Weathers effect on the free space optics communication system

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ABSTRACT

Unlicensed spectrum is used in free space optics (FSO) communication, significantly increasing available bandwidth. Regardless of the weather, the most immediate concern is the link's performance and availability. Changes in the weather might impact the reliability of the link substantially. As a result, iterative optimization is being used to reduce the impact of weather and geography on FSO communication. In addition to enhancing visibility, this enhancement also reduces the bit error rate (BER). The system's wireless optical communication technology supports a data rate of up to 10 Gbps. The proposed wireless optical communication performance is compared to existing technologies regarding the visible distance, quality factor, BER, and eye diagram in various meteorological circumstances. Simulations show that the proposed work is more efficient.

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1. INTRODUCTION

Fast data transfer rates, broad bandwidth, and low power consumption are only some of the benefits of free space optic (FSO), a technology solution for telecommunications. Yet, in order to get the most out of the FSO system, it is important to analyze the modulation used in real-world conditions. FSO is a type of optical communications system that does not necessitate a license to transmit data, but does necessitate a direct line of sight (LOS) connection between the communicating devices. Since optical communication is costly to set up and use, it is not available in rural regions. More FSO communication can be seen recently [1]-[4]. When the information-carrying photons are absorbed and scattered by external environmental circumstances like rain, haze, fog, and snow, the resulting signal quality suffers [5]. By scattering, and absorption, fog, haze, mist, snow, and rain cause turbulence in the atmosphere [6]. Due to attenuation from atmospheric turbulence and other weather conditions, the FSO channel's potential is limited when broadcasting across free space [7]. Atmospheric effects can cause signal losses in FSO and can be split into two groups:

- Atmospheric attenuation
  a. Absorption
  b. Scattering
- Atmospheric turbulence
  a. Laser beam deformation

Scattering, absorption, and turbulence are the main causes of signal attenuation and distortion, hence the atmosphere is considered a fascinating dynamical channel for the transmission of electromagnetic waves. Light waves disperse when they collide with particles or molecules that are extremely dissimilar in size and shape. Yet absorption is a quantum phenomenon, and the atmospheric windows are based on wavelength. By using air channels as a propagation medium, FSO technology takes advantage of the fact that the parameters of this medium are random functions of both space and time. Clouds, snow, haze, fog, and rain, are just some of the many things that might reduce the strength of an optical signal. Furthermore, FSO communication is also impacted by link distance and path loss [8], [9]. This paper has many contributions in relation to previous research. For the same attenuation coefficient of 20, 30, 70 dB/km, the distance has been increased and the quality factor of the signal has been increased thanks to the beam divergence of 0.25 mrad and the receiver and transmitter aperture of 30 cm.

2. METHOD

Using light propagation in the free space, FSO is a technology that can transmit data between locations without the use of optical fiber or radio frequency (RF) technology. Maintaining an apparent LOS between the transmitter and receiver is essential for FSO technology when optical fibres are impractical. The atmosphere causes some distortions in light transmissions. Light beam loss occurs in all types of precipitation, including fog, rain, snow, and haze, because molecules diffuse and scatter the light. Electromagnetic waves have their range reduced due to atmospheric distortion caused by rain. You can see the transmitter, atmospheric channel, and receiver that make up a wireless optical link in Figure 1. Transmission over wireless media requires an optical modulator, which turns an electrical signal into an optical one.

The optical signal is transmitted over a wireless medium and received by a receiver before being transformed into an electrical signal for further usage. Subsystems of the transmitter include the pulse generator and modulator, spectrum analyzer, switching mechanism and optical amplifiers. The pulses created by the pulse generator carry information in electrical form. A modulator changes the baseband signal into a high frequency that may be transmitted. An optical meter measures the quantity of energy that can be sent. The frequency of the input signal is displayed on a graph by the spectrum analyzer. The fork and switching subsystems determine the circuit's connecting path. Optical amplifiers can be selected or omitted. The closer the receiver is to the switch, the more effective the control is. Specifically, boosting the signal may not be necessary if the receiver is close. This switch connects to an amplifier and the receiver to increase signal quality in remote regions. The optical amplifier allows you to counteract the ambient effects by raising the signal's intensity. It is, therefore, possible to enhance a transmitter's range without increasing its transmit power. Attenuation occurs primarily in the wireless channel. As a result of the atmosphere's effects, the signal strength can be drastically reduced. Calculating attenuation is done as shown in [10]-[19].

The system's output is tested using a bit error rate (BER) analyzer with attenuation levels of 20, 30, and 70 dB/km for three different optical transmission air conditions. The optical amplifier amplifies weak signals before being detected by the photodetector. Reduces the communication's BER and lessens noise. Before the loss of information in the noise, the optical power level should be increased, especially in optical communication over long distances. Atmospheric conditions can considerably impact the signal strength of wireless optical communication. The fork/switch circuit in Figure 1 can be used to alter the receiver's distance. When the distance between the transmitter and receiver is narrow enough, the switch will select the circuit without an optical amplifier; otherwise, it will select the amplifier. The receiver and transmitter must be able to change their visible distance when moving, use of wavelength division multiplexing (WDM) to achieve high data rates [17], [20].

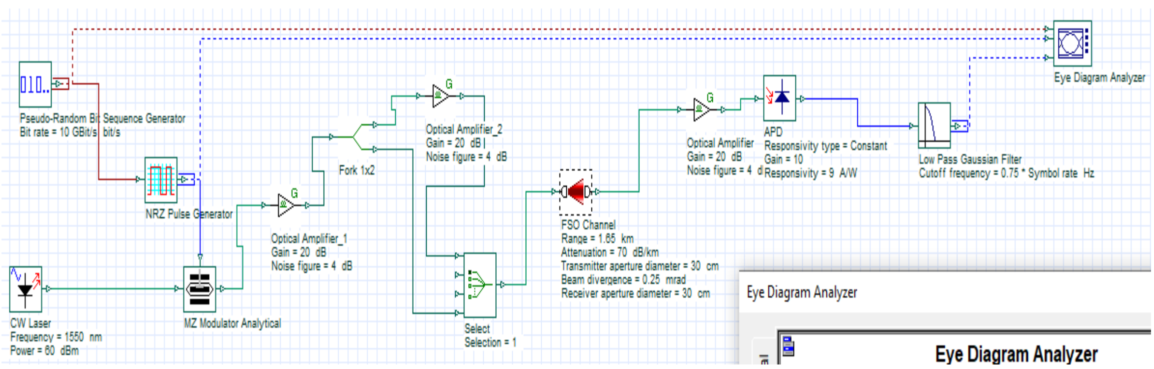

Figure 1. Adaptive FSO architecture shown schematically

3. MATHEMATICAL MODEL DESCRIPTION

In the event of fog, free-space optics communications are prone to interruptions [21]-[25]:

$$\alpha_{fog}(\lambda) = \frac{3.912}{V}\left(\frac{\lambda}{55*10^4}\right)^{-q} \quad (1)$$

where λ is the signal's wavelength, and V is the transmission range in km. The parameter q is regarding the transmission distance. The loss of beam depends on the scattering loss coefficient; rain, snow and the total attenuation are given by (2)-(4).

$$\alpha_{scat}(\lambda) = \frac{17}{V}\left(\frac{550}{\lambda}\right)^{0.195V}, \text{dB/km} \quad (2)$$

$$\propto = \propto_{fog}(\lambda) + \propto_{snow}(\lambda) + \propto_{rain}(\lambda) + \propto_{scat}(\lambda), \text{dB/km} \quad (3)$$

$$\propto_{rain} = 1.076\, R^{0.67}\ \frac{dB}{Km} \quad (4)$$

The attenuation of snow $\propto_{snow}$ where S is the rate of snow in mm/h. While a and b are parameters which in the case of dry snow given as (6).

$$\propto_{snow} = a\, S^{b}\ \frac{dB}{Km} \quad (5)$$

In case of dry snow.

$$a = 5.42\text{x}10^{-5}\,\lambda + 5.495876,\ b = 1.38 \quad (6)$$

4. RESULTS AND DISCUSSION

Figure 1 shows how the FSO is used to build the optical system as a whole. The optical transmitter can only send data at a rate of 10 Gbps, and The data is encrypted with the help of an non-return-to-zero (NRZ) pulse generator. The continuous wave (CW) laser is suited as an optical source for its high power and short wavelength. BER reduction and visible distance maximizing solutions have been tested in various meteorological conditions. Opti System 15 evaluates the Q factor and BER.

4.1. Conditions in which the atmosphere is hazy

Because of this, long-distance propagation is still possible even though the power and quality of the signal decrease as the distance rises. This effect is amplified by raising the transmit strength of optical communications due to numerous safety considerations (including issues with aviation exposure). A reliable FSO connection can be achieved without increasing transmit power. The suggested adaptive and iterative approach has permitted 5,000 m distance propagation without repeaters in the foggy wireless environment. Long-distance optical signal propagation without compromising service quality is shown in Figure 2 (i.e., the BER). In optical communications, the Q-factor is used to evaluate link quality. The Q-factor diminishes as the link length increases, reflecting the loss of signal strength. The results are shown in Table 1 in comparison with the results of previous years.

4.2. In the presence of rain and fog

Like hazy wireless environments, rain and mist significantly attenuate optical signals. Whether it's raining or misting, the weather still affects us. Despite a rise in the attenuation of signals in the air, we have been able to keep our bit error rate close to zero at distances of up to 3,500 meters by employing the optimal design. As the signal strength of an optical link decreases with distance, that link's usefulness is constrained. Past a certain range, the signal is no longer usable due to atmospheric attenuation, dispersion, and reflection.

The receiver, on the other hand, cannot recover the signal because of the noise. Thus, Figure 3 reveals a decrease in factors with distance. It is possible to communicate beyond 3.5 kilometres in an unlicensed frequency because of the revolutionary optical communication concept (rainy and hazy). In contrast to traditional RF and optical communications, this exceptional distance coverage is not accomplished at the expense of throughput or communication reliability. Ten Gigabits per second of error-free data can be transferred in this unlicensed channel. The results in Table 2 are compared with the results of previous years.

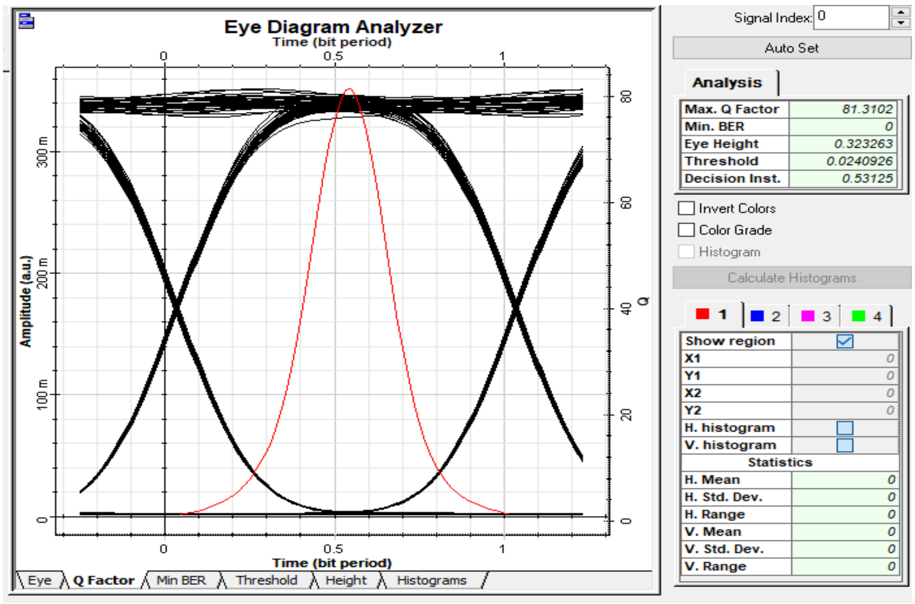

Figure 2. Eye diagram analyzer, distance 5 km, and wavelenght 1,550 nm, attenuation 20 dB/km

Table 1. Results in atmosphere is hazy, attenuation 20 (dB/km)

Reference	Visibility distance (m)	Q-factor	BER	Data rate (Gbps)
Ashraf *et al.* [12]	3,500	57,0486	0	10
Lema [17]	4,685	58,762	0	10
Proposed (optimization)	5,000	81,3102	0	10

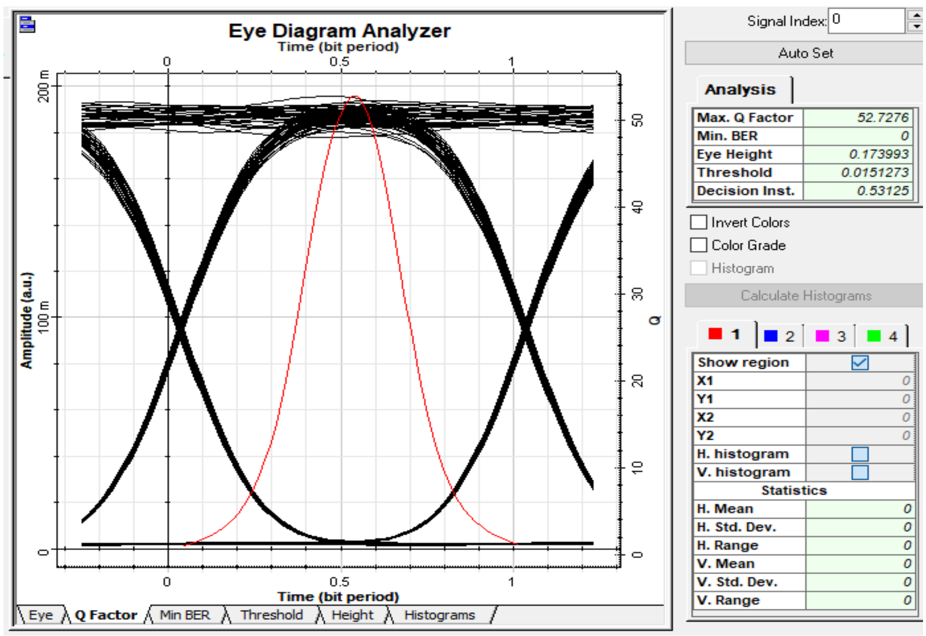

Figure 3. Eye diagram analyzer, distance 3.5 km, and wavelenght 1,550 nm, attenuation 30 dB/km

Table 2. Results from in the presence of rain and fog, attenuation 30 (dB/km)

Reference	Visibility distance (m)	Q-factor	BER	Data rate (Gbps)
Ashraf *et al.* [12]	2,500	34,0397	$2.855e^{-254}$	10
Lema [17]	3,314	34.20	$1.1544\ e^{-256}$	10
Proposed (Optimization)	3,500	52,7276	0	10

4.3. In the presence of a hazy atmosphere

Compared to damp and misty conditions, a foggy atmosphere greatly reduces the optical signal (more than twice the worse effect). As a result, the signal falls more quickly than usual. The conventional unlicensed optical wireless communication link cannot communicate over long distances. As a result, optical communication systems should be able to adapt to changing atmospheric circumstances by altering their parameters and circuitry. The maximum distance that can be reliably communicated with the suggested optical architecture has reached 1,550 m. While it is feasible to communicate effectively over long distances, the cost of doing so may be prohibitive. For example, it is well-known that higher transmission power is required to provide longer-distance coverage.

Figure 4 shows that the Q-factor of the rainy and hazy conditions is still okay at the 1,650 m distance. In addition, the BER is practically nonexistent in this situation. FSO communication can be maintained across a distance of more than 1.65 kilometres (70 dB/km) without additional repeaters, thanks to the proposed iterative optimization and design. A further plus is that the proposed method takes account of the current channel status while also adapting to changing atmospheric conditions. The results in Table 3 are compared with the results of previous years.

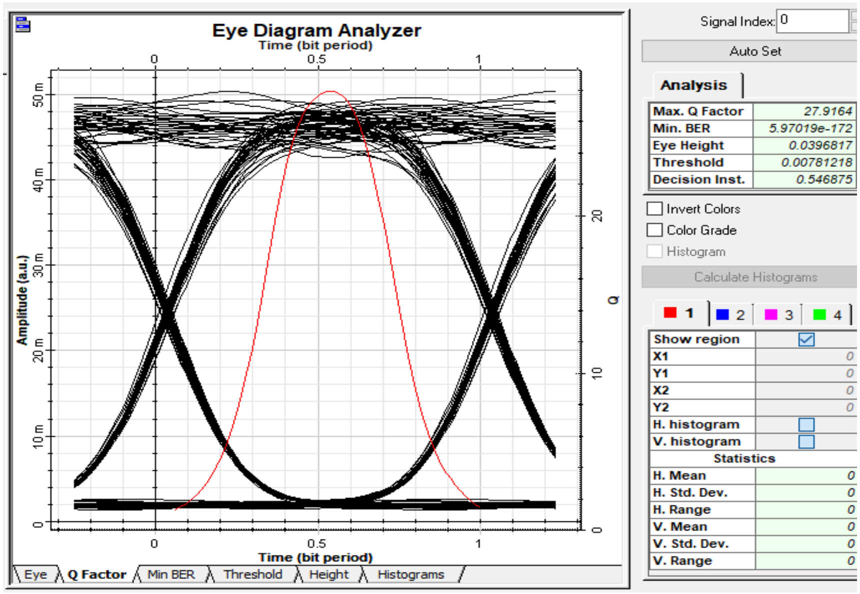

Figure 4. Eye diagram analyzer, distance 1.65 km, and wavelenght 1,550 nm, attenuation 70 dB/km

Table 3. Results in the presence of a hazy atmosphere, attenuation 70 (dB/km)

Reference	Visibility distance (m)	Q-factor	BER	Data rate (Gbps)
Ashraf *et al.* [12]	1200	17.5354	$3.841e^{-69}$	10
Lema [17]	1550	9.8265	$8.72786\ e^{-88}$	10
Proposed (Optimization)	1650	27.9164	$5.97019\ e^{-172}$	10

5. CONCLUSION

While the FSO enables promising communication characteristics, optical signal degradation over a wireless link is straightforward. Environmental factors, such as wind and rain, can significantly weaken the signal and substantially impact both the data and the BER. New iterative optimization algorithms and an enhanced optical communication link design have been proposed as a result of this study's findings, which should help mitigate the effects of climate change. Different types of weather, such as haze, mist, rain, and fog, were used to evaluate the optical link's performance in terms of distance saw signal quality, bit error rate, and eye diagram. The system's performance has been evaluated, and its QoS guarantees are its dependability and throughput. The visibility distance can be increased without sacrificing the BER, datarate, or Q-factor found in recent studies by optimizing the length of the optical amplifier and improving the design of the optical link. Under the proposed design, the maximum guaranteed QoS visibility distance is determined for each set of weather conditions. The simulation results show that the visibility distance, Q factor, and BER can be improved with little to no increase in system complexity.

REFERENCES

[1] F. Khair, D. Zulherman, and R. Auliana, "Software-based simulation to analyze the variation of digital modulation and atmospheric condition on the free space optic (FSO) link performance," *JURNAL INFOTEL*, vol. 14, no. 3, pp. 214–219, Aug. 2022, doi: 10.20895/infotel.v14i3.758.

[2] M. Singh, J. Kříž, M. M. Kamruzzaman, V. Dhasarathan, A. Sharma, and S. A. Abd El-Mottaleb, "Design of a high-speed OFDM-SAC-OCDMA-based FSO system using EDW codes for supporting 5G data services and smart city applications," *Frontiers in Physics*, vol. 10, Jul. 2022, doi: 10.3389/fphy.2022.934848.

[3] P. K. Sahoo and A. K. Yadav, "A comprehensive road map of modern communication through free-space optics," *Journal of Optical Communications*, Dec. 2021, doi: 10.1515/joc-2020-0238.

[4] K. M. Abdulhussien, A. H. Ali, and S. A. Kadhim, "Radio over Free space optical communication system experimental setup and performance analysis," in *2018 3rd Scientific Conference of Electrical Engineering, SCEE 2018*, Dec. 2018, pp. 323–326, doi: 10.1109/SCEE.2018.8684148.

[5] M. Singh, J. Malhotra, M. S. M. Rajan, V. Dhasarathan, and M. H. Aly, "Performance evaluation of 6.4 Tbps dual polarization quadrature phase shift keying Nyquist-WDM superchannel FSO transmission link: Impact of different weather conditions," *Alexandria Engineering Journal*, vol. 59, no. 2, pp. 977–986, Apr. 2020, doi: 10.1016/j.aej.2020.03.031.

[6] A. K. B. Rahman *et al.*, "Impact of rain weather over free space optic communication transmission," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 1, pp. 303–310, Apr. 2019, doi: 10.11591/ijeecs.v14.i1.pp303-310.

[7] V. K. Mani and V. Kumar, "Free-space optical channel performance under atmospheric losses using orthogonal frequency division multiplexing," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 3, pp. 1571–1579, Mar. 2022, doi: 10.11591/ijeecs.v25.i3.pp1571-1579.

[8] A. A. B. Anis, C. B. M. B. Rashidi, and S. A. Aljunid, "Analysis using multiple free space optic channel with amplification to mitigate haze attenuation," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 2, pp. 546–554, May 2019, doi: 10.11591/ijeecs.v14.i2.pp546-554.

[9] M. I. Basudewa, Z. H. Bagaskara, S. S. A. Damita, R. F. Putra, and D. Ahmadi, "Bit error rate performance analysis for free space optic communication," *IOP Conference Series: Materials Science and Engineering*, vol. 850, no. 1, p. 012056, May 2020, doi: 10.1088/1757-899X/850/1/012056.

[10] D. Jain and R. Mehra, "Performance analysis of free space optical communication system for S, C and L band," in *2017 International Conference on Computer, Communications and Electronics, COMPTELIX 2017*, Jul. 2017, pp. 183–189, doi: 10.1109/COMPTELIX.2017.8003961.

[11] F. T. Mahmood, A. H. Ali, and A. H. A. Haeder, "Analysis study of quality factor and bit error rate at wavelength change," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 27, no. 1, pp. 301–308, Jul. 2022, doi: 10.11591/ijeecs.v27.i1.pp301-308.

[12] M. Ashraf, G. Baranwal, D. Prasad, S. Idris, and M. T. Beg, "Performance analysis of ASK and PSK modulation based FSO system using coupler-based delay line filter under various weather conditions," *Optics and Photonics Journal*, vol. 08, no. 08, pp. 277–287, 2018, doi: 10.4236/opj.2018.88023.

[13] M. K. El-Nayal, M. M. Aly, H. A. Fayed, and R. A. AbdelRassoul, "Adaptive free space optic system based on visibility detector to overcome atmospheric attenuation," *Results in Physics*, vol. 14, p. 102392, Sep. 2019, doi: 10.1016/j.rinp.2019.102392.

[14] S. Chaudhary and A. Amphawan, "The role and challenges of free-space optical systems," *Journal of Optical Communications*, vol. 35, no. 4, pp. 327–334, Jan. 2014, doi: 10.1515/joc-2014-0004.

[15] S. Bloom, E. Korevaar, J. Schuster, and H. Willebrand, "Understanding the performance of free-space optics [Invited]," *Journal of Optical Networking*, vol. 2, no. 6, p. 178, Jun. 2003, doi: 10.1364/jon.2.000178.

[16] D. A. Kadhim, A. J. Allah Shakir, A. N. Mohammad, and N. F. Mohammad, "System design and simulation using (OptiSystem 7.0) for performance characterization of the free space optical communication system," *International Journal of Innovative Research in Science, Engineering and Technology (An ISO*, vol. 3297, 2007, doi: 10.15680/IJIRSET.2015.0406132.

[17] G. G. Lema, "Free space optics communication system design using iterative optimization," *Journal of Optical Communications*, Jul. 2020, doi: 10.1515/joc-2020-0007.

[18] M. F. Talib, M. S. Anuar, and C. B. M. Rashidi, "Performance of geometrical effect in wavelength filtrate detection using 10gbps data rate for free space optical communication system," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 13, no. 2, p. 575, Feb. 2019, doi: 10.11591/ijeecs.v13.i2.pp575-583.

[19] A. Almukhtar, A. Abass, and M. Ali, "Effect of fiber-telescope coupling losses on wideband wavelength division multiplexing in free space optical communications," *Engineering and Technology Journal*, vol. 40, no. 2, pp. 350–357, 2022, doi: 10.30684/etj.v40i2.2194.

[20] A. Trichili, M. A. Cox, B. S. Ooi, and M.-S. Alouini, "Roadmap to free space optics," *Journal of the Optical Society of America B*, vol. 37, no. 11, p. A184, Nov. 2020, doi: 10.1364/josab.399168.

[21] A. M. Alatwi, A. N. Z. Rashed, A. S. Parvez, B. K. Paul, and K. Ahmed, "Beam divergence and operating wavelength bands effects on free space optics communication channels in local access networks," *Journal of Optical Communications*, Aug. 2020, doi: 10.1515/joc-2019-0276.

[22] S. Adnan, M. Ali, and F. Hakwar, "The air bubbles effect for underwater optical wireless communication using 650 nm wavelength," *Engineering and Technology Journal*, vol. 37, no. 10A, pp. 398–403, Oct. 2019, doi: 10.30684/etj.37.10a.3.

[23] P. Paliwal, J. Shreemali, P. Chakrabarti, and S. Poddar, "Performance optimization of hybrid RAMAN-EDFA based WDM-FSO under adverse climatic conditions," *Materials Today: Proceedings*, Feb. 2021, doi: 10.1016/j.matpr.2020.12.624.

[24] M. Singh, S. N. Pottoo, A. Armghan, K. Aliqab, M. Alsharari, and S. A. Abd El-Mottaleb, "6G network architecture using FSO-PDM/PV-OCDMA system with weather performance analysis," *Applied Sciences (Switzerland)*, vol. 12, no. 22, p. 11374, Nov. 2022, doi: 10.3390/app122211374.

[25] I. Mohamed, R. Saleh, and A. Salih, "Enhancing the FSO link range under very clear air and thin fog conditions in Albayda-Libya," in *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering, MI-STA 2022 - Proceeding*, May 2022, pp. 574–579, doi: 10.1109/MI-STA54861.2022.9837641.

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