

ATM-FIR: IMPACT OF ATMOSPHERIC ATTENUATION ON FREE-SPACE OPTICAL COMMUNICATION IN COASTAL ENVIRONMENT

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Abstract – Free space optical (FSO) communication uses optical beams to transmit data. In order to transmit data, line-of-sight must be maintained between the transmitter and receiver. Data rates are high, spectrum is license-free, and deployment costs are low with FSO links. However, atmospheric conditions contribute significantly to the degradation of FSO link performance. Furthermore, it is challenging for learning algorithms to determine the optimal threshold value. To overcome these challenges, a novel ATM-FIR model has been proposed for addresses the effect of atmospheric attenuation on FSO communication in coastal environments. It examines the environmental factors such as snow, rain, haze, fog, and dust impact the efficiency of optical wireless communications using an FSO system. The model considers atmospheric attenuation under different weather conditions, accounting for visibility and operating wavelengths in the context of FSO links. The optimized lipschitz exponent (OLE) is applied before transmission through the FSO medium in coastal areas. The OLE function is used to measure the informational data from atmospheric channels. On the receiver side, the system includes an optical filter, FDM, and a demultiplexer to convert the signal into an electrical form. The proposed models are validated across a wide range of temperature and humidity conditions, demonstrating strong performance in FSO connections within coastal environments.

Keywords – Atmospheric factors, Free-Space Optical system (FSO), Optimized Lipschitz function (OLE).

1. INTRODUCTION

FSO is recognized as the most significant technology in the progression of future broadband systems due to its extensive growth in a short period for its powerful features such as high bandwidth, higher data-transfer rates, low cost and operation with an unlicensed spectrum [1]. Weather influences several parameters of FSO communication systems and they change significantly over time [2]. There have been several published studies on the effectiveness of atmospheric aerosol-induced degradation of the FSO system

[3]. FSO communication is fundamentally classified into two categories indoor systems and outdoor systems [4]. Various electronic devices under wireless personal area networks (WPANs) can be connected through the FSO link [5].

The terrestrial FSO system establishes point-to-point laser links between two nodes and transports the message signal modulated on intensity, phase or frequency of the optical carrier [6]. The main factor causing quality degradation in FSO is its susceptibility to various air turbulences caused by poor weather conditions [7]. As the optical beam propagates through a line-of-sight FSO link, atmospheric particles cause signal attenuation [8]. The main drawback of FSO communication system lies in its sensitiveness to weather condition or more precisely atmospheric turbulence conditions [9]. The following are the paper's main contributions:

- The primary purpose of this research is to create a novel ATM-FIR model has been proposed for addresses the effect of atmospheric attenuation on FSO communication in coastal environments.
- The model considers atmospheric attenuation under different weather conditions, accounting for visibility and operating wavelengths in the context of FSO links.
- The OLE is applied before transmission through the FSO medium in coastal areas.
- The OLE function is used to measure the informational data from atmospheric channels. On the receiver side, the system includes an optical filter, FDM, and a demultiplexer to convert the signal into an electrical form.
- A model for the link between T , R_H and β over FSO channels in coastal region the OLE function

measures the informative data from the atmospheric channels.

The structure of the paper is organized as follows, section-2 describes the literature survey, the proposed ATM-FIR was explained in section-3, the performance results and their comparison analysis were provided in section-4 and section-5 encloses with conclusion and future work.

2. LITERATURE SURVEY

This chapter describes the main traditional techniques for spectrum sensing and explains the methodologies and constrains of each traditional methodology. In this chapter, the limitations of several conventional approaches for spectrum sensing are also discussed.

In 2022 Almogahed, et al., [10] proposed a FSO system DFE strategy in MDM uses seven simultaneous 2.5 Gbps MDM channels to transmit data at 17.5 Gbps in Hermite-Gaussian modes, and in order to decrease the effects of turbulence in the atmosphere, seven DFE techniques are used at the receiver. From the experimental outcomes, it can be seen that when the attenuation is increased, the distance between the two points decreases.

In 2022 Yu, J [11] et al., had suggested a method to detect and semantically decode the symptoms of a stroke using real-time, multi-modal ECG bio signals. It uses an ensemble framework that combines CNN and LSTM in real-time stroke illness prediction while a person is moving around. In predicting stroke sickness in real-time while travelling, they developed and deployed a system employing an ensemble framework that combines CNN and LSTM.

In 2022 Kumar, A.K [12] et al., had proposed the effectiveness of DL models for predicting respiratory rate. The biosensor data collection that includes ECG data. Long short-term memory networks, CNN-LSTM, Bidirectional LSTM, attention-based LSTM networks and convolutional-LSTM networks are some examples of deep learning models. According to the findings, BiLSTM with Bahdanu Attention performs the best for biosignals.

In 2022 Suresh Kumar, et al., [13] proposed a FSOC has been used in a number of different technical applications, highlighting cutting-edge developments that have been adopted or are currently being used. Applications of the FSOC in different modern communication and other industries, including as remote sensing, LAN, networking, surveillance, WLAN, satellites, and so forth, as well as a number of ground-breaking advantages, some restrictions, and related mitigation strategies.

In 2022 Abou-Rjeily, C., [14] presented the relaying strategies and performance analysis for cooperative FSO networks using buffer-aided (BA) parallel relaying with two relays. The current selective relaying technique, which concurrently activates the most potent source-relay and relay-destination optical links, is firstly examined asymptotically. Develop close-form precise formulas for the asymptotic values of outage probability and average packet latency then propose improvements to this method.

In 2020 Jain, P., et al., [15] described the FSO channel with K-Phase Shift to transmit OFDM signals. The double generalized gamma distribution is used in keying modulation. For various orders of K-PSK modulation under light, moderate, and heavy turbulence, a novel closed form expression of BER was simulated. Furthermore, BER performance is better in minor turbulence than in moderate or heavy turbulence.

In 2021 Surantha, N., et al., [16] had developed an accurate model to categorize different stages of sleep using features of ECG-extracted heart rate variability. The characteristics were selected and the no. of hidden nodes was determined using the integration of PSO and extreme learning machine (ELM). The accuracy test results for classes 6, 4, 3, and 2 were 62.66%, 71.52%, 76.77%, and 82.1%, respectively, for the combined PSO and ELM.

From the above literature survey, the existing approaches are challenging for learning algorithms to determine the optimal threshold value. To overcome these challenges, a novel ATM-FIR model has been proposed for addresses the effect of atmospheric attenuation on FSO communication in coastal environments. As part of this method, the OLE function measures the atmospheric channels that provide informative data. On the receiver end the system comprises of an optical filter, FDM, de-multiplexer for retrieving the electrical form.

3. PROPOSED ATM-FIR

In this section, the proposed ATM-FIR has been described in detail. The user sends the data to the OLE. After, the transmitting over the FSO medium. The data transmitted over the FSO system is affected by coastal environmental factors like air, temperature, fog & Haze and relative humidity factors. On the receiver end, the system contains of an LED, FDM, de-multiplexer, LNM and optical filter.

3.1. Free Space Optical Communication (FSOC)

A type of optical communication called FSO communications delivers visible and infrared (IR) beams across the atmosphere. Instead of streaming data through glass fibre, this method transmits data via the air using lasers and LEDs. High data rates and short distances make this approach particularly effective, and it can meet broadband requirements. Full-duplex (bidirectional) data, phone, and video transmission at up to 10Gbps is made possible by the LOS (line of sight) technique known as FSO.

High-frequency signals are swiftly sent from one place to another via an FSO. FSO technology employs unlicensed spectrum above 300 GHz and can be easily deployed or uninstalled, in contrast to a dedicated optical fibre link. FSO systems were once hailed as a solution to the last-mile issue since they could connect end users to the existing optical fibre and RF network infrastructure.

3.2. FSO Attenuation Co-efficient dependence with respect to water vapour air

Water vapour is invisible to the human eye as it is a gaseous form of water. At dew point temperature (T_D), air that has been cooled down will be saturated with water

vapour. A collection of vapour will eventually turn into liquid dew during this phase. The relative humidity is one indicator of humidity (R_H), which is the proportion of change in air temperature to the difference between the maximum saturated density and the actual vapour density. As the R_H ratio gets closer to unity, the air will be fully saturated with

water vapor and overflowing with it, creating rainy conditions. R_H is distinguished by

$$R_H = \frac{\text{instantaneous absolute humidity}}{\text{maximum absolute humidity}} * 100 \quad (1)$$

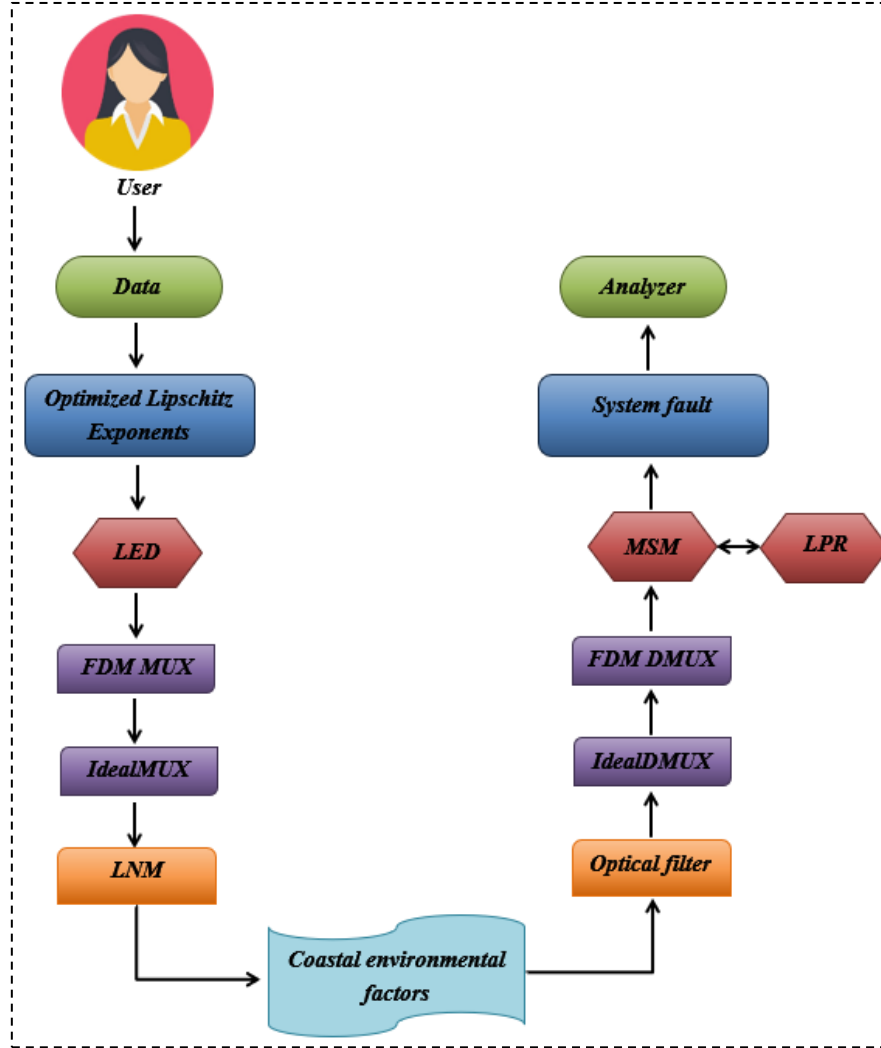


Figure 1. proposed ATM-FIR methodology

The estimation for the conversion between T_D , T and R_H is given below simply as:

$$R_H = 100 - 5 (T - T_D) \quad (2)$$

If R_H is greater than 50%, the formula's accuracy is approximately 1°C. The ensuing design is,

$$R_H = M \frac{T_D}{T} * 100 \quad (3)$$

when a proportionality constant M is used. With respect to our measurements, $M = 0.95$. A more precise illustration of the R_H in relation to T_D and T is provided by

$$R_H = \frac{\exp(\frac{15.526 * T_D}{423.04 + T_D})}{\exp(\frac{15.526 * T}{423.04 + T})} * 100 \quad (4)$$

The equations show the negative correlation between R_H and T .

3.3. FSO Attenuation coefficient dependence with respect to temperature

Classifying the effects of temperature changes in a coastal environment has been shown by a thorough review of the pertinent literature. Assume that β is the channel attenuation coefficient in kilometres per square meter. The current temperature is always directly correlated with the attenuation coefficient. Therefore, the relation between T and β can be illustrated as,

$$\frac{d\beta}{dT} \propto (-\beta) \Rightarrow \frac{d\beta}{\beta} = -kdT, \quad (5)$$

The inverse relationship between β and T is represented by the negative symbol, and k is constant. Within the temperature range (0 to T), the result of integrating both sides of (1) is

$$\int_{\beta_0}^{\beta} \frac{d\beta}{\beta} = - \int_0^T kdT \quad (6)$$

The overall model of the temperature-related attenuation coefficient can therefore be written as,

$$\text{Model 1: } \beta = ye^{-kT}, \quad (7)$$

Anywhere $y = \frac{1}{\beta_0}$ is a constant. Scaling and decaying parameters, respectively, are used to describe the constants y and k . The experimental measurements can be used to estimate it for specific temperatures. Consequently, y and k depend on wavelength.

3.4. The effect of the FSO attenuation coefficient on relative humidity

Based on the density of the atmospheric water vapour, a significant amount of the transmitted optical power is absorbed by atmospheric moisture. By substituting (2), (4), and (3) into (7), the following expressions are obtained, which support the development of a model to explain the association between the relative humidity and the FSO link attenuation coefficient:

$$\text{Model 2(a): } \beta = ye^{-k(T_D + \frac{100-R_H}{5})} \quad (8)$$

$$\text{Model 2(b): } \beta = ye^{-kM \frac{T_D}{R_H}} * 100 \quad (9)$$

The root mean square error can be used to identify the model that represents a coastal environment the most accurately. Additionally, the ethics of fit R^2 based on our predicted values for T , R_H and β .

3.5. Environmental Attenuations

Due of fog particles close resemblance to light in wavelength to light, fog is the most crucial element in FSO connectivity. The air attenuation coefficient is calculated based on the incident beam's wavelength and visibility.

$$\alpha = \frac{3.91}{v} \left(\frac{\lambda}{\lambda_0}\right)^{-p} \quad (10)$$

where P is a measure of the size distribution of the scattering particles, λ_0 denotes the visible reference wavelength of 500 nm, v denotes visibility (km), and λ denotes the transmission wavelength of 500 nm.

According to the Kruse model, equation (10) can be used to calculate the attenuation of the transmitted signal under various weather circumstances. The following formula can be used to get the atmospheric attenuation in dB:

$$\tau = 4.4392 * \alpha * M \quad (11)$$

where L is the separation between the receiver and the transmitter

One of the environmental conditions that causes attenuation in an FSO system is rain. As a result of the optical signal's much shorter wavelength than that of a raindrop, rain has less of an effect than fog. Additionally, rainfall attenuation can be computed as follows:

$$Ch_{diff} = \left\{ \frac{(n+1)(n_{element}+1)}{4\pi^2 a_1^2 a_2^2} P_c dp_\rho T_{fc}(\psi_1) T_{cn}(\psi_1) \cos^n(\psi_1) \cos(\delta_1) \cos n_{element}(\gamma_1) \cos(\psi_1) \right\}, 0 \leq \psi_1 \leq \psi_c, \psi_1 \geq \psi_c \quad (16)$$

Here a_1 & a_2 is the transmitter and recipient points are separated by reflective walls, and the opposite is true for the

$$A_{rain} = 1.026 * R^{0.67} \text{ (db/km)} \quad (12)$$

where R represents the mm/hr rain rate.

3.6. Channel Model

There are three primary channels in the proposed FSO System: a transmitter, an atmospheric channel and a receiver. The transmission and reception paths, the receiver's field and the transmitter angle of vision are used to classify the channel. The following pathway discusses both the outdoor and indoor diffusion channels:

Outdoor Diffusion channel:

Equation can be used to characterize the overall atmospheric attenuation over the FSO lines (13).

$$P_r = P_t \frac{b_2^2}{[b_1^2 + \theta L]^2} e^{-\beta L} \quad (13)$$

where, P_r is the acquired power (μW),

P_t is the transmission of power (μW),

b_1 is the width of the transmitter aperture (m),

b_2 is the size of the receiver aperture (m),

L is the link distance (km),

θ are the diverging beams (mrad),

β is the amplification factor (1/km).

The collecting aperture area is used to calculate the total of the transmitted and collected power. It is estimated inversely related to all of the link range square and the beam divergence square. As per the Beer-Lambert rule:

$$\tau = 3.4932 \beta \text{ (dB/km)}, \quad (14)$$

where τ is the link amplification (dB/km). Calculate β the result is calculated by dividing the received power by the sent power, both are given in Db, and the result is then multiplied by the distance in kilometers and the constant 3.4932.

Indoor Diffusion Channel:

Because it depends on so many different factors, It is more difficult to forecast the loss in optical links for diffuse connections that are not directed. The expression, "power received at the detector," provides information about power.

$$Pk_{LOS} = Ch_{LOS}(0) + Ch_{LOS}(0)Pk_{ty} = Ch_{LOS}(0) + \sum_{reft} Ch_{LOS}(0) Pk_{ty} \quad (15)$$

The light reflected by complete wall surfaces can be analytically evaluated by subdividing the reflecting surfaces into tiny reflecting components called dA. Consequently, the channel (DC) Dark current gain for first-order reflection is given by,

recipient and target points. Γ_1 - angle of irradiance component and effectiveness of reflection (ρ).

4. RESULTS AND DISCUSSION

In this work, pay attention to the ambient aspects of R_H , T_D and T . The attenuation coefficient is determined using parameters that are fitted for the transmission distance using the difference in decibels between the power provided and the power received instantly. The $RMSE$ and R^2 values that can be used to assess how well the suggested model and the measured data are regressed were extracted by the MATLAB curve fitting tool box. Throughout the relationship between, be clear and avoid packed facts are T , R_H and β over a portion of the sampled period. By focusing on changes, it is possible to evaluate experimentally the absorption effects at wavelength within the atmospheric transmittance in T and R_H in the air. Figure.2 shows that T and R_H have an inverse relationship.

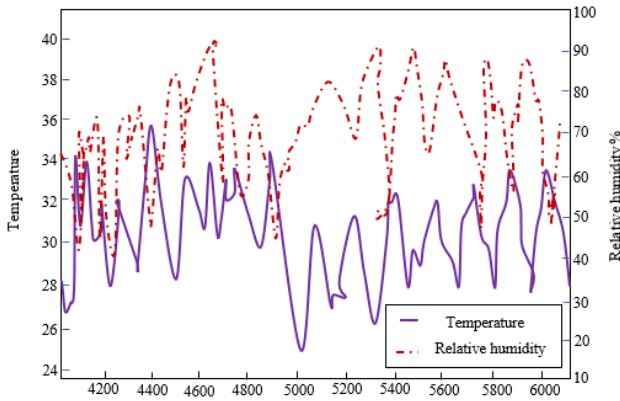


Figure 2. Relation between temperature and relative humidity

Figure.3, illustrates the connection between the noted T and the β . In this instance, as seen in Figure.4, β changes inversely with T . By utilizing a curve-fitting technique to the findings obtained at 1550 and 1310 nm, taking into account the measurements on β and T , the exponential attenuation models were established.

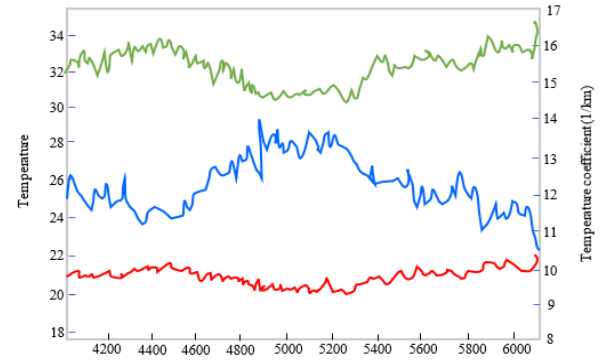


Figure 3. Temperature and attenuation coefficient relationship over time

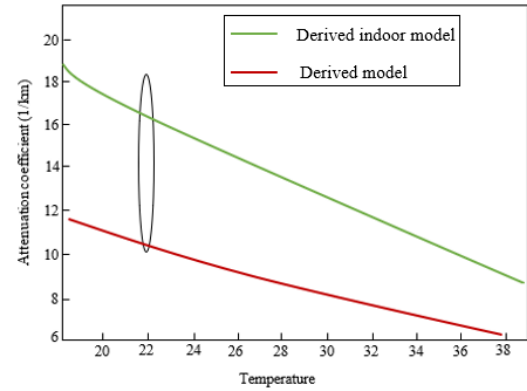


Figure 4. Temperature verification of the outdoor attenuation model.

The results of the curve-fitting models are shown in Figure.5, together with the measured values that make up the β values. The exponentially regressed attenuation model β values at both wavelengths are capable of providing a good fit to the measured data. Furthermore, it suggests that at the shorter wavelength, the FSO connection will deteriorate more quickly as transmission distance increases at the same temperature. From figure 6, it can be seen that changes in R_H have a proportional impact on the measured β Values. Therefore, β rises as R_H rises.

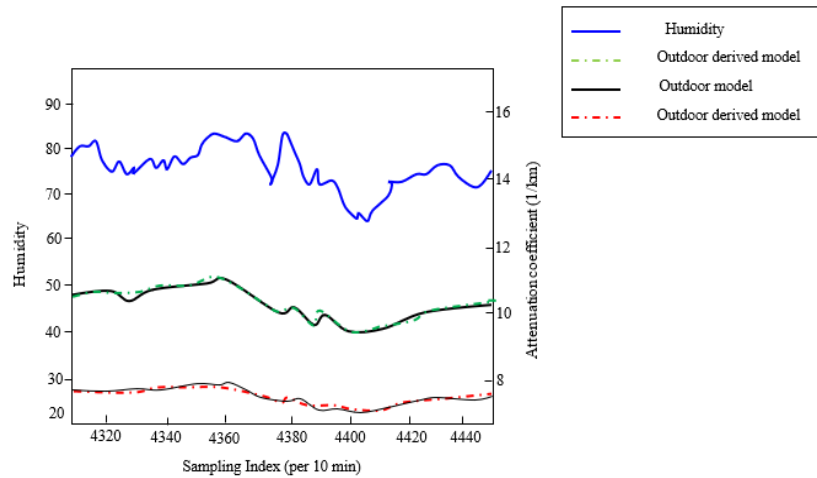


Figure 5. The correlation between the attenuation coefficient and relative humidity over time.

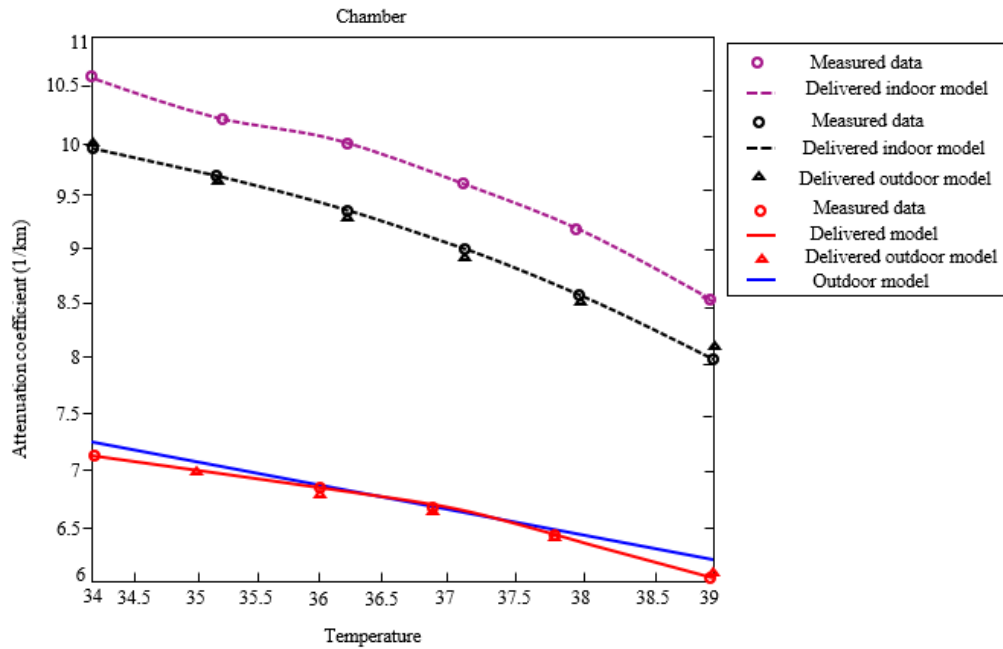


Figure 6. Using interior observations to validate the outdoor attenuation models.

5. CONCLUSION

In this research, a novel ATM-FIR model was proposed for addresses the effect of atmospheric attenuation on FSO communication in coastal environments. It examines the environmental factors such as snow, rain, haze, fog impact the efficiency of optical wireless communications using an FSO system. In the context of FSO links, the model takes visibility and operational wavelengths into account while taking atmospheric attenuation under various weather situations into account. The OLE is applied before transmission through the FSO medium in coastal areas and used to measure the informational data from atmospheric channels. On the receiver side, the system includes an optical filter, FDM and a demultiplexer to change the signal into an electrical form. The proposed models are validated across a wide range of temperature and humidity situations, demonstrating strong performance in FSO connections within coastal environments.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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