International Journal of Scientific & Engineering Research, Volume 4, Issue 7, July 2013
ISSN 2229-5518

Analysis of FSO Communication Links for Mid And Far Infrared Wavelengths

Rajan Miglani

Abstract— Atmospheric attenuations pose biggest challenge in implementing Free Space Optical Communication (FSO) links. Studying atmospheric attenuation as function of cumulative aerosol particle size distribution gives more reliable results rather than taking meteorological visibility as lone factor. Theoretically speaking, wavelengths of Mid IR and Far IR region may exhibit higher immunity against atmospheric attenuation against lower spectral regions but however in practical terms, the effect of totality of system and link parameters negates any such inherit advantage which means that considering the dynamic microenvironment, FSO link does not exhibit any attenuation immunity using higher spectral bands. Increase in transmitted optical power and higher receiver sensitivity along with appropriate selection of photo detector not only improves BER of system but also increases the range of communication.

Index Terms— FSO attenuation Models, Digital Signal to Noise Ratio (DSNR), Generalized Link Margin (GLM), Transmittance, Bit Error Rate (BER) .

1 INTRODUCTION

Free Space optical communication (FSO) is fiber less point-to-point Infrared (IR) spectrum based optical communication link between optical transreceivers which are separated by atmosphere as physical medium. Compared with conventional RF systems, FSO has various inherit advantages like, IR spectrum is unregulated and hence doesn't needs any licensing, due to point-to-point configuration laser beam generated are narrow and invisible to human eye, making data impossible to intercept. Most FSO systems are plug and play devices, independent of transmission protocol and data rates [1].

The performance of FSO links is significantly limited and handicapped due to absorption and scattering phenomena of atmosphere. Fog event and strong snow events are the most adverse weather conditions because they result in high specific attenuation to optic waves [2]. Several models describing the relationship between atmospheric visibility and related optical attenuation have been published [3,4,5]. The Kruse [3] and Kim [4] models were based on the visibility definition for a 0.55 µm wavelength. Al Naboulsi models were obtained by interpolating results from FASCOD software [5]. Our core work remained in creating understanding about wavelength selection which could help design systems that may be immune to atmospheric visibility degradations. The growing perception that wavelengths of higher order (10µm) will offer high link reliability [6,7], needs to be looked into again as this claim seems to be lopsided and considerable work has been done by [8] to contradict the claims of advantage of higher wavelengths.

This paper has been divided in five sections. Section I contains brief reference to initial epmerical theories that related atmospheric attenuation as function of wavelength used and visibility. Wavelength selection from perspective of system and link parameters has been studied in Section II. In Section III results obtained from Optiwave™ have been presented to contradict the claims the efficiency of higher order wavelengths. Results and Conclusions have been compiled in Section IV while future research scope ideas have been listed in Section V.

2 SECTION I

The premier work in FSO domain started with empirical formula given by Kruse [3] which relates the system attenuation with atmospheric visibility

$$\gamma(\lambda) = \frac{3.912}{V}\left(\frac{\lambda(nm)}{550}\right)^{-q} \tag{1}$$

The coefficient q depends upon

$$q=\begin{cases} 1.6 & V > 50\ kms \\ 1.3 & 6kms < V < 50kms \\ 0.585V^{1/3} & V < 6kms \end{cases} \tag{2}$$

where V is visibility in Kms and λ is wavelength in nm and $\gamma(\lambda)$ represents specific attenuation. While Kruse suggested lower attenuation for higher wavelengths, Kim et. al[4] came up with interesting modifications in coefficient q.

$$q=\begin{cases} 1.6 & V > 50\ kms \\ 1.3 & 6kms < V < 50kms \\ 0.16V + 0.34 & 1kms < V < 6kms \\ V - 0.5 & 0.5kms < V < 1kms \\ 0 & V < 0.5kms \end{cases} \tag{3}$$

[4] States, wavelength selection has no effect in case of low visibility conditions (up till 500 meters) with as shown in figure 1. However beyond 500 meters of visibility, both Kim and Kruse predict same idea of decreasing attenuation with increasing wavelength; however Kim proposed lower dip in attenuation, figure 2(a).

Al Naboulski et. al [5] extended the attenuation and wavelength selection relation based on distribution particle and their size rather than just studying the visibility. [5] Predicted attenuation relationship based on results from FASCODE, which is software based analysis tool for real time atmospheric behaviour toward atmospheric attenuation. The fundamental of FACODE lies with Mie scattering phenomena which is again extension of aerosol particle size distribution. [9] Relates particle distribution with particle size as:

$$n(r) = ar^{\alpha}\exp(-br) \tag{4}$$

Where n(r) represents number of particle per unit volume per unit increment of radius r while a,b,a represent characteristic of particle size distribution. From figure 2(b) conclusion can be drawn that for given visibility as the wavelength increases, it approaches the particle size and hence attenuation

International Journal of Scientific & Engineering Research Volume 4, Issue 7, July-2013
ISSN 2229-5518

increases. For this, [5] categorised fog into two types based on their particle size density and distribution, Advection fog and Convection Fog.

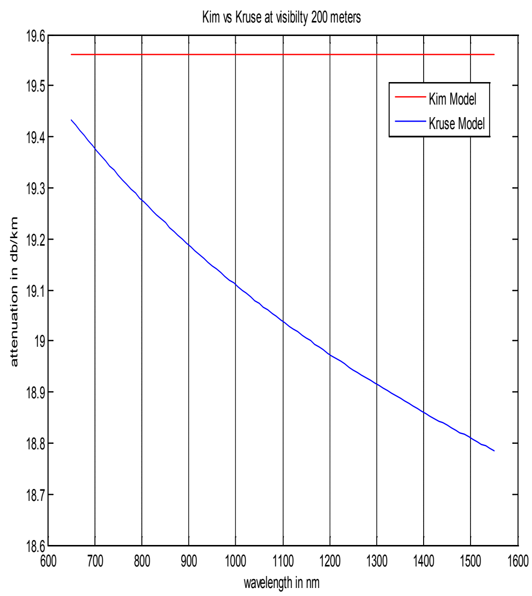

Fig. 1 Kim v/s Kruse model for visibility 200 meters at different wavelengths

3 SECTION II

Since the studying atmosphere attenuation as function of visibility presents only the half picture in understanding wavelength selection hence it became it must be understood very clearly that the microenvironment in which a FSO link operates is highly dynamic, unpredictable and out of human control hence it becomes necessary to study the effect of atmosphere on system and link parameters and then use the totality of these parameter aspects to decide the optimum operational levels which finally can better idea about wavelength selection. The received power law model which uses receiver sensitivity as bases for deciding link availability provided interesting results. The received power also called as Generalised Link Margin is calculated as [10]

$$Pt = Ps\ \frac{L\times D^2}{d^2\times R^2\times 1e6}10^{(-\alpha.R/10)} \qquad (5)$$

P_t , Ps are transmitted and received optical power in watts, L is transmit and receive optical losses(100%), D is receiver aperture diameter (met), R is link Range (Km), a is specific atmospheric attenuation in db/Km. Figure 3, describes system with visibility 8 kms while link range was studied at 0.2, 2 and 6 kms, with transmitted power 35mW. The received power showed very little or no improvement with use of wavelengths of higher orders, however increasing transmitted power does offer promising results but then practical limitations of using higher powers must be kept in mind.

Another important system parameter is Signal to Noise Ratio (SNR) at receiver end. Since the FSO system deals with digital data, hence SNR has been modified to be called as Digital Signal to Noise Ratio (DSNR) and is given as [6]:

$$DSNR = \frac{RPs}{\sigma_0+\sigma_1} \qquad (6)$$

P_s is received power, R is receiver responsivity, σ_o is current variance in absence of any signal while σ_1 is current variance in presence of received signal. As in case of Figure 4, the advantage of using of higher wavelength is negated on account of absorption that takes over the entire link range.

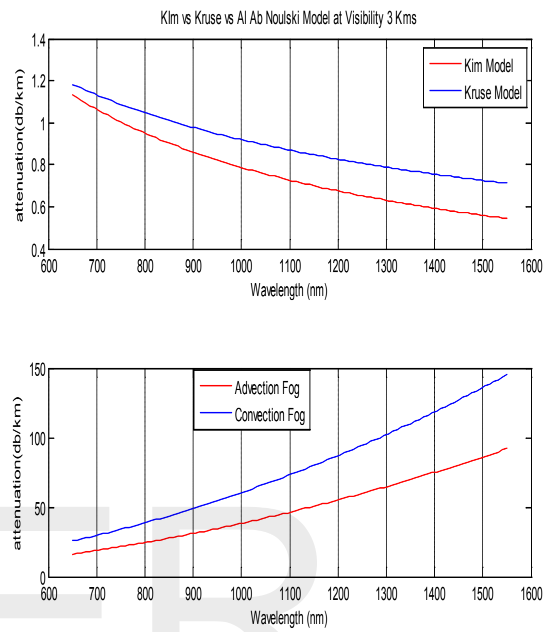

Fig. 2 (a) Kim v/s Kruse Model for visibility 3 Kms (b) Fog models using Al AB Noulski Model

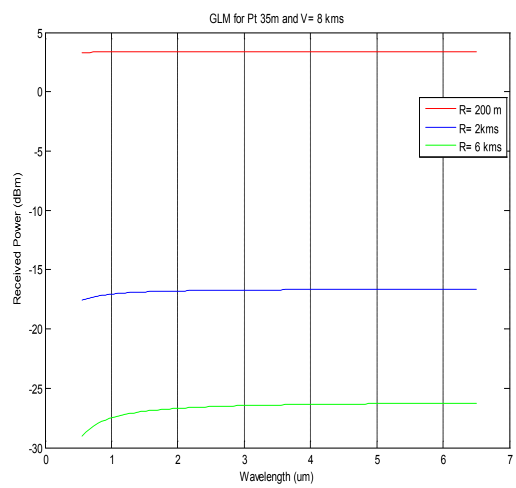

Fig. 3 Generalized Link Margin (GLM) for different System Ranges at visibility 8 Kms.

Transmittance as given by Beer's Law is also an important feature in context with transmission of optical data in free space. Transmittance defines the ability of optical pulse of par-

International Journal of Scientific & Engineering Research Volume 4, Issue 7, July-2013
ISSN 2229-5518

ticular wavelength to penetrate through minute atmospheric obstacles which range from aerosol particles, fog, smoke, snow and rain etc and is given by:

$$\tau = e^{-\gamma L} \quad (7)$$

Where τ is transmission coefficient, γ is atmospheric attenuation (dB/Km) and L is link range in Kms. Figure 5 describes Beer's Law for link range of 2 kms under different visibility conditions of 1, 5, 10 kms, Though this law suggest better transmittance at increasing wavelengths but it must be noticed that for higher visibilities the somewhat transmittance saturates beyond 3µm- 4µm mark while for very low visibilities the improvement is although linear but not very appreciable.

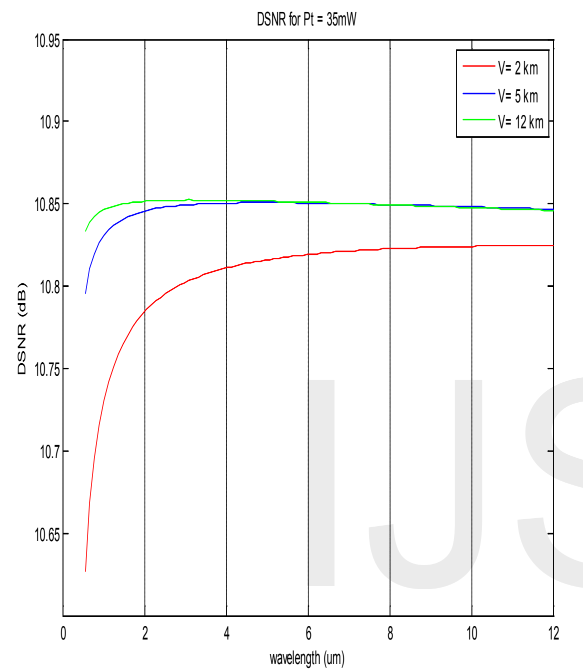

Fig. 4 DSNR for a receiver at different visibilities at different wavelengths.

4 SECTION III

In this section the simulating environment provided by Optiwave™ was used to ascertain the degree of correctness of theoretical results with ones obtained using Matlab as discussed in previous section. Optiwave™ helps to create a virtual environment using wide range of practically available lasers, detectors, optical and electrical amplifiers and all other necessary equipment required to design a virtual system that works exactly the same way as the any real world application may have performed.

In our case a externally modulated laser along with random data bit generator was used as the transmission equipment. On receiver side PIN diode was used along with other necessary demodulating equipments separated by the transmission medium, atmosphere. The system was tested for wide range of parameters which include range, wavelength, atmospheric attenuation and transmission power.

Figure 6a shows eye patter for system with range 500meters, atmospheric attenuation 80dB/Km, receiver sensitivity -30dBm and transmission power 35mW. This system was simulated for wide range of wavelengths ranging from 0.785µm to 6.1µm, but in all cases the BER remained similar i.e. 3.16×10^{-11}. However when the transmission power was raised to 45mW, the BER improved to 4.18×10^{-17}, as shown in figure 6b, thus implying that under foggy conditions, longer wavelength does not help.

Another interesting fact that came during study was that for same system and using similar parameters NRZ modulation outperformed the RZ modulation scheme in terms of BER at receiver. Also if receivers' sensitivity has improved to -50dBm, the range could be further extended while maintaining optimum BER levels, figure 7. In this case the transmission range was successfully enhanced to 680 meters while BER was 8.63×10^{-10}, under similar atmosphere as stated in above case.

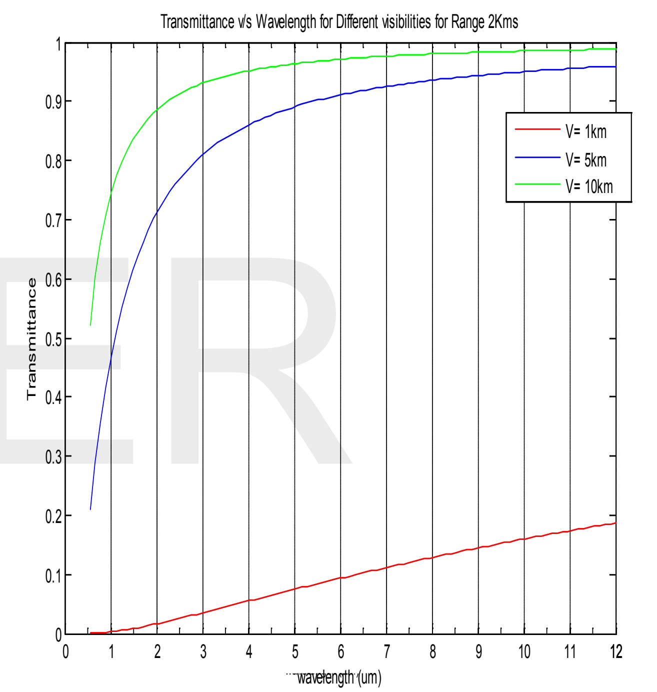

Fig. 5 Transmittance as observed using Beers Law

Use of PIN diode as against APD in receiver section gave improved BER. This particularly because the multiplying factor in APD, which not only enhances the gain but also enhances other undesirable factors like shot noise, thermal noise and background noise. The performance of the two has been tabulated in table 1.

5 RESULTS AND CONCLUSIONS

From the above study it can be concluded that the visibility alone cannot be taken as factor for considering the atmospheric attenuation as considered in empirical methods of Kruse and Kim. While Kruse law is extrapolation of Koschmieder's Law, fails to justify the link performance under severe foggy weather. Kim's law which came as an improvement over the former solved the mystery of like behaviour

International Journal of Scientific & Engineering Research Volume 4, Issue 7, July-2013
ISSN 2229-5518

under intense foggy weather where visibility falls to less than 6kms but then both of these empirical approaches fail to study the physical and structural composition of link environment. The dynamism of atmosphere which includes visibility as a factor of aerosol particle size and its physical particle distribution must be taken into account to get real time atmospheric conditions.

FSO Link and System Parameters	Transmitter Power (mW) / Receiver Sensitivity (dBm)	BER using PIN Diode	BER using AP Diode
Range= 500 meters Wavelength=1550 nm EML source, NRZ Mod^n Atmospheric attenuation= 80dB/Km	35mW / -30 dBm	3.6×10^{-11}	1.3×10^{-10}
	45 mW / -30 dBm	1.8×10^{-16}	8.6×10^{-17}
Range= 680 meters Wavelength=1550 nm EML source, NRZ Mod^n Atmospheric attenuation= 80dB/Km	35 mW / -50 dBm	8.6×10^{-10}	1.3×10^{-4}
	45 mW / -50 dBm	2.8×10^{-13}	4.6×10^{-6}

Table 1 Comparison of BER for PIN and APD at different transmitted power and receiver sensitivity at different ranges

System attenuation as function of wavelength, presents only the half picture from the transmitter point of view hence the selection of wavelength must be based on link and system parameters as well. Factors like link range, wind current, uneven aerosol distribution, receiver noise etc. negate the advantage lower attenuation using higher wavelength achieved during transmission. Thus has been confirmed while studying the receiver DSNR and received power, which displayed no such advantage of wavelength. However the only advantage which itself was again quite negligible was witnessed below the Mid IR region i.e. below 3 μm - 4μm.

Enhanced power at transmitter and improved receiver sensitivity can be very effectively used to make system immune to atmospheric vulnerabilities but it also helps to extend the system range while maintaining optimum level of BER. This can be done using Externally Modulated Laser (EML) sources coupled with optical amplifiers like EDFA at transmitter side while at receiver side PIN photodiodes can be used that offer higher receiver sensitivity.

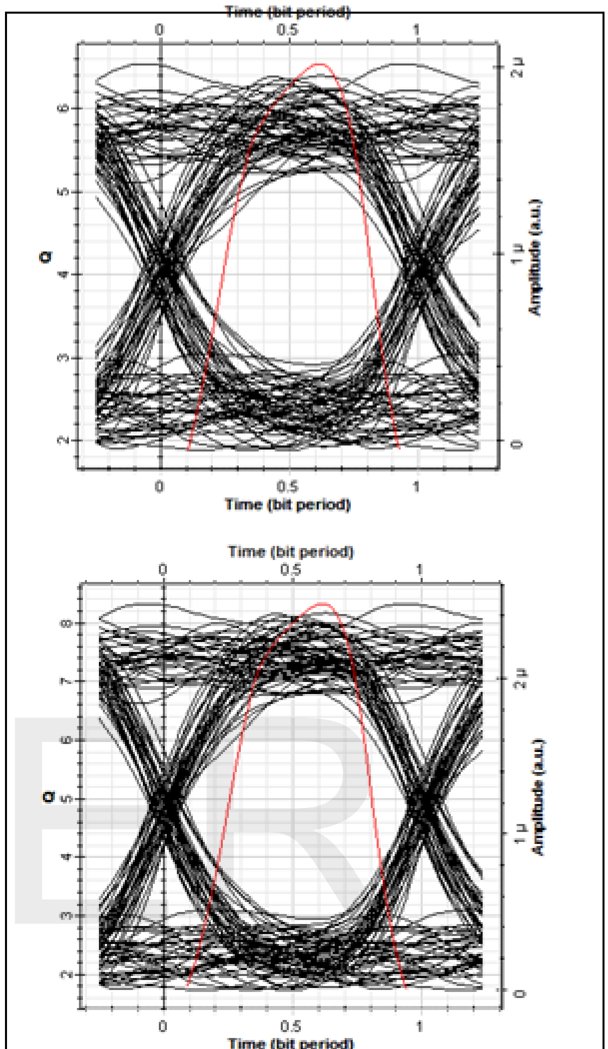

Fig. 6 Eye Pattern for virtual FSO system at transmitted power (a) 35mW (b) 45mW

6 FUTURE SCOPE

Since it has been very much concluded that optimization of FSO systems depend upon totality of system and link parameters and not on spectral variation alone. Hence our future course of action will focus be to integrate different microwave wireless modulation techniques with FSO systems along with building FSO system and test its response for different ranges of collimating lenses used in telescope so as to improve the light collimation and gathering ability at transmitter and receiver respectively.

REFERENCES

[1] Z. Bielecki, W. Kolosowski and J. Mikolajczyk, "Free Space Optical Communication using Quantum Cascade Lasers", PIERS Proceedings, Cambridge, USA, July 2-6, 2008

[2] Martin Grabner, Vaclav Kvicera," Experimental Study of Atmospheric Visibility and Optical Wave Attenuation for Free space optics

International Journal of Scientific & Engineering Research Volume 4, Issue 7, July-2013
ISSN 2229-5518

communication", Czech Science Foundation project No. 102/08/0851

[3] P. Kruse, L. McGlauchlin, R. McQuistan, "Elements of Infrared Technology: Generation, transmission and detection". John Wiley & Sons, 1962

[4] I. I. Kim, B. McArthur, E. Korevaar, "Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications," Proc. of SPIE, 4214, 2001, pp. 26-37

[5] M. Al Naboulsi, H. Sizun, F. de Fornel,,"Fog attenuation prediction for optical and infrared waves," Journal of SPIE, Optical Engineering, 43, 2004, pp. 319-329.

[6] Haim Manor, Shlomi Arnon,"Performance of an optical wireless communication system as function of wavelength," Vol. 42 No. 21, Applied Optics, July 2003

[7] Maha Achour," Free-Space Optics Wavelength Selection: 10 µ Versus", Ulm-Tech.

[8] E.Korevaar, I.Kim, B.McArthur," Debunking the recurring myth of magic wavelength for free space optics", Optical Wireless Communication,SPIE 4873,155, 2002

[9] Maher Al Naboulsi, Frédérique de Fornel, Hervé Sizun, "Measured and predicted light attenuation in dense coastal upslope fog at 650, 850, and 950 nm for free-space optics applications", Optical Engineering 47(3), 036001 ,March 2008

[10] White paper on Generalised link margin, "Defining a Common Standard for Evaluating and Comparing Free-Space Optical Products," by fSONA Communications, www.fsona.com.