Critical Events of Fog Attenuation Using Visibility Data in Lahore, Pakistan

Sultan Mahmood Yasir[1*], Muhammad Salman[2], Muhammad Shoaib Saleem[3]

[1*] Govt. Swedish Pakistani College of Technology, Gujrat

[2] Effat University, Jeddah, KSA

[3] University of Management and Technology Lahore, Sialkot Campus, Sialkot

sultanmahmood.yasir@gmail.com, msalman@effatuniversity.edu.sa

muhammad.shoaib@skt.umt.edu.pk

Abstract

Free-space optics (FSO) communication system is mature, unique and promising technology which is used in various countries to meet high data rate demand and last mile connectivity. FSO link has a capacity to be utilized as a primary communication links by replacing RF communication systems because of its advantages of unregulated bandwidth, broader spectrum of frequency at low power consumption. These days researchers have great interest in this technology because of several features and benefits of larger bandwidth, less power consumption, low installations cost, simple to install, no congestion in spectrum, secure and reliable communication without issues of right of way. In free space optical communication, environment layer is used for signal transmission which can be effected from severe weather conditions like smog, dust, smoke, rain and fog etc. In all these severe weather environments, winter fog is one of the main problem because of it offers high optical attenuation on communication link. In this investigation the entire winter season has been observed. There are four fog events which attenuate the optical signal most. Optical attenuation is estimated using three famous fog prediction models like Al Naboulsi, Kim and at wavelengths of 850nm, 1350nm, and 1550 nm.

Keywords: Free space Optical (FSO) link, Optical wireless communication (OWC), Fog.

Introduction:

In Free space optical (FSO) system environmental field is used as medium for signal broadcast. Fiber optical communication and FSO communication systems are very similar to each other except transmission medium. LASER and LED are used in optical transmitter as a source which transduce electrical signal into optical signal [1]. The optical signal has advantages of unlicensed bandwidth with high speed data communication by utilizing low power consumption [2]. From last two or three decades FSO communication has become a subject of great interest for researchers to fulfill hunger of bandwidth for various communication terminals [3]. FSO link is a line of sight communication (LOS) can be intercepted because of invisible optical transmission so known to be one of the secure communication link [4]. A FSO link contains of an optical transmitter, receiver and atmospheric layer for transmission of optical signal like any other communication systems [5]. FSO communication link is suitable for long and short communication links and can be used for indoor and outdoor communication applications. Outdoor long or short links are affected by the ambient light [6] and weather conditions like fog, haze, snow, smoke, and dust while indoor communication links are affected from local light sources [7]. Fog is one of the weather conditions which affect the performance of FSO communication link and considered as a major challenge [8]. Fog event limits the visibility of atmospheric field which offers attenuation for optical signals propagated through atmospheric layer. Optical attenuation due to fog increases bit error rate (BER), decreases data rate (DR) and signal to noise ratio, reduces link margin (L.M), received power (R.P) and in worst fog events where visibility limits to few meters, FSO communication link has a question mark on its availability [9]. Different investigations have been made to explore atmospheric effects on FSO communication links [10]–[13]. The performance of a FSO communication link is highly affected by the severe weather conditions therefore there is a need to do detailed analysis on performance of FSO link in diverse weather conditions on specific location well before system installment [14].

Visibility data is collected from Regional office of Pakistan Meteorological department Lahore to estimate atmospheric attenuation due to fog. There are various fog prediction models are available but we have used most important and used Al Naboulsi, Kim and Kruse models at 850 nm, 1350 and 1550 nm wavelengths.

This paper is prearranged in the following in five sections. Section I contain introductory information's about FSO communication link, challenges of FSO communication system and literature reviews. Sections II contain complete information of fog attenuation prediction models like Kim, Kruse and Al Naboulsi. Section III shows simulation results and discussions. Conclusion and future work is in section IV and V respectively.

Fog Attenuation Models:

Optical wireless communication links use atmospheric layer for optical signal transmission. Weather conditions like smog,

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dust, smoke, rain and fog etc. In the atmospheric layer appears and affects the visibility of the channel. The leading challenge for FSO link is fog which appears in the month of December and January every year in Lahore, Pakistan. These fog events of different time periods appear near the earth surface randomly and reduce the visibility to few tens of meters of the atmospheric layer or atmospheric channel [15]. There are various environmental factors involves in the formation of fog and these factors are Liquid Water Content (LWC), Drop Size Distribution (DSD), Temperature, that reduce the atmospheric visibility [16]. There is variety of fog prediction model available in literature but in this paper we have used three famous fog prediction models named as Al Naboulsi, Kim and Kruse which are used for estimation of atmospheric attenuation for optical beam due to foggy conditions. These fog attenuation prediction models are described as under;

A fog layer is appeared on earth surface a t a height of 300 to 400 feet approximately when horizontally; visibility on the earth surface reduces to 1km or less [17], [18]. Normally fog events occurred after sun setting due to cooling of earth surface and this cooling is caused by divergence effect of long wave radiation. In Lahore, normally fog events appear in the month of December-January. The relative humidity increases as cooling increases this increase in humidity activate the fog droplets. Typically in fog formation humidity reaches to 85and above percent and above and temperature reduces to 3ºC to 5ºC.

The atmospheric visibility is as range or link distance where the 550 nm highly changed transmitted ray is attenuated to a fraction of transmitted power [19]. Unit of optical attenuation is in dB/km. For transmittance of 2 % Kim and Kruse model is given by

$$Speci\_Atten = \frac{17}{Visibility} \times \left(\frac{\gamma}{\gamma_o}\right)^{-\alpha} \quad \text{(dB/km)} \tag{1}$$

For transmittance of 5% is given by

$$Speci.\_Atten = \frac{13}{Visibility} \times \left(\frac{\gamma}{\gamma_o}\right)^{-\alpha} \quad \text{(dB/km)} \tag{2}$$

Where, visibility unit is KMs, [20]

γ = Transmitted optical Beam wavelength

γ_o = Reference Wavelength

α = size distribution

$$\alpha = \begin{cases} 1.6 & if\ V \succ 50Km \\ 1.3 & if 6Km \succ V \succ 50Km \\ 0.585V^{\frac{1}{3}} & if\ V < 50Km \end{cases} \tag{3}$$

Kruse model is sensitive to wavelength as compare to Kim and Al-Naboulsi models. For higher wavelength Kruse estimates less optical attenuation but for visibility less than 1km it cannot estimate optical attenuation correctly [7] Kim has presented a different definition of size distribution "q" , when visibility is less than half of km there is no benefit of using high wavelength [21]. Values of "α" for Kim model are as under.

$$\alpha = \begin{cases} 1.6 & if\ V \succ 50Km \\ 1.3 \quad + & if 6Km \succ V \succ 50Km \\ 0.16V + 0.34 & if\ 1Km < V < 6Km \\ V - 0.5 & If IKm < V < 1Km \\ 0 & if\ V < 0.5Km \end{cases} \tag{4}$$

Al Naboulsi model is used to predict optical attenuation due to convection and advection fog. The fog formed when warm and wet air passes over terrestrial surfaces or over cold maritime is called advection fog [22]. In Advection fog liquid water contents (LWC) have values of $0.20 g/m^3$ and 20μm diameter of particles [23]. The attenuation coefficient for advection fog presented by Al Naboulsi is given by;

$$\beta_{adv}(\gamma) = \frac{0.11478\gamma + 3.8367}{Visibility} \tag{5}$$

Whereas fog due to the cooling of earth surface after sun set is known as convection or radiation fog. The attenuation coefficient of a radiation fog provided by Al Naboulsi is given by;

$$\beta_{rad}(\gamma) = \frac{0.18126\gamma^2 + 0.13709\gamma + 3.7502}{Visibility} \tag{6}$$

$$A_{speci} = \frac{10}{In10}\beta(\gamma) \quad \text{(dB/km)} \tag{7}$$

Whereas A_{speci} = precise attenuation

γ = Attenuation coefficient.

Simulation Results:

Visibility, humidity and temperature data is collected from regional office of Pakistan Meteorological Department situated at Jail Road Lahore from 01 Dec, 2014 to 28 February 2015.This data is specifically from area of Allama Iqbal international airport, Lahore.

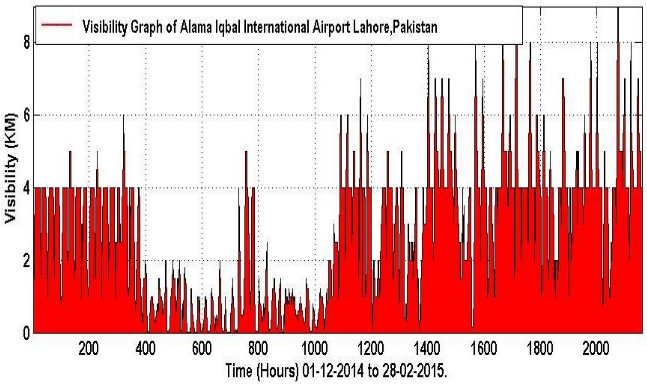

Figure 1: Visibility graph during 1 Dec. 2014 to 28 Feb. 2015.

The visibility graph of the Lahore air field shown in figure 1 illustrates the minimum visibility of to 0.01km and maximum visibility of 9km.The mean visibility of the visibility graph is 2.82km.At minimum visibility the humidity of the atmospheric layer reaches to 100% which is note able in the humidity graph during fog event from 01, Dec. 2014 to 28, Feb, 2015. Data statistics of the humidity graph in figure 2 shows that minimum humidity is 18% and maximum humidity of 100% .Mean value of the humidity is 73.25%.

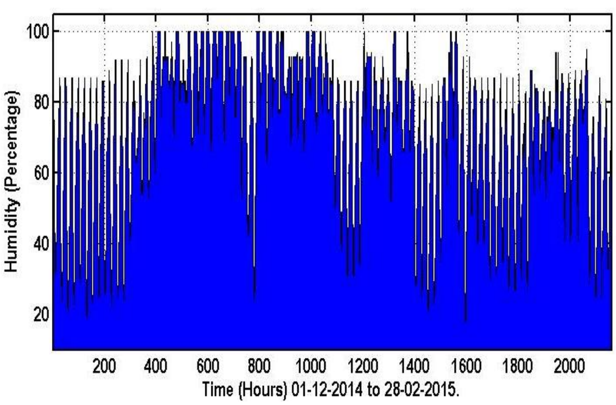

Figure 2: Humidity Graph during 01-12- 2014 to 28-2-2015.

During foggy event temperature of the atmospheric layer reaches to 3C° to 5°.Figure 3 illustrates the temperature graph during period of 01, Dec.2014 to 28, Fab. 2015. Data statistics shows that minimum wet bulb temperature is 2.5C° and maximum temperature is 19.5C°.Mean value of the temperature was 10.23C°.

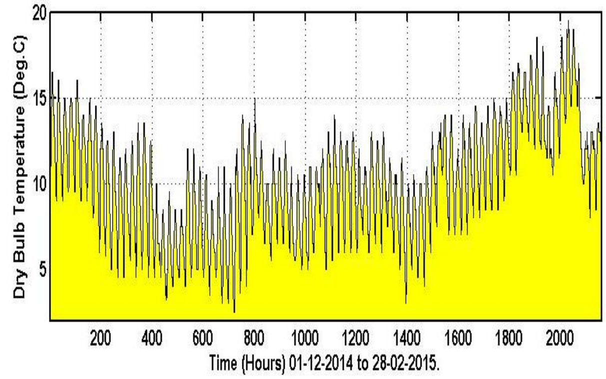

Figure 3: Temperature Graph during 01-12- 2014 to 28-2-2015.

Attenuation Graph of against visibility of Lahore:

Attenuation graph shown in figure 4 is for period of three months from 01-12-2014 to 28-02-2015.The optical attenuation graph clearly shows high spikes detected in the last week of December 2014 to first week of January 2015.Data statistics shows that maximum attenuation at wavelength of 1550nm is 1141dB/km for visibility range of 10 meters and minimum attenuation is 0.4049dB/km for visibility range of 9km.The mean attenuation of the total period is 27.92dB/km with standard deviation of 113.8dB/km.

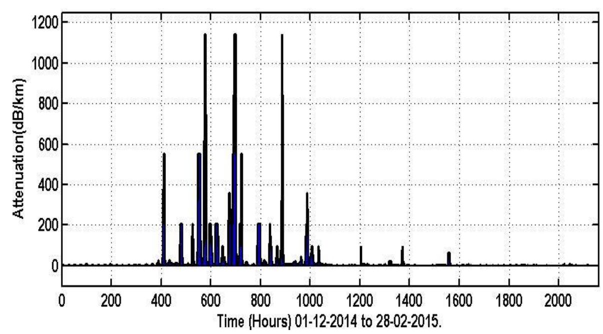

Figure 4: Attenuation Graph at 1550nm Graph during 01-12-2014 to 28-2-2015.

Comparison of Fog Attenuation Models:

Fog attenuation model at 1550nm wavelength is show in figure 4 for visibility of Lahore airfield using three different attenuation models. Data statistic shows that using Al-Naboulsi model optical attenuation at 10meter visibility is 1629dB/km and at 1km visibility of 16.29dB/km and mean value of 84.49dB/km. Similarly data statistics for Kim model are 1300dB/km at 10meter visibility and 13dB/km at 1km visibility while mean value is 67.44dB/km. For Kruse models data statistics shows that at 10meter visibility optical attenuation is 1141dB/km and 7.09dB/km at 1km visibility range while mean value is 50.97dB/km.

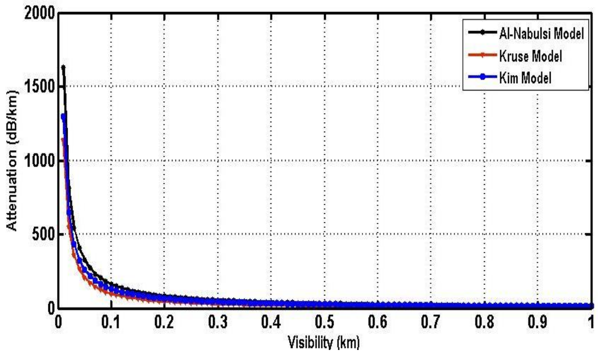

Figure 5: Comparison of different Attenuation Model.

Selected Fog Events:

There is several fog events occurred during the Dec, 2014 to Feb., 2015 in Lahore but very critical are four which are selected for analysis. Visibility measurement from Pakistan Metrological Department is used for estimation of optical attenuation during fog events. These critical events are given below in Table 1.

Table 1: Selected fog Events during 15 Dec, 2014 to 15 Jan, 2015

Event No.	Event Date	Start Time	End Date	End Time
1	29-12-14	12:00am	30-12-14	1:00pm
2	3-01-15	12:00am	04-01-15	12:00pm
3	08-01-14	9:00 pm	10-01-15	12:00pm
4	10-01-15	11:00pm	12-01-15	12:00pm

Optical attenuation is calculated for fog event no 1 appeared on 29 December 2014 from 12:00 AM to 1:00 PM. Optical attenuation is calculated against visibility graph shown in Fig.6 Fig.7, 8 and 9 represents the attenuation graphs at 850nm, 1350nm and 1550nm wavelengths using Al-Naboulsi, Kim and Kruse Models.

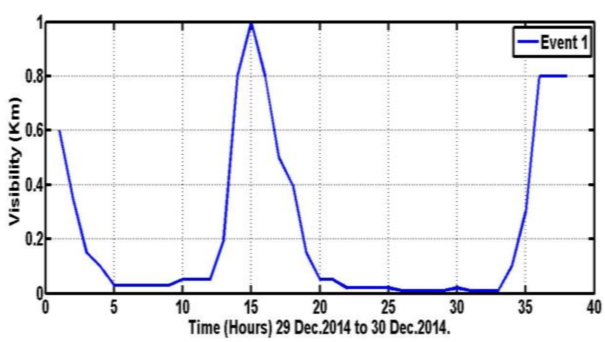

Figure 6: Visibility Graph of Event 1.

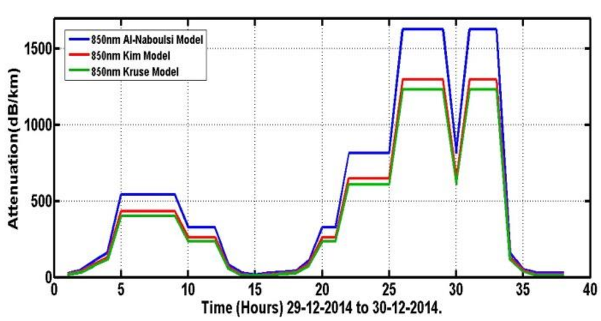

Figure 7: Comparison of Attenuations Models at 850nm.

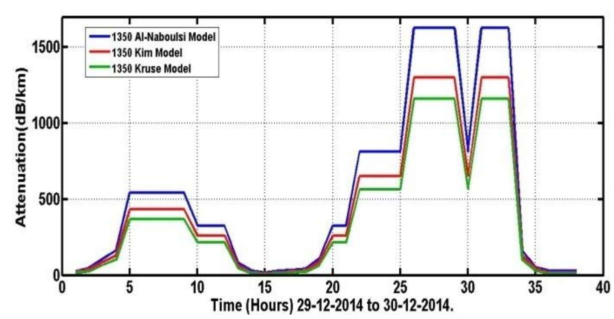

Figure 8: Comparison of Attenuations Models at 1350nm.

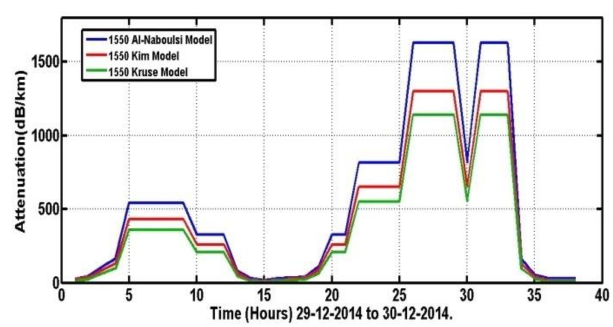

Figure 9: Comparison of Attenuations Models at 1550nm.

Table 2: Data Statistics of Event 1.

Al Naboulsi Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	16.28	1629	547.6
1350nm	16.28	1629	547.6
1550nm	16.28	1629	547.6
Kim Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	13	1300	436
1350nm	13	1300	436
1550nm	13	1300	436
Kruse Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	10.07	1231	407.2
1350nm	7.68	1161	379.1
`1550nm	7.09	1141	371.1

Table 2 shows the data statistics of Al-Naboulsi, Kim and Kruse models during fog events noted during 15 December 2014 to 15 January 2015.Al-Naboulsi and Kim model have constant maximum attenuation of 1629dB/km and 1300dB/km on 850nm, 1350nm and 1550nm respectively. Kruse model have same attenuation of 1231dB/km, 1161dB/km and 1141dB/km for wavelengths of 850nm and 1350nm and 1550nm for visibility of 10 meters.

In the second section, attenuation is calculated for the fog event no 2 appeared on 3 January 2014 (12:00 AM PST) to 4 January 2014 (12:00 PM PST).Fig.10 shows the visibility graph of the event and Fig. 11, 12 and 13 illustrates the optical attenuation at 850nm,1350nm and 1550nm wavelengths using Al-Naboulsi, Kim and Kruse fog attenuation models.

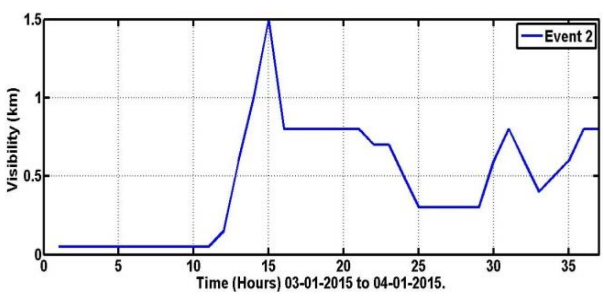

Figure 10: Visibility Graph of Event 2.

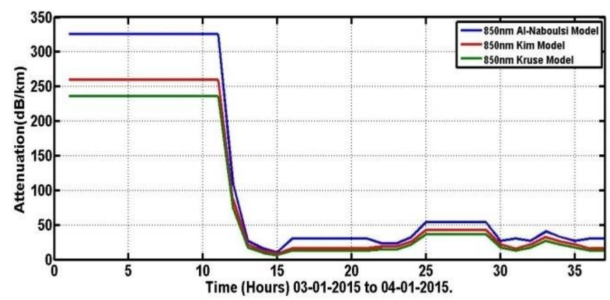

Figure 11: Comparison of Attenuations Models at 850nm.

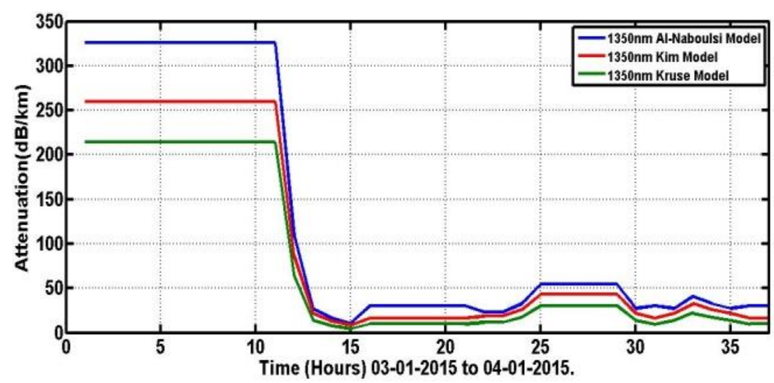

Figure 12: Comparison of Attenuations Models at 1350nm.

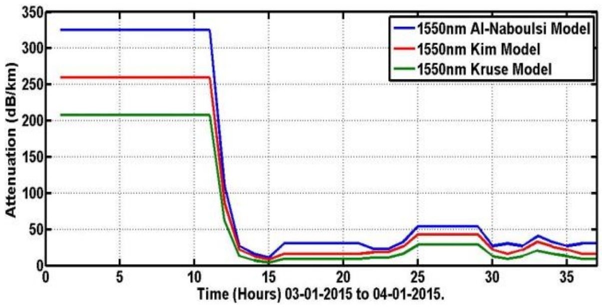

Figure 13: Comparison of Attenuations Models at 1550nm.

Table 3: Data Statistics of Event 2.

Al Naboulsi Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	10.85	325.7	122.3
1350nm	10.85	325.7	122.3
1550nm	10.85	325.7	122.3
Kim Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	8.6	260	95.62
1350nm	8.6	260	95.62
1550nm	8.6	260	95.62
Kruse Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	6.47	236	85.29
1350nm	4.7	214.3	76
`1550nm	4.33	208	73.39

Table 3 shows the data statistics of Al-Naboulsi, Kim and Kruse models during fog events noted during 03, Jan.2015 to 04, Jan. 2015.Al-Naboulsi and Kim model have maximum constant attenuation of 325.6dB/km and 260dB/km on 850nm, 1350nm and 1550nm respectively. Kruse model have maximum attenuation of 236dB/km, 214.3dB/km and 208dB/km for wavelengths of 850nm, 1350nm and 1550nm respectively.

In the third section, optical attenuation is estimated for fog occurrence no 3 appeared on 8, Jan. 2015 (9:00 PM PST) to 10, Jan. 2014 (12:00 PM PST). Figure 14 illustrates the visibility graph of the event. Fig. 15, 16 and 17 shows the attenuation of the event at 850nm, 1350nm and 1550nm wavelengths using Al-Naboulsi, Kim and Kruse models.

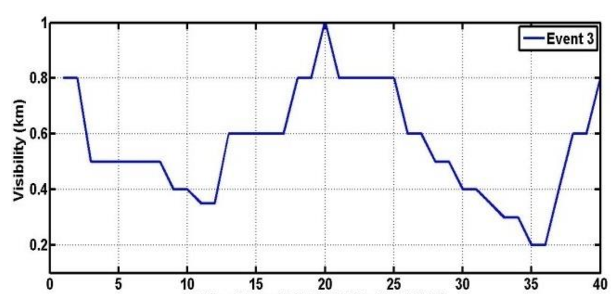

Figure 14: Visibility Graph of the Event 3.

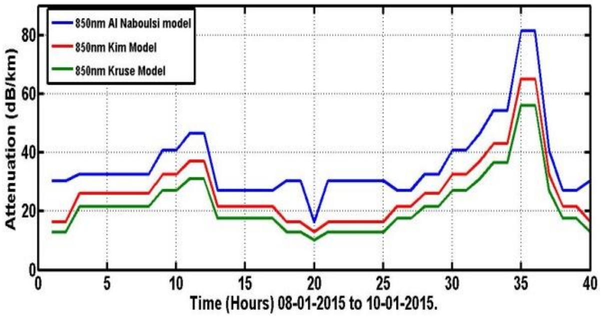

Figure 15: Comparison of Attenuations Models at 850nm.

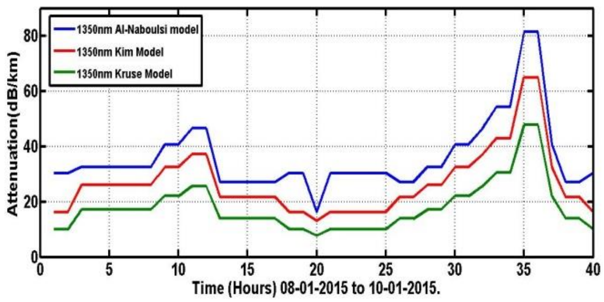

Figure 16: Comparison of Attenuations Models at 1350nm.

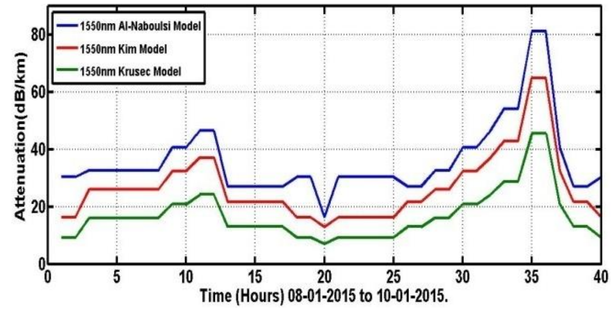

Figure 17: Comparison of Attenuations Models at 1550nm.

Table 4 shows the data statistics of Al-Naboulsi, Kim and Kruse models during fog events noted during 08, Jan. 2015 to 10,Jan. 2015.Al-Naboulsi and Kim model have maximum constant attenuation of 81.4dB/km and 65dB/km on 850nm, 1350nm and 1550nm respectively. Kruse model have maximum attenuations of 56dB/km, 47.8dB/km and 45.6dB/km for wavelengths of 850nm 1350nm and 1550nm respectively.

Table 4: Data Statistics of Event 3

Al Naboulsi Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	16.28	81.43	35.98
1350nm	16.28	81.43	35.98
1550nm	16.28	81.43	35.98
Kim Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	13	65	26.71
1350nm	13	65	26.71
1550nm	13	65	26.71
Kruse Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	10.07	56	22.06
1350nm	7.68	47.8	17.84
`1550nm	7.09	45.6	16.76

In the fourth section, attenuation is considered for the fog occasion which appeared on 10 January 2015 (11:00 PM PST) to 12 January 2015 (21:00 PM PST). Figure 18 illustrates the visibility graph of the event. Fig. 19, 20 and 21 shows the attenuation of the event at 850nm, 1350nm and 1550nm wavelengths using Al-Naboulsi, Kim and Kruse models.

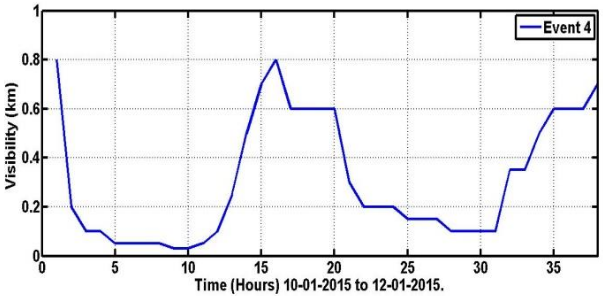

Figure 18: Visibility Graph of the Event 4.

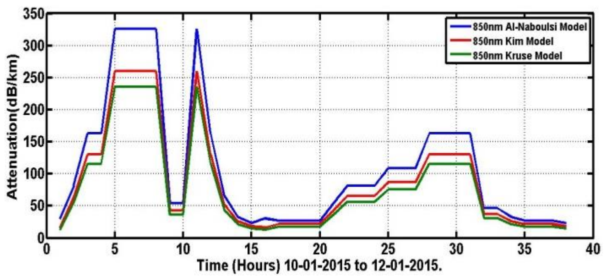

Figure 19: Comparison of Attenuations Models at 850nm.

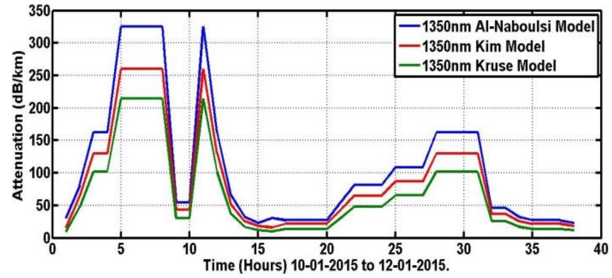

Figure 20: Comparison of Attenuations Models at 1350nm.

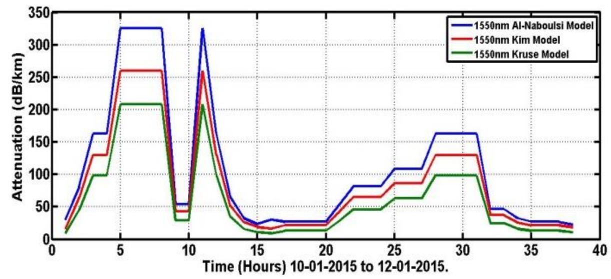

Figure 21: Comparison of Attenuations Models at 1550nm.

Table 5: Data Statistics of Event 4:

Al Naboulsi Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	23.26	325.7	108
1350nm	23.26	325.7	108
1550nm	23.26	325.7	108
Kim Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	16.25	260	85.75
1350nm	16.25	260	85.75
1550nm	16.25	260	85.75

Kruse Model			
Wavelength	**Min.(dB/km)**	**Max.(dB/km)**	**Mean(dB/km)**
850nm	12.82	236	75.69
1350nm	9.97	214.3	66.5
`1550nm	9.28	208	63.97

Table 5 shows the data statistics of Al-Naboulsi, Kim and Kruse models during fog events noted during 10, Jan. 2015 to 12, Jan. 2015.Al-Naboulsi and Kim model have maximum constant attenuation of 325.7dB/km and 260dB/km on 850nm, 1350nm and 1550nm respectively while Kruse model have maximum attenuation of 236dB/km,214.3dB/km and 208dB/km for wavelengths of 850nm, 1350nm and 1550nm respectively.

Results Summary:

Figures and Tables shown in section III shows four different fog events occurred in December 2014 and January 2015.Data statistics of fog event 1 shows that extreme attenuation goes up to 1629dB/km (for 10 meters Visibility) during 29, Dec.2014 to 30, Dec. 2014 and it is due to extreme dense continental fog in Lahore, Pakistan by Al-Naboulsi model. Other fog prediction models like Kim and Kruse model showed lower attenuations for 850nm, 1350 nm and 1550 nm wavelengths. It is also noted that Kim and Al-Naboulsi models are not sensitive to wavelength because both have estimated same attenuations for 850nm, 1350nm and 1550nm wavelengths.

Conclusions and future work

In this paper attenuation offered in environmental field for FSO link is estimated from visibility data. It is concluded that fog events causing high optical attenuation due to frequently appearing in months of December and January every year in Lahore. Different fog attenuation forecast models are used to estimate optical attenuation of particular four vital fog events. In this research observation, maximum attenuation goes up to 1629dB/km, 1300dB/km and 1141dB/km for Al-Naboulsi, Kim and Kruse model respectively for visibility range of 0.01km at 1550nm wavelength. Estimated data statistics of optical attenuation shows that a reliable FSO communication link is highly affected by the extreme fog events occurred in mid of December to first week of January. These fog events has a question mark on reliability of FSO communication links for a very short period of time (max. one month in a years) and rest of the period a reliable optical communication link with good availability can be developed in Lahore, Pakistan by choose of suitable link budget, link margin and link range of FSO installations. Lahore is one of the polluted cities in the word do events of fog becomes denser due to aerosol particles dissolved in the air. It is also noted that these fog events appears for short period of time in a year which cannot discourage application of FSO technology in that specific city for high data rate communication in future.

In this paper optical attenuation is predictable from visibility data of Lahore airport. Behavior of fog attenuation at different wavelength and optical attenuation for visibility of Lahore is useful estimation which can be considered as a reference and further utilized for performance analysis of FSO communication link under dense fog conditions at Lahore.

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