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Research Article

Performance Analysis of Dual-Beam Free Space Optical Communication Link under Dust and Rain Conditions

Sultan Mahmood Yasir,[1] Naeem Abas,[1] Shoaib Rauf,[1] Muhammad Shoaib Saleem,[2] and Aun Haider[2]

[1]*Department of Electrical Engineering, University of Gujrat, Hafiz Hayat Campus, Gujrat, Pakistan*
[2]*Department of Electrical Engineering, University of Management and Technology Lahore, Sialkot Campus, Sialkot, Pakistan*

Correspondence should be addressed to Naeem Abas; naeemkalair@uog.edu.pk

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Free space optical (FSO) communication has become an enduring and well-established communication technology in the last few decades with several advantages of high data rate, enormous bandwidth, low power consumption, transportable technology without right of way, and inherently secure line of a sight communication system. The invisible, intensity-modulated signal of light propagated through the air and detected on the receiver side experiences attenuation because of uneven distribution of rain droplets, suspended dust aerosol particles, and the droplet size distribution of fog particles in atmospheric layer degrade performance of FSO communication link. The ever-increasing demand for high data rate has quest for an innovative research for a communication link. In this paper, the performance of a dual-beam FSO communication link is evaluated under rain and dust as attenuation conditions. The system parameters, such as link distance transmitted and received power, link distance, diameter of transmitter and receiver aperture, and divergence angle, are optimized for a metropolitan FSO communication link. Dual-beam FSO communication signal propagated through an estimated attenuation level at 30 dBm transmitted power for link distance up to 2.5 km. The optical power splitter and power combiners are used in the simulation to estimate different channel parameters without the MIMO technique. The information signal of the 10 Gbps data rate is internally modulated using the NRZ generator, externally modulated by the Mach-Zehnder, and an optical signal transmitted through a dual-beam optical spectrum frequency of 193.1 THz using power splitter technique apart from each other. A comprehensive analysis is performed to design and assess robust optical communication systems through efficiency parameters such as received power, optical signal-to-noise ratio (OSNR), bit error rate (BER), and Q-factors. Results show that received optical power is a weather-dependent variable that shows a decreasing pattern as weather attenuation increases. Likewise, Q-factor and OSNR show similar decreasing trend with introduction of rain and dust as attenuator; however, BER increases in presence of attenuation.

1. Introduction

FSO communication is mature communication technology used for wireless communication links for backhaul communication networks at high data rates without any electromagnetic interference, with advantages of reliability and range/link distance. The ever-increasing demand for data rate has forced researchers to find the ultimate solution for the existing and upcoming applications in the cellular network of the 5th generation because of bandwidth congestion of radio frequency. FSO communication has advantages of bandwidth, compared to optic fiber cable with several advantages of easy and portable installations, so it is better to replace high-cost optical fiber cable with an FSO link [1]. Optical wireless communication is a visible light communication system in which optical signals are traveled through the environmental layer, causing the loss of propagated signal along with the propagation channel and reducing the intensity of the transmitted signal at the optical receiver side [2]. There are several weather conditions like rain, dust, aerosol particles, and fog that degraded the performance of the FSO system [3]. Scintillation is another effect of an atmospheric layer

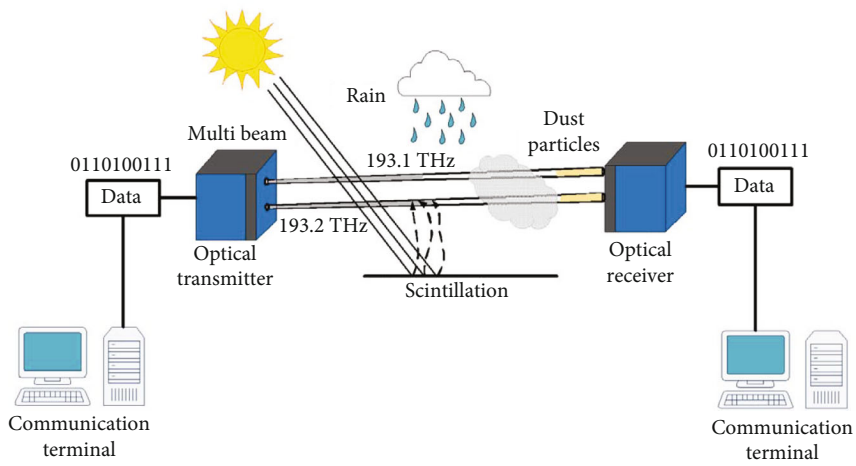


Figure 1: Multibeam FSO communication channel under rain and dust attenuation.

that may vary the intensity of the modulated optical signal traveled through the atmospheric channel and various automatic tracking techniques have been developed to deal with such problems [4]. To mitigate the scintillation effect, MIMO techniques can be used in which multiple laser beams are traveled through an atmospheric channel and are detected on multiple receiver apertures [5]. FSO communication is a mature technology utilized nowadays in numerous applications, such as backhaul communication networks, fiber backup networks, metropolitan area networks, and end-user networks to solve bottleneck issues of indoor and outdoor communication [6]. Several studies have been reviewed on atmospheric turbulence. It is observed that the channel attenuation is wavelength-dependent and optical signals behave differently [7–10]. A new optical Hermite-Gaussian mode multiplexing technique is also investigated for radio over free space optical communication (Ro-FSO) for connectivity between different picocells using a spatial correlator over a link distance of 500 meters. [11].

Lahore, a much populated metropolitan city, is an industrial hub and capital of province Punjab, Pakistan, and is ranked 42nd populated in the world [12]. Fog attenuation is one of the main performance degrading environmental factors that affects the performance of FSO communication link in December and January in Punjab, Pakistan. Optical attenuation due to fog can be a question mark but it can be mitigated by suitable link budget design, link margin, and link distance [13]. In the FSO communication system, the beam traveled through the environmental channel suffers from severe weather. A study has been carried out to investigate the effect of solar irradiance on FSO communication link based on Binary Phase shift Keying(BPSK), On-Off Keying (OOK), and differential phase shift keying (DPSK) [14]. An investigation for 10Gbps FSO communication has already been performed under the rain and dust attenuation conditions. Dust attenuation is estimated using the V-TSD model for suspended air particles and the visibility of the channel. Attenuation due to dust and rain is predicted in the paper [15]. The V-TSD model defines the experimental correlation with channel visibility and particles suspended in the airfield [16]. In the FSO communication system, another performance evaluating parameter for system design is the wavelength that can affect the link performance and receiver sensitivity of detection [17]. Raindrops are water droplets of a radius of 200 to 200 μm. These are significantly larger than a wavelength of an optical light source. These remained in the atmospheric layer for a short interval of time, so due to these factors, the rain has less effect on the performance of wireless optical communication as compared to other environmental factors [18]. The link distance is another geometrical design parameter of the FSO communication system. It has a significant effect on the performance of the FSO communication system [19]. There are several proposed techniques that are examined to mitigate the effect of the number of co-propagating models grouped at the receiver side including the single mood filtration techniques and offset launch technique [20, 21]. The performance of the communication system is correlated with severe weather conditions. A comprehensive investigation under various weather conditions must be carried out before the physical installation of the communication system [22]. Geometrical losses are the constant losses related to the design of FSO communication links. Geometrical design parameters are fixed parameters of a communication system that have significant importance. FoV (Field of View) on the receiver side must be according to the footprint because the greater FoV will also produce noise in the original information signal [23]. The investigation report shows that, in geometrical design elements, divergence angle size is an important factor for long-distance FSO communication links. The result shows that, as the divergence of beam increases, BER is also increased. The author has suggested a beam divergence angle of 0.25 mrad for a link distance up to 70 km [24]. To improve performance of FSO communication system, different techniques are investigated, and it is common practice to use OFDM that is widely used in adverse weather. The performance can be improved with the help of semiconductor optical amplifier (SOA) for long-distance communication links [25]. A multibeam FSO communication link with the MIMO technique is used to mitigate the rain attenuation using two different carrier frequencies of 193.1 THz and 193.2 THz [26]. To mitigate the effect of specific fog attenuation, four beams are used with the MIMO technique to

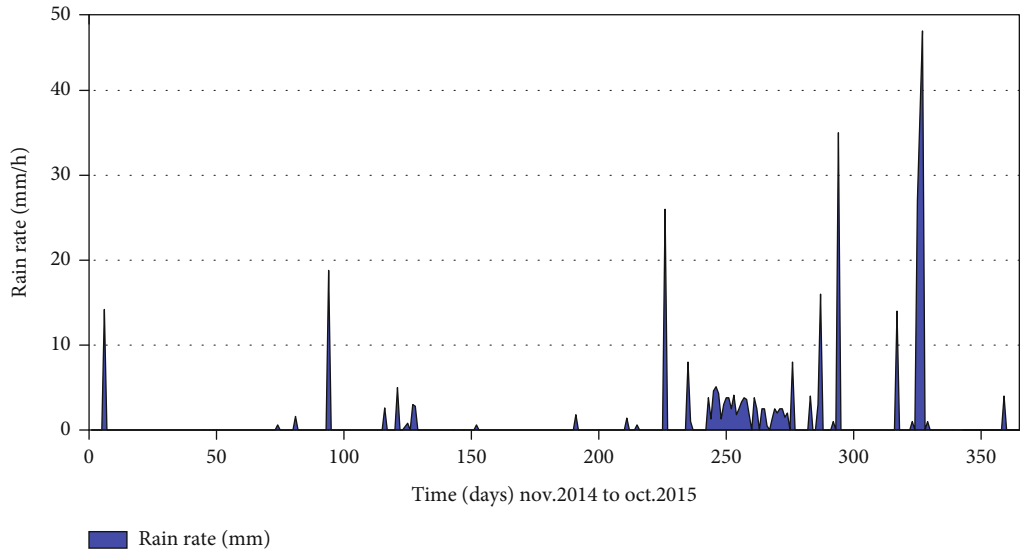


Figure 2: Rain rate (mm/hr) graph for Nov. 2014 to Nov. 2015 [15].

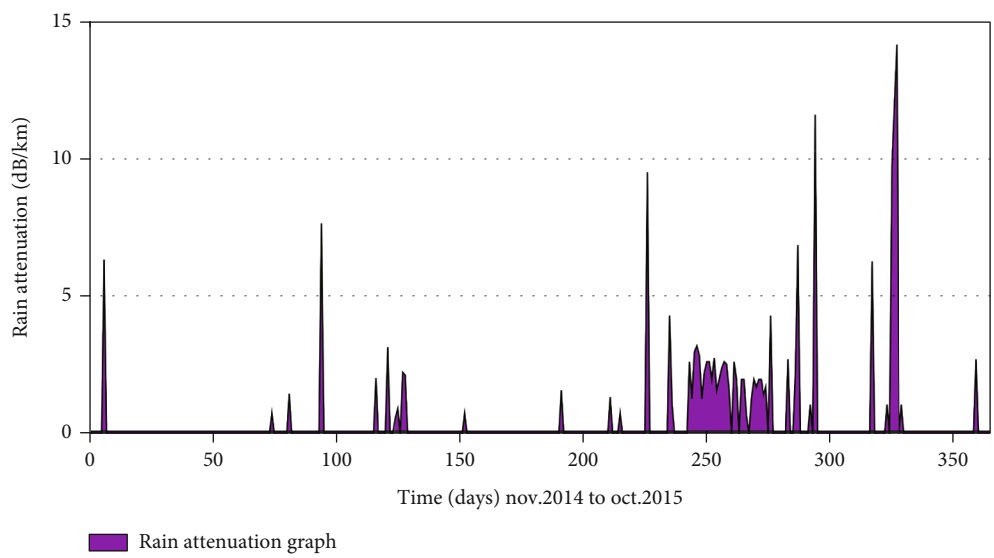


Figure 3: Rain attenuation graph [13].

Table 1: Estimated data statistics for rain attenuation from the graph.

Sr. No	Rain rate (mm/h)	Attenuation (dB/km)
Maximum value	47	14.19
Minimum value	1	0
Mean value	25.5	0.5031
Std. Deviation	14.58	1.655

investigate an FSO link for link distances of 1.7 km, 1.55 km, 1.5 km, and 1.4 km. The result shows that the quality of the signal enhances with multiple beams in communication [27].

In this paper, FSO communication link performance is examined under the rain and dust conditions in Lahore airfield. An information signal of 10 Gbps is transmitted using optical transmitter through dual-beam propagation using power splitter-combiner and analyses performed to improve FSO communication. The performance evaluating factors like OSNR, BER, and Q-factors are studied and simulated to find an FSO communication link under the rain and aerosol concentrations in the airfield of Lahore, Pakistan, to develop a fast metropolitan communication link in between different institutions especially universities and colleges.

2. Channel Model

FSO communication is an optical wireless communication link that can be used for indoor and outdoor data transmission. An optical signal is transmitted through an environmental layer or atmospheric channel. In indoor communication, channel noise is induced due to artificial lighting sources of similar wavelengths and in outdoor

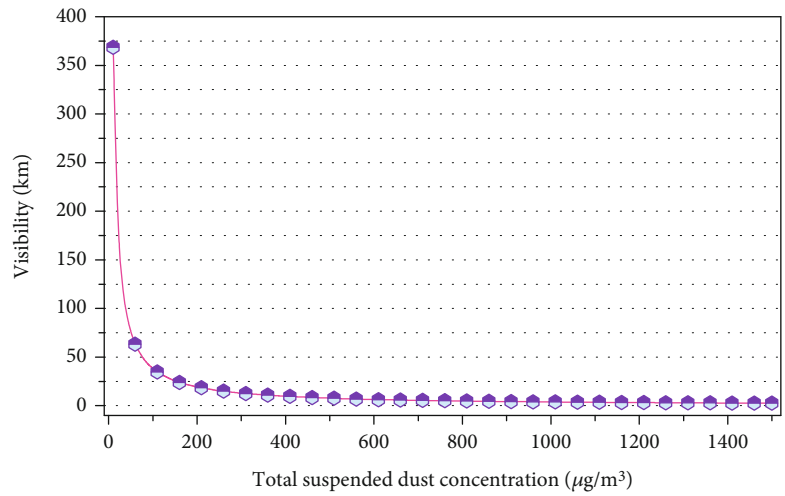


Figure 4: Illustration of visibility and concentration V-TSD model for Lahore, Pakistan.

Table 2: Data statistics of concentrations, visibility, and estimated attenuation in Lahore, Pakistan.

Location	C (μg/m^3)	Visibility (km)	Attenuation (dB/km) [29]
Walton	860	4.5961	10.48
Shadman	1350	2.9487	16.71
Township	745	5.2936	9.04
Misrishah	1192	3.3330	14.69
Charing Cross	1192	3.3330	14.69
City railway station	1523	2.6187	18.99
Bhatti Chowk	854	4.6279	10.41
Mazang Chungi	670	5.8764	8.10
Bund Road	1104	3.5944	6.7482
Choburgi Chowk	1210	3.2842	14.94
Niazi Chowk	1308	3.0419	16.17

Table 3: RF-spectrum data statistics of dual-beam FSO channel for link distance of 2.5 km at 193.1THz.

Attenuation (dB/km)	Signal power (dBm)	Noise power (dBm)	Maximum RF_C (Hz)
Clear sky (0.1 dB/km)	15.58	-52	3.199x10^{11}
Moderate attenuation (9.5 dB/km)	-31.42	-60	3.199x10^{11}
High attenuation (18.99 dB/km)	-78.8	-60.18	3.199x10^{11}

communication, natural light is a source of the noise. Optical transmitters transmit information in the form of light through the medium, experiencing atmospheric turbulence. The response of atmospheric attenuation was investigated using simulations or measuring the response of the channel on the receiver side. Scintillation is due to variation of temperature causing scattering of light signal to produce a pointing error on the receiver side whereas scattering and turbulence are two independent environmental factors and investigated using total impulse response (TIR). Figure 1 shows a block diagram of the multibeam FSO communication channel.

The droplet size distribution of rain and size of dust particles are random variables and scatter the light signal. The rain rate and dust concentration may be varied in the different areas, so the dual-beam propagation system may have variations in performance that effectively reduces the BER and improve the quality and reliability of the communication system.

2.1. Rain Attenuation. Rain and haze are environmental factors that cause optical attenuation for the FSO communication signal. Rain contains water droplets with a diameter larger than 0.5 mm. These water droplets scatter the optical signals causing pointing error at the receiver side [28]. The rain attenuation model for optical communication is expressed as: [15].

$$\alpha_{\text{rain}} = 1.076R^{0.67}\,\text{dB/km}, \tag{1}$$

where "R" represents a rain rate. The severity of rain attenuation depends upon the rain rate (mm/hour). The droplet size of rain is significantly larger than the wavelength of the laser used in FSO communication and has less attenuation as compared to fog attenuation. In this paper, we are investigating the effect of rain and dust on the FSO communication system for Lahore, Pakistan, and for this purpose, rain data is collected from the regional metrological department to simulate a rain attenuation model. The maximum rain rate recorded in Lahore on 23 Nov. 2015 was 47 mm/hr as shown in Figure 2 [15]. The estimated attenuation for the heaviest value of rain attenuation is 14.19 dB/km, as shown in Figure 3. Estimated data statistics for rain attenuation are presented in Table 1.

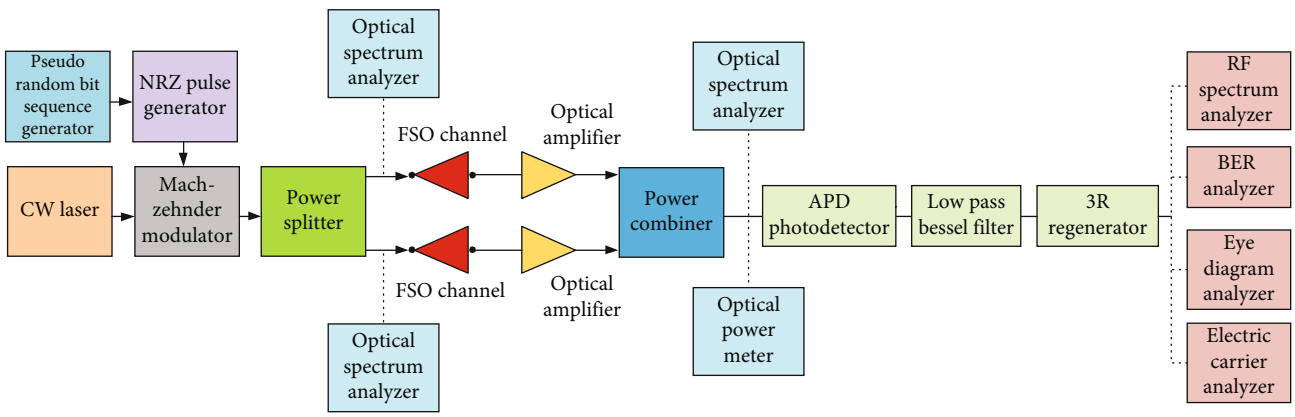


Figure 5: Simulation of dual-beam FSO communication link.

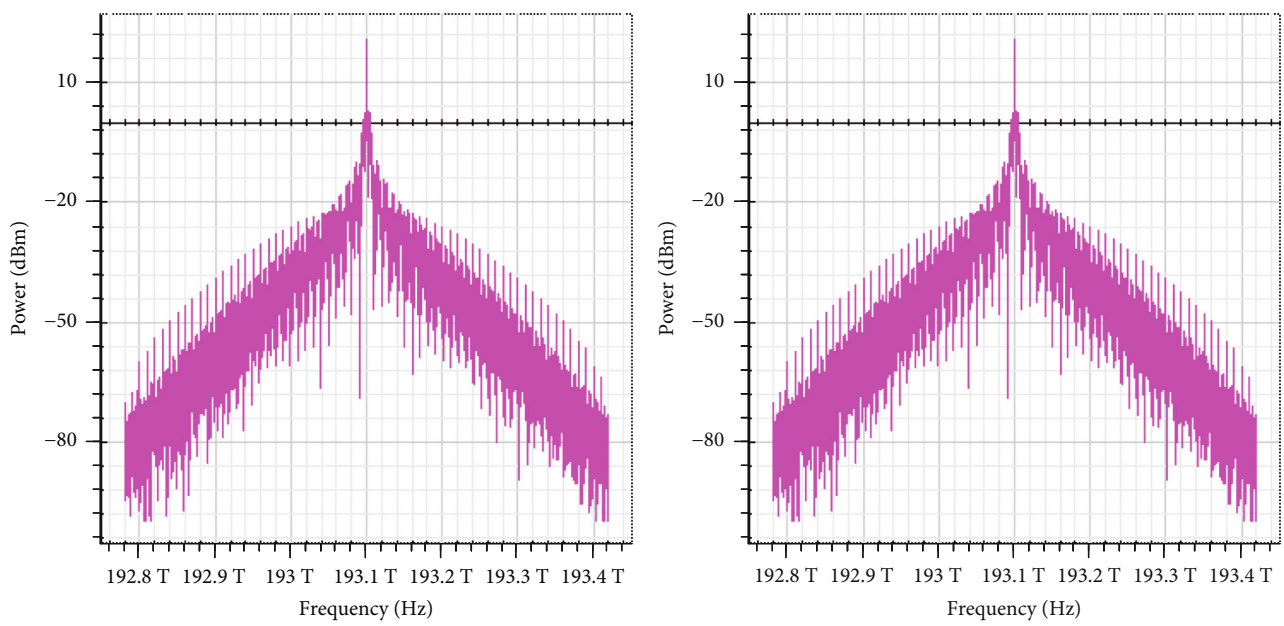


Figure 6: Optical spectrums of split dual-beam FSO Communication System on transmitter side.

2.2. Dust Attenuation. A joint investigation was made by the Pakistani, British, and Portuguese scientists to find out the concentration of different elements exhausted in the air by various industries in Lahore and they found the following concentration of these elements (Zn, Pb, C, and Ni) in different areas of Lahore with the help of Atomic Absorption Spectroscopy method [9]. The visibility of the atmospheric channel due to these concentrations was estimated using the visibility total suspended dust model (V-TSD Model). The mathematical equation for the V-TSD model is given below [15]:

$$C_{VTSD} = \frac{4050}{V^{1.016}} \tag{2}$$

where V is the visibility of the environment and C_{VTSD} is the total suspended dust concentration in μg/m^3. The graphical representation of the V-TSD concentration model is shown in Figure 4 [13]:

1523 μg/m^3 is the highest concentration of suspended aerosol particles found in the area of the city railway station. The estimated optical attenuation due to total suspended dust particles is given in Table 2. The dust model used to estimate dust concentration is as under [29]:

$$\alpha = 52 \times V^{-1.05}\,\mathrm{dB/km}, \tag{3}$$

where V is the visibility in km and α is attenuation. This attenuation model is valid for the wavelength of 1550 nm and it is mostly used to estimate dust attenuation for FSO communication systems.

The invisible beams of FSO communication transmitted in the environmental channel suffer from scattering and absorption phenomena because of element concentration

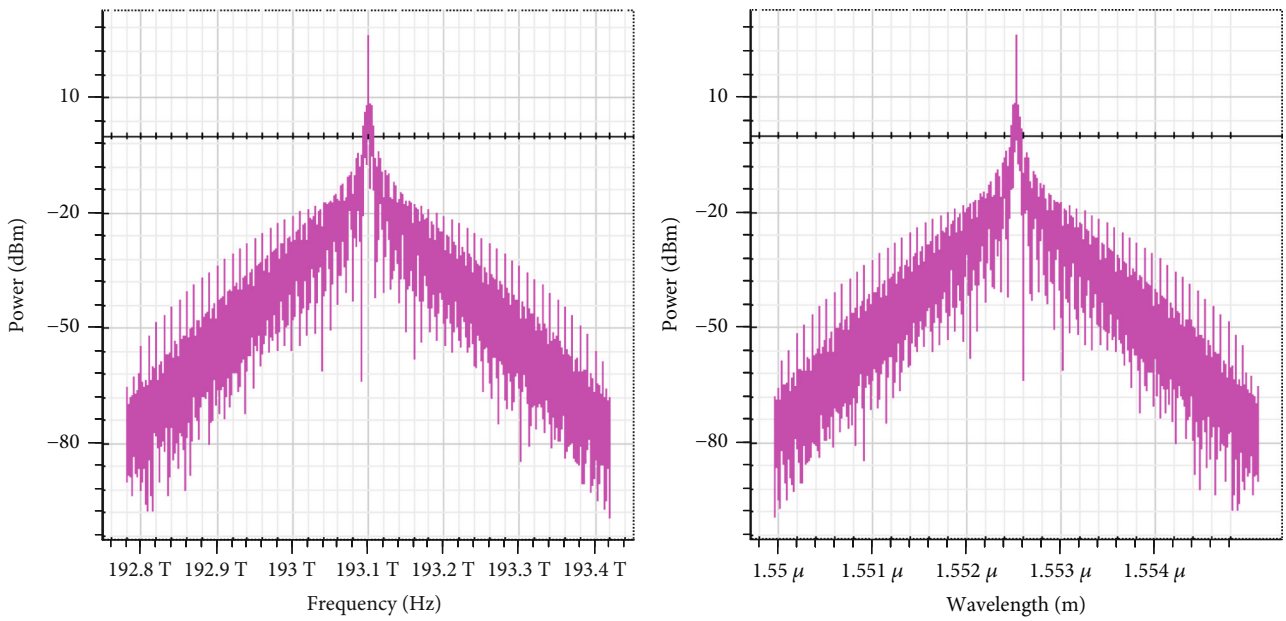


Figure 7: Optical spectrum of combined dual-beam FSO communication system on receiver side.

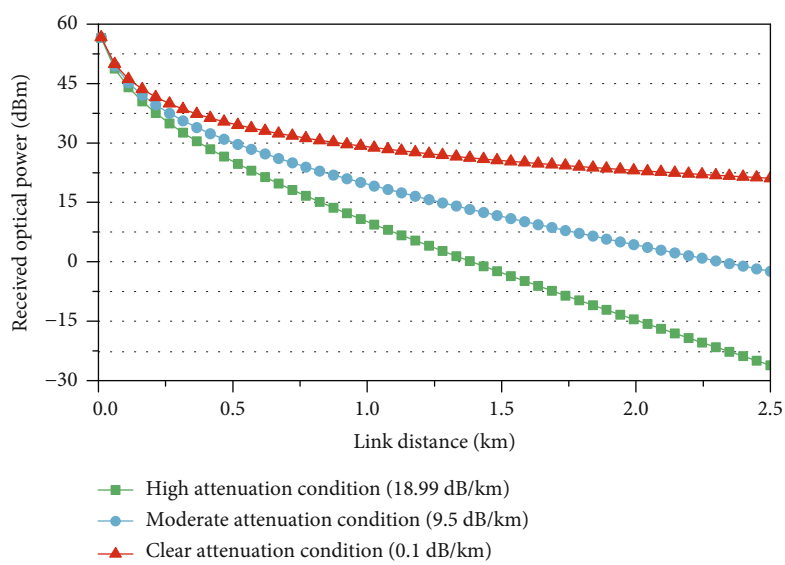


Figure 8: Illustration of received optical power and link distance correlation.

and total suspended dust, smog, fog, smoke, mist, haze, and rain droplets in the airfield. In the FSO communication system, a correlation between transmitted and received power for a link distance of L is described by Beer LambertâĂŹs [27]:

$$\tau(\lambda, L) = \frac{P_R}{P_T} \exp\left(\gamma(\lambda, L)\right), \tag{4}$$

where $\tau(\lambda, L)$ is transmittance of optical beam, $\gamma(\lambda)$ attenuation coefficient m^{-1}, P_R is received power of the optical signal, and P_T is the optical power of transmitter. The attenuation coefficient $(\gamma(\lambda)$ is the sum of absorption and scattering can be estimated as [30]:

$$\gamma(\lambda) = \gamma_m(L) + \gamma_a(L) + \beta_m(L) + \beta_a(L), \tag{5}$$

where $\gamma_m(L)$ and $\beta_m(L)$ are molecular absorption and scattering coefficients and $\gamma_a(L)$ and $\beta_a(L)$ are aerosol absorption and scattering coefficients, respectively. The link budget equation can be written as [31]:

$$P_R = P_T \times \frac{D_R^2}{\left(D_T + (\theta \times L)^2\right)} \times 10^{-\alpha L/10}, \tag{6}$$

where $D_R(\mathrm{m})$ is receiver aperture, $D_T(\mathrm{m})$ is diameter of transmitter aperture, $\alpha(\mathrm{dB/km})$ is attenuation, and $\theta(\mathrm{mrad})$ is

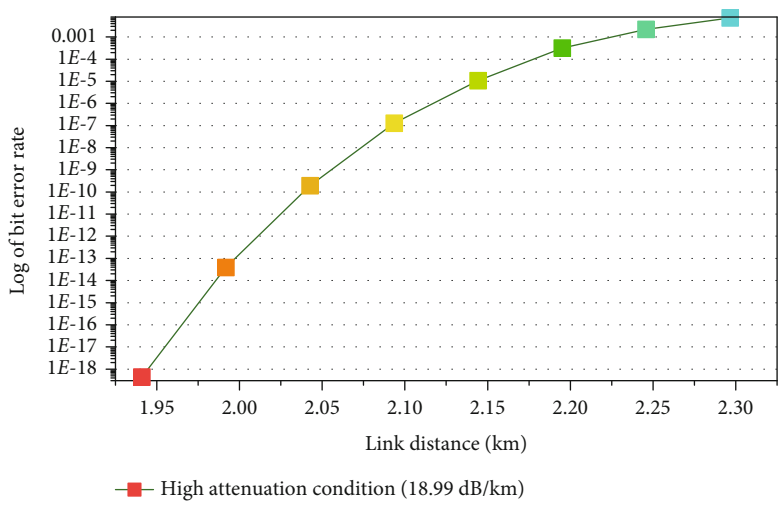


Figure 9: Illustration of BER and link distance correlation.

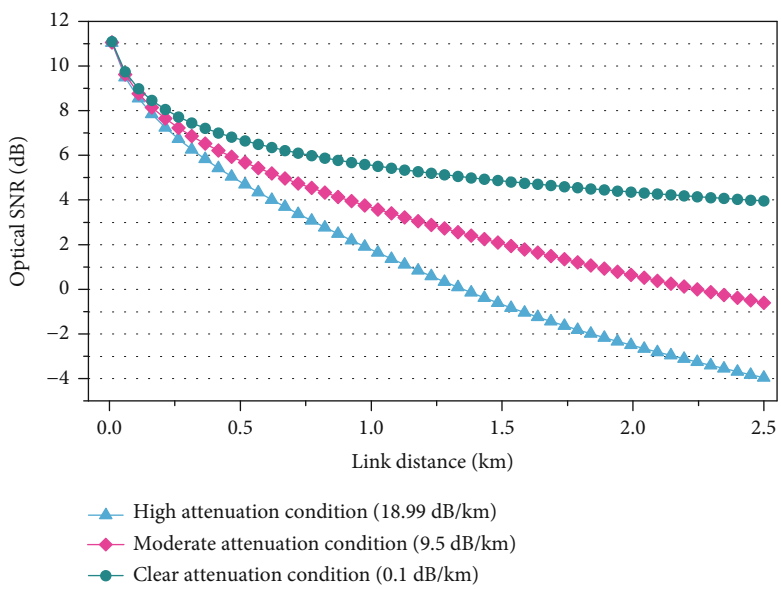


Figure 10: Illustration of OSNR and link distance correlation in clear, moderate, and high attenuation conditions.

divergence angle. The maximum attenuation due to rain and total suspended dust particles are 14.19 dB/km and 18.99 dB/km given in Tables 2 and 3. In this paper, analyses are performed under the following attenuation considerations, under clear sky condition, moderate, and higher attenuation at 0.1 dB/km, 9.5 dB/km, and 18.99 dB/km.

3. Design and Simulation of Dual-Beam FSO Link

In FSO communication, it is valuable to know what happened with a signal when transmitted through the environmental layer under various degrading factors, especially under rain and dust conditions. Under clear sky conditions, optical signal realistically receives optical attenuation as function path loss realistically; there is always a loss of signal power in the environmental channel. Optisys software was used to simulate the dual-beam FSO communication system consisting of a transmitter, an environmental channel for dual-beam signal propagation, and receivers to analyze channel impulse response under various estimated values of rain rate and dust attenuation. A dual-beam FSO system outlined and simulated as shown in Figure 4 for study and analysis under the expected impact of attenuation on three R's (range, rate, and reliability) of the FSO link in Lahore, Pakistan. In this article, a dual-beam FSO communication system simulated for a 10 Gbps data rate using two separate beams for link distance up to 2.5 km. A pseudorandom bit sequence (PRBS) generator is used to generate sequences of bits in the optical transmitter. A nonreturn zero (NRZ)

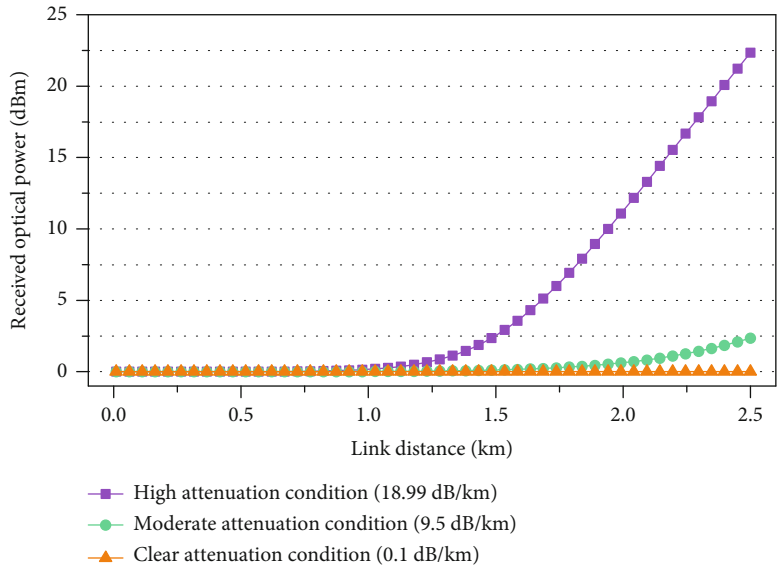


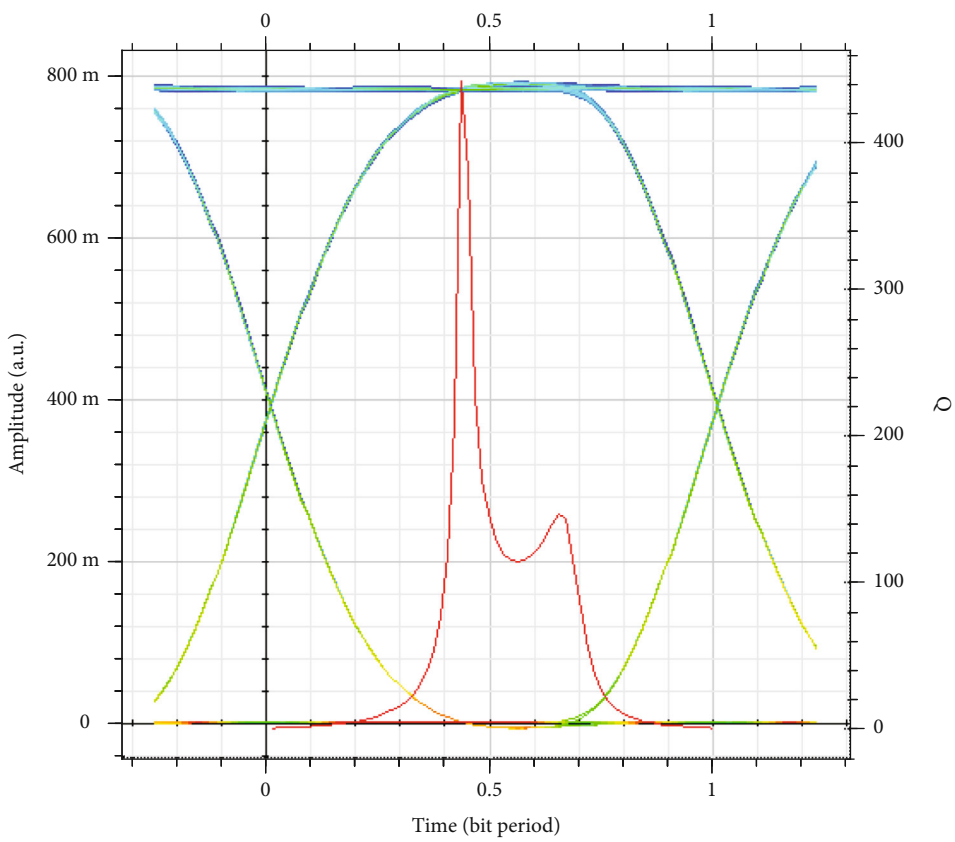
Figure 11: Illustration of noise power distribution throughout FSO channel.

generator is used to generate current pulses according to generate a sequence of 0's (off bits) and 1's (on bits) to modulate binary information in the form of current. CW laser is used for an optical source with a frequency of 193.1 THz at 30 dBm transmitter power. The scattering effect will fade the signal on the receiver side, so while designing an optical transmitter, it is also important to select a suitable size of divergence angle, a diameter of the transmitter, and receiver apertures so that geometrical losses can be reduced [23]. The geometrical design parameters of FSO channels are 1.5 mrad divergence angle and 5 cm and 20 cm diameters of transmitter and receiver apertures. NRZ pulses from the pulse generator and optical beam of CW laser are modulated by the Mach-Zehnder. The intensity-modulated signal is split by a power splitter into two FSO channels that have an optical amplifier of 20 dB gain and a figure noise of 4 dB. The optical transmitter uses the wavelength of 1552.5 nm for both optical beams for transmission of the optical signals. The FSO channel beams are combined with the power combiner at the receiver side with internal interferences. An avalanche photodetector (APD) receives an optical signal and is transduced into an electrical signal. On the receiver side, APD has response of 1 A/W with a gain of 3 dB followed by a low pass Bessel filter (LPBF) with a cut-off frequency of 0.8-bit rate that is utilized to annulled high-frequency contents of the electrical signal The geometrical design parameters of FSO channels are 1.5 mrad divergence angle and 5 cm and 20 cm diameters of transmitter and receiver apertures. NRZ pulses from the pulse generator and optical beam of CW laser are modulated by the Mach-Zehnder. The intensity-modulated signal is split by a power splitter into two FSO channels that have an optical amplifier of 20 dB gain and a figure noise of 4 dB. The optical transmitter uses the wavelength of 1552.5 nm for both optical beams for transmission of the optical signals. The FSO channel beams are combined with the power combiner at the receiver side with internal interferences. An avalanche photo detector (APD) receives an optical signal and is transduced into an electrical signal. On the receiver side, APD has response of 1 A/W with a gain of 3 dB followed by a low pass Bessel filter (LPBF) with a cut-off frequency of 0.8-bit rate that utilized to annulled high-frequency contents of the electrical signal [32]. The 3R generator is used to reproduce the original bit sequence and to generate an electrical signal from the received signal. The quality of the received signal is analyzed using BER and an Eye diagram analyzer. The optical receiver reproduces the original data signal encoded in the optical carrier. The RF-spectrum analyzer was used to find the frequency response of CW laser and signal power in the frequency domain.

An optical spectrum analyzer is used to measure the optical frequency, wavelength, and signal strength on the transmitter and receiver sides. The received power is analyzed to observe the values of signal and noise power. To enhance the quality and reliability of the FSO communication system, an optical signal beam is split into a dual-beam with a power splitter and combined at the receiver side with a power combiner. The simulation block diagram of the system is shown in Figure 5.

4. Results and Discussion

A dual-beam FSO communication system performance is studied and analyzed under the rain and suspended dust concentrations in the airfield of Lahore, Pakistan. The performance of the optical communication system is simulated and evaluated under various attenuation (clear 0.1 dB/km, moderate 9.5 dB/km, and high attenuation 18.99 dB/km) conditions. Figure 6 shows the optical spectrums of both transmission channels with the same maximum and minimum amplitudes of 27.23 dBm and -106.059 dBm.



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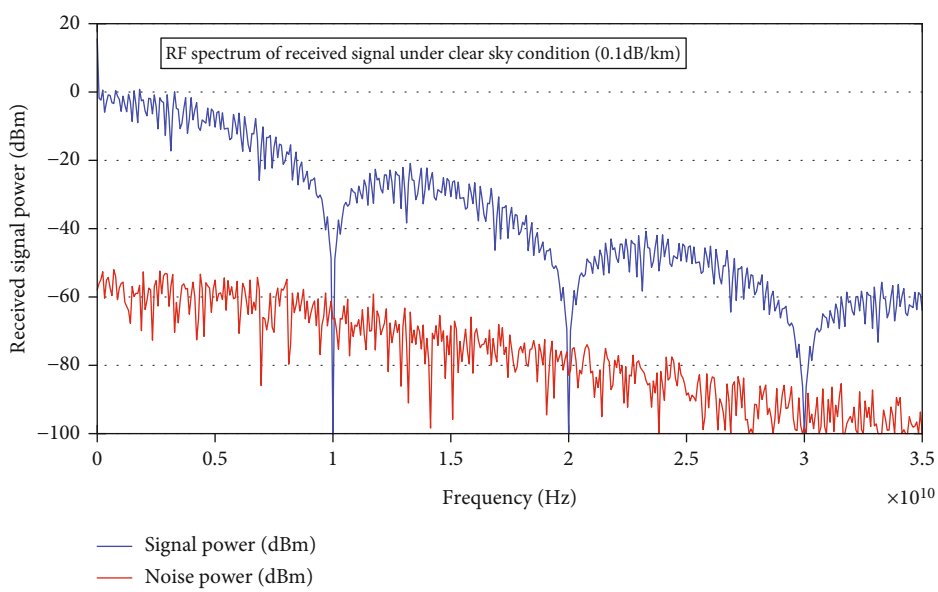


(b)

Figure 12: (a) Eye diagram under clear sky condition. (b) Signal power and noise power spectrum under clear sky condition.

CW laser Beam propagated through atmospheric attenuation of 18.99 dB/km for a link distance of 2.5 km and combined using a power combiner. The optical spectrum of both independent FSO channels illustrated in Figure 7 has maximum and minimum signal power amplitudes of -27.15 dBm and -103.5 dBm. The centralized frequency of 193.1 THz remains the same as the received power signal varies due to atmospheric attenuation.

It is observed that path loss increases with the increase in link distance between optical transmitters and receivers. This path loss due to optical attenuation limits the received optical power at the receiver side. There is a sturdy relationship

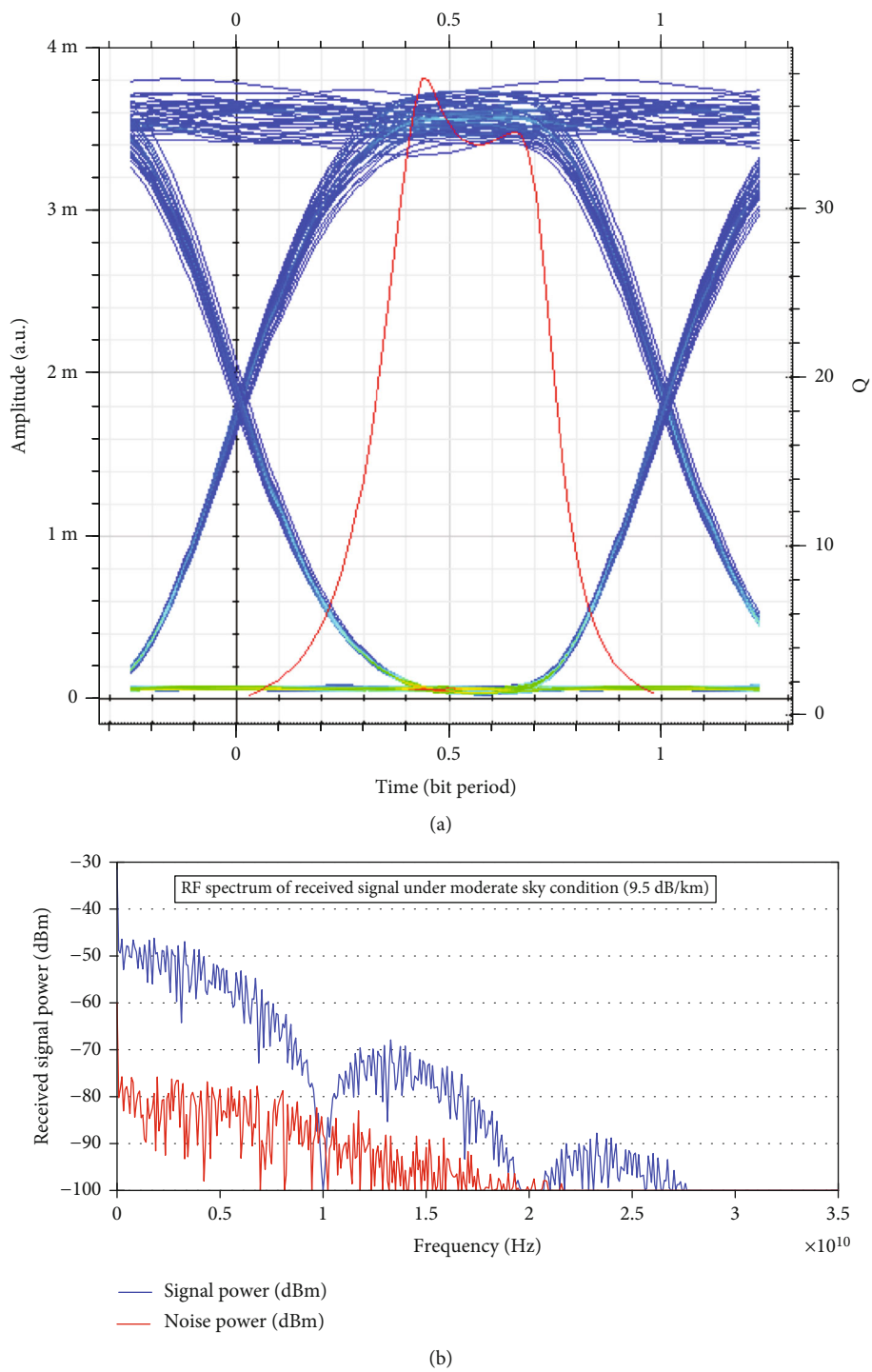
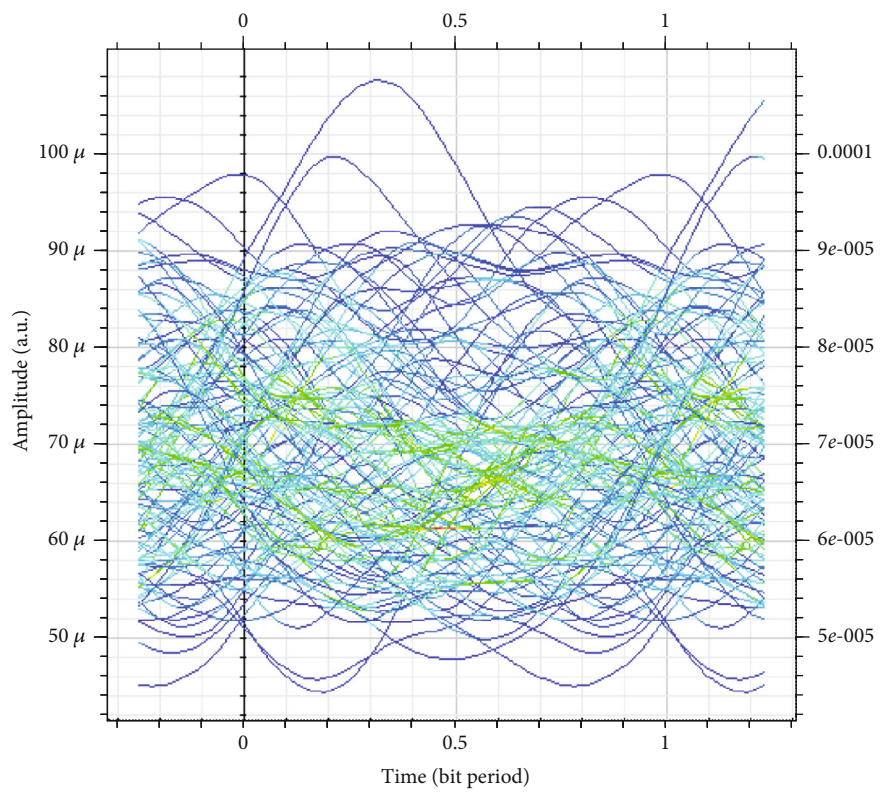


Figure 13: (a) Eye diagram under moderate sky condition. (b) Signal power and noise power spectrum under moderate condition.

between transmitter power and link distance [33]. This relationship between link distance (km) and received optical power is simulated under clear (0.1 dB/km), moderate (9.5 dB/km), and high attenuation (18.99 dB/km) conditions illustrated in Figure 8. It is observed that the reduction of received optical power was significant under high attenuation conditions, reducing the link margin for the 10Gbps communication rate for a link distance of 2.5 km. Data statistics are for 2.5 km link distance under clear, moderate, and high attenuation conditions, and minimum received powers are 21.1 dBm, -2.404 dBm, and -26.15 dBm. Under clear and moderate attenuation conditions, range, data rate, and reliability are not affected. But under high attenuations, FSO communication system performance is tainted and become unreliable.

Figure 9 illustrates a relationship between log BER and link distance under various attenuation conditions (clear, moderate, and high attenuation). For a reliable communication link, the BER rate must not be greater than the value of



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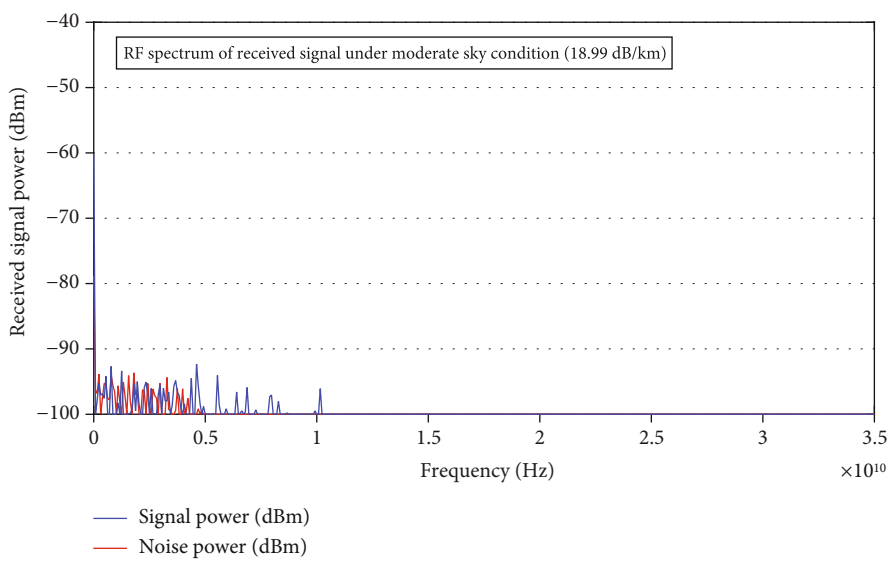
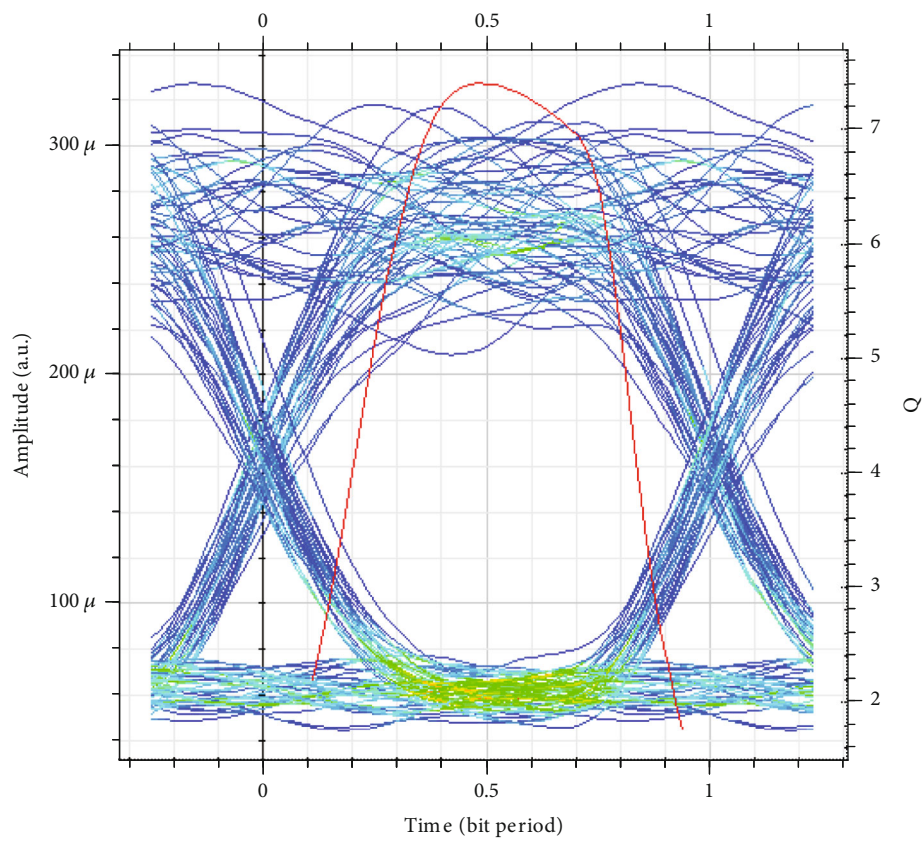


(b)

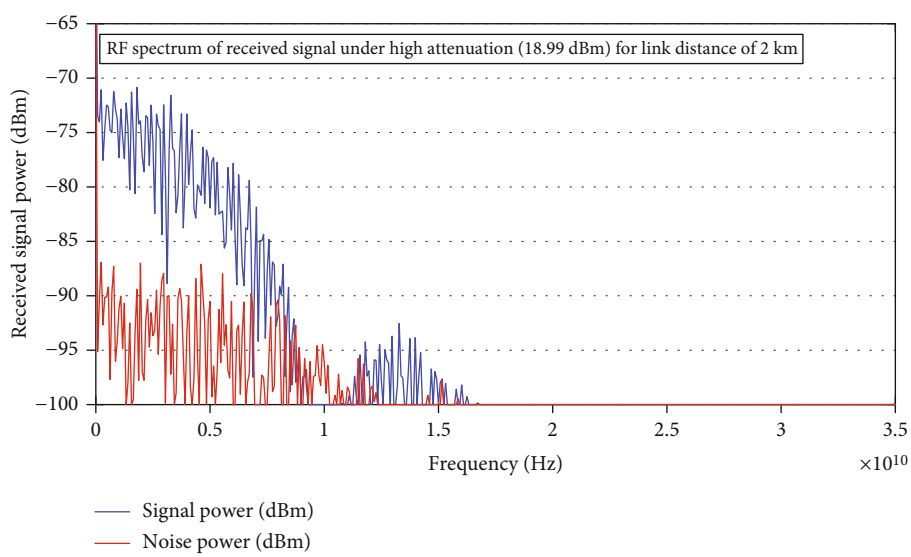
Figure 14: (a) Eye diagram under higher attenuation condition (b) Signal power and noise power spectrum under higher attenuation condition.

Table 4: Data statistics of dual-beam FSO channel for link distance of 2.5 km at 193.1THz.

Attenuation (dB/km)	Received optical power (dBm)	Quality of signal (min)	Bit error rate (max)	OSNR (dB) Minimum	RF_C (Hz) Maximum
Clear sky (0.1 dB/km)	21.1	415	Low (0)	3.96	$3.199x10^{11}$
Moderate attenuation (9.5 dB/km)	-2.404	40.7	$8.81x10^{-304}$	-0.6145	$3.199x10^{11}$
High attenuation (18.99 dB/km)	-21.15	0	High (1)	-3.96	$3.199x10^{11}$



(a)



(b)

Figure 15: (a) Eye diagram under higher attenuation condition for 2 km link distance. (b) Signal power and noise power spectrum under higher attenuation condition for 2 km link distance.

Table 5: Data statistics of dual-beam FSO channel for link distance of 2 km at 193.1 THz.

Attenuation (dB/km)	Received optical power (dBm)	Quality of signal (minimum)	Bit error rate (maximum)	OSNR(dB) Minimum	RF_C (Hz) Maximum	Signal power (dBm)	Noise power (dBm)
High attenuation (18.99 dB/km)	-14.86	7.86	2.609×10^{-15}	-0.512	3.199×10^{11}	-56.06	-60.15

$1x10^{-9}$ is considered ideal [34]. It has been observed in this study that BER and link distance are proportional to each other, as illustrated in Figure 9. Under clear and moderate attenuation conditions, the communication link remained reliable for up to a link distance of 2.5 km with zero and $8.81x10^{-304}$, respectively. For under higher attenuation of 18.99 dB/km, BER is very high and has limited the reliability of the communication link.

The Q-factor is another performance evaluation parameter for the FSO communication system. A reliable optical communication link depends on BER and Q-factor, which are contrariwise with each other. Q-factor decreases with an increase in link distance. Q-factor of dual-beam FSO communication link is reliable under clear and moderate attenuation conditions for 2.5 km link distance with minimum values of approximately 464 and 42.89. This system becomes unreliable under high attenuation conditions for link distance up to 2.5 km with a minimum Q-factor of zero. OSNR is another performance monitoring parameter considered for the evaluation reliability of an optical communication system. The OSNR and BER are inversely proportional to each other so that a good and reliable FSO communication link has higher OSNR, higher Q-factor, and lower BER. A comparison of OSNR and link distance at different attenuations is illustrated in Figure 10. Under a clear sky and moderate attenuation conditions, a dual-beam FSO communication design is suitable for up to 2.5 km link with minimum values of 3.96 and -0.6145 but, under higher attenuation, OSNR reduces to -3.962 dB. As link distance increases, OSNR decreases due to the noise lumped in the optical communication link.

This noise is an unwanted, undesired signal produced due to electronic signal processing in optical communication devices, lightning in the environmental channel, and background noises. These noise sources also corrupt the channel estimations [35]. In this simulation, the CW laser has noise dynamics of 3 dB and optical amplifiers with 4 dB noise figures for each FSO channel. Such thermal noise reduces the OSNR of the FSO communication system. Figure 11 illustrates the log noise correlation ship with link distance. Noise signal increases with an increase in link distance under different attenuations. In clear and moderate attenuation conditions, the maximum value of log noise is 0.01403 dBm and 2.367 dBm, and under higher attenuation conditions value of log, noise power is 22.35 dBm.

The quality of the received signal is observed through performance evaluating factors Q-factor, OSNR, BER signal, and noise power of the dual-beam FSO communication system. Figures 12–14 illustrate performance under clear, moderate, and higher attenuation conditions. The eye diagram analyzer and BER analyzer were used to evaluate the quality of the received signal. The bit pattern under clear sky conditions with signal power and noise power is illustrated in Figure 12. It is observed that the pattern of the bits is very compact and tells a good quality of the signal at maximum radio frequency (RF) $3.199x10^{11}$ Hz with a very high Q-factor of 415 and zero BER mentioned in Table 3, whereas the received signal and noise observed by using an RF-spectrum analyzer are 15.58 dBm and -52 dBm given in Table 3. The attenuation has degraded the communication system performance so received power is reduced to -31.42 dBm with noise power of -60 dBm. If atmospheric attenuation increases, the performance of the system decreases. Figure 13 illustrates the performance of the system under a moderate attenuation condition. The pattern of the transmitted bits looks scattered due to moderate attenuation conditions with a de-shaped eye diagram. The Q-factor reduces to 40.7 with a BER of $8.81x10^{-304}$ n in Table 4.

Under higher attenuation conditions, the reliability of this communication system is badly affected as illustrated in Figure 14. The received optical power reduced to -21.15 dBm also reduces Q-factor to zero (0) and increases BER to high (1) as given in Table 4. The eye diagram shows a highly scattered bits pattern. This system under higher attenuation is no more reliable for a data rate of 10 Gbps. The effect of reducing received power can observe from the received power of -78.8 dBm with noise power of -60.18 dBm. It is observed that the communication system for a data rate of 10 Gbps is not reliable for this range or link distance (2.5 km).

The dual-beam FSO system data statistics show that under higher attenuation conditions, 10 Gbps data can be transmitted successfully with reliability up to a 2 km link distance with a Q-factor of 7.86 as illustrated in Figure 15.

The performance evaluating factors OSNR and BER are 0.512 dB and $2.609x10^{-15}$, with reasonable and acceptable received signal power of -56.06 dBm and noise power of -60.15 dBm and bit pattern as given in Table 5.

5. Conclusions

In this paper, the authors analyzed and proposed a dual-beam FSO communication system. The performance of the dual-beam FSO system has been studied and examined under the rain and suspended dust concentration attenuation conditions. The performance of the dual-beam FSO communication link has a degrading impact under rainy and dusty environmental conditions. More the rain rate offers high optical attenuation by absorption and scattering the transmitted signal. Similarly, higher values of the dust or aerosol particles definitely have higher absorption and scattering effect. A reliable, higher data rate (10 Gbps) communication link can be maintained for attenuation value up to 9.5 dB/km for a link distance of 2.5 km transmitted power (30 dBm) with a Q-factor of 40.7 with zero (0) BER. The higher attenuation reduces the reliability by affecting the link distance between the optical transmitter and receiver. It is observed that a reliable and efficient dual-beam FSO communication link can be implemented for up to 2 km with a data rate of 10 Gbps for Lahore airfield under attenuation of 18.99 dB/km with a Q-factor of 7.86 and BER of $2.609x10^{-15}$ but higher attenuation can degrade the performance of a dual-beam FSO communication link by increases BER, reduces Q-factor and OSNR, and making the system unreliable. This research will be helpful in designing a high-speed data metropolitan FSO communication network to interconnect different institutions, colleges, and universities in the future.

Data Availability

The simulation data used to support the findings of this study are available from the corresponding author upon request.

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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