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Free space optics attenuation model for visibilities ranging from 9 to 12 Km

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Abstract

Atmospheric optical links are particularly affected by weather conditions. In this article, visibility and attenuation have been recorded over a distance for a terrestrial free space optical link operating with a 780nm wavelength. This paper has shown the experimental optical link attenuation measurements results performed for visibilities ranging from 9-12 km. The existing models showing the relationship between atmospheric visibility and optical attenuation do not match well if compared with recorded data. Appropriate expressions which has consolidated Kruse attenuation model have been derived. The comparison of the corrected model to field data has shown the accuracy of the proposed modification.

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Keywords: Terrestrial optical link, visibility, attenuation model, free space optics, FSO.

1. Introduction

Free space optics (FSO) systems are communication systems using optical signals through the atmosphere. These systems have multiple advantages[1-4] as the high-bandwidth compared to microwave systems, spatial isolation from other interferers because of its narrow beam width and high optical gain. In addition to all these, free space optical transmission links up to now are license free. Modulation from a laser beam is used to send optical binary information. The output modulated optical signal propagates through the atmosphere from an emitter to a receiver. Despite the above enumerated advantages, one of the important challenges attached to free space optical communication is fading. Due to its composition, the atmosphere attenuates differently all electromagnetic waves. It is well known that the performance of atmospheric optical links is quite limited by the atmospheric turbulence. Atmospheric turbulence is due to the lack of homogeneity of the refractive index on the propagation way of the light.

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It looks like electromagnetic waves in the optical spectrum are strongly attenuated in the direction of propagation of the optical beam because of the diffusion and the absorption processes within the atmosphere. Events like mist and strong snow are undesirable weather conditions since they weaken optical waves. Free space terrestrial and spatial optical communication links are concerned[5-7]. To address the limitations due to fading and increase the system performance, different techniques such as error control coding schemes, adaptive optics technics and antenna array approach for microwave systems have been introduced with the optical source and receiver's system architecture[2]. It has been shown that there exist a relationship between visibility (with respect to the weather conditions) and optical attenuation. Many models describing the relationship between visibility and optical attenuation in different conditions have been published[8-15]. The most widely used are Kruse[13] and Kim[8,14] models based on the visibility definition at a wavelength of 550 nm. However, these models are global and not appropriated to describe more accurately experimental data collected in reduced interval of visibility conditions such as 9 Km to 12 Km. In this article, we have presented a corrected Kruse's propagation model for visibility interval ranging from 9 km to 12 Km based on experimental collected data of an optical link. FSO is still attracting researchers[16-17].

The rest of the paper is organized as follows. Section 2 is dedicated to the description of the wireless optical communication system used in this work. Section 3 presents the gap between the collected data with the existing model. In section 4, we have derived an explicit expression which leads to the modification of Kruse attenuation model and then we have simulated the new model to show its accuracy. We have ended this paper by a conclusion.

2. Description of the system

The intensity "I" of a ray of light propagating through a medium could be described as:

$$I(x) = I_0 . e^{(-ax)} \tag{1}$$

where

-I_0 is the intensity at a reference position,

-x is the distance from the reference position, and

-a is the attenuation for a unit of distance.

Accurate prediction of attenuation is an important engineering task which is performed in order to get good communication link performance of the system to be deployed. Many papers have reported the relationship between the visibility and attenuation. Visibility v (in unit of distance) is the meteorological optical range (MOR) defining how far away objects can be seen under conditions. In the case of light, it depends on the colour and daylight conditions. It had been measured in[10] for wavelength of 550nm. Atmospheric visibility is generally measured in airports; however it is possible to get the characteristics of visibility in regions where atmospheric optical links are deployed. Fig.1 below depicts the atmospheric optical link deployed in the context this work.

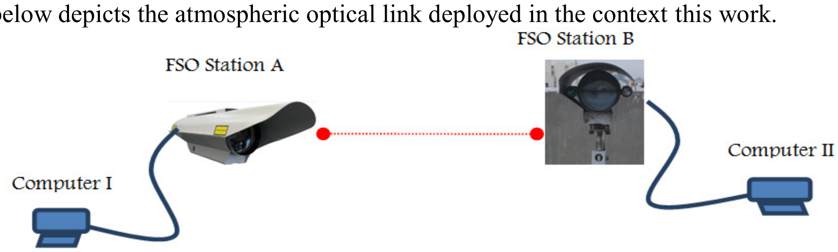

Fig. 1: Deployed experimental FSO station

The considered system operates at a wavelength of 780 nm. The divergence of the beam is 5mrad. The record of the optical received power in real-time has been performed at two minutes regular interval. Daily measurements have been carried out from July to August 2013. The visibility data measured by the local agency of meteorology has been associated. Our measurements were performed in term of cumulative minutes. The recorded visibility data were most of the time above 7km.

3. Limitations of Kruse prediction model visibility

In this section, we have presented the statistics of the collected data and compared it with Kruse prediction model. It has been noticed that the received power is affected by the daily changing atmospheric conditions and more specifically by visibility. It has been noticed that, when visibility degrades the attenuation increases, and when the visibility improves the attenuation decreases. This correlation was noticed during all the field measurements. The table below presents statistical results of the attenuations recorded from july to august.

Table 1: Measurements statistics from July to august.

5 days of a week	Minimal attenuation in dB	Maximal attenuation in dB	Average of attenuation in dB	Standard deviation in dB	Confidence interval through the averages of the attenuation
Week 1	0	0,342537	0,051423	0,0812	[0,03 to 0,07]
Week 2	0	0,3151705	0,1689429	0,2815	[0,13 to 0,20]
Week 3	0	0,877392	0,227388	0,2048	[0,19 to 0,26].
Week 4	0.5	0,3621217	0,1153164	0,1053	[0,09 to 0,13]
Week 5	0	0,2227639	0,0613217	0,0924	[0,04 to 0,07]

The statistical values recorded show that there is a great similarities for the measurements performed for visibilities between 9 Km and 12 Km. Kruse has proposed an attenuation model for wider interval of visibilities ranging from 6Km to 50 Km in[10] and this is expressed as:

$$\beta(\lambda)=\beta_{\alpha}(\lambda)=\frac{3.912}{V}\left[\frac{\lambda_{\mu m}}{0.55\mu m}\right]^{-q} \tag{2}$$

with q=1.3 for 6Km ≤v≤50 Km

Where β denotes the attenuation, "v" corresponds to the visibility and "q" is a constant at a wavelength of 780nm.

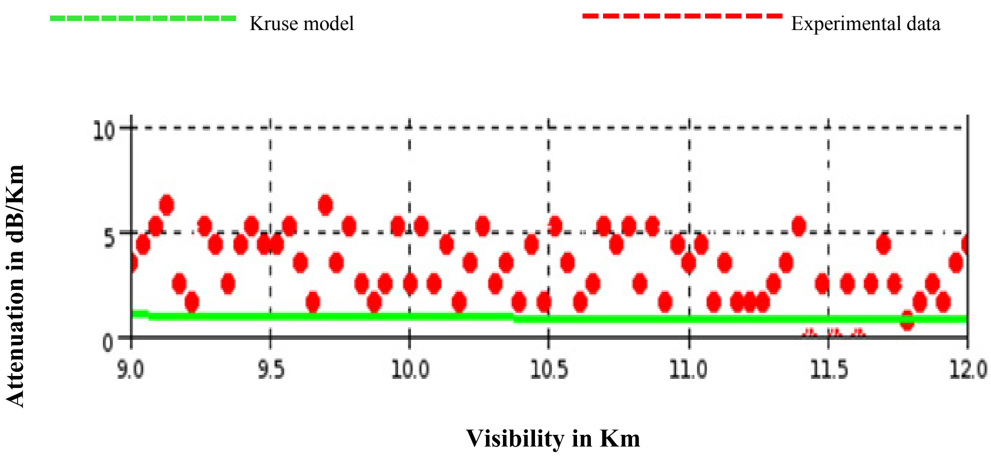

Fig. 2: Comparison of the field measured attenuation with Kruse model

The graphs in Fig. 2 shows the evolution of attenuation per kilometer with respect to the visibility of collected data in comparison to the theoretical prediction of attenuation based on Kruse model.

Based on the data recorded, we have determined the specific attenuation per kilometer for visibilities between 9Km and 12Km and compared it with Kruse' model. We have considered this model since it is a global model including Kim's model for the visibilities considered. The model defined by Al Naboulsi[10] cannot be considered in our comparison because it only takes into account an environment where the visibility is less or equals to 1km. It can be seen in Fig. 2, the gap between the empirical model predefined by Kruse, and the recorded data in the considered area for visibilities between 9km and 12km.

4. Improved model of attenuation for visibilities between 9 km and 12km

Based on the attenuation (a) and visibility (v) recorded as finite samples, the objective is to make an adjustment to "a" in "v". This lead to determine a function f (a = f (v)) which is closer to the considered sample. Linear regression method and namely the method of least squares which consist of finding the function f that minimizes the sum of least squares between the values of a_i and those of $f(v_i)$ is used as :

$$\sum_{i=1}^{n}(a_i - f(v_i))^2 \quad (3)$$

So the model for linear regression is given by:

$$a_i = \beta_1 + \beta_2 v_i \quad \forall i \in \{1,...,n\} \quad (4)$$

with

$$\beta_2 = \frac{\operatorname{cov}(a,v)}{\operatorname{var}(v)}$$

$$\operatorname{cov}(a,v) = \frac{1}{n}\sum_{i=1}^{n}(v_i - \bar{v})(-\bar{a} + a_i) \quad (5)$$

$\bar{a}, \bar{v}$ correspond respectively to the mean values of attenuation and visibility.
Var(v)=cov (v ,v), and n is the considered sample size.
Points are considered in a daily measurement basis so that they remain in the vicinity of the mean value. However, for the same values of visibilities and different days, we have considered the average attenuations to match with the visibility in order to better reflect attenuation reported. The following Table.2 shows the different parameters of the function.

Table 2: Predicting function parameters

Average value for the attenuations in dB	Average value for visibilities in km	Covariance of a and v	Variance of v	Coefficient β2
0,26035	10,4075	-0,14821813	1,07564875	-0,13779417

We come out with an expression which better fit the experimental attenuation "*a*" in dB with the visibility "*v*" in km as:

a (dB) = -0.13779417*v* + 1,69444281 (6)

where 9 Km ≤v ≤12 Km

Since the visibility depends on weather conditions, we have mainly focused our study on the parameter q predefined by Kruse' model as equals to 1.3 for visibilities between 6km and 50km. This interval includes the one (9 km to 12km) which have been investigated in this work. Kim has already investigated visibilities less than 6km. A good question has been to check if this q parameter which is a constant in Kruse model for visibilities considered does not actually depends on the visibility. Then, we have chosen a sample of 100 measurements for specific attenuations recorded to make a correspondence with Kruse' model in order to determine different values for the parameter q, and start a statistical study of these values to observe its behavior with respect to the visibility. Different attenuations per kilometer and corresponding visibilities for different days have been taken into account to build a representative sample. Table 3 presents the results of the parameters according to the performed regression.

Table 3: Values of the parameters for the function f

Average value for the parameter q	Average value for the visibility in km	Covariance of q and v	Variance of v	Coefficient β2
-2,22869892	10,61233625	1,32657264	2,09492344	0,63323204

Then, the parameter q expression is derived as :

$$q = 0.63554139v + 8,97327645 \quad (7)$$

where 9 Km ≤v ≤12 Km

With this new expression of the parameter q, we have made the same comparison between recorded attenuations and Kruse' model in Fig. 5.

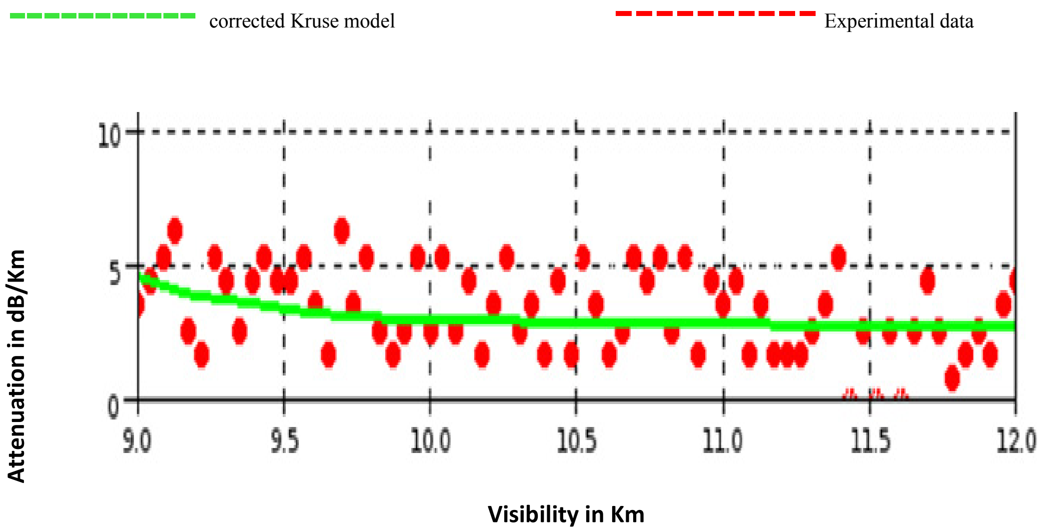

Fig. 3: Comparison of the recorded attenuation to modified Kruse' model

With these new set of values for q, we noticed that our proposed modified Kruse model best describes the recorded attenuations. This confirms q also that depends on the visibility. Then the modified Kruse ' model can be rewritten as follows:

$$\beta(\lambda)=\beta_{\alpha}(\lambda)=\frac{3.912}{\mathrm{V}}\left[\frac{\lambda_{\mu m}}{0.55\mu m}\right]^{-q} \quad (8)$$

with ***q*=0.63554139*v – 8.97327645** for 9 km ≤v≤ 12 km.

5. Conclusion

Terrestrial free space optical link attenuation has been subject to numerous investigations. Based on collected field data, this paper has shown the limitations of existing attenuation models precisely for visibility ranging from 9 Km to 12 Km. More explicit and accurate expression of the parameter "q" previously considered as a constant in Kruse empirical attenuation formulas for different visibility interval has been derived in order to fill the gap between theory and experience. The comparison of our proposed Kruse rewritten model based on field data has shown the accuracy of the reformulated attenuation model.

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