Performance Investigation of OFDM-FSO System under Diverse Weather Conditions of Bangladesh

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ABSTRACT

Free space optical (FSO) communication systems which are deployed for last mile access, being considered as a suitable alternative technology for optical fiber networks. It is one of the emerging technologies for broadband wireless connectivity which has also been receiving growing attention due to high data rate transmission capability with low installation cost and license free spectrum. However, the widespread use of FSO technology has been hampered by the randomly time varying characteristics of propagation path mainly due to atmospheric turbulence, sensitivity to diverse weather conditions and the nonlinear responsivity of laser diode. This paper presents the performance investigation of an OFDM-FSO system over atmospheric turbulence channels under diverse weather conditions of Bangladesh. The channel is modeled with gamma-gamma distribution using 16-QAM modulation format and 4×4 multiple transceiver FSO system. All possible challenges are imposed on the system performance such as atmospheric attenuation, turbulence, pointing error, geometric loss etc. The refractive index structure parameter and atmospheric attenuation coefficient for different weather conditions are calculated by using the data, collected from Bangladesh Meteorological Department. The acquired results can be fruitful for scheming, forecasting and assessing the OFDM-FSO system's ability to transmit wireless services over turbulent FSO links under actual conditions of Bangladesh.

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1. INTRODUCTION

The ever increasing bandwidth demand calls for the tremendous growth and progress in information and communication technologies. Radio frequency has been being utilized for several decades but there are a set of barriers to their further expansion due to spectrum congestion, licensing issues, interference from unlicensed bands, low bit rate and multipath fading. Therefore, the research focus is towards exploiting optics to address the challenges of increasing bandwidth demand. Although fiber networks offer huge bandwidth and core network is relying mostly on it, still challenges of deploying optical fiber is not feasible in some remote and in rural areas, thus those places lack broadband network connectivity. In this scenario, terrestrial FSO technology appears to be a promising solution for the last mile network.

Free space optical (FSO) communication has achieved significant importance as a consequence of its unique features such as huge bandwidth, license free spectrum, narrow beam divergence, easy and quick deployment ability and low power requirement [1]. Moreover, it provides high speed connection up to Gbps, which is far more beyond the alternative systems. It has increasingly attracted attention for a number of applications such as last mile access, back-haul for wireless cellular networks, metro network extensions, military, disaster recovery, enterprise connectivity and many more. However, despite of great potential of FSO communication, its performance is limited by the unfavorable regional climatic conditions like rain, cloud, fog, haze, pollution etc. The strength of transmitted optical signal gets attenuated significantly due to absorption and scattering. Also random fluctuations in the irradiance of the received optical laser beam caused by atmospheric turbulence may lead to serious degradation in BER performance and make the communication link infeasible [2].

Orthogonal Frequency Division Multiplexing (OFDM) system has received considerable attention due to its high data rates and immunity to frequency selective multipath fading transmission technique for wireless communications, along with high spectrum efficiency. Hence, this technique is being imposed in many new broadband communication schemes, such as WLAN, DVB-T2, and WMAN 802.16m [3]. It also allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments [4]. The analysis of BER performance suggested that OFDM is better than CDMA which has been incorporated in most existing 3G systems [5].

In this paper, we present the analysis of an OFDM-FSO link over atmospheric turbulent channel considering the impact of the diverse weather conditions of Bangladesh. Higher order modulation technique such as 16-QAM is used to utilize the bandwidth of OFDM-FSO link system efficiently. The analytical transmission error performance of OFDM-FSO system is observed over moderate atmospheric turbulence by varying bit rate and link distance under different weather conditions of Bangladesh. The atmospheric attenuation coefficient for different weather conditions and refractive index structure parameter are calculated by using the data, collected from Bangladesh Meteorological Department. Gamma-Gamma distribution is used to describe the turbulent-induced fading which covers the weak to strong turbulence regimes [6]. The effect of TX/RX aperture area upon the FSO system performance along with the comparison between single and multiple (4×4) aperture systems are also shown. This analysis will be very useful to scheme, predict and assess the performance of OFDM-FSO system under real weather conditions of Bangladesh and other places having similar subtropical monsoon climate.

2. SYSTEM AND CHANNEL MODELING

Figure 1 shows the basic configuration of OFDM-FSO system. In OFDM-FSO transmission system, QAM modulated RF signal is first converted into optical signal by the use of laser diode and then transmitted through the turbulent atmosphere by using FSO antenna. At the receiver end, the optical signal is received by FSO antenna and it is converted into RF signal using photo detector. In this transmission system, higher order modulation with less design complexity is used to transmit and receive the optical signals.

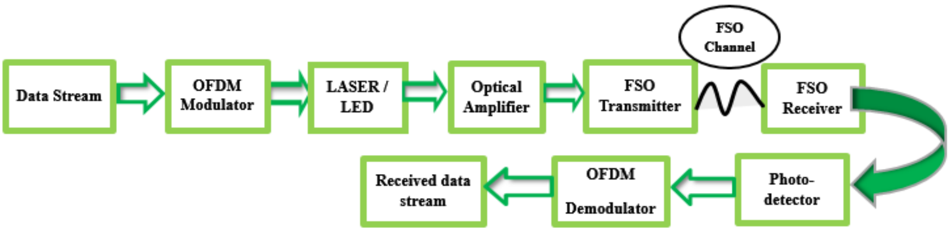

Figure 1. Basic architecture of OFDM-FSO system

2.1. OFDM signal transmission and receiption over FSO link

The basic concept behind OFDM technology is the division of a wideband frequency selective channel into multiple narrow band flat fading sub-channels in which the data bits can be transmitted in parallel through a large number of orthogonal subcarriers where the bandwidth of each subcarrier is much less than the channel coherence bandwidth [7].

Figure 2 shows the transceiver architecture of OFDM [8]. The input data is a serial stream of coded symbols. Serial to parallel converter converts the input serial data stream into a parallel stream of OFDM symbols. Higher order modulation such as 16-QAM is used as a mapping technique because it leads to increased spectral efficiency. After mapping the spectrum, an IFFT is used to find the corresponding time waveform. Training and Pilot symbols are also sent along with the transmitted data which helps in channel estimation. Cyclic prefix is also added at the starting of each symbol in order to avoid inter symbol interference and inter carrier interference [9]-[11]. Cubic interpolation techniques have been used to function as the digital to analog (DAC) converter. After the DAC, the parallel data is shifted back into the serial symbol stream. Later, this RF-OFDM signal is converted into an optical signal by using laser diode and transmitted through free space atmospheric channel.

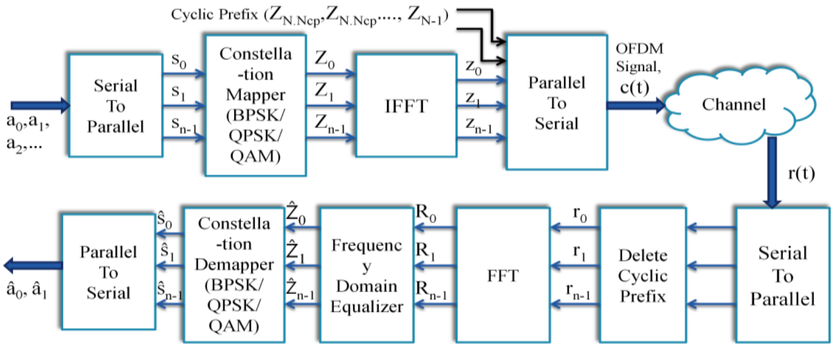

Figure 2. Transmitter and Receiver architecture of OFDM

The optical signal is received through FSO receiver and all reverse operations are carried out at the receiver side. With the help of photodetector optical signal is converted into RF electrical signal. The signal is sampled with analog to digital converter and guard retrieval is used for removal of guard bands. A single tap equalizer is applied to the subcarriers data to compensate for channel distortions. Fast Fourier Transform (FFT) is used to convert the signal back into the frequency domain. Finally, QAM decoder is used for demapping the symbols which are then converted from parallel to serial so that the further investigations can be carried out in terms of Bit Error Rate (BER) [12].

2.2. FSO channel characteristics

Free Space Optics (FSO) refers to the technology where modulated infrared or visible beams are transmitted through the air or atmosphere to obtain broadband communications. It consists of three subsystems: transmitter telescope, free space channel and receiver telescope [13]. The main objective of FSO is to receive a stronger signal that would result in higher link margin and greater link availability.

To evaluate the performance of FSO system, parameters are classified into two categories: Internal parameters and External parameters. Internal parameters are the system-specific design parameters such as: transmitter power, wavelength, transmitter and receiver aperture diameter, receiver sensitivity, beam divergence, transmitter and receiver losses. External parameters are the non-system-specific parameters (which can't be influenced by the designer) and deals with the climatology of the installation site, scintillation, atmospheric attenuation, window loss and pointing errors etc. [13].

The FSO link equation is given by Equation (1) [14]:

$$P_{received} = P_{transmitted} \frac{d_R^2}{(d_T + \vartheta D)^2} 10^{-\tau\frac{D}{10}} \quad (1)$$

Where, d_T and d_R are the transmitter and receiver aperture diameter respectively in m, ϑ is the beam divergence in mrad, D is the distance between optical transmitter and receiver in km and τ is the atmospheric attenuation coefficient (dB/km).

The geometric losses occur due to the spreading of the transmitted beam between the transmitter and receiver and can be approximated with the following formula [14]:

$$G_L\,(dB) = 20 \log \left[\frac{d_R}{d_T + \vartheta D}\right] \quad (2)$$

3. IMPACT OF ATMOSPHERE ON FSO SYSTEM IN PERSPECTIVE OF BANGLADESH

The performance of FSO system is primarily dependent upon the climatology and the physical characteristics of its installation location. The primary factors affecting system performance include atmospheric attenuation causing scattering and absorption and atmospheric turbulence causing scintillation.

3.1. Atmospheric attenuation

Atmospheric attenuation which degrades signal quality in a FSO system link, is generally dependent upon fog, low clouds, rain, dust, snow and various combinations of each. Fog typically dominates the signal aggravation. The several ways of signal degradation and attenuation by atmosphere includes absorption, scattering and scintillation. Being dependent on the local conditions and weather, all these effects vary with time. Atmospheric attenuation is given by the Beer's law [15] which is as follows:

$$\tau = exp^{-\beta D} \tag{3}$$

Where, τ is the atmospheric attenuation; D is the distance between transmitter and receiver (km); β is the total attenuation coefficient and given as:

$$\beta = \beta_{absorp}\beta_{scattering} \tag{4}$$

Here, β_{absorp} is the molecular and aerosol absorption. The value of this parameter is considered as too small, so we can neglect it. $\beta_{scattering}$ is the molecular and aerosol scattering and it has a greater effect than absorption [15].

Scattering can be classified into three types: (a) Rayleigh scattering, (b) Mie scattering and (c) Non-selective scattering. Rayleigh scattering is negligible in the infrared waveband. Mie scattering occurs when the particles causing the scattering are equal to or larger than the wavelengths of radiation and it is the dominant scattering process in terrestrial FSO system. Non-selective scattering dominates when atmospheric particle size is much larger than the incoming radiation wavelength [16].

3.1.1. Rain

As the radius of raindrops (100–1000 μm) is significantly larger than the wavelength of typical FSO systems, so scattering due to rainfall is called non-selective scattering. The rain scattering coefficient can be calculated using Stroke Law as shown in Equation (5) [17]:

$$\beta_{rain\ scatt} = \pi r^2 N_r Q_{scat}(\frac{r}{\lambda}) \tag{5}$$

Here, r is the radius of raindrop in cm, N_r is the rain drop distribution in cm^{-3} and Q_{scat} is the scattering efficiency. The raindrop distribution N_r can be calculated by using the following equation [17]:

$$N_r = \frac{R}{1.33(\pi r^3)V_L} \tag{6}$$

Where, R is the rainfall rate (cm/sec); and V_L is the limiting speed of raindrop which is given by [17]:

$$V_L = \frac{2r^2\rho g}{9\eta} \tag{7}$$

Therefore, the rain attenuation can be calculated by using Beer's law as:

$$\tau = exp^{-\beta_{rain\ scatt}D} \tag{8}$$

Table 1. Raindrop Parameters for rain Attenuation Calculation

Parameter	Value
Gravitational Constant, g	980 cm/s^2
Viscosity of air, η	1.8×10^{-4} (g/cm)
Radius of raindrop, r	0.05 cm
Water density, ρ	1 g/cm^3
Wavelength, λ	1550 nm
Q_{scat}	2

Using the values of the raindrop parameters given in Table 1 and data collected from the Meteorological Department of Bangladesh [18], we have calculated average rainfall rate for monsoon, pre-monsoon, post-monsoon period and their attenuation (shown in Table 2) utilizing the above mentioned formulas.

Table 2. Rainfall Rate and Rain Attenuation Coefficient in Bangladesh

Type	Rainfall Rate, R (cm/sec)	Attenuation (dB/km)
Pre-Monsoon	4.7×10^{-6}	6.55
Monsoon	1.66×10^{-5}	23.12
Post-Monsoon	2.1345×10^{-6}	2.97

3.1.2. Fog

Transmitted optical beams in free space are attenuated mostly by the fog droplets which is the key contributor to optical power/irradiance attenuation. The scattering coefficient β_a due to fog can be expressed in terms of visibility and wavelength by the following expression [17]:

$$\beta_a = (\frac{3.912}{V})(\frac{\lambda}{550\ nm})^{-p} \tag{9}$$

Where, V is the visibility in km, λ is the incident laser beam wavelength in nm and p is the size distribution of the scattering particles which typically varies from 0.7 to 1.6 corresponding to visibility conditions from poor to excellent. The particle size-related coefficient is found from the Kim model shown in Table 3:

Table 3. Scattering Particle Sizes at different Visibility Range (Kim Model)

Scattering Particle size, p	Visibility Range (km)
1.6	V>50
1.3	6<V<50
0.16V + 0.34	1<V<6
V- 0.5	0.5<V<1
0	V<0.5

The visibility at different foggy weather conditions of Bangladesh are collected from Bangladesh Meteorological Department [18] and for these visibility values the attenuation coefficients are calculated using the Kim Model. Table 4 shows the visibility and the calculated signal attenuation at different foggy weather conditions of Bangladesh.

Table 4. Signal Attenuation at different Foggy Weather Conditions of Bangladesh

Weather Condition	Visibility (km)	Attenuation (dB/km)
Light Fog	0.9	12.47
Moderate Fog	0.5	33.96
Heavy Fog	0.2	84.9

3.2. Atmospheric turbulence

When signal is travelling through free space, atmospheric turbulence becomes an important factor results in random fluctuation of the refractive index along the optical propagation path. Inhomogeneity in the temperature, pressure and wind variations lead to change in the refractive index fluctuation. Atmospheric turbulence causes phase shifts of the propagating optical signals resulting in the wave front distortions and these distortions also cause intensity distortions, referred to as scintillation [19].

Refractive index structure parameter C_n^2 determines the turbulence strength and clearly depends on the geographical location, altitude and time. A number of parametric models have been formulated to describe the C_n^2 profile and a commonly used model to describe it is the Hufnagel-Valley model given as [20]:

$$C_n^2(h) = 0.0059\left(\frac{v}{27}\right)^2 (10^{-5}h)^{10} \exp\left(-\frac{h}{1000}\right) + 2.7\times10^{-16}\exp\left(-\frac{h}{1500}\right) + T_0 \exp\left(-\frac{h}{100}\right) \tag{10}$$

Where, h is the altitude in meter, v is the wind speed at high altitude in m/s and T_o is the turbulence strength at the ground level, $T_o = 1.7\times10^{-14}\ m^{-2/3}$.

The value of altitude and wind speed are collected from Bangladesh Meteorological Department [18] and using these values C_n^2 is calculated which is in between 1.15×10^{-14} to 1.7×10^{-14} $m^{-2/3}$. We consider the value of C_n^2 as 1.7×10^{-14} throughout the whole simulation.

The gamma-gamma (GG) distribution is used to describe the PDF of the irradiance fluctuations and to model atmospheric fading [20]-[22]. In this case the probability of a given intensity I_R of gamma-gamma scintillation model is [23]:

$$P(I_R) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\gamma(\alpha)\gamma(\beta)} I_R^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta I_R}\ ) \quad ; \quad I_R > 0 \tag{11}$$

Where, $\gamma(..)$ is the Gamma function, $K_{\alpha-\beta}$ (..) is the modified Bessel function of the second kind, α and β are the variances of the small and large scale eddies respectively defined as [24]:

$$\alpha = \left[\exp\left(\frac{0.49\sigma_R^2}{\left(1+1.11\sigma_R^{\frac{12}{5}}\right)^{\frac{7}{6}}}\right) - 1\right]^{-1} \tag{12}$$

$$\beta = \left[\exp\left(\frac{0.51\sigma_R^2}{\left(1+0.69\sigma_R^{\frac{12}{5}}\right)^{\frac{5}{6}}}\right) - 1\right]^{-1}$$

And the Rytov variance,

$$\sigma_R^2 = 1.23C_n^2\, k^{7/6}\, D^{11/6} \tag{13}$$

Where, k= 2π/λ is the wave number with λ being the wavelength, and D is the link distance.
Turbulence effect can be mitigated by using multiple transceivers. Multiple TX/RX combinations can raise the received power at the receiver. Thus the maximum achievable distance and BER can be improved [25]. Also, if the size of receiving aperture is larger than a spatial scale size that produces the irradiance fluctuations, the receiver will average the fluctuations over the aperture and the scintillation effect will be reduced [26].

3.3. Optical loss, window loss and pointing error

Optical loss depends on the characteristics of the equipment and lens quality. The value of this loss can be known from the component manufacturer. If FSO transceivers are installed behind windows within a building, an additional optical power loss occur due to the window glass attenuation. Coated windows show much greater attenuation than uncoated glass windows and its actual magnitude is typically wavelength dependent [14].

Pointing error is one of the key challenges faced by FSO links and additional power penalty is usually incurred due to imperfect alignment of the transmitter and receiver [14]. For shorter FSO links this might not be an issue, but for longer link distance pointing error can’t be neglected.

4. DESIGN PARAMETERS OF OFDM-FSO LINK

An OFDM-FSO system is developed in which all possible atmospheric challenges for Bangladesh is considered under moderate atmospheric turbulence. The design parameters used for observing the performance of OFDM-FSO link in Bangladesh are shown in Table 5:

Table 5. Value of the Design Parameters for Performance Analysis

Parameter Name	Value	Parameter Name	Value
Bit Rate	40 Gbps	Dark Current	10 nA
Modulation Type	16 QAM	Thermal Power	$100e^{-24}$ W/Hz
Num. of OFDM Sub-Carriers	256	Amplifier Gain	10 dB
Num. of used Sub-carriers	80	Noise Margin	4 dB

Parameter Name	Value	Parameter Name	Value
Num. of Prefix Point	50	FSO Link Length, D	0.1 km-4 km
Num. of Training Symbol	10	FSO Transmitter Aperture Diameter, d_T	0.025 m
Num. of Pilot Symbol	9	FSO Receiver Aperture Diameter, d_R	0.6 m
CW Laser Power	20 dBm	Beam Divergence, ϑ	2 mrad
Line width	0.15 MHz	Transmitter Loss	1.8 dB
Channel Wavelength	1550 nm	Receiver Loss	1.8 dB
Photodetector Type	PIN	Additional Losses	2 dB
Responsivity	1 A/W	Refractive structure Index for Moderate Turbulence, C_n^2	1.7×10^{-14} $m^{-2/3}$

5. RESULTS AND DISCUSSIONS

The simulation results are divided into the following sections: BER Vs Link distance for different weather conditions of Bangladesh under moderate atmospheric turbulence at a fixed bit rate; Performance analysis of OFDM-FSO system by varying bit rate; Impact of moderate and strong atmospheric turbulence; Effect of aperture size on FSO performance along with the comparison between single and multiple aperture system.

5.1. BER Vs Link distance for different weather conditions of Bangladesh under moderate turbulence

In this paper, BER and received power are considered as performance parameters to characterize the OFDM-FSO system performance over fading atmospheric turbulence channels and atmospheric attenuations. By varying link distance, BER is recorded for different weather conditions of Bangladesh at 40 Gbps data rate. During these simulations, all possible challenges are considered under moderate atmospheric turbulence.

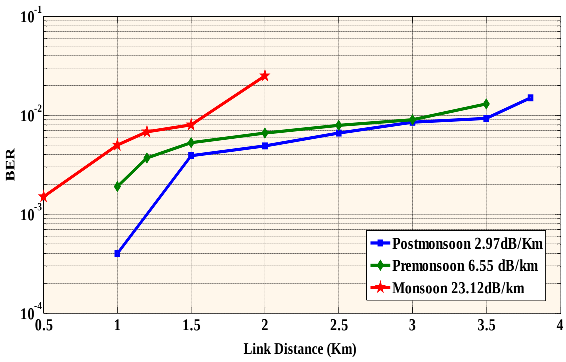

Figure 3. BER Vs Link distance at rainy weather

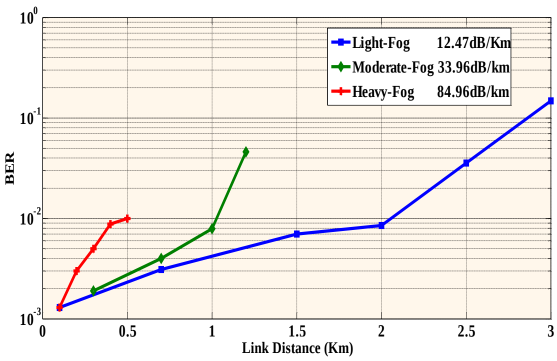

Figure 4. BER Vs Link distance at foggy weather

Figure 3 and Figure 4 depict the BER Vs link distance for rain and fog respectively showing the effect of attenuation on BER. With the increase of link distance, the transmitted signal strength gets attenuated due to different weather conditions. Consequently, the BER also degrades.

From Figure 3, we can conclude that the maximum attainable link distance during pre-monsoon, monsoon and post-monsoon periods of Bangladesh are 3 Km, 1.5 Km and 3.5 Km respectively to maintain a BER performance in the order of 10^{-3} at 40 Gbps bit rate.

Similarly from Figure 4, it can be concluded that the maximum attainable link distance during light fog, moderate fog and heavy fog conditions are 2 Km, 1 Km and 0.4 Km respectively maintaining a BER at the order of 10^{-3}. Table 6 summarizes these results. After this link margin, transmitted data gets severely attenuated with increased BER which is difficult to recover.

Table 6. Maximum Link range For Rain and Fog (from Figure 3 and Figure 4)

Weather	Attenuation (dB/Km)	Bit Rate	Link Distance (Km)	BER	$P_{Receieved}$ (dBm)
Pre-Monsoon (Moderate rain)	6.55		3	9×10^{-3}	-23.28
Monsoon (Heavy rain)	23.12	40Gbps	1.5	8×10^{-3}	-32.28
Post-Monsoon (Light Rain)	2.97		3.5	9.3×10^{-3}	-15.30
Light Fog	12.47	40Gbps	2	8.5×10^{-3}	-25.043

Weather	Attenuation (dB/Km)	Bit Rate	Link Distance (Km)	BER	$P_{Receieved}$ (dBm)
Moderate Fog	33.96		1	7.9×10^{-3}	-28.096
Heavy Fog	84.9		0.4	8.8×10^{-3}	-20.303

5.2. BER vs bit rate for different weather conditions of Bangladesh under moderate turbulence

Figure 5 shows the BER performance of OFDM-FSO transmission system as a function of bit rate for heavy rain and moderate fog under moderate atmospheric turbulence. It is clear that the performance starts to degrade with the increase of bit rate. Also it can be seen that at the range of 1 Km, 45 Gbps can be sent at a BER of 7×10^{-3} during heavy rain whereas 43 Gbps can be sent at a similar BER under moderate fog but within the range of 0.7Km. Beyond this bit rate, transmitted signal gets attenuated with a BER greater than 10^{-3}.

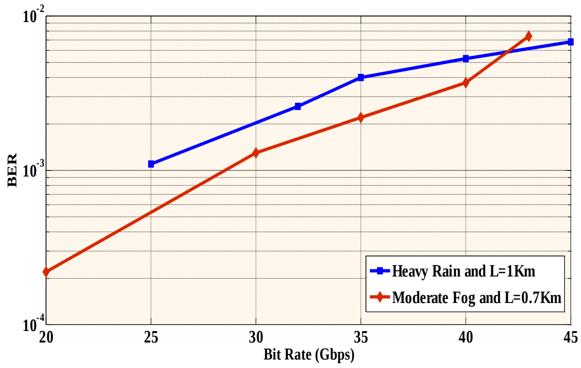

Figure 5. BER vs bit rate for heavy rain and moderate fog

5.3. Impact of moderate and strong atmospheric turbulence

The FSO link performance is affected by the scintillation due to different types of atmospheric turbulence. Table 7 illustrates the effect of moderate and strong turbulence on OFDM-FSO system performance under heavy rain and moderate fog weather conditions of Bangladesh. It is seen that the effect of turbulence deteriorates the link performance. For moderate turbulence, BER remains in the order of 10^{-3} whereas it becomes 10^{-2} under the influence of strong turbulence. Therefore, if we want to keep the BER of strong turbulence in the order of 10^{-3}, we have to compromise the data rate and/or link distance.

Table 7. Effect of Turbulence on OFDM-FSO Performance

Turbulence Type, C_n^2	Attenuation (dB/km)	Link Distance (Km)	BER
Moderate ($1.7e^{-14}m^{-2/3}$)	23.12 (Heavy rain)	1.5	8.0×10^{-3}
	33.96 (Moderate Fog)	1	7.9×10^{-3}
Strong ($4.58e^{-13}m^{-2/3}$)	23.12 (Heavy rain)	1.5	3.3×10^{-2}
	33.96 (Moderate Fog)	1	3.0×10^{-2}

5.4. Effect of aperture size variation on OFDM-FSO performance along with comparison between single and multiple aperture systems

In this section, different TX/RX aperture diameter values are used for the analysis of system performance considering all possible losses under moderate turbulence. Table 8 shows that the BER is minimum when d_T=2.5 cm and d_R=60 cm with 20 dBm power at 40 Gbps data rate and 0.7 km link range in moderate foggy weather.

From Table 8, it can be said that the larger the receiver aperture area, the smaller the Bit Error Rate. It also elicits that there is a huge BER improvement while using 4×4 aperture system compared to the corresponding single aperture system.

Table 8. BER Performance of Single and 4×4 Multiple Aperture System

Type	d_T (cm)	d_R (cm)	BER
4×4 Multiple Beam	2.5	25	3.3×10^{-2}
	2.5	40	1.0×10^{-2}
	2.5	60	4.4×10^{-3}
	5	25	5.0×10^{-2}
	5	40	1.1×10^{-2}
	5	60	7.0×10^{-3}
	8	25	4.7×10^{-2}
	8	40	1.9×10^{-2}
	8	60	9.0×10^{-3}
Single Beam	2.5	60	2.0×10^{-1}

6. CONCLUSION

This paper investigates the OFDM-FSO system performance in Gamma–Gamma fading under diverse weather conditions of Bangladesh. The data from Bangladesh Meteorological Department are used for calculating the refractive index structure parameter and atmospheric attenuation coefficient for different weather conditions. The calculated attenuation coefficient, misalignment and other losses are taken into account during this investigation considering moderate atmospheric turbulence. BER is used as performance parameter and link distance is varied from 0.1km–4km at 40 Gbps data rate to observe the system performance. The investigation provides the maximum attainable link ranges keeping a BER in the order of 10^{-3} at different weather conditions. Heavy fog is found to be the worst weather condition for OFDM-FSO system where the maximum attainable link range is found as only 0.4 km at a BER of 8.8×10^{-3}, whereas for light rain weather condition the maximum attainable link range is 3.5 km at a BER of 9.3×10^{-3}. The effect of transmitter and receiver aperture size variation on OFDM-FSO performance is also investigated, which shows that if the receiver aperture area is increased the BER is reduced. The comparison between single and multiple aperture system illustrates that there is a huge BER improvement while using 4×4 aperture system compared to the corresponding single aperture system. The outcomes of this paper would help in designing FSO links over longer distances for Bangladesh and promote the usage of this technology beyond the last mile solution in near future.

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