

Analysis/Simulation of Unavailability of FSO Link Due to FOG in Karachi & Lahore

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Abstract — Now a day's transmission of data using infrared light in free space through laser is keen interest of researchers as compared to traditional fiber optics and RF transmission due to its inherent advantages, such as low cost, easy to install and maintain high bandwidth in license free spectrum, Like other unguided media the local climate degrades the system performance of FSO system. The effect of fog on narrowband (780 nm to 850nm & 1529 nm to 1600 nm) transmission of FSO system is maximum due to the smaller size of particle of water as compared to rain where the size of particle is large. In our proposal of current work the two highly populated metropolitan cities of Pakistan ((i) Karachi-the city with less dense fog & (ii) Lahore-the city with more dense fog) are selected for calculation of signal attenuation due to fog. The statistical measurement of the fog for the whole year is obtained in terms of the Visibility from the secondary data available with civil aviation. On the availability of the statistical measurements the four well known fog attenuation models (i) Krus model, (ii) Kim model, (iii) Al-Naublsi advection model and (iv) Al-Naublsi convection model have been used for calculation of unavailability/ absence of the FSO link. These models have been simulated in Matlab 2011Rb for calculation of fog attenuation. Result shows that FSO is good choice for Karachi city instead of Lahore city because its climate does not degrade the signal power at long distance and availability of link is maximum. This measurement will helpful for implementation of FSO system in Climate of Pakistan.

Keywords — FSO, Fiber Optics, Terrestrial Microwave, FOG Attenuation.

I. INTRODUCTION

Free Space Optics transmission system with narrow light beam propagating through the outdoor atmosphere is currently utilized more intensively in telecommunication networks^[1].

Free Space Optical communication has the tremendous potential to provide communication link for future high data rate demanding applications^[2]. Now a day's numbers of mobile subscribers reach up to 10 million in Pakistan with more demand of multimedia services^[3]. Due to that operators need more bandwidth on last mile nodes so they replace terrestrial microwave to fiber optics because it supports more data rate at license free bandwidth. The main disadvantage of fiber optic cable is costly deployment and difficult maintenance despite of microwave having advantages over above factors but support less data rate and requires licensed spectrum.

FSO is the solution for last mile access problem due to its inherent advantages like very narrow beam, ease of maintenance, quick installation, license free bandwidth and more over almost no accumulation into end delays^[4]. Despite of their several advantages, the effects of propagation impairment, like fog seriously limit the

availability of the FSO link, since the strong attenuation of the electromagnetic due to scattering mechanism. If the attenuation value exceeds the system fade margin defined for a maximum allowed value of bit error rate (BER), the transmission is interrupted and the FSO system becomes unavailable^[2]. The popularity of FSO could be hampered if sufficient measures will not taken to cater the atmospheric attenuation under adverse weather conditions, maintaining line of sight link due to sway and vibration in the buildings. This would cause link failure, low throughput, poor link availability and degraded system performance^[5]. This Paper focus on the unavailability of the FSO links due to Fog in Pakistan climate.

II. FREE SPACE OPTICS

Free space optics (FSO) is also called optical wireless technology that transmits data, voice and video in the form of light in free space. It is a wireless broadband technology, which requires clear line of sight (LOS) between pair of FSO transceivers. This technology seems to be new for the telecommunication industries, but actually it has been used by the military and NASA for about 30 years. The history of the FSO started in the late of 1960 when Dr. Erhard Kube, a German scientist later regarded as the father of the FSO technology, published a white paper which explained about the possibility of data transmission through the atmosphere using light beams^[6].

The need for FSO is accelerated by several factors, First factor when more and more bandwidth is needed by the customer, which means that more data access must be provided. Second factor is the economic consideration, in which Cost is an important factor to the broadband communication industries, as they are trying to offer bandwidth using the lowest cost possible in order to increase the revenue. The third factor is the fact that the FSO technology brings new possible services that may not be fulfilled by another access technology. For example, using the FSO technology, it is possible to install a high speed data connection in a remote area within 3 days, use it for a special occasion which lasts only several hours, and then after that uninstall everything back^[7].

The Federal Communication Commission (FCC) does not regulate spectrum above 300 GHz. Therefore, unlike most lower-microwaves frequencies such as LMDS and FSO communication systems do not require operating licenses. Due to proximity to the visible spectrum the wavelength in the near IR spectrum have nearly the same propagation properties as visible light.

In basic point-to-point transmission system, an FSO transceiver (link head) is placed on either side of transmission path. A main requirement of operating an FSO system is unobstructed line-of-sight between the two

networking locations; FSO systems use light to communicate, and light cannot travel through solid obstacles such as walls and trees. FSO system is composed of three basic stages; a transmitter, the propagation channel, and a receiver.

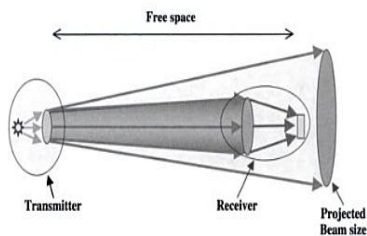


Fig.1.(b) Schematic diagram of FSO

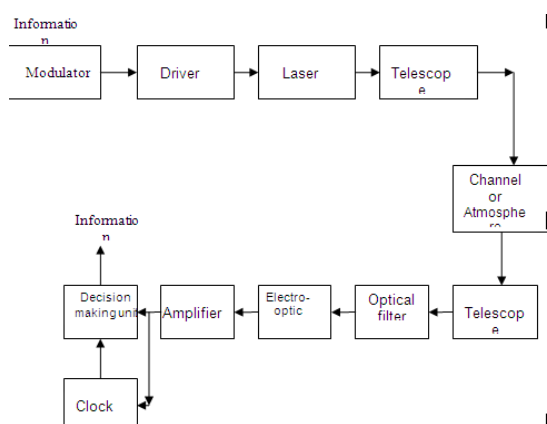


Fig.1.(a) Simple block diagram of optical wireless system

The optical part of the transmitter involves a light source and a telescope assembly. The telescope can be designed by using either lenses or a parabolic mirror. The telescope narrows the beam and projects it towards the receiver. In practical applications, the beam divergence of the transmission beam varies between a few hundred micro radians and a few mili radians.

A. FSO: As an Alternative of Terrestrial Microwave and Fiber optic cable

The RF spectrum is becoming increasingly crowded, and demand for available bandwidth is growing rapidly. However, at the low carrier frequencies involved, even with new bandwidth allocations in the several gigahertz region. This line-of-sight communications technology avoids the wasteful use of both the frequency and spatial domains inherent in broadcast technologies. Optical wireless provides a secure high data-rate channel exclusively for exchanging information between two connected parties. There is no spectrum allocation involved since there is no significant interference between different channels, even between those using the exact same carrier frequency^[4].

The achievable bandwidth in a laser system is equal or better than in a fiber optic cable system and substantially higher than in RF systems. Telecommunication systems using light propagation in atmosphere in atmosphere (free space) are less costly than Optical fibers. Unlike optical fiber cables, FSO equipments are recoverable and moveable and requires less than a fifth of the capital

outlay of comparable ground-based fiber optic technologies^[8].

B. Wavelength Selection

FSO normally used each common optical wavelength. The first widely used beam light wavelength interval is between 780 nm and 850 nm. Using this interval, an inexpensive, reliable, and high performance light beam can be made. They usually have a lower average lifetime compared to the beam light which operates in the wavelength interval between 1529 nm and 1600 nm. But because of the atmospheric conditions and due to the laser safety regulations 1550 nm is better suited for transmission. The losses due to Mie-scattering in haze or light fog at longer wavelengths (1550 nm) are smaller than at shorter ones (850 nm). The latter wavelength interval has low atmosphere attenuation and high component performance which makes it possible to implement the wave division multiplexing (WDM), however the components are more expensive compared to the former ones^[7].

C. Availability of FSO Link

Availability ratio estimation is needed during FSO network planning. The availability of FSO systems depends on local climatic conditions several parameters are taking into account but the most affected parameter which mainly degrade the optical power of FSO link is fog and is often estimated from atmospheric visibility statistics. The visibility is (roughly) a distance where the 550 nm collimated light beam is attenuated to a fraction (5%, or sometimes 2%) of an original power. It is measured regularly near the airports, for example. Once the visibility statistics are known, the attenuation statistics can be obtained provided the relation between these two quantities is known^[9].

III. FOG

Fog consists of fine water droplets suspended in the air with diameters less than 100 μm . Fog induces spontaneously decrease in visibility. It is admitted in theory that fog exists when visibility is decreased to less than 1 km and the relative humidity of the air reaches the saturation level (relative humidity close to 100%). A dense fog can induce extremely reduced visibility: to only a few meters sometimes. Fog is characterized by several physical parameters such as liquid water content, average particle size, particle size distribution and decrease in visibility^[2].

Fog can be divided into two categories Radiation fog and scattering fog.

The radiation fog is related to the ground cooling by radiation. It appears when the air is sufficiently cool and becomes saturated. So this is a fog which generally appears during the night and at the end of the day. Particle diameters vary weakly around 4 μm and the liquid water content varies between 0.01 and 0.1 g/m^3 ^[10]. The scattering fog is formed by the movements of wet and warm air masses above colder maritime or terrestrial surfaces. It is characterized by a liquid water content

higher than 0.2 g/m³ and a particle diameter close to 20 μm^[10].

A. Effects of Fog on FSO Link

The main challenge to implement an outdoor short-range optical wireless link is the atmospheric attenuation, CAUSED by the absorption and scattering. Water particles and carbon dioxide mainly cause the absorption of optical signals, whereas fog, rain, snow and clouds cause the scattering of optical signals transmitted in free space. This scattering causes portion of the light beam travelling from a source to deflect away from the intended receiver^[9]. Among various atmospheric effects on FSO communication, fog is the most deterrent attenuating factor. Fog causes significant attenuation of the optical signals for considerable amount of time and is thus highly deterrent for achieving high availability in FSO transmissions. The main reason of significantly high attenuations due to scattering in different fog conditions is that the size of fog particles is comparable to the transmission wavelengths of optical and near infrared waves^[11].

Research studies have shown that optical attenuations can reach up to 120 dB/km in moderate continental fog environments (Graz, Austria) in winter season and 480 dB/km in dense maritime fog environments in summer months Besides different fog conditions; rain and snow restrict FSO availability^{[11], [12]}.

B. Fog Attenuation models

As discuss above Fog is the most degrading component for optical transmission. Widely accepted models are the Kruse model and the Kim model^[13]. The limitations of these two models define in^[8] and gives two more models Al naboulsi Advection, Al naboulsi Convection. So these four models are found from literature review for the fog attenuation calculation.

The damping coefficient for the Kruse model can be calculated by the following equation.

$$\alpha_{fog} = \frac{3.912}{V} \left(\frac{\lambda}{\lambda_0} \right)^{-q} [km^{-1}] \quad (1)$$

Where,

V=Visibility at = 0 [km]

= signal wavelength and

λ_0 = reference wavelength for measurement of V [nm] with

$$q_{Kruse} = \begin{cases} 1.6 & V \geq 50 \text{ km} \\ 1.3 & 6\text{km} \leq V < 50 \text{ km} \\ 0.585V^{1/3} & V < 6 \text{ km} \end{cases} \quad (2)$$

The Kim model equals the Kruse model for visibilities > 6 km. For lower visibilities the Kim model is more accurate. Factor q for Kim model is given by:

$$q_{Kim} = \begin{cases} 0.16V+0.341 & \text{km} < V \leq 6 \text{ km} \\ V - 0.5 & 0.5 \text{ km} < V \leq 1 \text{ km} \\ 0 & V \leq 0.5 \text{ km} \end{cases} \quad (3)$$

Al Naboulsi advection (scattering) fog model is defined as

$$A = 10 \log(e) \frac{0.11478\lambda + 3.8367}{V} \quad (4)$$

Al Naboulsi convection (Radiation) model is defined as

$$A = 10 \log(e) \frac{0.1812\lambda^2 + 0.13709\lambda + 3.8367}{V} \quad (5)$$

Then using FASCOD software, they derived interpolation formulas applicable at the wavelengths from 0.69 μm to 1.55 μm for visibilities between 0.05 and 1 km^[8]. Al Naboulsi models were compared with experimental data measured on the site “La Turbie” at Nice, France where the transmission of light with the wavelengths 0.85 and 0.95 μm through dense fog was investigated^[14].

IV. FSO LINK BUDGET EQUATION

The link equation for a free-space optical system is defined as the amount of received power is proportional to the amount of power transmitted and the area of the collection aperture. It is inversely proportional to the square of the beam divergence and the square of link range. It is also inversely proportional to the exponential of the product of the atmospheric attenuation coefficient (in units of 1/ distance) times the link range means due to small variation in atmospheric attenuation can huge change on received power.

$$P_R = P_T \frac{A_{receiver}}{(Div.Range)^2} e^{(-\alpha.Range)} \quad (6)$$

Where,

P_R = Power received

P_T = Power transmit

$A_{receiver}$ = receiver area

Div = Bean divergence

α = atmospheric attenuation factor $\frac{1}{km}$

R = range

Looking at this equation, the variables that can be controlled are: transmit power, receive aperture size, beam divergence, and link range. The atmospheric attenuation coefficient is uncontrollable in an outdoor environment and is roughly independent of wavelength in heavy attenuation conditions. Unfortunately, the received power is exponentially dependent on the product of the atmospheric attenuation coefficient and the range. This means that a system designer can choose to use huge transmit laser powers, design large apertures, and employ very tight beam divergences, but the amount of received power will remain essentially unchanged the only other variable under the designer's control is link range^[15].

V. FOG IN LAHORE AND KARACHI

Pakistan is situated in continent of Asia between 23.30 degree and 36.45 degree latitude (North) and 61 degree and 75.45 degree longitude (East) and having four season

in over all country but for this thesis work two main urban areas of Pakistan Karachi and Lahore are selected those having more numbers of mobile subscribers and also more construction areas ,tall buildings and other obstacles in LOS links geographically situated at Latitude & longitude 24°48'N 66°59'E and 31°33'N 74°20'E respectively. Availability of FSO link is based on long term observation of metrological conditions of local climate where the link will be installing and also for the whole country. In Pakistan there is no keen interest in the measurement of fog just measure at the airports for air traffic control system. The research cities are metropolitan cities so there is huge air traffic cross over these cities due to that fog is measured at both cities airports.

Lahore is more dense area as compared to Karachi. From different metrological sites metrological data is found. There are 20 fog events occur in Lahore and only four events occur at Karachi in 2011. Given as tables

Table 1: Events of fog occurrence at Lahore in 2011

SN	MM : DD	Value of visibility in terms of (KM)			Event
		High	Average	Low	
1.	Jan: 1	0	0	0	Fog
2.	Jan: 6	2	1	1	Fog
3.	Jan: 7	8	1	0	Fog
4.	Jan: 8	2	1	1	Fog
5.	Jan: 9	2	1	0	Fog
6.	Jan: 10	3	1	0	Fog
7.	Jan: 11	4	2	0	Fog
8.	Jan: 12	4	2	0	Fog
9.	Jan: 13	4	3	0	Fog
10.	Jan:15	1	0	0	Fog
11.	Feb:15	5	4	1	F, R,T
12.	Mar:3	5	3	0	Fog, R
13.	Nov:23	3	2	0	Fog
14.	Nov:24	2	1	0	Fog
15.	Nov:25	4	2	0	Fog
16.	Nov:26	4	3	1	Fog
17.	Dec:27	4	2	0	Fog
18.	Dec:28	4	2	0	Fog
19.	Dec:29	3	2	0	Fog
20.	Dec:30	4	2	1	Fog
21.	Dec:31	4	2	1	Fog

Table 2 : Events of fog occurrence at Karachi in 2011

SN	MM:DD	Value of visibility in terms of (KM)			Event
		High	Average	Low	
1.	Jan: 9	9	5	0	Fog
2.	Jan: 12	7	5	0	Fog
3.	Oct:16	8	5	0	Fog
4.	Nov: 17	16	7	1	Fog

In Lahore there are 6 events in which average value of fog is 1km, 9 events of the value of 2km, 3 events of 3km, 2 events of 0km and only one event of 4km and in Karachi there are 4 events occur in whole year three of them having 5km visibility and only one have 7km visibility as shown in table below

Table 3 : All four models calculations for Lahore in 2011

S. No.	MM: DD	Average	krus	Kim	Al nabousli advection	Al nabousli convection
1.	Jan: 1	0	0	0	0	0
2.	Jan: 6	1	2.1339	2.3303	4.0188	4.4847
3.	Jan: 7	1	2.1339	2.3303	4.0188	4.4847
4.	Jan: 8	1	2.1339	2.3303	4.0188	4.4847
5.	Jan: 9	1	2.1339	2.3303	4.0188	4.4847
6.	Jan: 10	1	2.1339	2.3303	4.0188	4.4847
7.	Jan: 11	2	0.9114	0.9872	2.0094	2.2423
8.	Jan: 12	2	0.9114	0.9872	2.0094	2.2423
9.	Jan: 13	3	0.5440	0.5576	1.3396	1.4949
11.	Jan:15	0	0	0	0	0
12.	Feb:15	4	0.3737	0.3543	1.0047	1.1212
13.	Mar:3	3	0.5440	0.5576	1.3396	1.4949
14.	Nov:23	2	0.9114	0.9872	2.0094	2.2423
15.	Nov:24	1	2.1339	2.3303	4.0188	4.4847
16.	Nov:25	2	0.9114	0.9872	2.0094	2.2423
17.	Nov:26	3	0.5440	0.5576	1.3396	1.4949
18.	Dec:27	2	0.9114	0.9872	2.0094	2.2423
19.	Dec:28	2	0.9114	0.9872	2.0094	2.2423
20.	Dec:29	2	0.9114	0.9872	2.0094	2.2423
21.	Dec:30	2	0.9114	0.9872	2.0094	2.2423
22.	Dec:31	2	0.9114	0.9872	2.0094	2.2423

Table 4 : All four models calculations for Karachi in 2011

S. No.	MM: DD	Average	krus	Kim	Al nabousli advection	Al nabousli convection
1.	Jan: 9	5	0.2775	0.2401	0.8038	0.8969
2.	Jan: 12	5	0.2775	0.2401	0.8038	0.8969
3.	Oct:16	5	0.2775	0.2401	0.8038	0.8969
4.	Nov: 17	7	0.1453	0.1453	0.5741	0.6407

VI. PROPOSED FSO LINK SETUP

In This paper we proposed and select the maximum transmitter power for FSO system because weather degrades the signal power at maximum level due to wireless medium and also select the maximum aperture area 20cm because light is emitted from LASER in coherent nature as it travel the distance it follows inverse square law due to that light scattered and its power decrease linearly with increases the link distance. Our selected areas are urban due to that the link distance must be in the range of 0.75km to 2.5km because in these areas

numbers of users are greater so micro and Pico cells are used to increase the system capacity but due to increase the numbers of handoff some umbrella cells are also used but those umbrella cells are not in our interest and in hardware specification we found the range of FSO transceivers that must be fit in our selected area, due to compatibility with optical fiber cable 1.55 μ m wavelength is selected because most of the fiber optic components used this wavelength.

Our final proposed parameter is divergence angle and we select the 2mrad minimum value of beam divergence due to that reason that this value transmitted the narrow beam of light from the transmitter so transmitted data become secure. We conclude these setup parameters that become the best choice for various operators in Pakistan and summarized these parameters in following table.

Table 5: System Parameters

S. No.	Parameter	Available range	Proposed value
1	Transmitted power	140mW to 320mW	320
2	Receiver aperture area	10cm to 20cm	20cm
3	Beam divergence	2mrad to 10mrad	2mrad
4	Wavelength	0.69 μ m to 1.55 μ m	1.55 μ m
5	Range	50m to 3200m	2500m
6	Received power	-35dbm to -15dbm	-28dbm

VII. LINK BUDGET CALCULATION

The FSO link budget equation involved six parameters five from these mention in table V-1 by putting these values according to propose FSO link setup we simulate the link and the remaining one parameter is fog attenuation which is a function of operation wavelength 1.55 μ m. Other attenuation parameters like molecular and aerosol scattering coefficients are eliminate because they have negligible effect on FSO link. other losses that are due to wind, haze, mist, snow etc. are not focused in my paper so I normalized other losses make them zero only the fog attenuation is taking into account .

We summarized all simulation condition into six cases as shown in table

Table 6 : Simulation conditions

S.No.	Case No	Ave: Visibility (km)	Days in 2011
1.	Case 1	1 km	6 jan, 7jan, 8jan, 9jan,10jan and 24 nov
2.	Case 2	2 km	11jan,12jan, 23nov, 25nov, 27dec, 28dec, 29dec, 30dec, 31dec
3.	Case3	3 km	13jan, 3mar, 26nov
5.	Case 5	5 km	9jan, 12jan, 16oct
6.	Case 6	7 km	17nov

VIII. SIMULATION RESULTS

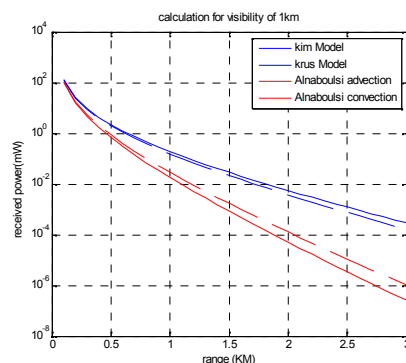


Fig.2. (a)

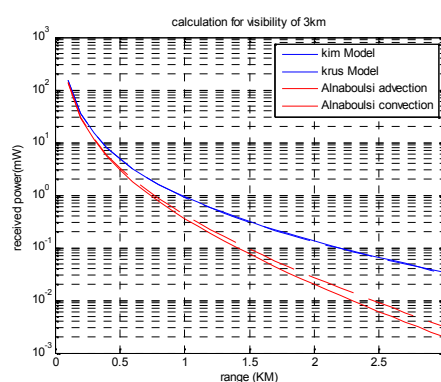


Fig.2. (b)

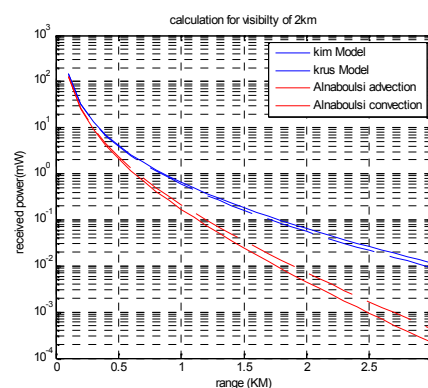


Fig.2. (c)

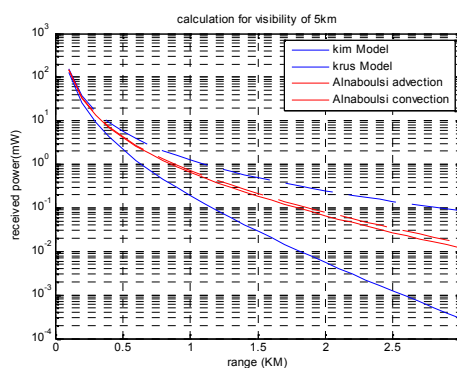


Fig. 2(d)

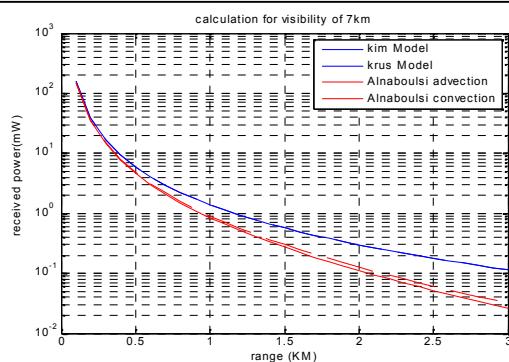


Fig.2. (e)

In the fig 2(a) the signal will become loss within the range of 1km because receiver can receive the signal up to 0.04mW (-28 db) so the link is unavailable for 12 to 16 hours maximum.

In fig 2(b) the signal will become loss according to Kim, krus, Al-nablousi advection and convection model within the range of 2150m, 2250m, 1443m and 1250m respectively because receiver can receive the signal up to 0.04mW (-28 db) so the link is unavailable for 12 to 16 hours maximum.

In fig 2(c) the signal will become loss according to Kim, krus, Al-nablousi advection and convection model within the range of 2811m, 2803m, 1735m and 1471m respectively because receiver can receive the signal up to 0.04mW (-28 db) so the link is available according to kim and krus model but unavailable according to Al-nablousi advection and convection model for 12 to 16 hours maximum.

In fig 2(d) the signal will become loss according to Kim, krus model above the range of 3000m so the link is available and according to Al-nablousi advection and convection model the range of received signal are 2000m and 2213m respectively because receiver can receive the signal up to 0.04mW (-28 db) so the link is unavailable for 12 to 16 hours maximum.

In fig 2(e) the signal will become loss according to Kim model the range of received signal is greater than 3km but according to krus model the range is 1409m and Al-nablousi advection and convection model tell us the range of 2430m and 2288m respectively because receiver can receive the signal up to 0.04mW (-28 db) so the link is available according to kim model but unavailable according to krus, Al-nablousi advection and convection model for 12 to 16 hours maximum.

IX. CONCLUSION

The purpose of this paper is to identify the link establishment problem due to fog attenuation calculation in climate of Pakistan. Two cities of Pakistan are selected first one is Karachi for less dense fog area and second one is Lahore for more dense fog area because both cities are highly populated, immense in mobile subscribers and other communication. The fog attenuation model calculation helps the telecommunication companies for system implementation.

Four models are simulated in Matlab environment to find out in which condition what will be the link establishment and unavailability chances.

In this thesis measurement setup for FSO link in the year 2011, the following simulation results are found.

If there were any FSO link in the range with 1Km in Lahore and Karachi then the link become unavailable for 49 hours in Lahore and there is no single event of unavailability in whole year in Karachi.

If link distance increases half Km then results are same as for 1Km in both cities Lahore and Karachi.

If link distance increase further half Km (2Km) then in Lahore the link unavailability duration is approximated 70 hours but in Karachi the link unavailability is zero. For the link distance 2.5Km the link unavailability in Lahore is approximated 4 days and in Karachi the link unavailability is for 20 hours according to Al-Naboulsi advection and convection models but Kim and Krus model shows that the unavailability of link is zero for Karachi.

If distance becomes greater than 2.5 Km the link is not available in Lahore as well as in Karachi.

This conclusion shows that FSO is best choice for Karachi because its climate does not degrade the signal power at long distance and availability of link is maximum, but in Lahore there is unavailability of link for duration of 95 hours, 70 hours and 49 hours when link range is 2.5Km, 2Km and 1Km respectively.

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