International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Enhance Data and Power Transmission in Free-Space Optical Systems Under Environmental Circumstances

Mudher. M. Hussein[1], Asst. Prof. Mishari .A .Askar[2]

Submitted: 22/01/2023 **Accepted:** 28/03/2023

Abstract

Free space optics is one of the new technologies that is now being utilized to replace radio frequency wireless communication because of its benefits, including cost, speed, bandwidth, few mistakes, and effective communication. The FSO offers far higher-quality services than the RF communication network. Free space optics is an unlicensed band, which makes it less expensive than technology that is licensed. Communication is affected by atmospheric conditions since the atmospheric channel is employed for transmission. This study tries to maintain communication and send data under normal and turbulent conditions

Keyword : FSO, LOS, QAM, RF, OFDM.

1-Introduction

The telegram, which was developed in 1885, is the first example of wireless technology. Changes in technology are occurring as time goes on. Currently, every user expects a high-speed network, which the RF network cannot deliver. As a result, we must look to alternative technologies, such as optical fiber, to meet our needs. In recent years, optical transmission has received increased attention [1]. Information is wirelessly transmitted through optical transmission, also known as free space optics or optical wireless communication (FSO). The FSO is a technology that allows us to send signals through atmospheric channels that take the shape of light. The PD (photodiode) at the receiver end receives the light signal that is produced by the laser or LED and is sent via the atmosphere. The FSO generally sends the information signal via the infrared spectrum. Although atmospheric circumstances have less of an impact on IR wavelengths, some ranges are distorted as a result of atmospheric molecular activity [2]. One of the most ancient approaches, free space optics, dates back to the seventh century. At that time, the Romans and Greeks more firmly utilized sunlight for communication [3]. The employment of fire, smoke, semaphore, and other point-to-point communication techniques is described next [4]. One of the earliest wireless phones to be created, the picture phone, has not yet seen widespread commercial use [5]. As technology evolves, new developments like the discovery of the laser and the light-emitting diode (LED) affect how optical wireless communication is transmitted. Information is still sent via filament bulbs today, although the FSO market used to be somewhat restrictive. The development of the laser aided in the advancement of the FSO.For the transmission of the speech signal, video, etc. in optical wireless communication, the transmission must be in line of sight with the reception part. Free-space optics provide several benefits over traditional systems, including enormous bandwidth that allows for the transmission of massive amounts of data and tiny beam divergences that allow for the transmission of signals over great distances with little to no misalignment. It also aids in achieving high security since the narrow beam is challenging to penetrate, requires less power and mass, is simple to install, has a fast speed, and is less expensive than conventional technology because the expense of fiber and digging has been eliminated. The FSO is divided into many transmission categories, such as ultra-short-range communication, which refers to communication that occurs within a wireless LAN, or ultra-short-range communication, which refers to communication that occurs between chips. This kind of communication occurs in a conference room, a room, etc.; medium-range communication occurs through a local area network. It happens in a public setting, on campus, at a business, etc. [6] surveillance network, a backhaul system, etc. This network can communicate across distances of up to 100 kilometers between satellites, and it uses ultra-long-range

---

[1] College of Computer Science and Mathematics, Department of computer science, Tikrit University, Saladin, (Tikrit), 34001, Iraq, Dr.mshary.alshmmry@tu.edu.iq

[2.] College of Computer Science and Mathematics, Department of computer science, Tikrit University, Saladin, (Tikrit), 34001, Iraq, Muder.M.Hussein22ms@st.tu.edu.iq

technology. [7] This communication has a very wide range. Broadcasting, satellite-to-satellite communication, and other applications employ this sort of communication. The atmospheric impact is a disadvantage of this technology since, as we have already established, the atmosphere serves as the route for it. The coverage area is also a disadvantage. Due to the FSO's limited coverage area and line of sight which is necessary for free space optic Three obstacles stand in our way when discussing atmospheric effects: turbulence, absorption, and scattering. The many types of molecules that are present in the atmosphere play a role in atmospheric absorption. [8] We already know that water readily absorbs light; hence, the presence of atmospheric water vapor contributes to atmospheric absorption. The effect that also exists in guided optical communication is scattering. The phenomenon of light flowing through a material and being dispersed by airborne particles is known as scattering. The radius of the particle through which the scattering occurs determines how much scattering occurs. The scattering is brought on by the deviation in the angle of the light. The forms of scattering that occur are known as Rayleigh scattering when the particle's radius is less than its wavelength, and when it is virtually Now let's speak about the atmospheric weather, such as rain, fog, snow, etc., which also affects how well our communication systems operate. [1] Because the wavelength we utilized for communication is nearly identical to the wavelength at which the effect of fog occurs, the effect of fog is more pronounced in all of these weather situations than all other effects. Because of absorption, scattering, and reflection, it can alter the properties of the optical signal or entirely obstruct the flow of light. The impact of snow is dependent on snow particle size; in certain instances, very big snow particles totally block the light that must transmit. Now, we are thinking about the losses that are by modifying the reflective index of the light, which is influenced by the temperature, solar wind, and air pressure. [9] We experience information loss as a result of the signal fading or sparking caused by this sort of impact. The signal's fluctuation results in a change in its amplitude and phase, which prevents the receiver end from receiving the correct information or signal and lowers the network's performance. To lessen the impact of turbulence, many theories are presented. When the swirl's dimensions are greater than the transmitter beam's dimensions, it causes the beam to randomly deviate from its intended course and is referred to as beam steering. Beam wandering is a typical occurrence in long-distance communication, such as satellite communication. Scintillation is the process of irradiance variations at the receiver caused by the swirl's ability to function as a lens to focus and defocus the incoming beam if the eddy diameter is of the order of the beam dimension. In order to lessen the impact of scintillation, many sorts of models are utilized. These models, which go by the names log-normal, K distribution, and I-K distribution, are frequently utilized at low turbulence levels. We had to switch to new models, such as the Double Gamma-Gamma model, the Double Weibull distribution model, and the Gamma-Gamma (GG) model, when the amount of turbulence grew (DGG). When the distortion's size is smaller than the beam's dimension, a quasi-static model, etc., is said to be beam spreading. The influence of the beam spreading is felt at the receiver section, where both the receiver aperture angle and the strength of the signal at the receiver end are impacted [10]. The term "background effect" refers to the additional influence that lowers the signal quality. This effect happens when we reflect light, disperse sunlight, or transform optical signals into electrical signals. The majority of the time, background radiation causes this impact. At the transmitter end, many sorts of modulation methods are used to get around all the aforementioned limitations. These modulation techniques enable us to change the information-carrying signal's delivered signal strength. Amplitude modulation, phase modulation, frequency modulation, and polarization modulation are the many forms of modulation used in optical wireless communication. These many modulation techniques are employed in accordance with the scenario's needs, which are concealed by energy efficiency, power requirements, spectrum efficiency, etc. [11] In this research, we discuss the FSO communication with an emphasis on the modulation strategies applied to enhance the link performances.

2.Free space optic communication

The phrase "free space optical communication" describes a connection that is made between communicating nodes that are physically separated from one another by an atmosphere that serves as an unguided medium in between them. The most crucial need for an FSO connection is the existence of a line of sight between two FSO units. Each unit contains an optical transceiver with a laser transmitter and a receiver, enabling full duplex or bidirectional communication. Every FSO unit uses a high-power optical source to convert network traffic into light pulses (such as a laser or an LED). For the purpose of receiving information, one lens in the transmitter emits light to another lens in the receiver through the environment. The received signal is then connected to the network after being converted back to a digital signal. [12]. A block schematic of an FSO system's essential architecture may be seen in Figure 1.

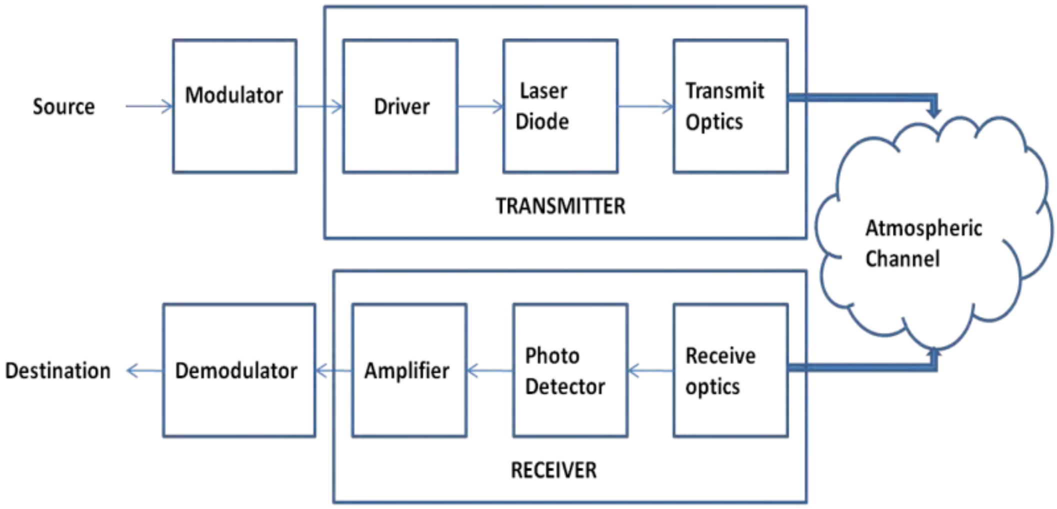


Figure 1: Block diagram of a FSO communication system

3-literature review

O. B. Yahia et al. described a hybrid RF/FSO transmission system for SatCom in the year 2022. According to weather data gathered from sensors and used for context awareness, the satellite in this technology chooses between RF and FSO connections. They built outage probability (OP) expressions and took into consideration a variety of meteorological factors to assess how effectively the planned network would operate. The diversity order is also determined using asymptotic analysis. The suggested technique outperforms dual-mode, traditional hybrid RF/FSO communication in terms of OP and also offers some power gain, according to the results [13]. This was found by contrasting the two approaches.

S. C. Tokgoz et al. (2022) looked at the physical layer's role in hybrid FSO-mmWave system security. This examination took place in the presence of several eavesdroppers of various kinds. For FSO and mmWave communications, respectively, Weibull fading channels and exponential air turbulence are taken into account. They show that the analytical formulations and the data-based Monte Carlo simulations match up perfectly [14].

In the year 2022, G. D. Verma et al. proposed a combined dual-hop free-space optical (FSO) and radio frequency (RF) communication system. This system employs hybrid automated repeat request (H-ARQ) protocols on both hops to serve the end user through a decode-and-forward (DF) relay. The asymptotic analysis, which is used to calculate the diversity gain, provided useful insights into the system's performance, according to the findings. This was discovered to be true since it helped with the diversity gain computation. Monte Carlo simulation is utilized to confirm the study's findings [15].

Mehtab Singh and colleagues (2021) proposed a novel design for a radio-over-free-space optical (RoFSO) transceiver based on MDM-OFDM. As primary assessment criteria, the signal-to-noise ratio (SNR) and power total were used to assess connection strength and accessibility under the influence of both a clean environment and a variety of dust situations. The results showed that next-generation uses increased the rating of data through an acceptable SNR [16]

In the year 2021, Magdalena Garlinska et al. presented an examination of the effects of meteorological conditions on the strength of radiating recipients and the laboratory implementation platform for the FSO structure. Under a range of meteorological situations, this study is an operation that takes place in the upper third of the atmosphere (8–12 m). According to the results of the analytical study and the data that was gathered, near-infrared waves have weaker transmission properties than optical radiation, with a wavelength of about 10 meters in low-light situations. This proves that it is absolutely feasible to create FSO linkages in the 8–12 m band [17].

A balancing center and a laser fog sensor might be used, according to Mazen Abdel-Latif and colleagues' study from 2020, to improve the performance of wireless optical connections (FSO). The wireless optical connection utilized MIE dispersion; the system was simulated using the MATLAB and OPTISYSTEM programming environments; and the transmitted signal had a wavelength of 1550 nm. The study's conclusions show that when the quality factor was present in environments with moderate, light, and very light fog, it increased from 3.6 percent to 44.45 percent [18].

To determine the impact that dust has on the effectiveness of FSO linking transport and the amplitude modulation of the wave, Maged A. Esmail and his colleagues conducted an experiment. You may view their conclusions here (2019). The results show that a small viewing range significantly affects the performance of the all-optical FSO link, leading to a high bit error rate (BER). The same dusty circumstances were used to analyze the FSO-RF frequencies. The results showed that the RF connection was unaffected by the dust storm, making it a great backup for the FSO link in situations where there was an abnormally high amount of dust [19].

In their 2019 study, Ghassan Al-Nawaimi and colleagues suggested adopting packet length optimization to increase data transfer speeds in free-space optical (FSO) systems. The average ASNR measurement was obtained by the receiver and transmitted back to the transmitter. When the suggested approach was combined with adaptive modulation and coding (AMC) and a fixed package length, the traditional FSO experienced a gain of 0.8–1.9 dB [20].

A survey was carried out by Mustafa Zaman Choudary and colleagues to contrast and evaluate the various designs and uses of OWC tools (2018). The goal of this study was to better comprehend the distinctions between optical wireless networks (OWC) and the current generation of radio frequency technologies [21].

4-Proposal work and Result

standard attenuation range

Clear air	0.43
Haze	4.2
Moderate rain (12.5 mm/h)	5.8
Heavy rain (25 mm/h)	9.2
Light fog	20
Moderate fog	42.2
Heavy fog	125

4.1 FSO system with clear weather condition

This system tested for 1.25 Gb/s with transmitted power of 15.563 dBm for a distance of 17km with clear weather conditions. (clear weather 0.43dB/km). The general diagram of the FSO system is depicted in Figure 4.1.

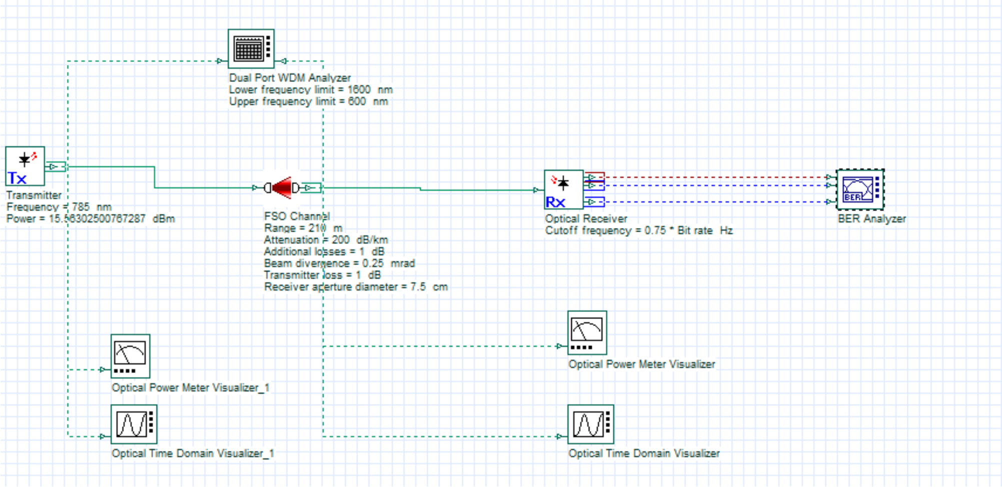


Figure 4.1 FSO system

Transmitter parameter

Parameter	Value	Unite
Wavelength	785	nm
Frequency Spacing	100	GHz
Power	15.56	dBm
Excitation	10	dB
Line width	10	MHz
Modulation Type	NRZ	Non Return Zero

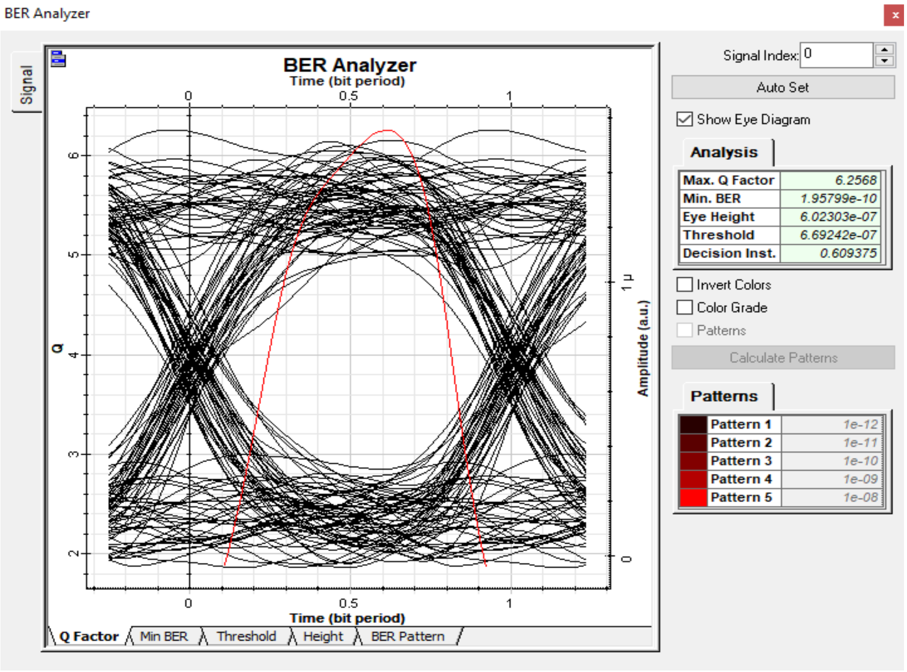
FSO Parameter

Parameter	Value	Unite
Range	17	km
Attenuation	0.43	dB/km
Additional losses	1	dB
Beam divergence	0.25	mrad
Transmitter losses	1	dB

Receiver Parameter

Parameter	Value	Unite
Photodiode	PIN	
Gain	3	
Receiver aperture diameter	7	cm
Receiver losses	0	dB

The eye diagram of the FSO system is represented in Figure 4.2. The system shows the minimum BER value of 1.5 ×10-10 for clear weather with attenuation of 0.42 dB/km. The FSO system tested for a 17km transmission distance with 15.54 dBm.



Signal Index: 0

☑ Show Eye Diagram

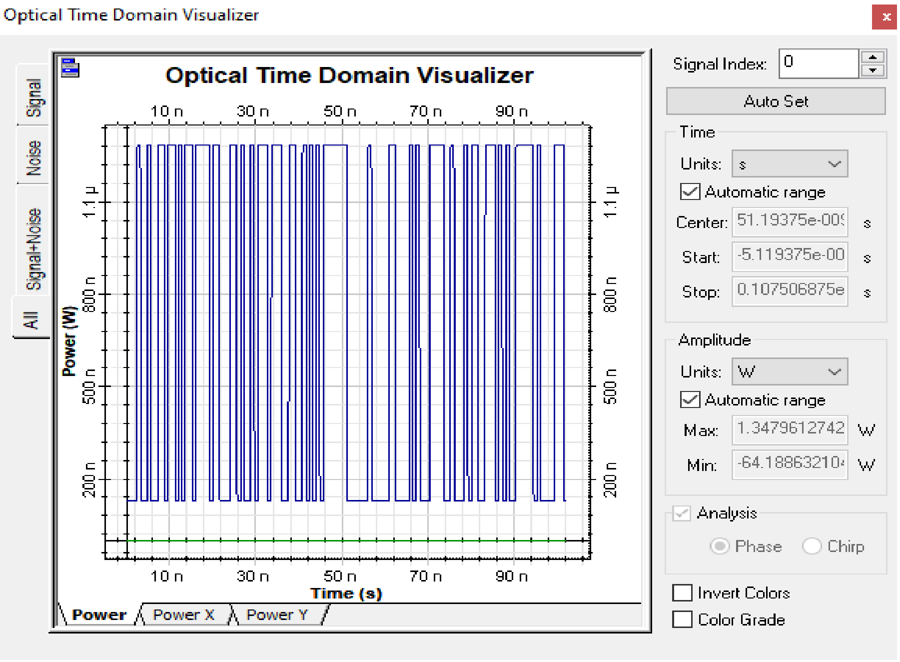
Max. Q Factor	6.2568
Min. BER	1.95799e-10
Eye Height	6.02303e-07
Threshold	6.69242e-07
Decision Inst.	0.609375

☐ Invert Colors
☐ Color Grade
☐ Patterns

Pattern 1	1e-12
Pattern 2	1e-11
Pattern 3	1e-10
Pattern 4	1e-09
Pattern 5	1e-08

Figure 4.2 Eye Diagram of the FSO system with Clear Weather Condition.

Figure 4.3 represent the optical time domain visualizer, where the system shows that the data has a power of 1.34 W.



Signal Index: 0

Units: s
☑ Automatic range
Center: 51.19375e-00 s
Start: -5.119375e-00 s
Stop: 0.107506875e s

Units: W
☑ Automatic range
Max: 1.3479612742 W
Min: -64.18863210 W

☑ Analysis
● Phase ○ Chirp

☐ Invert Colors
☐ Color Grade

Figure 4.3 Optical Time Domain Visualizer of Received Signal for the Clear Weather.

The variation of the BER with different transmitted power represents in Figure 4.4. The system was evaluated at a 17km transmission distance.

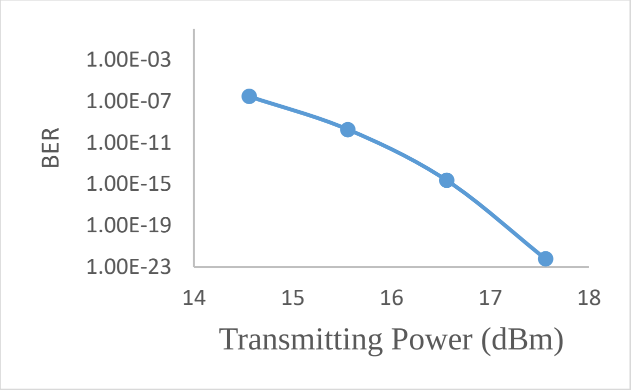


Figure 4.4 BER Variation with Transmission Power for the Clear Weather Condition

The variation of the received power with different transmitted power represents in Figure 4.5. The system was evaluated at a 17km transmission distance.

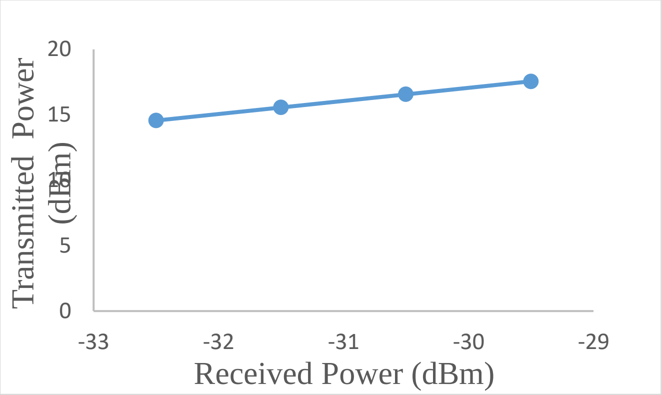


Figure 4.5 Received Power Variation with Transmission Power for the Clear Weather Condition

The variation of the BER with different transmitted distances is represented in Figure 4.6. The system was evaluated at 15.53 dBm as transmission power..

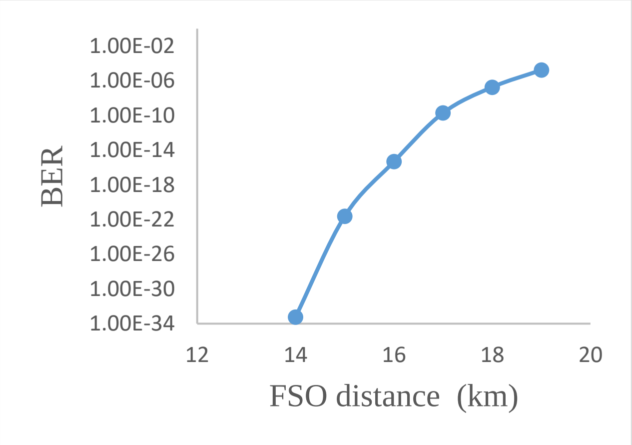
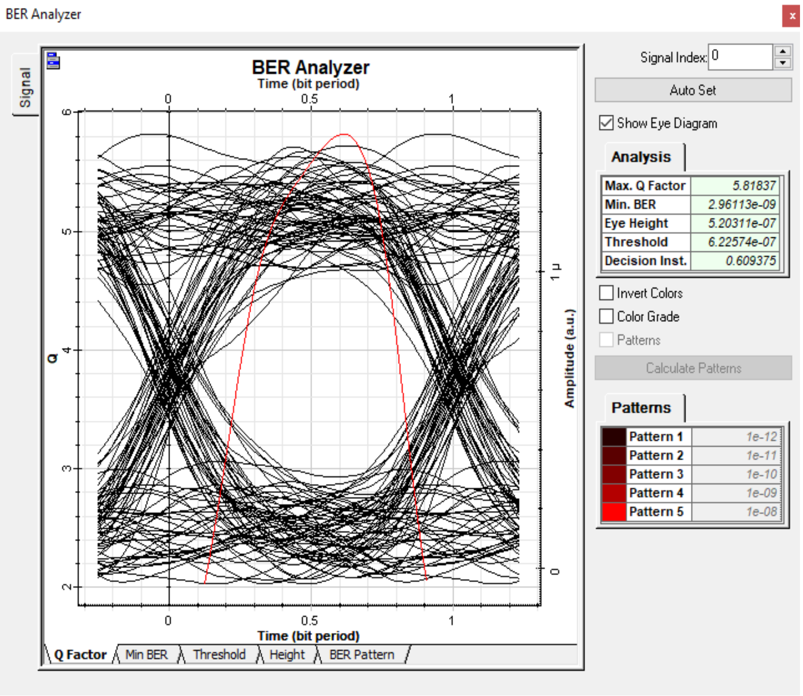


Figure 4.6 BER Variation with Transmission Distance for the Clear Weather Condition

4.2 FSO system with haze weather condition

This system tested for 1.25 Gb/s with transmitted power of 15.563 dBm for a distance of 4.5 km with the haze weather conditions

The eye diagram of the FSO system is represented in Figure 4.7. The system show the minimum BER value of 1.5 ×10-10 for clear weather with attenuation of 4.2 dB/km. The FSO system tested for a 4.5 km transmission distance with 15.54 dBm



Signal Index: 0

☑ Show Eye Diagram

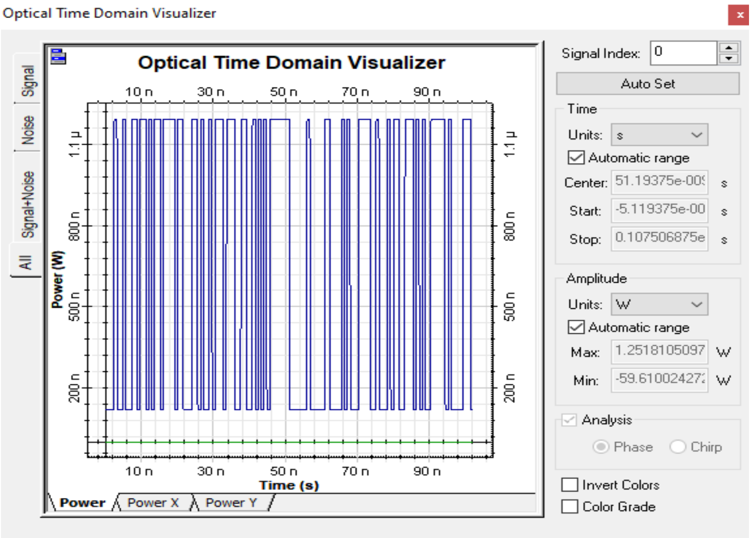
Max. Q Factor	5.81837
Min. BER	2.96113e-09
Eye Height	5.20311e-07
Threshold	6.22574e-07
Decision Inst.	0.609375

☐ Invert Colors
☐ Color Grade
☐ Patterns

Pattern 1	1e-12
Pattern 2	1e-11
Pattern 3	1e-10
Pattern 4	1e-09
Pattern 5	1e-08

Figure 4.7 Eye Diagram of the FSO system with Haze Weather Condition.

Figure 4.8 represent the optical time domain visualizer, where the system shows that the data has a power of 1.25 W for the haze weather condition.



Signal Index: 0

Time
Units: s
☑ Automatic range
Center: 51.19375e-00 s
Start: -5.119375e-00 s
Stop: 0.107506875e s

Amplitude
Units: W
☑ Automatic range
Max: 1.2518105097 W
Min: -59.61002427 W

☑ Analysis
○ Phase ○ Chirp

☐ Invert Colors
☐ Color Grade

Figure 4.8 Optical Time Domain Visualizer of Received Signal for the Haze Weather.

The variation of the BER with different transmitted power represents in Figure 4.9. The system was evaluated at a 4.5 km transmission distance.

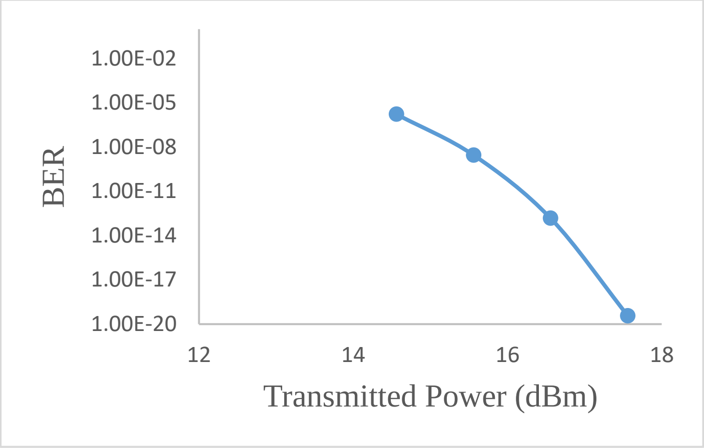


Figure 4.9 BER Variation with Transmission Power for the Haze Weather Condition

The variation of the received power with different transmitted power represents in Figure 4.10. The system was evaluated at a 4.5km transmission distance.

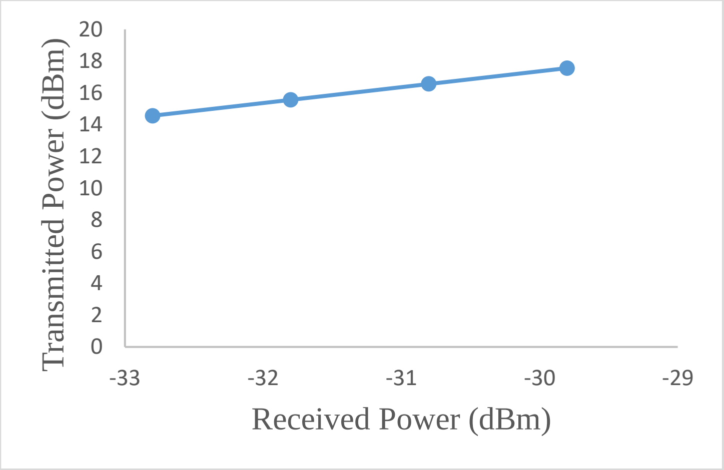


Figure 4.10 Received Power Variation with Transmission Power for the Clear Weather Condition

The variation of the BER with different transmitted distances represents in Figure 4.11. The system was evaluated at 15.53 dBm as transmission power.

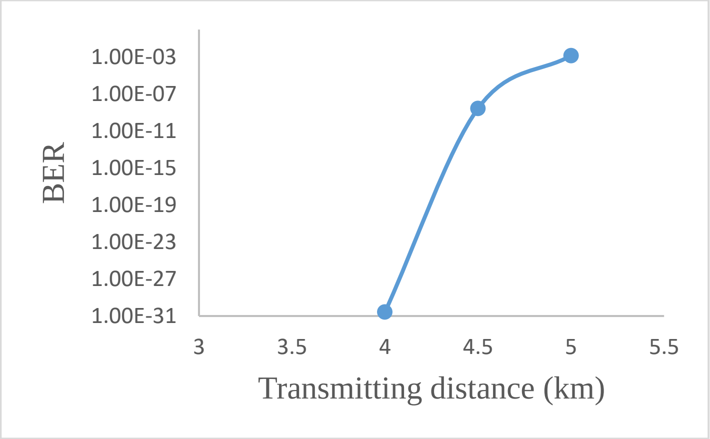
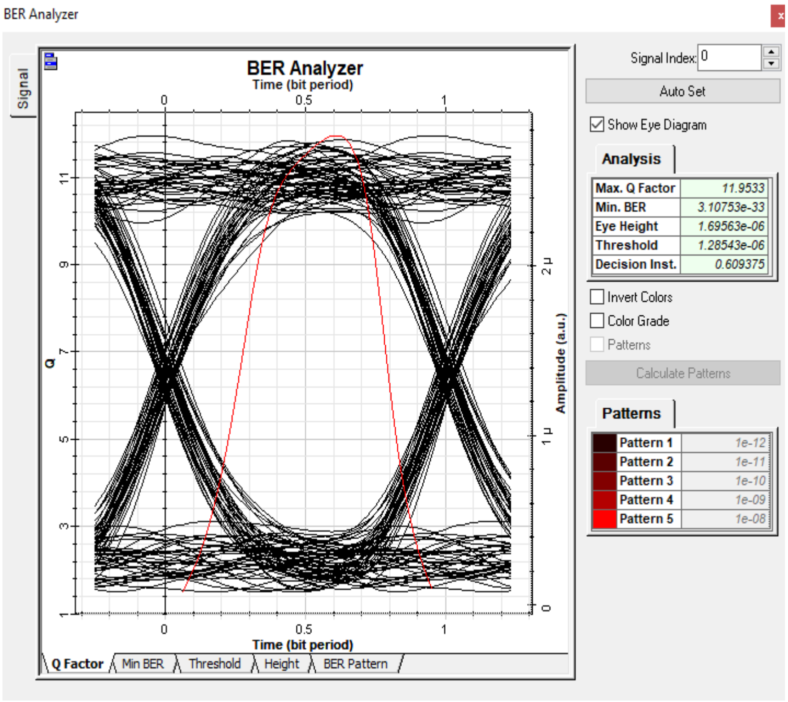


Figure 4.11 BER Variation with Transmission Distance for the Haze Weather Condition

4.3 FSO system with heavy rain weather condition

This system tested for 1.25 Gb/s with transmitted power of 15.563 dBm for a distance of 2.3 km with heavy rain weather conditions of 9.2dB/km.

The eye diagram of the FSO system is represented in Figure 4.12. The system show the minimum BER value of 3.1 ×10-33 for heavy rain weather with attenuation of 9.22 dB/km. The FSO system tested for a 2.3 km transmission distance with 15.54 dBm



Signal Index: 0

☑ Show Eye Diagram

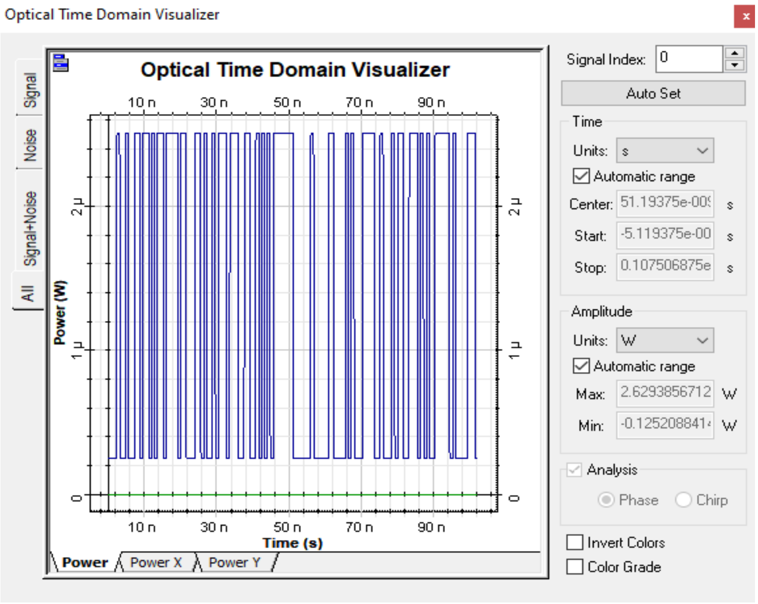
Max. Q Factor	11.9533
Min. BER	3.10753e-33
Eye Height	1.69563e-06
Threshold	1.28543e-06
Decision Inst.	0.609375

☐ Invert Colors
☐ Color Grade
☐ Patterns

■	Pattern 1	1e-12
■	Pattern 2	1e-11
■	Pattern 3	1e-10
■	Pattern 4	1e-09
■	Pattern 5	1e-08

Figure 4.12 Eye Diagram of the FSO system with Heavy Rain Weather Condition.

Figure 4.13 represent the optical time domain visualizer, where the system shows that the data has a power of 2.6 W.



Signal Index: 0

Time
Units: s
☑ Automatic range
Center: 51.19375e-00(s
Start: -5.119375e-00 s
Stop: 0.107506875e s

Amplitude
Units: W
☑ Automatic range
Max: 2.6293856712 W
Min: -0.125208841 W

☑ Analysis
● Phase ○ Chirp

☐ Invert Colors
☐ Color Grade

Figure 4.13 Optical Time Domain Visualizer of Received Signal for the Heavy Rain Weather.

The variation of the BER with different transmitted power represents in Figure 4.14. The system was evaluated at a 2.3 km transmission distance.

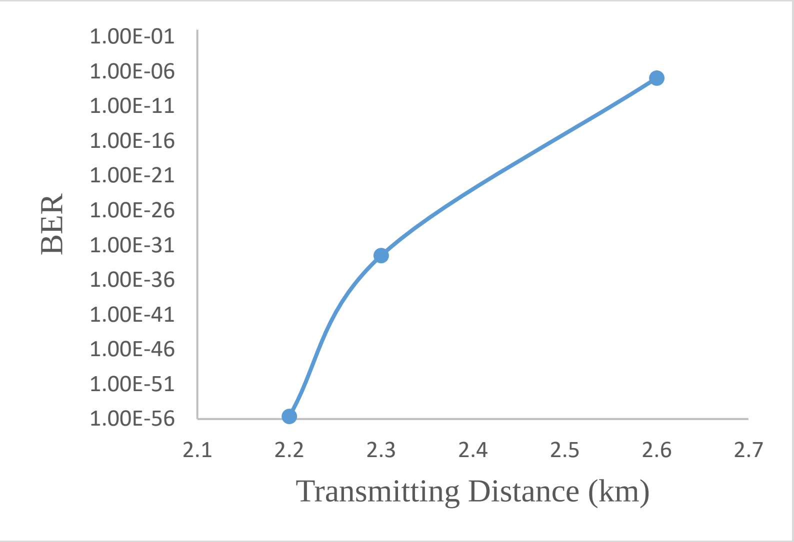


Figure 4.14 BER Variation with Transmission Power for the Heavy Rain Weather Condition

The variation of the received power with different transmitted power represents in Figure 4.15. The system was evaluated at a 2.3 km transmission distance.

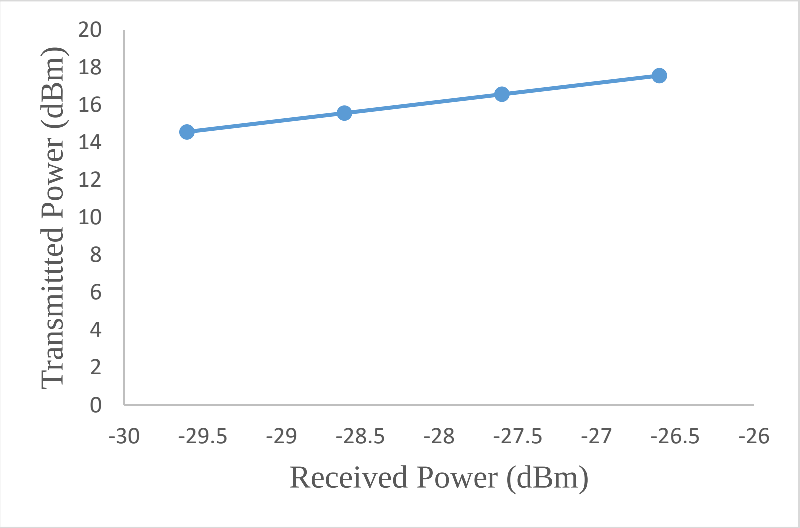


Figure 4.15 Received Power Variation with Transmission Power for the Heavy Rain Weather Condition

5-Conclusion

As discussed in this scientific article, FSO communication systems operate on the principle of a clear line of sight between the source and the interface, which means that laser beams sent into outer space are typically exposed to turbulence in the form of winds, rain, dust, snow, etc., which significantly alters the beam's shape. In terms of absorption, scattering, and refraction, the transmitter or the router The suggested technique helps to maintain excellent communication even in poor weather.

References:

[1] Khalighi MA & Uysal M (2014), Survey on Free Space Optical Communication: A Communication Theory Perspective, *IEEE Communications Surveys and Tutorials*, pp.2231-2258.

[2] Bloom S, Korevaar E, Schuster J, & Willebrand H (2003), Under-standing the performance of free-space optics, Journal of Optical Networks, Vol. 2, no. 6, pp. 178–200, Jun. 2003.

[3] Holzmann GJ & Pehrson B, The Early History of Data Networks (Perspectives). Hoboken, NJ, USA: Wiley, (1994).

[4] Huurdeman AA, The Worldwide History of Telecommunications, Hoboken, NJ, USA: Wiley-Interscience, (2003).

[5] Lee S, Kwon JK, Jung SY, & Kwon YH (2012), Evaluation of visible

[6] Light communication channel delay profiles for automotive applications, Eurasip Journal Wireless Communication Network, Vol.12, no. 1, pp. 370-378.

[7] Chan VWS (2003), Optical satellite networks, Journal of Light and. Technology, Vol. 21, no. 11, pp. 2811–2827.

[8] Kaushal H et al. (2017), Free Space Optical Communication, Optical Networks, Springer.

[9] Andrews LC, Phillips RL, Hopen CY, & Al-Habash MA (1999), Theory of optical scintillation, Journal of Optical Society, Vol. 16, no. 6, pp. 1417–1429.

[10] Wayne DT (2010), The PDF of irradiance for a free space optics communication Channel: A physics based model at the University of Central Florida

[11] Kaur G, Singh H, Sappal AS (2017), Free Space Optical Using Different Modulation Techniques' Review, International Journal of Engineering Trends and Technology, Vol. 43, no.2, pp.412-410.

[12] G. D. Verma, A. Mathur, Y. Ai, and M. J. I. C. L. Cheffena, "Mixed dual-hop IRS-assisted FSO-RF communication system with H-ARQ protocols," vol. 26, no. 2, pp. 384-388, 2021.

[13] O. B. Yahia, E. Erdogan, G. K. Kurt, I. Altunbas and H. Yanikomeroglu, "A Weather-Dependent Hybrid RF/FSO Satellite Communication for Improved Power Efficiency," in IEEE Wireless Communications Letters, vol. 11, no. 3, pp. 573-577, March 2022, doi: 10.1109/LWC.2021.3136444.

[14] S. C. Tokgoz, S. Althunibat, S. L. Miller and K. A. Qaraqe, "On the Secrecy Capacity of Hybrid FSO-mmWave Wiretap Channels," in IEEE Transactions on Vehicular Technology, vol. 71, no. 4, pp. 4073-4086, April 2022, doi: 10.1109/TVT.2022.3148238.

[15] G. D. Verma, A. Mathur, Y. Ai and M. Cheffena, "Mixed Dual-Hop IRS-Assisted FSO-RF Communication System with H-ARQ Protocols," in IEEE Communications Letters, vol. 26, no. 2, pp. 384-388, Feb. 2022, doi: 10.1109/LCOMM.2021.3129594.

[16] M. Singh, S. N. Pottoo, J. Malhotra, A. Grover, and M. H. Aly, "Millimeter-wave hybrid OFDM-MDM radio over free space optical transceiver for 5G services in desert environment." Alexandria Engineering Journal, vol. 60, no. 5, pp. 4275-4285, 2021, doi: 10.1016/j.aej.2021.03.029.

[17] M. Garlinska, A. Pregowska, I. Gutowska, M. Osial, and J. Szczepanski, "Experimental Study of the Free Space Optics Communication System Operating in the 8–12 μm Spectral Range." Electronics, vol. 10, no. 8, p. 875, 2021, doi: 10.3390/electronics10080875.

[18] M. Abdullatif, M. Haji Ali, and R. Khal, "Proposed Method For Improving The Performance Of Wireless Optical Link FSO Using The Center Of Balance With a Laser Fog Sensor." Association of Arab Universities Journal of Engineering Sciences, vol. 27, no. 4, pp. 72-78, 2020, doi: 10.33261/https://doi.org/10.33261/jaaru.2020.27.4.007.

[19] M. A. Esmail, A. M. Ragheb, H. A. Fathallah, M. Altamimi, and S. A. Alshebeili, "5G-28 GHz Signal Transmission Over Hybrid All-Optical FSO/RF Link in Dusty Weather Conditions." IEEE Access, vol. 7, pp. 24404-24410, 2019, doi: 10.1109/access.2019.2900000.

[20] G. Alnwaimi, H. Boujemaa, and K. Arshad, "Optimal Packet Length for Free-Space Optical Communications with Average SNR Feedback Channel." Journal of Computer Networks and Communications, vol. 2019, pp. 1-8, 2019, doi: 10.1155/2019/4703284.

[21] M. Z. Chowdhury, M. T. Hossan, A. Islam, and Y. M. Jang, "A Comparative Survey of Optical Wireless Technologies: Architectures and Applications." IEEE Access, vol. 6, pp. 9819-9840, 2018, doi: 10.1109/access.2018.2792419.