Tropical Terrestrial Free Space Optical Link Performance Analysis

https://doi.org/10.3991/ijim.v16i12.30119

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Abstract—Free Space Optical (FSO) has a very good potential alternative solution to Radio Frequency (RF) to provide high terrestrial wireless communication. In tropical region, the only drawback of FSO is atmospheric attenuation due to mainly haze and rain. This study investigates the performance of FSO system over link distances that ranges between 9 km to 12 km as the average visibility in Kuala Lumpur, Malaysia is 10 km. Two models used to predict the atmospheric attenuation, namely Kruse model and modified Kruse model. These models are valid to predict the haze attenuation for visibilities that range between 9 to 12 km. The modified/corrected Kruse model shows some limitations in the prediction of haze attenuation over longer wavelength. However, the study indicates that attenuation due to haze is low, while air quality in Kuala Lumpur, Malaysia is acceptable. As the size of haze particles varies from 0.01 to 1 µm, the longer wavelength is preferable as 1550 nm to enhance FSO performance compared to 850 nm and 600 nm wavelengths. Thus, the longer wavelength is the optimal choice to enhance the FSO performance as it caused low scattering.

Keywords—FSO, FSO link budget, haze attenuation, visibility

1 Introduction

FSO is a form of Optical wireless communication that allows information transmission by converting data into light pulses. It allows for the light pulses to be propagated through the atmosphere instead of optical cables. FSO offers several attractive features over other wireless technologies like high data rates, protection from interference, high bandwidth, and low cost and power. FSO communication technologies have been introduced to overcome the bandwidth limitations of RF spectrum [1–2]. As the demand for bandwidth keeps increasing every day, a new solution should be introduced to fulfil these requirements.

FSO uses free space as a transmission medium and sends optical data signal at a very high rate. It basically uses light to transmit data between a pair of the transceiver as shown in Figure 1 [3]. Many research has been conducted on the development of FSO systems at the early stage. Among this research was during the 1960s to develop

FSO prototype which conducted by one of the most commercial manufacturers of FSO systems, namely as Lightointe [4].

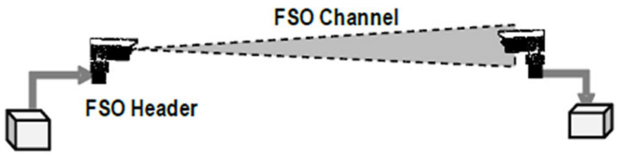

Fig. 1. FSO system's components [3]

FSO is a very potential solution to provide a wireless communication link for a higher data rate. It occupies the spectrum from 380 nanometres (nm) to 750 nm corresponding to a frequency spectrum of 430 terahertz (THz) to 790 THz. FSO has various advantages which are easy installation, license-free communication, immune from electromagnetic interference, provide high data rate to support broadband data services with very high security. The only drawbacks of FSO are atmospheric turbulence which will degrade the quality of signal and pointing, acquisition and tracking (PAT) due to unguided beam [5]. Furthermore, the signals in the atmosphere are attenuated, absorbed, and scattered due to the turbulences and atmospheric variations. FSO suffers from attenuation due to the atmospheric attenuation caused by scattering and absorption. The scattering of optical signal caused by haze, fog, rain and snow. Meanwhile, carbon dioxide and water particles caused the absorption of the optical signal [6]. The scattering will cause a portion of the light beam travelled from source to deflect from the intended receiver. Among the aforementioned atmospheric effects on FSO communication, haze is one of the causes of optical attenuation, especially in Malaysia. Moreover, feasible estimation of haze effect on FSO attenuation in a tropical climate weather conditions can be correlated with measured visibility data in Malaysia, where the average visibility in Malaysia is about 10 km [7, 8]. Attenuation due to haze can be obtained based on the visibility range. One study shows a close relationship between optical attenuation, and visibility, with respect to weather conditions and induced corrected/modified Kruse model [9]. Earlier attenuation models describe the relationship between optical attenuation and visibility by considering different conditions. Among the popular models are Kruse and Kim's models based on the visibility defined at the 550 nm wavelength. These models are also predicting atmospheric attenuation based on visibility range. Therefore, in this study, we will examine the performance of FSO system in Malaysia using Kruse and corrected/modified Kruse models for visibility that ranges between 9 km and 12 km as they are close to the average visibility in Malaysia.

1.1 FSO haze attenuation and link budget

The effect of haze attenuation can be assessed by estimating the exponential Beer-Lambert law, as follows [10]

$$\tau = e^{-\sigma l} \quad (1)$$

Where σ is the Scattering coefficient
l is the Propagation distance (km)

The scattering coefficient can be expressed using Kruse empirical formula, as shown below [11]:

$$\sigma = \frac{3.91}{V}\left(\frac{\lambda}{550\,nm}\right)^{-q} \tag{2}$$

Where V is the Visibility (km)
λ is the Wavelength (nm)
q is the Size distribution of the scattering particles

Whereas the particle size distribution, q, is defined as:

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

The q value of Kruse formula has been modified into which called corrected/modified Kruse model [9]. This model developed based on field data for visibilities from 9 km to 12 km. Using Linear regression method to find the function f, that minimizes the sum of the least squares between a values and $f(v_i)$, is used to produce equation related to particle size distribution, q as [9]:

$$q = 0.63554139V - 8.973276459\,Km < V < 12\,Km \tag{4}$$

In order to evaluate the performance of FSO system in tropical climate condition; FSO link budget equation is needed, and it can be obtained as [8]:

$$P_r = P_t - Geo - O - \tau_{haze} \tag{5}$$

Where P_t and P_r are the transmitted and received power, respectively, Geo is the geometric loss and O is the optical equipment losses, and is given by [8]:

$$Geometric\,loss\,(dB) = 20\log\left(\frac{L\theta}{D}\right) \tag{6}$$

Where L is the FSO link distance (km)
θ is the Divergence angle (mrad)
D is the Receiver lens diameter (m)

FSO link budget usually defines at the FSO receiver-side and after deducting all possible losses; any excess power is defined as link margin, which is allocated for any fade attenuation due to weather conditions. Thus, the fade margin can be obtained as:

$$FM = P_r - R_x\,Sensitivity \tag{7}$$

FSO system's parameters in the Table 1 are assumed to obtain the FSO link budget. These parameters are used by most FSO commercial systems [12–13].

Table 1. Parameters of FSO transceiver

Specification	
Transmit power	24 mW
Wavelengths	850 & 1550 nm
Sensitivity	−45 dBm
Beam divergence	2 mrad
Transmitter lens	2.5 cm
Receiver lens	8 cm

2 Results and discussion

In this paper, the FSO system performance is analyzed under haze condition for the tropical region. Wavelengths of 600 nm, 850 nm and 1550 nm used to evaluate the FSO system performance. Figure 2 shows haze-induced atmospheric attenuation in dB as a function of visibility. As the evaluation considers for Malaysian weather; one-year visibility values was used for 2015 from [8]. The graph shows, the highest visibility is 14 km, and it is corresponding to 1 dB/km for 600 nm, 0.5 dB/km for 850 nm and 0.2 dB/km for 1550 nm attenuation for Kruse model. Meanwhile, for the corrected/modified Kruse model, it predicts over 9 km to 12 km link distance as the validity of the model [9]. However, this corrected Kruse model gives high attenuation for 1550 nm wavelength, which is 55dB/km for 9 km visibility. Furthermore, 600 nm tends to show the lowest attenuation for all range visibility for corrected Kruse model, which is 3 dB/km.

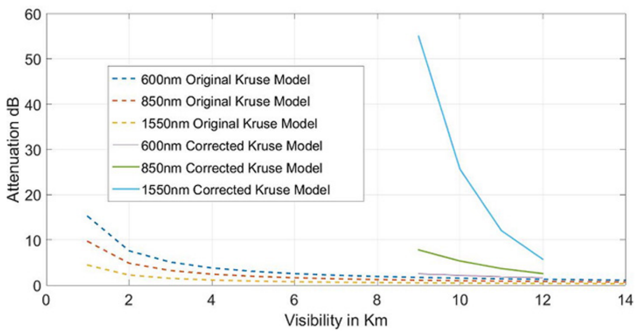

Fig. 2. Attenuation versus visibility range (1 km–14 km)

Another group of visibility values was also used from [8] over one month to predict the attenuation, as shown in Figure 3. As of October 2018, the highest visibility was found to be only 9 km, and most of the time the visibility was 8 km to 9 km. Using Kruse model, the attenuation for 600 nm, 850 nm and 1550 nm for 9 km are 3 dB/km, 2 dB/km and 1 dB/km, respectively. Meanwhile, over 1 km visibility, the attenuation for 600 nm, 850 nm and 1550 nm are 15 dB/km, 10 dB/km and 5 dB/km respectively. On the other hand, using the corrected Kruse model, for 6 km visibility, the attenuations are 5 dB/km and 27 dB/km for 600 nm and 850 nm respectively. In this case, only two wavelengths are considered due to 1550 nm tends to give higher attenuation, which resulted in the hard observation of attenuation to the other wavelengths.

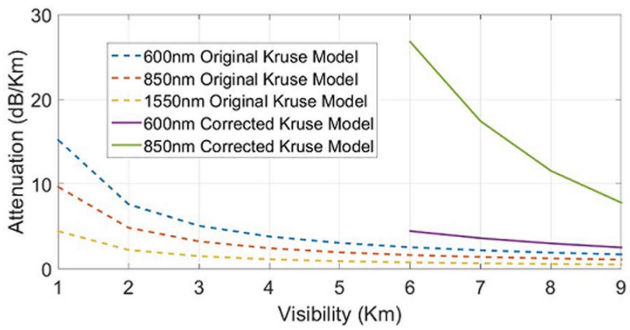

Fig. 3. Attenuation versus visibility range (1 km to 9 km)

Thus, from both Figures 2 and 3, it shows that using Kruse model as wavelength increased the attenuation decreased. In contrast with the corrected Kruse model, as the wavelength increased, the attenuation also increased. As mentioned earlier, increased of FSO wavelengths compare to haze particles will minimize the effect of scattering. Meanwhile, as visibility increased, the attenuation decreased for both the original and corrected Kruse model.

Link margin is included for attenuation due to haze and is obtained as a function of varied distance of FSO link. Link margin is calculated using Kruse model and corrected Kruse model for one-year visibility data in [8] as shown in Figures 4 and 5, respectively. Link margin is obtained over distances from only from 9 km to 12 km for corrected Kruse model. In Figure 4, it clearly shows that as visibility increased, the fade margin decreased for Kruse model. Whereas, corrected Kruse model gives vice versa results from the Kruse model. Using Kruse model, a wavelength of 1550 nm gives the highest fade margin over 1 km visibility which correspond to 25 dB/km. Whereas, corrected Kruse model gives highest fade margin over 600 nm wavelength at 12 km, which correspond to 7 dB/km as depicted in Figure 4.

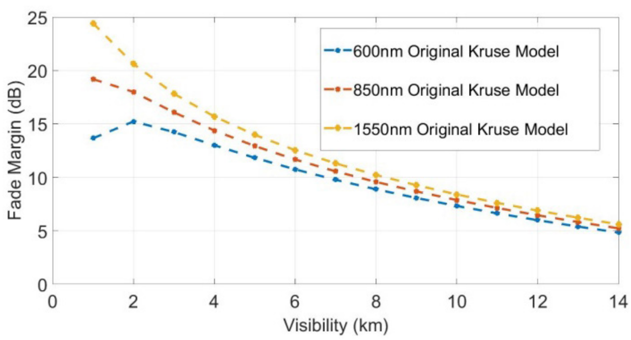

Fig. 4. Kruse model fade margin versus visibility

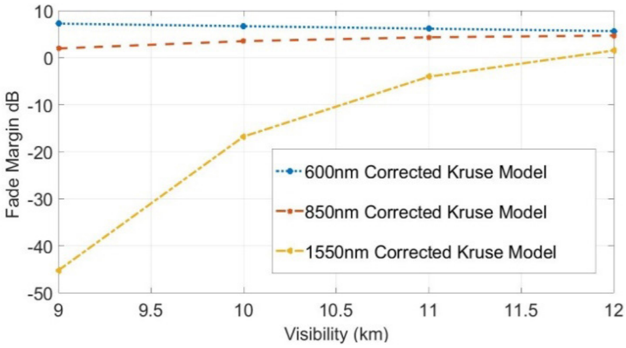

Fig. 5. Corrected Kruse model fade margin versus visibility

As link margin defined as the difference between the receiver sensitivity and received power; thus, the value of link margin will determine how much the system can tolerate for external parameters, mainly atmospheric attenuation. As shown in Figure 5, 1550 nm wavelength has a negative value of link margin, which indicate the link is incapable of transferring data and not available.

Link margin is estimated, as shown in Figures 6, 7 and 8. From Figure 6, shows the link margin for Kruse model over three different wavelengths using visibility values in [8]. It is clear that higher wavelengths induce higher link margin. Link margin is calculated over link distance ranging from 6 km to 9 km for corrected Kruse model as shown in Figures 7. The main reason of dividing the link margin into two different graphs is to get the exact values for link margin of 600 nm and 850 nm as shown in Figure 7. This is due from Figure 8 when considering all wavelength, link margin values for 1550 nm are not practical because at this wavelength, the link margin always negative.

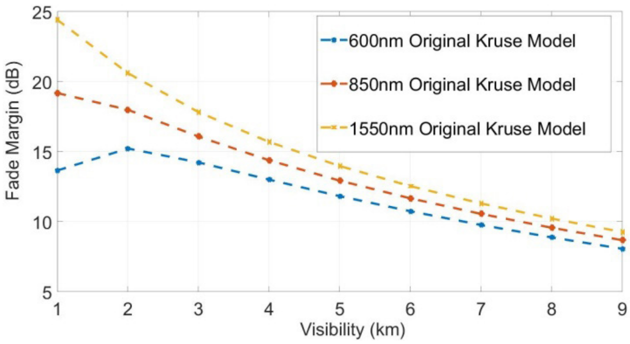

Fig. 6. Kruse model fade margin versus visibility

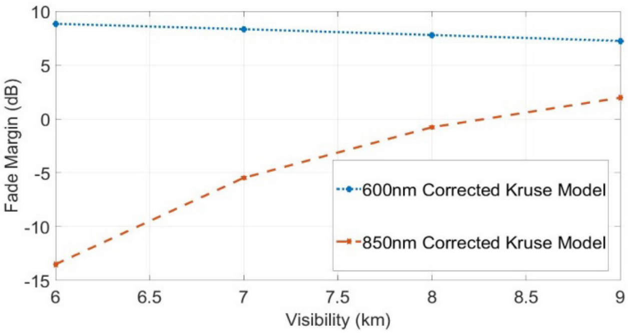

Fig. 7. Corrected Kruse model fade margin versus visibility

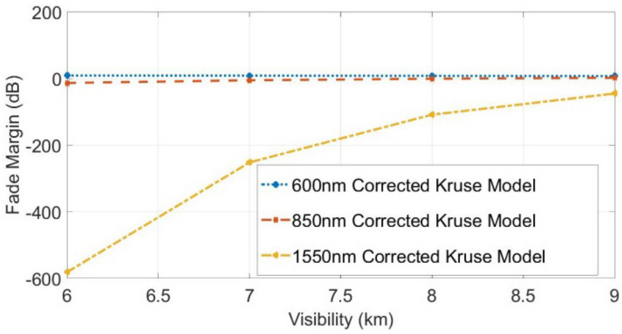

Fig. 8. Corrected Kruse model fade margin versus visibility

The above results show that corrected Kruse model gives contrast results for both attenuation and fade margin with respect to its wavelength over a link distance ranging from 9 km to 12 km, but attenuation is in closed agreement to Kruse model except over 1550 nm wavelength. Whereas; the attenuation will increase significantly over distances out of this range. Furthermore, link margin over 600 nm and 850 nm wavelength is appropriate but impossible to use 1550 nm wavelength as the link margin is always negative. Moreover, link margin out of 9 to 12 km link distance gives impractical values. According to the results in [9], it showed that attenuation decreased with increased visibility distance which matches the results in this study for both models.

3 Conclusion

FSO performance analysis is conducted in this study. The evaluation of FSO system performance is considered under the impact of haze attenuation in Malaysia. Two models are used to estimate the haze effect on the attenuation over the link distances ranging from 9 to 12 km. This range is considered as it is close to the average visibility in Malaysia. Results indicate that haze effect on attenuation is low, while the air quality is generally acceptable in Malaysia. In order to increase FSO link performance, the longer wavelength is preferable as 1550 nm gives better results compared to 850 nm and 600 nm wavelengths. Comparisons of haze attenuation and link margin between Kruse and corrected Kruse models are conducted in this paper. The corrected Kruse model shows constraints when using longer wavelength as haze attenuation, and link margin are unpredictable. This analysis can be used during the deployment of the FSO system, particularly under tropical environments.

4 Acknowledgement

This work was conducted at the IoT and Wireless Communication Protocols Lab, International Islamic University Malaysia (IIUM) and is partially funded by IIUM Publication Research Initiative Grant Scheme no. P-RIGS18-003-0003.

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Article submitted 2022-02-10. Resubmitted 2022-04-08. Final acceptance 2022-04-09. Final version published as submitted by the authors.