Terrestrial free space optical communications in bangladesh: transmission channel characterization

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Article Info	ABSTRACT
	This research work focused on transmission channel characterization of Free-Space-Optical (FSO) communications technology for deploying in the developing country like Bangladesh. To meet the tremendous amount of data traffic, mobile operators and ISPs need better solution than the existing RF and fiber optic communications. Moreover, Bangladesh is entering in the era of satellite communications by launching its own satellite. So, Bangladesh needs such communication technology that provides higher channel bandwidth, sophisticated transmission security and can cope channel dispersion. FSO is a good candidate that can meet all these features. The transmission channel characterization plays a significant role in optimizing the performance of FSO link. In this work, the channel characterization of FSO technology from the weather perspective of Bangladesh has been investigated thoroughly. The obtained results show that the atmospheric scattering effect does not hamper the short range FSO link performance, whereas, the atmospheric turbulence effect is not favorable to deploy FSO technology with reasonable quality signal unless it is optimized properly using antenna aperture averaging technique.

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1. INTRODUCTION

The volume of using smart phone applications and the number of internet users are increasing rigorously day by day. In the developing countries like Bangladesh, the demand of surfing very high speed internet and using smart phone's heavy applications are increasing enormously. To meet the increasing demand existing communication technologies like microwave communication, optical fiber technology are not capable enough considering ultra-high speed data, less interference, data transmission security and cost effectiveness. Thus, it requires the implementation of such an effective technology that is efficient to handle the increasing demand and overcome the limitations of existing technologies in the foreseeable future. Free-Space-Optical (FSO) is an optical communication technique that transmits data wirelessly for terrestrial and space communication systems through the propagation of the laser light in free space air [1]. FSO communication is the vital and most modern technology for the future ultra-high speed and huge capacity enabled mobile & data communication systems. FSO provides huge data rate than existing RF technology for wireless communication systems [1]. FSO operates between 780-1600 nm wavelength bands that allow optical communication without requiring fiber optic cable and licensed frequency spectrum [1].

The existing RF communication has limited licensed frequency spectrum, which is very expensive and hence, cannot offer huge data capacity. Moreover, the existing backbone networks of mobile phone operators are formed using optical fiber technology that increases the cost significantly [2]. In contrast, FSO

communication provides some additional advantages like FSO provides no dispersion loss to the optical signal which is a major concern in optical fiber communication [3]. The launching power of typical optical fiber is limited to few mW which can be overcome by using inline amplification or regeneration. However, FSO uses transmitter power, antenna gain, bandwidth expansion and sensitive receiver to overcome the channel loss [4-5]. Optical fiber technology provides high data rates with less data transmission security but FSO can provide ultra-high speed data rate with high data transmission security through transmitting the laser having narrow beam that is very much suitable for wireless data transfer in financial, legal, military and other sensitive information systems [3]. FSO also requires less mass and volume of equipment [6] in case of deployment, less diffraction and uses basic modulation technique which makes the transmitter design less complicated over existing RF communication [4, 7]. These properties make FSO a promising technology for next generation communication systems.

FSO communication includes a wide range of short and long distance wireless applications [8-9]. FSO system comprises with three major parts named transmitter that sends information in terms of optical signal using LED or Laser diode, then the signal propagates through free space transmission channel where air is the media and finally the receiver that receives the optical signal using photodiode to extract the original information [6]. This research work focuses to characterize the transmission channel characteristics of FSO link considering the weather conditions of Bangladesh to determine the feasibility of the deployment of this emerging technology.

The rest of the paper is outlined as follows. Section 2 discussed about a brief description of FSO technology and its deployment impairment. The atmospheric impact on FSO link performance has been described in section 3. The atmospheric attenuation effects in different weather conditions have been illustrated along with tabular data and graphs in section 4. The outcomes of this work and possible future work have been mentioned as conclusion in section 5.

2. OVERVIEW OF FSO TECHNOLOGY

The following Figure 1 represents the operational principle of FSO communication. There is a laser diode (LD) or a light emitting diode (LED) as the source of light, a modulator, a drive circuit for the light source to supply necessary power and a telescope for transmitting light in most of the transmitter used for FSO communication [6, 7, 10]. The modulator converts the bits of information into an electrical signal and modulates the light source to generate an optical signal depending on the modulation format. This modulated beam passes through a telescope (collimating lens) to expand the optical beam which reduces the diffractive effect that spread out the beam [10]. Then, the transmitted optical beam propagates through atmospheric channel, where it suffers some physical processes inherent to atmosphere like frequency-selective absorption, scattering, turbulence and sporadic misalignment of transmitter and receiver due to displacement [3]. The propagated signal is then collected by a receiver, which consists of a telescope, a matched optical filter, a decoder and a detector to get the output signal. The main purpose of the telescope is to collect the optical signal and to form the beam size small enough to fit into the detector [10].
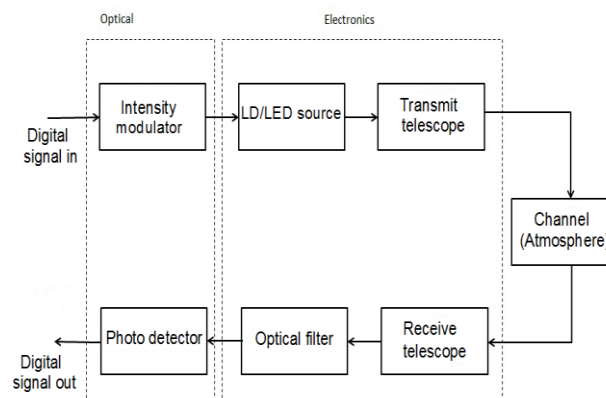

Figure 1. Typical block diagram of FSO communication systems

There is always a tradeoff among channel length, bit rate and error performance during designing the communication systems. In FSO communication, the link performance is truly influenced by weather conditions, the signal degradation caused by weather is known as atmospheric attenuation effects [4, 11, 12].

The most common atmospheric attenuation factors are beam divergence, absorption, scattering and refractive turbulence [4, 11]. In the following sections, the impact of atmospheric attenuation on FSO link performance to measure the feasibility of FSO link deployment is highlighted and theoretical assumptions are made.

3. IMPACTS OF ATMOSPHERE ON FSO

The atmosphere contains molecules like Nitrogen, Oxygen, Water and Carbon dioxide. Beside aerosols like haze, fog, dust, soil etc are also present in the atmosphere. All these molecules and aerosols contribute attenuation to wave travels through the free space. By definition the atmospheric attenuation is a process through which some or all electromagnetic energy is lost during propagation. There are three basic phenomenon, namely, absorption, scattering and atmospheric turbulence which add attenuation during the propagation [4, 12]. In case of optical signal propagation through free space the effect of absorption is negligible due to selective wavelength [1, 13, 14]. Absorption has a very little effect when the wavelength is in between 780 nm to 1662 nm [15]. Moreover, the wavelength 1550 nm offers some additional advantages [16], hence, the nominated wavelength in this work is 1550 nm. Therefore, it can be assumed that the atmospheric attenuation is contributed by scattering and turbulence effect only [11, 12].

3.1. Scattering effect on FSO

Due to the physical interaction among travelling electromagnetic wave, molecules and aerosols presented in the environment a dispersal of a beam of radiation in different direction is known as scattering [4]. A very crucial parameter to determine the nature of scattering is characteristic size parameter $x_0 = 2\pi r / \lambda$ where r is the radius of the aerosol particle and λ is the operating wavelength of the optical signal [16]. As typical wavelength used in FSO is in µm range so there is no logical reason of x_0 to be varied much less than 1. The typical value is either $x_0 \approx 1$ or $x_0 \gg 1$ [16]. Thus, the atmospheric attenuation due to scattering can be computed by Mie scattering theory when $x_0 \approx 1$ and Non-Selective (Geometrical optics) scattering when $x_0 \gg 1$ [17]. During the winter season, when the number of foggy days increases the optical signal in free space may be scattered heavily in Bangladesh. Mie scattering is applicable when fog and haze droplets exist in the atmosphere. The scattering coefficient is computed by [13, 15, 17].

$$\beta_{mie} = \left(\frac{3.91}{V}\right)\left(\frac{0.55\mu m}{\lambda}\right)^{i} \text{ [dB/km]} \tag{1}$$

Here, V is visibility range in km, λ is the incident wavelength in µm and i is the size distribution of the scattering particles, typically varies from 0.7 to 1.6 depending on the visibility condition in terms of range [16]. When the particle size is much larger compare to the wavelength of the operating signal the scattering occurs due to the non-selective or geometrical scattering. In Bangladesh rain may cause this type of scattering during rainy season. The scattering coefficient due to non-selective scattering is [18].

$$\beta_{nonselective} = \pi a^2 N_a Q_{scat}\left(\frac{a}{\lambda}\right) \tag{2}$$

Here, a is the radius of raindrop in cm, N_a is the raindrop distribution in cm^{-3} and Q_{scat} is the scattering coefficient which has usual value of 2 [18].

3.2. Atmospheric turbulence

The temperature above the earth surface becomes cooler as the altitude increases from the surface. This is because of release of solar radiation by the earth. That causes random change in refractive index [7, 19]. Addition to solar radiation, because of the variation of pressure and wind speed the refractive index also shows similar property. This inconsistent characteristic of refractive index causes atmospheric turbulence and can be viewed as discrete cells or eddies of different temperature acting like a refractive prism [7]. It causes wave front distortion by phase shifting of the propagating optical signal and intensity distortion. But between these two types of distortion, intensity distortion is the most significant and known as scintillation [15]. The effect of atmospheric turbulence becomes mostly indicative in the midday or mid night due to the maximum temperature difference created at these times allthough turbulence effect degrades the optical signal quality throughout whole day. The atmospheric turbulence loss caused by scintillation is proposed by Rytov and recommended by ITU is given as follows [15]:

$$\rho(L) = 2 \times \sqrt{23.17 \times k^{7/6} \times \times C_n^2 \times L^{11/6}}\text{(dB)} \tag{3}$$

Here, k is the optical wave number, L is the link length in km and C_n^2 is the refractive index structure parameter (RISP) in m$^{-2/3}$. The typical value of RISP C_n^2 is 1.3 for planer wave and 0.5 for spherical wave [18]. Basically it depends on the geographical location (altitude above sea level) and wind speed. A common and widely used model to determine this is Hufnagel-Valley (H-V) model [13, 14, 15].

4.   TYPICAL WEATHER CONDITION IN BANGLADESH

As the atmospheric attenuation and turbulence is dependent largely on the weather conditions mainly visibility, rainfall and wind speed [20, 21], our concern is on analyzing the feasibility of FSO technology in Bangladesh. Therefore, it becomes essential to test the weather impacts on FSO signal performance from the perspective of Bangladesh. For this purpose, seven cities of different regions named Dhaka, Rajshahi, Chittagong, Sylhet, Rangpur, Mymensingh and Barisal in Bangladesh have been selected and comply for the investigation. The reason behind selecting these cities not only because of their different weather and atmospheric diversity but also the result will represent the prospects of deploying this evolving technology here in Bangladesh.

The data of visibility from January 2013 to June 2016 is collected from the Bangladesh Meteorological Department (BMD) [22]. The data of visibility have been used to determine the Mie scattering effect. As Bangladesh faces not only heavy rainfall every year during monsoon, but also light to medium rainfall throughout the year. The rainfall data is also collected from BMD for the same tenure and same locations. But for calculating the atmospheric turbulence only data of wind speed from January 2013 to December 2015 is accessible for the same locations with the corresponding altitude.

4.1. Scattering coefficient due to mie and rainfall

The visibility data and the rainfall data are used to determine the total scattering coefficient. In case of analyzing visibility and rainfall data, monthly data from January 2013 to June 2016 has been accessed and calculated the maximum, minimum and average visibility and rainfall rate to analyse different condition like clear sky to worst case condition. First, the effect of Mie Scattering has been considered. The visibility has a direct effect on Mie Scattering. Figure 2 shows the change in visibility over time for the selected seven cities. Among the seven cities Rajshahi shows best result where the average visibility is more than 6 km,
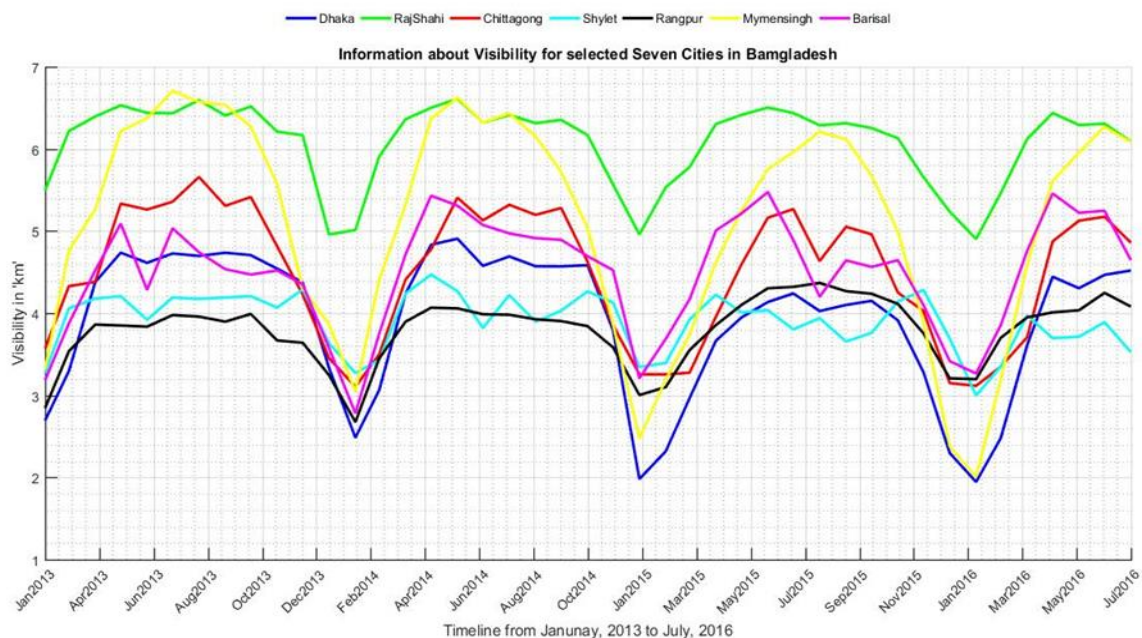

Figure 2. Change in visibility over time

while the maximum and minimum visibility are 6.6 and 5 km respectively. The visibility pattern of Mymensingh varies sharply during the whole year. Mymensingh reaches to the maximum visibility around 7 km around June and July each year then starts to fall and reaches to around 2 km in the winter season. Rangpur and Sylhet show the lower visibility pattern with an average visibility of 3.7922 km and 3.9015 km

respectively. It is seen from Figure 2 that during the month between April to October all other cities except Mymensingh maintain maximum visibility. At the beginning of the winter season (November) the visibility starts to decrease and the worst visibility condition appears during January to February each year in all over Bangladesh. As the visibility has direct impact on determining the Mie Scattering, so the Table 1 presents maximum, minimum and average visibility range, and Mie scattering coefficient for the selected seven cities.

Table 1. Mie scattring coefficient analysis among the selected cities

Cities	Average Visibility (km)	Maximum Visibility (km)	Minimum Visibility (km)	Average Mie Coefficient (dB/km)	Min Mie Coefficient (dB/km)	Max Mie Coefficient (dB/km)
Dhaka	3.905212	4.906452	1.9451	0.38565	0.284676	0.943451
Rajshahi	6.076479	6.6096	4.9032	0.213042	0.15383	0.28493
Chittagong	4.482219	5.658	3.1032	0.321283	0.234816	0.520669
Shylet	3.901533	4.47	2.9967	0.386129	0.322454	0.54471
Rangpur	3.792212	4.3677	2.6741	0.400845	0.332545	0.630595
Mymensingh	5.093088	6.7066	2.0064	0.270735	0.151605	0.907468
Barisal	4.485802	5.4741	2.7806	0.320941	0.245588	0.599803

From Table 1, it is clearly seen that cities with lower visibility show higher Mie scattering coefficient hence higher atmospheric attenuation. The attenuation due to Mie scattering is maximum in Dhaka, Rangpur and Sylhet. The average Mie scattering coefficients of these cities are 0.38565 dB/km, 0.400845 dB/km and 0.386129 dB/km respectively. While Rajshahi and Mymensingh show lower Mie scattering coefficient which are 0.213042 dB/km and 0.270735 dB/km. From Table 1, it can be easily considered the average visibility range for all over Bangladesh is around 4 km. One more point can be noted that Dhaka and Mymensingh show worst Mie scattering effect (maximum Mie scattering coefficient are 0.943451 dB/km and 0.907468 dB/km). While the city of Chittagong and Barisal can be considered as moderately Mie scattering affected areas.

Another dominant scattering factor for Bangladesh is rain. The rain profile for the selected cities has been plotted in Figure 3. Most of the rainfall occurs in between April to October each year. During the winter season the rainfall decreases but there is heavy fog in the atmosphere. Analyzing the rainfall data, it is found that Chittagong and Sylhet are the places where medium rainfall occurs. On the other hand, the amount of rainfall in Rajshahi, Rangpur, Dhaka, Mymensingh and Barisal can be considered as light rainfall region. Table 2 represents all rainfall data for the selected seven cities and also provides information about scattering loss due to rain respectively.
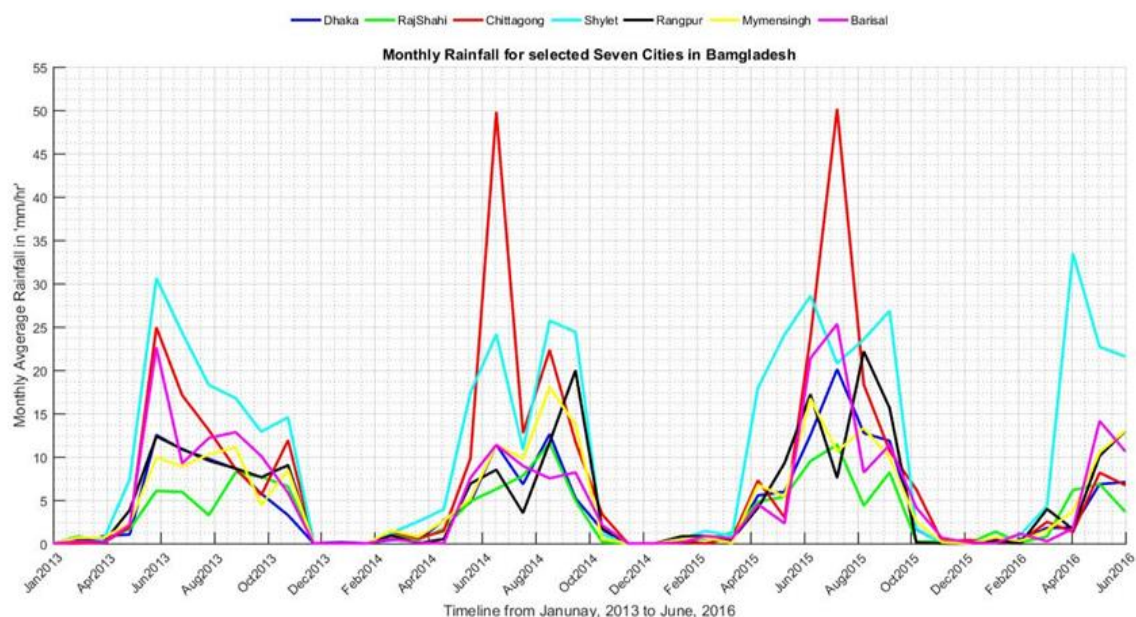

Figure 3. Rainfall for the selected seven cities of Bangladesh

Table 2. Non-selective scattering due to rainfall

Cities	Average rainfall in mm/hr	Maximum rainfall in mm/hr	Average Non-Selective Coefficient (dB/km)	Max Non-Selective Coefficient (dB/km)
Dhaka	4.47	20.10	2.015	8.539
Rajshahi	3.44	11.58	0.869	6.145
Chittagong	8.00	50.16	4.539	12.512
Sylhet	11.11	33.47	5.965	10.754
Rangpur	5.32	22.16	2.769	8.964
Mymensingh	5.15	18.03	2.629	8.068
Barisal	5.45	25.32	2.873	9.543

In calculating the scattering coefficient, the wavelength of the optical signal is considered as 1550 nm and the raindrop size is 0.003 cm. As Sylhet is in hilly region of Bangladesh and affected by rain, this city possesses most non-selective attenuation coefficient on an average (around 6 dB/km). The maximum rainfall occurs in Chittagong, so the worst scattering effect caused by rain seen in that city (more than 12 dB/km with an average of 4.539 dB/km). Meanwhile, the city of Rajshahi shows minimum non-selective scattering attenuation profile which has a coefficient of only 0.869 dB/km. One important outcome of this calculation is that all other cities of consideration have an average scattering coefficient from 2 to 3 dB/km. From the above analysis, it can be easier to consider the average link length and attenuation profile due to scattering for these cities. Table 3 shows the overall average scattering coefficient for the selected cities. It is clearly observed from the Table 3 that the dominant scattering factor is due to rain for all cities. Mie scattering plays comparatively small role in scattering attenuation.

Table 3. Total scattering coefficient for the selected cities

Cities	Average Link Length (km)	Average Mie Coefficient (dB/km)	Average Non-Selective Coefficient (dB/km)	Total Scattering Coefficient (dB/km)
Dhaka	3.90	0.385	2.015	2.4
Rajshahi	6.07	0.213	0.869	1.172
Chittagong	4.48	0.321	4.539	4.860
Sylhet	3.90	0.386	5.965	6.351
Rangpur	3.79	0.400	2.769	3.169
Mymensingh	5.09	0.270	2.629	2.899
Barisal	4.48	0.320	2.873	3.193

4.2. Atmospheric turbulence effect

Atmospheric turbulence effect causes beam steering, beam divergence and scintillation effect that degrades the performance of FSO link significantly [16, 17]. The optical turbulence is the result of variation of refractive index in the atmosphere. The variation of temperature in the atmosphere causes the variation of refractive index [17]. Temperature changes due to change of altitude and wind speed in the atmosphere [23]. Thus, altitude and wind speed are the crucial factors that determine the severity of the atmospheric turbulence effect. The variation of wind speed for the year 2013 to 2015 has been plotted in Figure 4 based on the data collected for the selected seven cities.

Figure 4 demonstrates that average wind speed is 1.085 m/s, 1.151 m/s, 3.263 m/s, 1.093 m/s, 1.564 m/s, 0.997 m/s and 0.884 m/s for Dhaka, Rajshahi, Chittagong, Sylhet, Rangpur, Mymensingh and Barisal respectively. It is also observed that maximum average wind speed is for Chittagong where altitude is 15 m and minimum average wind speed is for Barisal where altitude is 4 m. All the calculated results are arranged in the following Table 4.
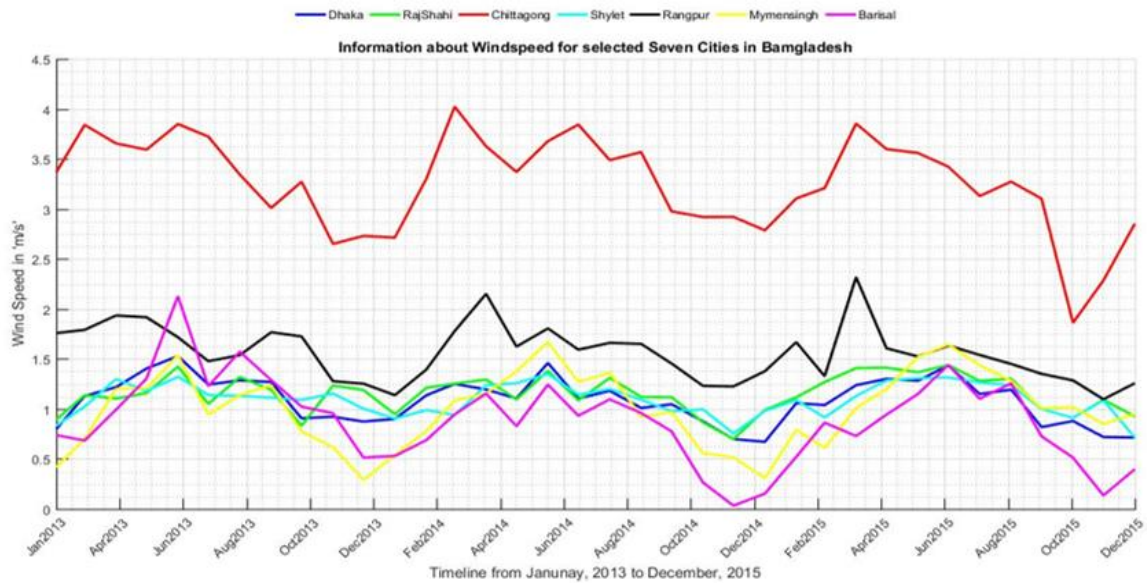
Figure 4. Wind speed profile for the selected seven cities

Table 4. Attenuation due to atmospheric turbulence

Cities	Altitude (m)	Average Wind Speed (m/s)	Maximum Wind Speed (m/s)	Average scintillation attenuation (dB)	Average scintillation index	Average RISP	Max scintillation attenuation (dB)	Max scintillation index	Max RISP
Dhaka	23	1.0851	1.5284	0.0353	1.65×10^{-5}	2.16×10^{-9}	0.0497	3.27×10^{-5}	4.28×10^{-9}
Rajshahi	23	1.1513	1.438	0.0561	4.18×10^{-5}	2.43×10^{-9}	0.0701	6.52×10^{-5}	3.79×10^{-9}
Chittagong	15	3.2635	4.022	0.0976	1.26×10^{-5}	1.28×10^{-9}	0.1202	19.18×10^{-5}	1.95×10^{-8}
Sylhet	26	1.0938	1.351	0.0377	1.89×10^{-5}	2.47×10^{-9}	0.0465	2.88×10^{-5}	3.77×10^{-9}
Rangpur	36	1.5642	2.318	0.0615	5.02×10^{-5}	6.92×10^{-9}	0.0911	11.0×10^{-5}	1.52×10^{-8}
Mymensingh	18	0.9977	1.669	0.0367	1.79×10^{-5}	1.43×10^{-9}	0.0613	5.00×10^{-5}	4.01×10^{-9}
Barisal	4	0.8843	2.127	0.0137	2.5×10^{-6}	2.54×10^{-9}	0.0330	1.45×10^{-5}	1.47×10^{-9}

The strength of atmospheric turbulence effect depends on the value of refractive index structure parameter (RISP). The refractive index strongly varies not only with the variation of altitude of the place, but also with geographic location, cloud cover and temperature variations [4]. The average RISP has been computed 2.16×10^{-9}, 2.43×10^{-9}, 1.28×10^{-8}, 2.47×10^{-9}, 6.92×10^{-9}, 1.43×10^{-9} and 2.54×10^{-10} for Dhaka, Rajshahi, Chittagong, Sylhet, Rangpur, Mymensingh and Barisal respectively. The maximum average RISP has been found for Chittagong and minimum for Barisal. The typical range of RISP is 10^{-17} m$^{-2/3}$ (considered as weak turbulence) to 10^{-12} m$^{-2/3}$ (considered as strong turbulence) [4]. Analyzing the computed data, it can be stated that the effect of atmospheric turbulence is strong in all the selected cities.

The received signal optical power variations cause scintillation effect [4]. The average scintillation index is measured 1.65×10^{-5}, 4.18×10^{-5}, 1.26×10^{-5}, 1.89×10^{-5}, 5.02×10^{-5}, 1.79×10^{-5} and 2.5×10^{-6} for Dhaka, Rajshahi, Chittagong, Sylhet, Rangpur, Mymensingh and Barisal respectively. The maximum average scintillation index is observed for Chittagong and minimum for Barisal. The increase of optical turbulence increases the scintillation index dramatically [4], the measured data also proves that. In calculating the attenuation due to scintillation, the link length is considered to be equal to the visibility length of each city. The maximum loss due to scintillation has been found in Chittagong with an average attenuation of 0.0976 dB, whereas, Barisal is less affected by this attenuation. One point must be mentioned that no cities under consideration have severe attenuation effects due to atmospheric turbulence.

5. CONCLUSION

This work focused on the prospects and the feasibility of the emerging FSO technology from the atmospheric context of Bangladesh. As mentioned earlier that Bangladesh is entering to a new era of satellite communications soon to meet the demand of largely increasing internet and high speed data communication amenities. The necessity of deploying FSO technology is becoming crucial to meet the demand in the near

future. Here, thorough investigation has been performed to identify the feasibility of deploying FSO technology in terms of propagation channel characterization. After analyzing the measured data, it can be stated that FSO technology is feasible for short range communications link, since the average visibility range in Bangladesh is very low which is around 4 km to keep the scattering attenuation in optimum range. Moreover, the analysis demonstrates that the atmospheric turbulence effect is strong in Bangladesh that can attenuate the signal quality significantly. In this circumstance, to optimize the turbulence effect antenna aperture averaging technique needs to be implemented at receiver end with greater accuracy. The measured data also shows that if it is possible to keep the atmospheric turbulence effect below the threshold value by applying effective method then FSO technology will be feasible as an alternative and effective technology in place of existing technologies for short range extremely high speed wireless communication links.

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