Comparison of Wavelength Propagation for Free Space Optical Communications

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Abstract

This paper presents the effect of atmospheric attenuation during severe hazy days for Free Space Optical Communications. The usage of Free Space Optical Communications is still rare in Malaysia due to environment factor. The FSO technology is also known as unguided beam or 'optical wireless' or infrared broadband. This study offers quick preliminary investigation on possible FSO performance based on wavelength selection before final commissioning and installation at site. Thus, FSO installers could make quick judgment before giving recommendation of a suitable wavelength to the customers. Preliminary evaluation of system performance of system performance is done by using local weather data obtained from metrological department. Current study among designers and FSO users show that 1550nm light produce less atmospheric attenuation in the transmission under all weather conditions. In this study, a suitable wavelength for FSO system is found for a particular site in low visibility. The best wavelength selection would result in optimized quality of FSO transmission in hazy conditions.

Keywords**: *FSO: Free Space Optical, Mie Scattering,*** Scattering Coefficient, Atmospheric Attenuation

1. INTRODUCTION

Free Space Optical (FSO) is still not widely used in Malaysia. This might be related to environmental factors. It is an unguided beam also known as 'wireless optical' or 'infrared broadband'. FSO can be used in various applications such as LAN to LAN connections, fiber backup, last mile access, metro network extensions and hybrid microwave/laser. An advantage of using FSO is no license required from Federal Communications Commission (FCC) to install FSO system. Apart from that, the cost of installation is primarily economic because there is no extra cost of digging the street to lay fiber. In term of communication security, FSO uses narrow laser beam which makes detection, interception and jamming very difficult. Moreover, FSO hardware is also portable and quickly deployable [1].

Despite having a lot of advantages, the system is sensitive to poor weather conditions, obstruction in line of sight, building movement and scintillations. However, the biggest limitation of FSO implementation is poor whether conditions. Besides being unpredictable, bad weather conditions such as rain, haze and fog are able to degrade the quality of FSO transmission. As a result, a thorough study on weather performance before the final commissioning and installation of an FSO system should be conducted to optimize the final system performance [2].

Besides that, selection of appropriate wavelength in FSO is also an important issue. The safety concern related to the effect of FSO beam to human eye and skin should be considered. The most common wavelength used for optical communication ranges from 0.85µm to 1.55µm. Many FSO installers utilize 780nm, 850nm and lately 1550nm beam. Wavelength of 1550nm produces higher power and more eye-safe compared to 780nm and 850nm wavelength. Wavelengths that are less than 1400nm allow the light to focus on the cornea and lens, thus causing potential hazard to human eye. In contrast, wavelength which is greater than 1400nm is absorbed by cornea and lens. Hence, eye is more protected. In addition, higher wavelength beam is able to penetrate haze, smog and fog [3].

Basically, the FSO system performance depends on the attenuation level at different visibility level. Because haze results in more particles stay longer in atmosphere compared to rain, it presents more serious degradation on FSO performance [4].

In normal practice of FSO, evaluation of FSO performance is conducted by testing the actual system at site. This process requires the FSO hardware to be installed temporarily at site to acquire the system performance. If the attenuation performance of the system is satisfactory, the system is then permanently installed and commissioned. On the other hand, if the system shows poor performance, necessary adjustment of system parameters and/or hardware is done. In this project, a more proactive method to forecast the system performance is proposed without having to physically install the hardware [5]. The alternative method requires only existing local weather data that can be obtained from the local meteorological department.

2. MIE SCATTERING

It occurs when the particle diameter is larger than one-tenth of the incident wavelength. Mie theory is applicable for scattering by isotropic spherical elements without quantum consideration of particle radiation by incident monochromatic light. Therefore, in the near infrared wavelength range, fog, haze, and aerosols particles are the major contributors to the Mie scattering process. Attenuation due to Mie scattering is a function of the visibility and laser wavelength. Meteorological visual range (Visibility) is the most important weather parameter needed to estimate FSO attenuation. In viewing a series of objects, it is noticed that the contrast between them and their background decreases with distance. Eventually the contrast becomes so little that the object can no longer be perceived; for the human eye this occurs when the contrast drops to about 2 percent; that is, the luminance of the object differs from that of the background by less. Visibility can be divided into 2 categories, which are low visibility and average visibility. The average visibility falls between ranges of 7 km to 16 km whereas the low visibility varies in the range of 0.5 km to 4.5 km. This value is obtained from the calculation of mean value of hourly visibility. The low visibility was calculated by using Equation 1 and 2. The results focused on low visibility only.

$$X = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

and

$$\sigma_x = \sqrt{\frac{n\sum x^2 - (\sum x)^2}{n^2}} \qquad (2)$$

where,

$\Sigma x_i = \{ x_1 + x_2 + \dots\dots\dots + x_n \}$, x = data and n = number of data

3. SCATTERING COEFFICIENT

The scattering coefficient can be expressed as a function of the visibility and wavelength. The scattering coefficient in hazy days can be determined by using the expression in equation (3) [6].

$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550nm}\right)^{-q} \qquad (3)$$

where :

V= visibility in kilometers, λ = wavelength in nanometers and q = the size distribution of the scattering particles (1.3 for average visibility (6km <V<50km) and $0.585V^{1/3}$ for low visibility (V<6km)).

4. ATMOSPHERIC ATTENUATION

The atmospheric attenuation is described by the following Beer's Law equation [1] and [7]:

$$\tau\,(\mathrm{R}) = - \frac{P(R)}{P(O)} = e^{-(\beta)R} \qquad (4)$$

where :

β = Scattering coefficient and R = Link Range (km)

Equation (4) can be converted to logarithms scale using Equation (5)

$$= -10 \log \frac{P(R)}{P(O)} \qquad (5)$$

$$= -10 \log e^{-\beta R}$$

$$= 10 \log e^{\beta R} \qquad (6)$$

5. RESULTS AND DISCUSSIONS

Figure 1 shows the performance of scattering coefficient at low visibility. The x-axis represents low visibility from 0.5km to 4.5 km. The curves were plotted based on Equation 3. The size distribution of scattering particles is $0.585V^{\frac{1}{3}}$. The size distribution for low visibility was taken from previous study model.

The graph also indicates performance of three different wavelengths i.e. the 780nm, 850nm and 1550nm. Scattering coefficient in extreme low visibility, 0.6km, is about 5.48km^{-1} when 780nm wavelength is used. On the other hand, the scattering coefficient for selection wavelength of 850nm and 1550nm are 5.26 km^{-1} and 3.91 km^{-1} respectively.

Scattering coefficient for 780nm and 850nm exhibits a small difference of 0.22km^{-1}. However, by using 1550nm as wavelength, the scattering coefficient effect becomes smaller compared to the scattering coefficients in 780nm and 850nm. The difference between 1550nm scattering coefficient and 780nm scattering coefficient is about 1.57km^{-1} while the results show difference between 1550nm scattering coefficient and 850nm is 1.35km^{-1}.

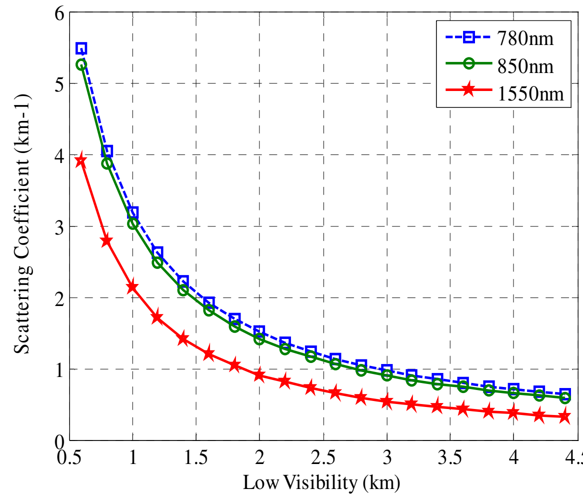

Figure 1: Scattering Coefficient in Low Visibility

Scattering coefficient for 780nm and 850nm exhibits a small difference of 0.22km^{-1}. However, by using 1550nm as wavelength, the scattering coefficient effect becomes smaller compared to the scattering coefficients in 780nm and 850nm. The difference between 1550nm scattering coefficient and 780nm scattering coefficient is about 1.57km^{-1} while the results show difference between 1550nm scattering coefficient and 850nm is 1.35km^{-1}.

From the analysis due to critical low visibility, wavelength 780nm exhibits high scattering coefficient effect. Even though the difference between 780nm and 850nm is 0.22km^{-1}, this comparison was made under severe low visibility. As a result, the best wavelength is 1550nm because it shows less effect in scattering coefficient compared to 780nm and 850nm wavelengths.

For low visibility of 4.4km, the scattering coefficient is about 0.64km^{-1} for wavelength of 780nm. The effect of scattering decreased to 0.59km^{-1} by selecting 850nm as wavelength. The scattering coefficient is reduced to 0.33km^{-1} with 1550nm. This shows that wavelength 1550nm is still producing less scattering coefficient compared to 780nm and 850nm wavelengths.

The scattering coefficient difference between 780nm and 850nm wavelength is 0.05 km^{-1}. In contrast, the scattering coefficient difference between 850nm and 1550nm wavelength is about 0.26 km^{-1}. In addition, the difference between 780nm and 1550nm wavelengths is 0.31km^{-1}.

Based on the results, 1550nm produced less scattering in low visibility range from 0.6km to 4.3km. By reducing the scattering coefficient, 1550nm wavelength can be used to optimize line transmission between transmitter and receiver.

The x-axis represents low visibility and the y-axis corresponds to atmospheric attenuation. Figure 2 indicate that the atmospheric attenuation is inversely proportional to the low visibility. The value of atmospheric attenuation is obtained from Beer's Law Equation 4. Link range between transmitter and receiver is within 1 kilometer. As the low visibility increases, the atmospheric attenuation decreases.

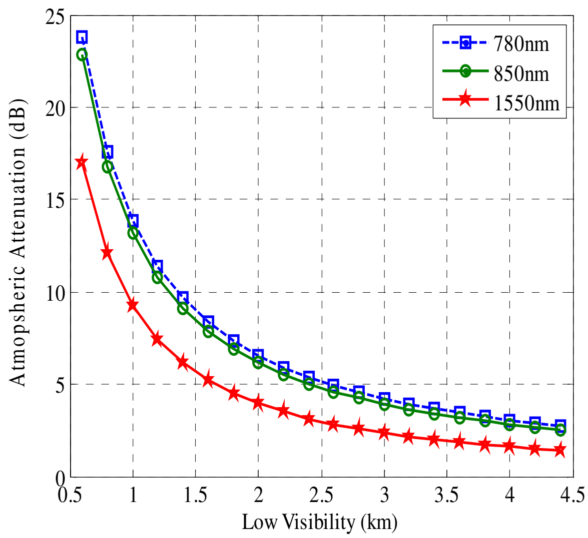

Figure 2: Atmospheric Attenuation due to Low Visibility.

Basically, the graph shows that wavelength with 1550nm give less effect of atmospheric attenuation. In the critical low visibility is 0.6km, produces about 23.82dB (780nm), 22.83dB (850nm) and 16.97dB (1550nm). In severe conditions, all wavelength produces atmospheric attenuation about 17dB to 24dB.

Low visibility at 4.3km produces atmospheric attenuation of 2.76dB (780nm), 2.54dB (850nm) and 1.43dB (1550nm). These results show that wavelength ratio of 780nm to 1550nm is 1.93 and ratio of 850nm to 1550nm is 1.78. Therefore, the performance of FSO with a wavelength of 1550nm is able to reduce nearly half of atmospheric attenuation that occurred in 780nm and 850nm. From the results it depicted that the performance of system with 1550nm is better than 850nm and 780nm in term of transmission losses.

Figure 3 shows the performance of three different wavelengths due to link range. It can be observed that the wavelength of 1550nm shows obvious difference in term of providing less effect of atmospheric attenuation compared to 850nm and 780nm wavelengths.

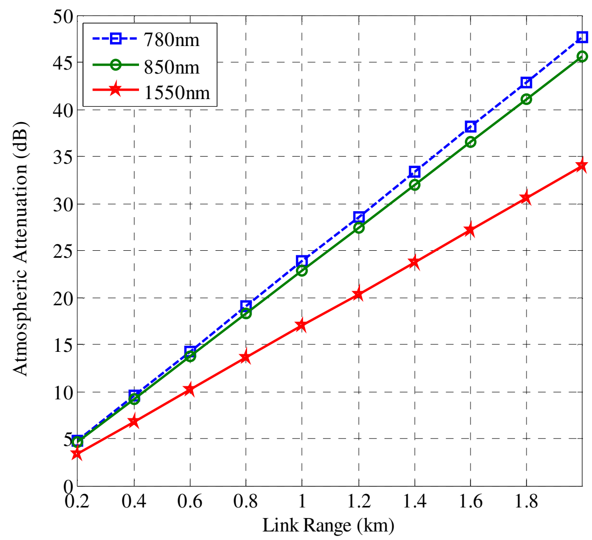

Figure 3: Performance of Atmospheric Attenuation (Low Visibility, V = 0.6km) due to Link Range

Besides that, the effect of varying the link range on the atmospheric attenuation in low visibility is also investigated. For low visibility 0.6km and link range of 0.2km, the atmospheric attenuation is about 4.76dB (780nm), 4.57dB (850nm) and 3.39 dB (1550nm). On the other hand, the atmospheric attenuation is about 47.64dB (780nm), 45.66 dB (850nm) and 33.95B (1550nm) at a distance of 2km. The increment of link range between transmitter and receiver contribute to high atmospheric attenuation effect. From the result obtained, it is recommended to have a shorter distance between transmitter and receiver to improve the FSO transmission systems. Another solution to improve the atmospheric attenuation is by using the 1550nm wavelength. The laser light with wavelength of 1550nm suffers less atmospheric attenuation than 850nm and 780nm.

6. Conclusions

FSO is an option that can be deployed as a reliable solution for high bandwidth short distance enterprise applications. The applications of FSO is quite slow in Malaysia but as the time running through FSO might become one of technology that could be used in the data transmission. Advantages of FSO over fiber optics technology are numerous including costing on average one-fifth the cost of installing fiber optic cable, portable, quickly deployable and cost effective [8]. Weather condition is one of the important factors that must be studied in FSO systems. So in this paper, the focused is on haze effects. The selection of wavelength is important in order to reduce scattering coefficient and atmospheric attenuation. From the result analysis, FSO wavelength with 1550nm produces less effect in scattering coefficient and atmospheric attenuation. Short link range between the transmitter and receiver can optimize the FSO system transmission. Based on the analysis, it is recommended to install FSO system with 1550nm wavelength and link range up to 2 km.

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REFERENCES

[1] M. Achour, "Simulating Atmopsheric Free Sapce Optical Propagation Part II : Haze, Fog and Low Clouds Attenuation", *Proceeding of SPIE*, volume 4873, Oct 2002, pp 1-12.

[2] S. Arnon, "Optimizing of Urban Optical Wireless Communication Systems", *IEEE Transactions on Wireless Communication*, Vol2. No4, 2003

[3] Hudson, Richard D, *Infrared System Engineering,* John Willey & Sons, New York/London/Sydney/Toronto, 1969

[4] S.Bloom, E.Korevaar, J.Schuster and H. Willebrand, "Understanding the performance of free space optics [invited]," *Journal Optical Networking 2*, 2003, pp 178-200.

[5] M. Schleissinger, *Infrared Technology Fundamentals* ,Marcel Dekker, 1994

[6] Isaac I.Kim, Ron Stieger, Carter Moursund, Micah Barclay, Prasanna Adhikari, John Schuster, Eric Korevaar, "Wireless Optical transmission of fast Ethernet, FDDI, ATM and ESCON protocol data using the TeraLink laser communication system", *Optical Engineering*, Dec 1998, pp3143-3155.

[7] Joseph C. Palais, "*Fiber Optic Communications Technology*", A book chapter, pp52-54, 4th edition, New Jersey:Prentice Hall Inc, 1998.

[8] Heinz A.Willebrand, Barksheesh S.Ghuman, "Fiber Optic Without Fiber", LightPointe Communications Inc., http://freespaceoptic.com/Fiber_Optics_Without_Fiber.htm, 2001.