Analysis of FSO Communication Links for Mid And Far Infrared Wavelengths

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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 negate any such inherent 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 transceivers which are separated by atmosphere as physical medium. Compared with conventional RF systems, FSO has various inherent advantages like, IR spectrum is unregulated and hence doesn’t need 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 Naboulski et. al [5] extended the attenuation and 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 higher 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 emperical 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

\[ \gamma(\lambda) = \frac{0.912}{V} \left( \frac{\lambda}{550} \right)^{-q} \]  

(1)

The coefficient q depends upon

\[ q = \begin{cases} 
1.3 & V > 50 \text{ kms} \\
0.85V^{1/3} & V < 50 \text{ kms} 
\end{cases} \]  

(2)

where \( V \) is visibility in Kms and \( \lambda \) 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.

\[ q = \begin{cases} 
1.6 & V > 50 \text{ kms} \\
1.3 & 6 \text{ kms} < V < 50 \text{ kms} \\
0.16V + 0.34 & 1 \text{ kms} < V < 6 \text{ kms} \\
0 & V < 1 \text{ kms} 
\end{cases} \]  

(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:

\[ n(r) = ar^a \exp(-br) \]  

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

\[ P_t = P_s \times \frac{L \times D^2}{d^2 \times R^2 \times 10^{-a \times R/10}} \]  

(5)

\( P_t \) and \( P_s \) 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]:

\[ DSNR = \frac{RPs}{\sigma_0 + \sigma_1} \]  

(6)

\( P_s \) is received power, \( R \) is receiver responsivity, \( \sigma_0 \) is current variance in absence of any signal while \( \sigma_1 \) 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.

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-
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 $\tau$ is transmission coefficient, $\gamma$ 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.

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. $3.16 \times 10^{-11}$. However when the transmission power was raised to 45mW, the BER improved to $4.18 \times 10^{-17}$, 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 $8.63 \times 10^{-10}$, under similar atmosphere as stated in above case.

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
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.

<table>
<thead>
<tr>
<th>FSO Link and System Parameters</th>
<th>Transmitter Power (mW) / Receiver Sensitivity (dBm)</th>
<th>BER using PIN Diode</th>
<th>BER using APD Diode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range= 500 meters, Wavelength=1550 nm EML source, NRZ Mod^a, Atmospheric attenuation= 80dB/Km</td>
<td>35mW / -30 dBm</td>
<td>3.6×10^{-11}</td>
<td>1.3×10^0</td>
</tr>
<tr>
<td></td>
<td>45 mW / -30 dBm</td>
<td>1.8×10^{-16}</td>
<td>8.6×10^1</td>
</tr>
<tr>
<td>Range= 680 meters, Wavelength=1550 nm EML source, NRZ Mod^a, Atmospheric attenuation= 80dB/Km</td>
<td>35 mW / -50 dBm</td>
<td>8.6×10^{-10}</td>
<td>1.3×10^0</td>
</tr>
<tr>
<td></td>
<td>45 mW / -50 dBm</td>
<td>2.8×10^{-13}</td>
<td>4.6×10^6</td>
</tr>
</tbody>
</table>

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.

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


