A Dominant Last Mile Connectivity Solution for 3G/4G Cellular Networks in Karachi

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Abstract:: The successful deployment of 3G network in Karachi mobile subscribers enjoyed multimedia features and meanwhile the huge multimedia data of mobile subscribers create more congestion connectivity at subscriber end. RF links does not support high data rate so alternate solution is fiber optic cable, but the under laying and maintenance of these cables is crucial problem in metropolitan cities due to huge traffic on roads. The final alternate solution is Free Space Links (FSO) because it eliminates the disadvantages of both traditional solutions. FSO is the transmission of data in line of sight (LOS) link, modulated by Infrared (IR) waves and travel via open air. So like all other open air setup it is weather sensitive and fog is the dominant phenomenon that causes unavailability of FSO links. In this paper unavailability event estimation are given using existing fog models on the basis of last four year visibility statistics data.

Keywords:*Fog Models, FSO Links, Unavailability Estimation, Full duplex, Line-of-sight*

1. Introduction

Free Space Optics FSO is the transmission of full duplex high data rate using optical signals in point to point manner through open air. At the transmission end electrical signals converted in to IR signals via laser and received by photo diode at receiving end. Furthermore FSO gives inherent advantages such as, no electromagnetic interference, need no license form regulation authority, secure due to narrow band, data rate equal to or greater than fiber optic cable, easy and quick deployment, low maintenance etc. In April 2014 after the successful biding of 3G/4G spectrum, Cellular service providers start a race for installation new 3G/4G sites and upgrades old sites. Furthermore, the number of broadband users on the network has a remarkable increase. Finally, increasing in the shipping of smart phone to Pakistan and mobile broadband service are also notable. Broadband services data sent by 3G/4G subscriber's results congestion on last mile connectivity, so existing last mile RF connectivity will reach up to bottleneck.

The alternate solutions include Fiber optic cable and free space optics. Due to metropolitan nature of network installation area, lying of fiber optic cable is difficult, time consuming and expensive solution makes service providers last in race. FSO is preferable solution at last mile connectivity due to easy deployment, cheapest and quick installation. Data travel from the open air makes FSO links weather sensitive. Three phenomena occur in the atmosphere when a light signal passes from molecules and aerosols presents in the atmosphere, scintillation, absorption and scattering. Scintillation can be removed by the proper design of FSO system [1]. Molecular absorption and scattering are negligible due to non-comparable size of the operating wavelength with molecules dimensions. From aerosols fog is the most affecting parameter due to comparable size of operating wavelength with the radius of fog particle. Absorption due to fog is negligible because fog is the suspended drops of water in air so they are transparent or weakly absorbed. Only scattering form the fog particles causes unavailability of FSO links due to LOS nature of link. Amount of fog is measured in terms of visibility, defined as must define. Visibility is regularly measured near airports for air traffic control (ATC) and updated on metrological sites. Karachi is the metropolitan city so it is also measured regularly for ATC purpose. On the basis of measured visibility fog attenuation models are used for converting the visibility values in optical attenuation factor[2] There are six existing fog models namely, Kruse, Kim, Al-noublsi advection, Al-noublsi convection, Ferdinandov and Grabner. This paper present the effect of fog on FSO link based on existing fog attenuation models and concludes the availability of FSO links deployment in Karachi Pakistan.The further paper is organized as section two provide the detail discussion about changes occur in telecommunication market of Pakistan, section three provides the discussion of the existing fog models, section four shows the visibility statistics of Karachi furthermore section five gives the parameters of FSO link and link budget equation, section six shows simulation results and finally the last section shows the conclusion.

2. Pakistan Telecommunication Market Divergence in 2015

According to the annual report 2015 of Pakistan Telecommunication Authority (PTA) [3] several notable changing occur in telecommunications market of Pakistan which enforces the service providers to upgrade the systems with cutting edge technologies. First factor is number of 3G/4G cellular service subscribers crossed 16.89 million in 2015 with a jump of 345%, from them 80% users used broad band data services. Second factor, the data usage after September 2014 3G/4G data increases from 2G data in June 2015 3G/4G broadband data reach up to 9.860 TB while 2G data is only 2.563 TB. Third factor, smart phone shipment to Pakistan is also increased and reaches up to 31% as compared to 2014 increase 17%. Fourth

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factor, the number of cell site growth is also increased, 3128 new cell sites were installed in last year. Furthermore, PTA starts a new project smart Pakistan which is a central web portal for m-services developing and hosting. Finally, in terms of improving the security of educational institutions PTA launch Mobile Emergency Alert System for Schools (MEASS). All the above discussed factors enforces that too much data sent by mobile subscribers, so at the last mile connectivity FSO is a strong candidate [4].

3. FSO Link Budget

When optical signal of specific wavelength emits form FSOTransmitter and propagate through open atmosphere (which consists molecules and aerosols) two natural phenomena affect the signal power scattering and absorption generally summarized in one term extinction. Furthermore, four parameters can be calculate for extinction measurement, molecular absorption α_m (λ), aerosols absorption α_a (λ), molecular scattering β_a (λ) and aerosols scattering β_m (λ) mathematically:

$$\gamma(\lambda) = \alpha_m (\alpha) + \alpha_a (\alpha) + \beta_a (\lambda) + \beta_m \quad (l)$$

Molecular absorption and scattering produce negligible effect on FSO link while maximum power degrade when fog (a type of aerosol) exist in atmosphere because operating wavelengthof FSO link is comparable with the radius of fog particles[must [5]. Fog consists water which have very weak absorption so it is negligible and can be minimized up to sanctification levelwith proper link design [must cite]. So in nut shell over all attenuation becomes

$$\gamma(\lambda) = \beta_m (\lambda) \quad (2)$$

According to Beer Lambert law the total transmittance is the Ratio of transmitted power to the received power at specific Distance mathematically:

$$\text{Transmittance} = e{-}\gamma^{(\lambda)L} \quad (3)$$

The link budget for FSO link is given in [must cite] as:

$$P_{received} = P_{transmitted} / A_{receiver} \times (Div \times L)^2 \times e{-}^{\beta(\lambda) \times L} \quad (4)$$

As shown in (4) Received power is proportional to the power transmitted and receiver area while inversely proportional with the square of the product of beam divergence and link distance. Finally received power is exponentially related withatmospheric loss (β (λ)). Due to exponential relation received power is quite sensitive with atmospheric loss a little change in β (λ) create a huge change in received power. Due to this exponential relation link designers need too much prior knowledge of the atmosphere where FSO link would be deployed specially fog existence. For this reason design of Fog Models are in keen interest of researchers since last decade. For the prior knowledge of atmosphere visibility is key parameter for calculating the specific fog attenuation.

4. Visibility Statistics of Karachi

Karachi is the largest and metropolitan city of Pakistan having population 24 million in an area of 1362 square miles. Currently Karachi faces crucial problem regarding traffic about.

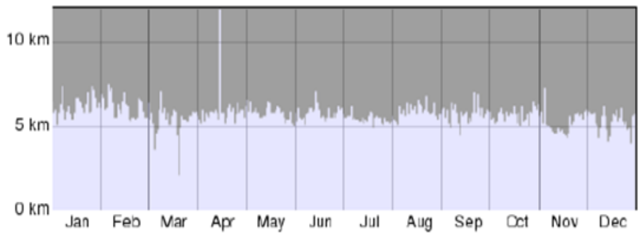

Figure. 1. Visibility statistics of Karachi in 2012

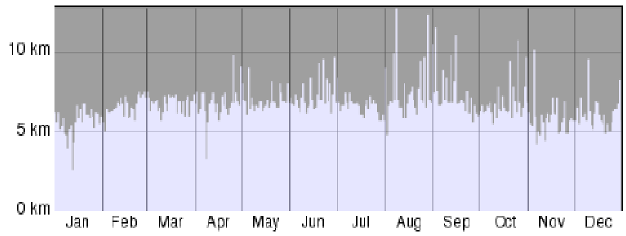

Figure. 2. Visibility statistics of Karachi in 2013

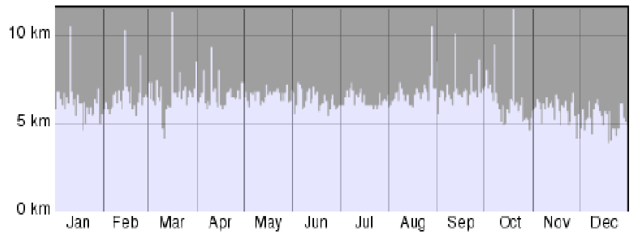

Figure. 3. Visibility statistics of Karachi in 2014

33% of all motor vehicle running on the roads of this withthe road density of 207 km in 100Km2 with poor maintenance and low quality construction also already limited road affected due to violation of on road-parking [gazdar2015transport]. Due to this factor lying of fiber optic cable is time consuming, risky and costly solution.As shown in Fig.1.

The lowest value of the visibility in November and December and maximum value in August over all 2 events occur in which minimum value of visibility is less than 4 Km out of 365 days in year 2012.As shown in Fig.2 the lowest value of the visibility in November and January and maximum value in June over all 4 events occur in which minimum value of visibility is less than 4 Km out of 365 days in year 2013. As shown in Fig.3 the lowest value of the visibility in November and December and maximum value in April over all 5 events occur in which minimum value of visibility is less than 4 Km out of 365 days in year 2014.

As shown in Fig.4 the lowest value of the visibility in November and January and maximum value in April over all 20 events occur in which minimum value of visibility is less than 4 Km out of 365 days in year 2015.For all four year visibility statistics data shown in table.1shows that in November visibility statistics has minimum values, while December has lowest values in 2012 and 2014 but for the January 2013 and 2015 shows minimum value of visibility. Furthermore, for maximum values April 2015 and 2014, June 2013 and August 2012 are dominant months.

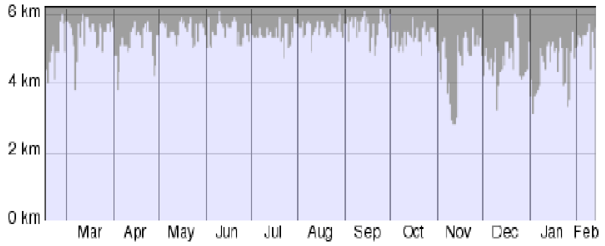

Figure. 4. Visibility statistics of Karachi in 2015

TABLE I
VISIBILITY STATISTICS OF KARACHI 2012 TO 2015

Year	Min: V (month)	Max: V (month)	Fog events for $V < 4Km$
2012	Nov, Dec	Aug	2
2013	Nov, Jan	Jun	4
2014	Nov, Dec	Apr	5
2015	Nov, Jan	Apr	20

Finally, there are total 31 fog events occur from 2012 to 2015in which the value of visibility is less than 4Km.

5. FOG Models

The main function of fog models is to convert the available visibility statistics V in to specific fog attenuation factor β(λ).The values of visibility is regularly update on meteorological sites so this one is easy and robust way for calculating the optical attenuation when light beam passes from fog particles. Several researches worked on the formulating the fog models every fog models having its on importance. At the first point they started a race for designing the fog models for calculating the specific attenuation factor from as much as minimum visibility values. In the beginning, two models were derived from Kochmieder law which describes the relation between visibility and specific attenuation factor[6].

$$\beta(\lambda) = 3.912 / V\ (\lambda/550)^{q} \qquad (5)$$

In [Kim] Kruse conclude the value of q by solving Kochmieder law in iterative manner and solve β(λ) from classical Mie theory. Furthermore, in our case we have only fog events when visibility less than 4 Km, so kruse gives the relation by setting the value of q as:

$$q_{\text{Kruse}} = 0.585 / V^{-1/3} \qquad (6)$$

In (2) all the wavelength attenuate in same way when V < 6Km and for the visibilities V ≤1Km specific fog attenuation factor become independent of operating wavelength of FSO link. so in [kim] suggest new value of q factor and given as: all wavelengths are not attenuated same way for the visibilities V < 6Km but kim split this range in to three section but this equation again not sufficient for the visibilities less than 0.5 km because the value of q=0, so fog attenuation factor become independent of operating wavelength. Another fog model is suggested in [grabner] which gives the value of q as a function of effective radius r_e of fog particles[7].

$$q = 2(\tanh (P_1 (w+P_4))-1)\ P2 \exp (-P_3 (w+P_5)^2) \qquad (7)$$

$$w = \log10\ (r_e) \qquad (8)$$

$$r_e = r_o(0.05/V)^{1/2} \qquad (9)$$

as shown in (6) that when the value of visibilities less than 0.05
Km, specific fog attenuation factor becomes independent of the wavelength. Finally the parameter Pi is depend upon selected range of operating wave length from whole transmission window[8]. In weak points of Kruse and Kim model addressed in terms of accuracy and conclude a new model by dividing fog in to two type advection and convection [9]. He further concludes that when visibility is less than 0.5 Km all wavelengths attenuate in same way and gives:

$$\text{att spec} = \frac{10}{\ln 10}\beta(\lambda) \qquad (10)$$

Where β(λ) is defined separate for advection and convection type of fog as:

$$\beta_{ADV}\ (\lambda) = 0.11478l + 3.8367/V \qquad (11)$$

And for convection fog type

$$\beta_{RAD}\ (\lambda) = 0.18126l2 + 0.13709l + 3.7502/V \qquad (12)$$

Advection and convection fog models are used for the entire transmission window of FSO link and validate for the visibilities up to 0.05 Km [10]. Another general fog models that is also designed from the kochmieder law by trickle it through taking 550nm operating wavelength so equation (1) becomes

$$\beta(550) = 3{:}912V^{-1} \qquad (13)$$

The generalized the values of operating wavelength l and V for entire transmission window and gives specific fog attenuation factor as a function of V and λ [11]

$$\beta(V,\lambda) = A\ (\lambda)\ V^{-Q\ (\lambda)} \qquad (14)$$

Where A (λ) = -2.656ln (λ) +2.499 and Q (λ) = 1.99ln (λ) +1.157 and both are the function of operating wavelength.

6. Methodology and Simulation parameters

As mentioned in (4) we select the FSO link parameters by the specification of various vendors and select the maximum transmitted power and receiver area because they are proportional to the received power[12,13]. The selection of receiver sensitivity is minimum because receiver having the capability to receive the minimum signal. Furthermore, the beam divergence is selected maximum available in specification of vendors due to having inversely relation with received power. Finlay, the main parameter is operating wavelength which is important for the calculation of specific fog attenuation factor which is exponentially related with received power. The entire transmission window for FSO is license free so system designers are free to select any transmission wavelength but mostly using the same wavelengths of fiber optics cable due to compatibility of the existing system and hardware range. The overall selected simulation parameters the shown in table.1 given below.

Table 2.FSO Link Setup

parameter	available range	selected value
Transmission power	140 to 320 (mW)	300 mW
Receiver sensitivity	-35 to 15 dBm	-32 dBm
Operating wavelength	0.69 to 1.55 μ m	1.55 μ m
Beam divergence	2 to 10 mrad	2 mrad
Receiver area	10 to 20 cm	20 cm

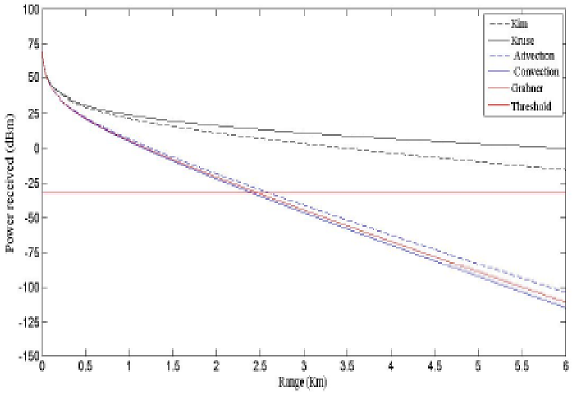

Figure.5. Link availability when visibility is 4 Km

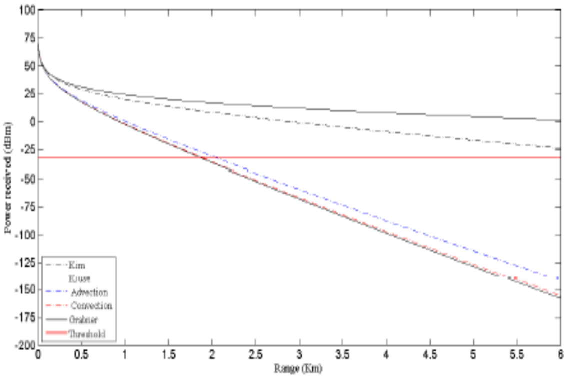

Figure. 6. Link availability when visibility is 3 Km

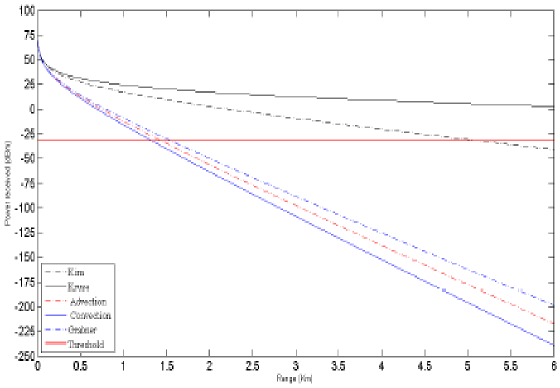

Figure. 7. Link availability when visibility is 2 Km

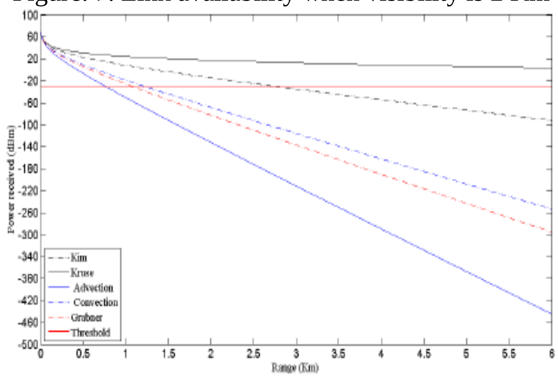

Figure.8. Link availability when visibility is 1 Km

7. Simulation Results

Fig.5 to Fig.8 shows the received power in dBm versus link distance (Range) when the visibilities are 4 Km, 3 Km, 2 Km and 1 Km respectively. Fig.5 shows that for the Link when visibility is about 4 Km according to Kim and Kruse link become available up to 6 Km range but for the Advection, Convection and Grabner model link become unavailable at the range of approximately 2.5 km. For the 3 Km visibility Fig.6 shows the received power versus range. Advection, Convection and Grabner model tell us that the link become unavailable at the range in between 1.5 to 2 Km but at the same time Kim and Kruse shows link is available up to the range of 6 Km. Fig.7 tell us that when the visibility is 2 Km according to Advection, Convection and Grabner link become unavailable in between the range of 1 to 1.5 Km. Kim model shows the unavailability occur in between 5 to 5.5 Km but Kruse model gives same result for all the visibilities less than 6 Km. Finally Fig.8 shows the range versus received power for the visibility is about 1 Km Advection, Convection and Grabner model shows that the in between 0.5 to 1.5 Km FSO link become unavailable but for the Kim link become unavailable at the distance 3 to 3.5 Km.

8. Discussion

In all four simulation scenarios the values of visibilities is in between 1 Km to 6 Km so Kruse model shows approximately same result and tells that the link become available. The Kim model for lower visibilities in range of 1 to 2 Km gives unavailability events for the FSO link that makes point to point link at the distance in between 2.5 Km to 5 Km. furthermore, Kim model is proved in under controlled laboratory condition [two citation my paper and other] but not in outer sides where FSO link practically installed. as shown in all simulation results other three fog models Advection, Convection and Grabner gives different results because Al-Naublsi derived Advection and convection models by addressing the drawbacks of Kim and Kruse model that, they ignore the drop size distribution of Fog particles, worked only on theoretical assumptions of Mie theory, shows independence between operating wavelength and fog attenuation. So by adding these revised calculation it shows greater attenuation. Finally, Grabner add two more parameter effective radius of fog particle and liquid water content LWC. LWC parameter is very easy, cheaper and faster method for finding fog attenuation in in-situ measurement.

9. Conclusion

Due to high density of mobile user and 3G services mobile services providers install too much sites in Karachi so cell sites comes closer the link distance is in between 0.75 Km to 1.5 Km except umbrella cells. All simulation results show the link become available at this range but for the lower values visibility may cause unavailability events.as visibility statisticsshows that there are only 29 fog events occurred in last four year. The overall discussion shown that the availability of FSO links for the link distance up to 2 Km is 99.99%, hence FSO is a dominant and cheaper solution for the last mile connectivity.

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