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Characteristics of free space optics communication link in an unusual haze

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The connectivity and presence of free space optics (FSO) systems dependent on weather conditions especially in unusual haze have been studied. The attenuation and visibility have been analyzed using different formulas and compared with the experimental study. In an unusual haze condition, the attenuation of signal follows the same pattern as obtained from the theoretical analysis. Attenuation due to scattering, which has been expressed as a function of the link distance, wavelength and meteorological visibility, has been calculated from the visibility data collected at Senai airport in Malaysia. Maximum attenuation about 20 dB/km has been observed due to the unusual haze in Malaysia.

Keywords: Free space optics, Visibility, Climate effects, Attenuation

1 Introduction

The free space optics (FSO) communication is a recent and growing technology that has found applications in many areas of the short and long-haul communications space from intersatellite links to interbuilding links. Inherent high carrier frequency in the range 20-375 THz enables FSO to provide communication with highest data rates. License free communication, easy installation, avoiding electromagnetic pollution and wiretapping safety are few other advantages. Additionally, FSO communication provides solution to problems like first/last mile access connectivity, broadband internet access to rural areas and disaster recovery etc[1,2]. Next generation high speed optical networks can employ FSO links in point-to-point or point-to-multipoint solutions[3,4]. Some of the possible implementation scenarios are delay free web browsing and data library access, electronic commerce, streaming audio and video, video on demand, video teleconferencing, real time medical imaging transfer, enterprise networking, work-sharing capabilities and high speed interplanetary internet links[5,6]. FSO communication has recently been investigated for ground-to-ground (short and long distance line of sight (LOS) terrestrial links), satellite uplink/downlink, inter-satellite, satellite or deep space probes to ground, ground-to-air (e.g., Unmanned Aerial Vehicle (UAV), High Altitude Platforms (HAP) etc.) /air-to-ground terminal. Despite great potential of FSO communication for its usage in the next generation access networks, its widespread deployment has been hampered by reliability and availability issues related to atmospheric variations. Atmospheric attenuation caused by a number of phenomena in the atmosphere, such as scattering, absorption and turbulence. Scattering in particular, which is a product of fog, haze, or low clouds, causes large variation in the received optical power and markedly limits the availability of FSO for a given transmission range. The effect of unusual haze effect on FSO link against on a specific day has been investigated. Usually as a tropical country Malaysia has a clear weather round the year but suddenly haze appeared only for a week at the end of June 2013 and affected the transmission link. Our study is to find out the effect of haze on signal strength in the FSO link. Here atmospheric attenuation is only considered for scattering. In the present paper, the results from our measurement campaigns have been used. The set of measurements was performed at the Senai airport, Johor at a test facility of weather broadcasting center near the Senai airport June, 2013.

2 Effect of Haze on FSO Link

The main challenge to implement an outdoor short-range optical wireless link is the atmospheric attenuation, caused by the absorption and scattering. Water particles and carbon dioxide mainly cause the absorption of optical signals, whereas fog, haze, rain, snow and clouds cause the scattering of optical signals transmitted in free space. This scattering causes portion of the light beam travelling from a source to deflect away from the intended receiver[7]. Among various atmospheric effects on FSO communication, haze is one of the most deterrent attenuating factors. Haze causes significant attenuation of the optical signals for considerable amount of time and is thus highly deterrent for achieving high availability in FSO transmissions. The main reason of significantly high attenuations due to scattering indifferent haze conditions is that the size of haze particles is comparable to the transmission wavelengths of optical and near infrared waves. This scattering process is classified as Mie scattering process and the optical attenuations in case of haze droplets can be accurately predicted by applying Mie scattering theory. However, it involves complex computations and requires detailed information of haze parameters like particle size, refractive index, particle size distribution that may not be readily available at a particular site of installation. An alternate approach is to predict haze attenuations based on the visibility range information. The visibility range is the distance to an object where the image contrast drops to a certain value ε[i.e. T(V)= ε. In 1924, Koschmieder[8] on the basis of intuitive evaluation of the contrast threshold, proposed the value 0.02 for ε. To meet aeronautical requirements, the world Metrological organization later adopted the value 0.05 because it ensured the requirement for reliably resolving a black object against the horizon in daylight at a wavelength of 550 nm, where the human eye has the highest sensitivity. Assuming that ε =0.05, the atmospheric attenuation coefficient is:

$$\alpha_e = \frac{-\ln(0.05)}{V} = \frac{3}{V} \quad \ldots(1)$$

Atmospheric attenuation expressed in the decibel scale is related to transmittance by:

$$A_{10}(L,V) = -10\log[T(L,V)] = 10\log_{10}(e)\,\alpha_e(V)L$$

and hence, the atmospheric attenuation co-efficient in the decibel per unit length is approximately:

$$\alpha_{10} = 4.343\ \alpha_e \quad \ldots(2)$$

The predominant phenomenon causing light attenuation in haze is the Mie scattering[9,10]. The atmospheric attenuation coefficient for attenuation due to scattering can be derived from Eqs (1 and 2), taking into consideration the wavelength dependence of α_e based on an empirical developed formula, the attenuation co-efficient due to scattering is given by :

$$\alpha_{10} = \frac{17}{V(Km)}\left(\frac{0.05}{\lambda}\right)^{-0.195V} \quad \ldots(3)$$

For the case of wavelengths in the range from the visible to the near-infrared light and visibility given in kilometers, it can be calculated according to the semi-empirical Kruse formula[9] modified for ε =0.05 as follows :

$$\alpha_{10} = \frac{13}{V(Km)}\left(\frac{\lambda}{\lambda_0}\right)^{-q} \quad \ldots(4)$$

where V (km) stands for visibility range, λ in nm stands for wavelength, λ_0 as visibility range reference (550 nm) and q is the particle size distribution co-efficient defined as:

$$q = \begin{cases} 1.6 & \text{if } V > 50Km \\ 1.3 & \text{if } 6Km < V < 50\,Km \\ 0.585V^{1/2} & \text{if } V < 6\,Km \end{cases} \quad \ldots(5)$$

The latest investigations indicate no wavelength dependence of the atmospheric attenuation co-efficient in foggy or hazy conditions. A new method for evaluating the particle size distribution co-efficient that respects this fact was proposed by Kim *et al*[10].

$$q = \begin{cases} 1.6 & \text{if } V > 50\,Km \\ 1.3 & \text{if } 6\,Km < V < 50\,Km \\ 1.6V + 1.34 & \text{if } 1\,Km < V < 6\,Km \\ V - 05 & \text{if } 0.5\,Km < V < 1\,Km \\ 0 & \text{if } V < 0.5\,Km \end{cases} \quad \ldots(6)$$

Further studies of attenuation due to scattering were conducted by a number of other researchers. Al-Naboulsi[11,12] proposed relations for attenuation caused by radiation and advection fog.

Radiation fog or haze, generally, forms during the night when the temperature of the ground surface drops due to the radiation of the heat accumulated during the day. When the air is cooled by the ground surface below the dew point, the condensation of water vapour and, consequently, the formation of ground fog occur. The attenuation coefficient for radiation fog is:

$$\alpha_{10\text{scat}}(V) = 4.343\frac{0.11478\lambda_{\mu} + 3.8367}{V}\left[\frac{dS}{Km}\right] \quad \ldots(7)$$

where λ_{μ} is the wavelength in microns.

Advection fog is formed when the warm and wet air moves above colder maritime or terrestrial e.g., snow covered surfaces. As in the previous case, the air in contact with the ground surface can be cooled below the dew point, which causes the condensation of water vapour. The attenuation coefficient for advection fog is given by:

$$\alpha_{10\text{scat}}(V) = 4.343\frac{0.18126\lambda_{\mu}^{2} + 0.13709\lambda_{\mu} + 3.7205}{V}\left[\frac{dB}{Km}\right] \quad \ldots(8)$$

3 Experimental Set-up

The link for infrared transmission measurement was developed by Light wave Communication Research Group at University Technology Malaysia. A measurement set-up for haze attenuations is developed as similar as possible to practical FSO systems by modifying our self-developed transmission systems. Basically, it consists of an optical transmitter and receiver system, each equipped in a waterproof housing mounted on a tripod with mechanical options for alignment. In the transmitter, one light-emitting diode (LED)–based light source and optical system are implemented. The light emitting diode is operating at 850 nm center wavelength and 50 nm spectral width at a full angle beam divergence of 2.4 deg. To have approximately the same power for the same wavelengths at the receiver, only one LED (L7558-01) is used at 850 nm, which emits 8-mW average optical power in total; however, the average emitted power after the lens is about 3.0 mW, the rest being radiated in a wider angle. Thus, for the specific wavelength, the average received optical power after a distance of 100 m is –20.5 dBm.

4 Results and Discussion

The performance of FSO system can be evaluated by the received optical power, link margin, data rate and BER of the system. So the received power due to the effect of haze can be evaluated. The received power depends upon the different parameters. Here it is measured for haze at a distance of 100 m FSO link. Figure 1 shows the received power in every hour on 21 June 2013. The power varies from −20.5 dBm to −22.1 dBm for 100 m FSO link due to the unusual hazy weather. The worst conditions were prevailed during 7:00 am to 11:00 am due to the haze.

Usually long-term haze events may cause significant attenuation of the optical path. One can notice the rapid change of received power when the haze is arriving and leaving the propagation path. But this is a sudden incident which interrupts the FSO link without any precautions. So it makes complications for the whole communication system and it makes quite significant attenuation.

Figure 2 shows the change in attenuation and visibility in every hour on 21 June 2013. It shows unstable condition of the FSO link. The attenuation varies from 1 to 16 dB with the visibility changes from 0.6 to 8 km. So the change in attenuation is quite significant. This complicates the investigation into the

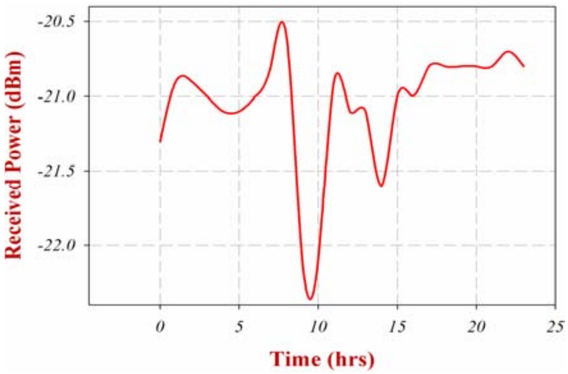

Fig. 1 — Variation of received power for 100 m FSO link

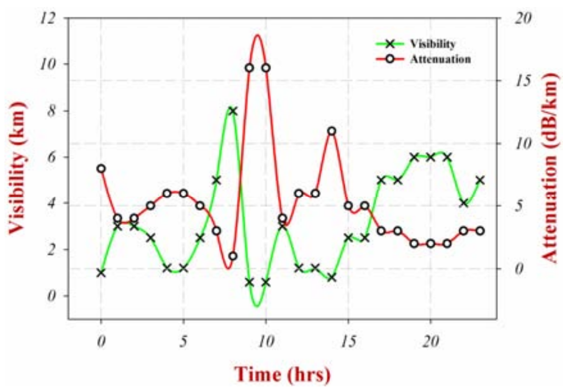

Fig. 2 — Variation of attenuation and visibility in every hr

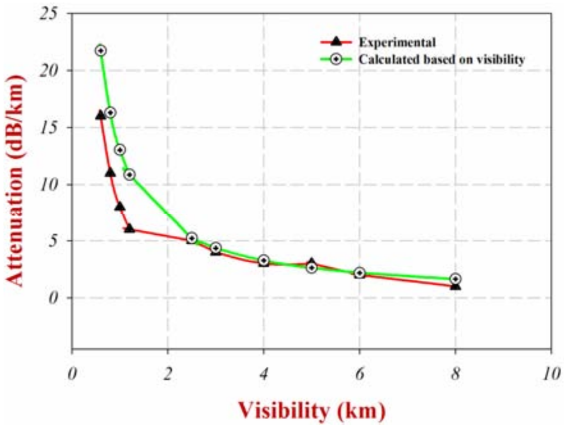

Fig. 3 — Relation between attenuation and visibility based on experiment and theory

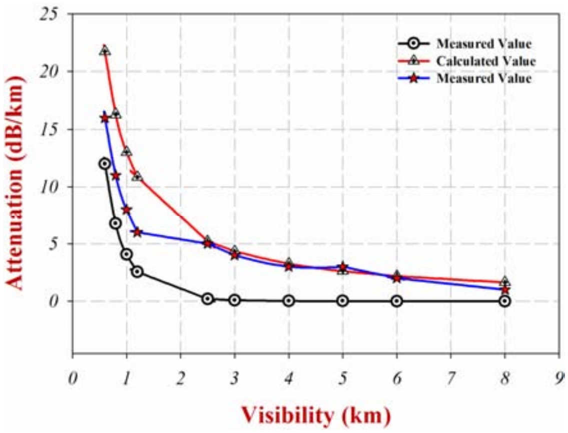

Fig. 4 — Comparison of attenuation and visibility based on experiment and theory

visibility versus attenuation relationship because; in this case the good time synchronization of both of the time series is needed to keep errors small. Perfect synchronization is not possible because visibility is only measured in one hour interval by the PWD11 detector but received power is measured in one minute interval.

Figure 3 shows the relationship between visibility and attenuation obtained from experiment and calculation based on visibility according to Eq. (1). Although, experimentally measured attenuation is higher than the calculated values but follows the same pattern of variation below the visibility range 2.5 km. For the visibility more than 2.5 km, both the values coincide and almost show the same result.

Figure 4 shows the comparison of relationship between visibility and attenuation obtained from measurement, calculation based on Eq. (1) and from

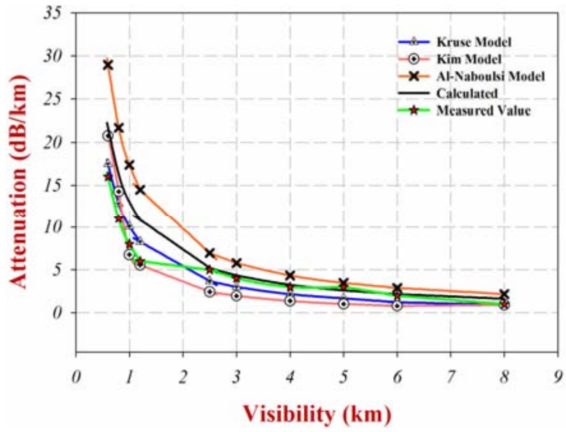

Fig. 5 — Comparison of different models calculated and measured attenuation data against a haze event in June 2013 for a visibility range up to 8 km

the empirical formula Eq. (3). The empirical formula has been introduced for Fog. But here the relationship fit well for haze.

Although the attenuation is lower than the experimental value and calculated attenuation according to Eq. (1) based on measured visibility but the variation follows the same pattern. The variation confirms the three different values follow the same pattern.

A graphical interpretation of the formulas given in Eqs (1), (4), (6) and (7) expressing attenuation due to scattering is shown in Fig. 5. All calculations presented below were performed for a wavelength of 850 nm. It is evident that the Naboulsi formula exhibits higher atmospheric attenuation as compared to the Kruse and Kim relation and, hence, they seem to be derived for =0.05. Our experimental results are very close to Kim model.

The FSO link availability is discussed here for calculated data collected within one day. However, the atmospheric conditions change from day to day from year to year and differ considerably according to the changing seasons. Example of the link availability calculated for the particular day from the visibility records obtained at the Senai airport in Joho, Malaysia. On the basis of the results obtained, it can be concluded that the unusualweather conditions cause evidently larger differences inlink availability than the weather conditions in normal. The fact that the monthly obtained link availability differs in dependence on the year and on the locality of the visibility measurement. Although the most critical day for link availability evidently differ in particular calculations, the typical hrs that exhibit great link availability variations include unusual hazy conditions.

4 Conclusions

FSO is the most promising candidate among different communication technologies when a high data rate link is required for a particular terrestrial and ground-space application thanks to its notable prime advantages. Despite its major advantages, this access technology suffers from severe availability and reliability challenges mainly due to different unusual weather effects like fog, rain, snow and clouds in the earth atmosphere. Future work can focus on identifying best parameters of different unusual weather conditions and fix the tolerance for the FSO network. Also it can be developed an adaptive algorithms to achieve optimal performance of this FSO link in different weather conditions.

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