetector (Rx). The total travel distance by laser is 100 m with reflection as mirror mounted on 50 m.

Figure 7 shows all the FEC techniques used in long distance data transfer. We store data at 230 kbps. The data transport rate is 3 Mb/sec when there are no errors and. As observed in Figure 7, lowest BER is given by BCH code technique.

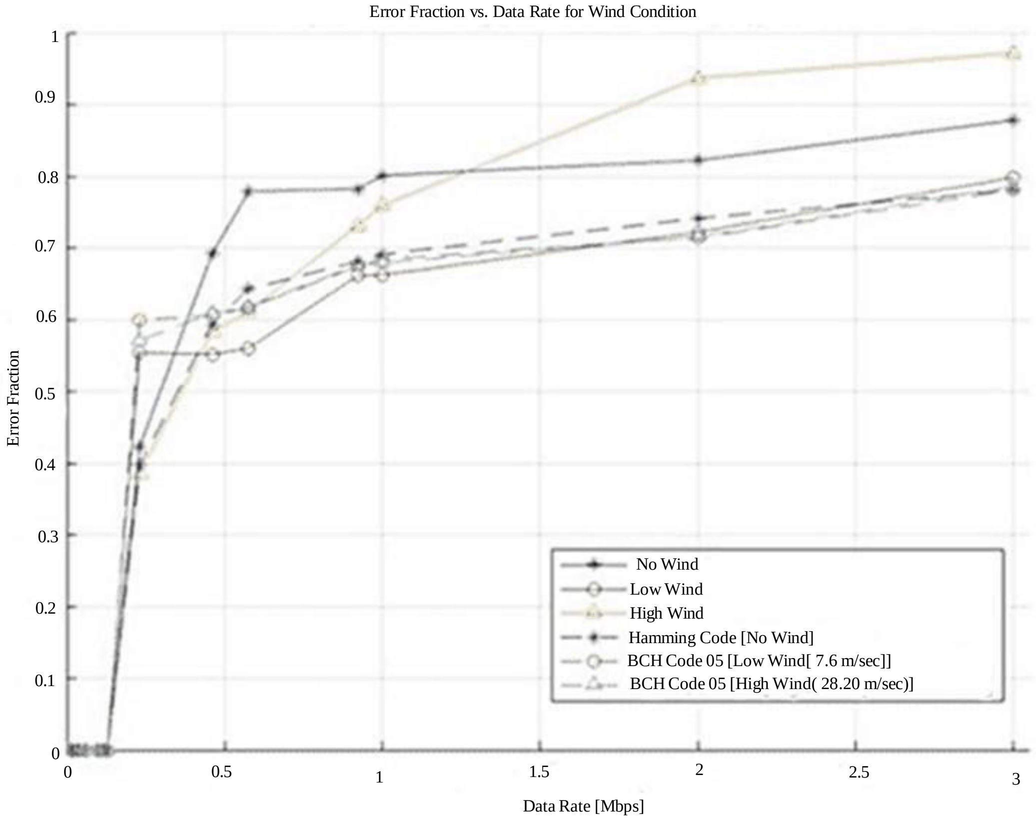

Figure 6. BER vs. Data rate turbulence chamber.

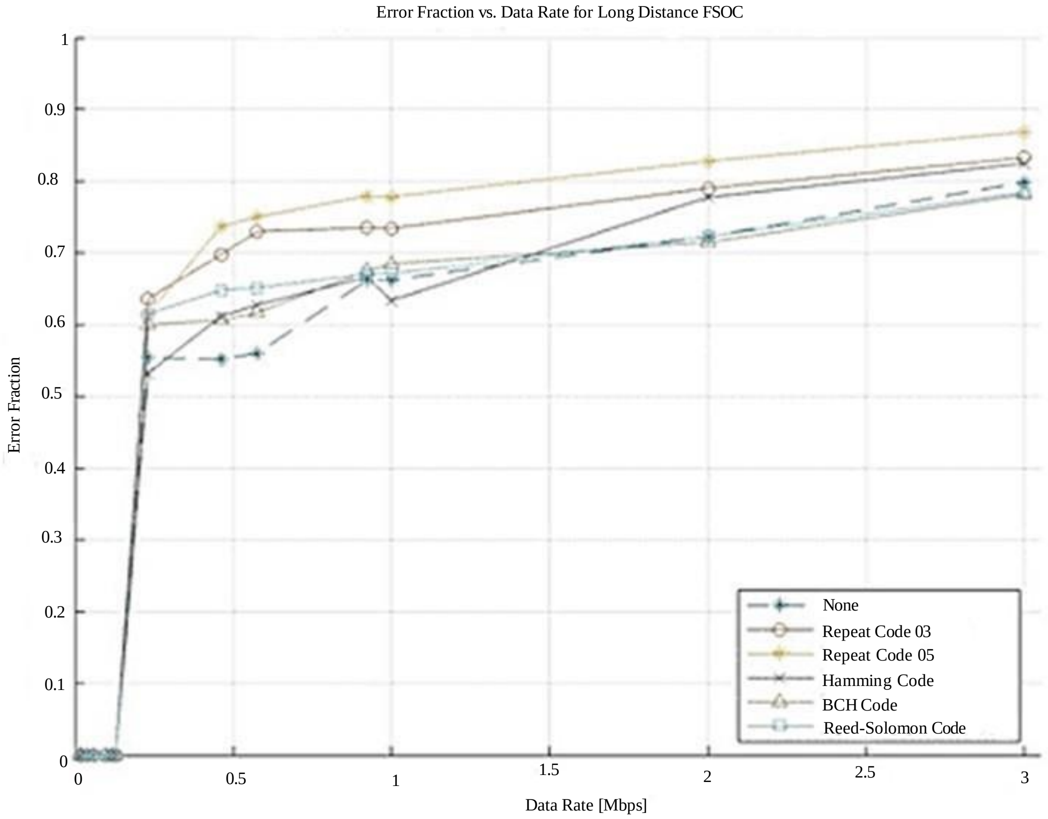

Figure 7. Error fraction vs data rate.

HOW TO CALCULATE BER

We calculate the BER (Bit Error Rate) using this method:

- The above setup reads both the reference and received files bit by bit.
- It counts the total number of bits and compares each bit to compute the number of erroneous bits.
- The BER is calculated as the number of bit error per unit time. It first retrieves the path of the received file from the GUI entry widget.
- Then, it opens both the reference and received files in binary mode.
- Inside the file reading loop, it reads one bit at a time from both files and compares each bit to count the number of erroneous bits.
- The total number of bits and the number of error bits are accumulated during the loop.
- After processing all bits, it calculates the BER by dividing the number of error bits by the total number of bits.
- Finally, it updates the text with the calculated BER value.

CONCLUSION

In this research work, we investigated the performance evaluation of adverse atmospheric effects on Free Space Optical Communication (FSOC). FSOC technology offers high bandwidth, low latency, and enhanced security compared to traditional wireless communication methods. However, atmospheric conditions such as fog, smoke, turbulence, and long-distance propagation can significantly degrade the quality and reliability of data transmission. We first discussed the importance of error correction techniques in combating transmission errors in FSOC systems. Techniques like Repeat Code, Hamming Code, BCH Code, and Reed-Solomon Code were explored to ensure data integrity over noisy channels.

The methodology section highlighted the comprehensive design analysis required for successful FSOC implementation. Internal system parameters such as transmitter power, beam divergence, and receiver aperture diameter were optimized alongside external factors like atmospheric attenuation and scintillation. Experimental setups including fog chambers, smoke chambers, turbulence chambers, and long-distance transmission tests were conducted to measure the impact of adverse atmospheric conditions on FSOC performance. BER (Bit Error Rate) vs. Data Rate plots were analysed for each condition, revealing the effectiveness of different error correction techniques under varying atmospheric challenges. Overall, our findings indicate that different error correction techniques perform optimally under specific atmospheric conditions.

The Hamming Code was most effective in low-fog scenarios, while BCH Code showed resilience in moderate to dense fog conditions. Repeat Code 05 performed well in both light and dense smoke environments, and BCH Code was robust against turbulence effects. Furthermore, in long-distance data transfer experiments, BCH Code demonstrated superior performance with the lowest BER, ensuring reliable data transmission over distances up to 100 m.

In conclusion, this study underscores the importance of understanding and mitigating adverse atmospheric effects in FSOC systems. By implementing appropriate error correction techniques and adapting system parameters to environmental conditions, FSOC can achieve reliable data transmission even in challenging atmospheric scenarios, thus realizing its potential as a high-speed, high-bandwidth communication solution for various applications.

Acknowledgement

I wish to express my sincere thanks and deep sense of gratitude to respected mentor and guide *Prof. Ganesh N. Gaikwad*, Professor in Department of Electronics and Telecommunication Engineering of Sinhgad college of Engineering, Vadgaon (BK), for the technical advice, encouragement and constructive criticism, which motivated to strive harder for excellence. We would also like to express our sincere thanks to *Dr. M.B. Mali*, Head, Department of E&TC, for his cooperation and useful suggestions. We would also like to thank *Dr. S.D. Lokhande*, Principal, Sinhgad College of Engineering. He always remains a source of inspiration for us to work hard and dedicatedly.

REFERENCES

1. Mandal SK, Bera B, Dutta GG. Free Space Optical (FSO) Communication Link Design Under Adverse Weather Condition. 2020 International Conference on Computer, Electrical & Communication Engineering (ICCECE), Kolkata, India. 2020; 1–6. doi: 10.1109/ICCECE48148.2020.9223023.
2. Rahman AK, Tom AL. Improving the Bit Error Rate Performance of Free Space Optical Communication due to Atmospheric Turbulence Effect using New Double Multiple-Input Multiple-Output Technique. 2020 13th International UNIMAS Engineering Conference (EnCon), Kota Samarahan, Malaysia. 2020; 1–4. doi: 10.1109/EnCon51501.2020.9299330.
3. Ijaz M, Ghassemlooy Z, Le Minh H, Rajbhandari S, Perez J. Analysis of fog and smoke attenuation in a free space optical communication link under controlled laboratory conditions. 2012 International Workshop on Optical Wireless Communications (IWOW), Pisa, Italy. 2012; 1–3. doi: 10.1109/IWOW.2012.6349680.
4. Rabinovich WS, Moore CI, Mahon R, Goetz PG, Burris HR, Ferraro MS, Murphy JL, Thomas LM, Gilbreath GC, Vilcheck M. Free-space optical communications research and demonstrations at the US Naval Research Laboratory. Applied optics. 2015 Nov 1;54(31):F189-200..
5. Kaushal H, Kaddoum G. Free space optical communication: challenges and mitigation techniques. arXiv preprint arXiv:1506.04836. 2015 Jun 16.
6. Yousif BB, Elsayed EE. Performance enhancement of an orbital-angular-momentum-multiplexed free-space optical link under atmospheric turbulence effects using spatial-mode multiplexing and hybrid diversity based on adaptive MIMO equalization. IEEE access. 2019 Jun 24; 7:84401-12.
7. Ghassemlooy Z, Le Minh H, Rajbhandari S, Perez J, Ijaz M. Performance Analysis of Ethernet/Fast-Ethernet Free Space Optical Communications in a Controlled Weak Turbulence Condition. J Lightwave Technol. 2012 Jul 1; 30(13): 2188–2194.
8. Kaur P, Jain VK, Kar S. Performance of free space optical links in presence of turbulence, pointing errors and adverse weather conditions. Opt Quant Electron. 2016 Jan; 48(1): 65(3p).
9. Barua B. Comparison of the Performance of Free-Space Optical Communication with OOK and BPSK Modulation under Atmospheric Turbulence. Int J Eng Sci Technol. 2011; 3(5): 4391–4399.
10. Gupta A. Comparative analysis of free space optical communication system for various optical transmission windows under adverse weather conditions. Procedia Comput Sci. 2016 Jan 1; 89: 99–106.