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Determination of rain attenuation parameters for free space optical link in tropical rain

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ABSTRACT

Free space optics (FSO) is a promising communication technique for various types of services in the optical access network. Single beam FSO system in tropical rainy weather is vulnerable to atmospheric rain attenuation, so it is necessary to have precise power law parameters of rain attenuation in tropical regions. In this study, the power law parameters k, and α are estimated as 2.03 and 0.74, respectively for the FSO applications in tropical South-East Asian weather. These parameters were evaluated by using least square mean equation (LSME) method with Levenberg–Marquardt optimization based on the one year collected heavy rain data. The obtained parameter values for tropical weather are contributed to improve link performance for high-speed networks.

1. Introduction

FSO is a line of sight (LOS) light communication system transmitted through atmosphere for broadband communication [1]. The principle of operation of an FSO system is based on a narrow laser beam of light which transfers the modulated digital signal from the transmission station to receiver station through the atmosphere [2]. So the transmitter and the receiver should be in clear line of sight (LOS) [3]. By realizing the exponential increase of the wireless capacity, seen in the past, leads to the convinced conclusion, that data rates of about a few tens of Gb/s will be required in 10 years from now [4]. An FSO system has a high bandwidth which allows it to transmit data at very high data rates [5], besides this, the system is preferred because of its several advantages [6], such as there are no fiber optic cables to lay, no expensive rooftop installations required, and no security upgrades necessary. Moreover, the system upgrades are generally simple and no RF license is required. This system can currently operate at speeds of up to 1.25 Gb/s [6], thus making FSO suitable for high bandwidth applications such as high-definition video streaming for multiple clients. However, FSO system suffers from one main drawback which is its link degradation. This is largely attributed to rain attenuation that causes the scattering of the laser beam especially when this beam passes through big sized raindrops. Rain attenuation is particularly severe and greatly dependent on various models of raindrop-size distribution [7]. Although there are limited studies available in the literature which has been carried out on temperate regions, nevertheless there is no appropriate model for predicting optical link rain attenuation due to tropical rain [8]. Most of the rain attenuation prediction models available in the literature were proposed for radio wave propagation, with only few prediction models have been proposed concerning FSO link by the international telecommunication union recommendation (ITU-R) based on France and Japan's measurements [7]. However both models were established on measurements conducted in low rain rates and are not applicable to tropical regions which normally experience heavy rain rates. On the other hand, models proposed by other researchers like Joss, and Marshal–Palmer based on DSD of rain have underestimated the measurement [9]. Recently [10] attempted to estimate the k and α values for tropical region. However a thorough analysis of the data presented concerning [10] reveals that the k and α values are also underestimated. For example using Eq. (1) the attenuation at a rain rate of 50 mm/h results in rain attenuation of 7.8 dB/km only, which is much less as compared to rain attenuation evaluated using k and

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Table 1
Rain attenuation prediction model proposed by ITU-R for FSO system.

Attenuation model	Author	Location	Coefficient (K)	Coefficient (α)	Region
Japan	ITU-R [17]	Japan	1.58	0.63	Temperate
Charbonneau	ITU-R [17]	France	1.076	0.67	Temperate

α proposed by France and japan model at same rain rate as 14 dB/km and 18 dB/km, respectively, although the study carried out by [10] was based on collection of rain data in Malaysia. Therefore, it is of a great interest to conduct measurements on tropical regions so that to accurately determine the power law parameters for these region, and it is necessary also to have detailed knowledge about rain effects on FSO channel in these regions [9]. In this paper we estimated new parameters concerning power law for rain attenuation, which were evaluated from the attenuation predicted over Free Space Optical link in the Malaysian tropical weather. These parameters were obtained by measuring the rain attenuation over an FSO link and the corresponding rainfall intensity for a period of one year. The parameters obtained are then compared with the parameters given by France and Japan rain attenuation prediction models.

The remainder of the paper is organized as follows: Section 2 describes current rain attenuation models. Section 3 explains the methodology of the work. The experimental setup is provided in Section 4. Finally, Section 5 demonstrates the results and discussions.

2. Rain attenuation prediction model

Modeling rain attenuation prediction model for tropical regions are based on guidelines adopted by the ITU-R. It is recommended that the rainfall data need to be collected at interval of 1 min in order to determine the rain rate [11]. This method is based on the relationship between the collected rain rates in mm/h and the received optical power [12]. Analysis concerning the effect of heavy rain on FSO link can be achieved by knowing the rain attenuation on the FSO channel and the corresponding rain rate [10]. In general, rain attenuation prediction modeling is performed using two methods, namely empirical method and the physical method [13]. Empirical method is based on relationship between observed attenuation distribution and corresponding observed rain-rate distribution measured at integration time of 1 min [14]. Whereas physical method is based on the attempt to use the physical behavior involved in the attenuation process [15]. The best commonly used raindrop size distributions that have been proposed by ITU-R are Marshal and Palmer distributions. A well-known empirical expression was developed by them. They proposed this expression by fitting their data with the Laws and Parsons data. The rain attenuation is one of the prominent factors in defining the reliability of microwave and millimeters system. The specific rain attenuation in dB/km is a basic quantity in calculation rain attenuation statistics for terrestrial and earth space path [16]. Rain specific attenuation is represented by power law given by in Eq. (1) [17].

$$\gamma_{\text{rain}} = k.R^{\alpha} = A_{\text{atmos}} \quad (1)$$

where γ_{rain} – rain attenuation (dB/km), R – rain intensity in mm/h, A_{atmos} – atmospheric attenuation which occurs in the link between FSO transceivers, k and α are rain coefficients.

The coefficients k and α depend on carrier frequency of the FSO system, and on the rain characteristics such as the temperature, the raindrop size distribution (DSD), and polarization [9]. The values of these coefficients can be obtained from ITU-R P.838-3 [18].

For the purpose of calculating the attenuation, it is appropriate to assume that the raindrops have spherical shape which makes the estimation of k and α values independent of vertical and horizontal polarization [12]. The values of k and α concerning prediction models that have been recommended by ITU-R based on France (Charbonneau's model) and Japan measurements, and other models that have been used for FSO rain attenuation prediction [19,20] are tabulated in Tables 1 and 2, respectively. The values of k and α specified by Charbonneau's model is evaluated based on measurements taken at very low rain rates in the range of 5 mm/h, because the measurements were carried out in Europe where rain fall rate is relatively very low as compared to tropical regions like South-East Asia [21]. As it is well known tropical regions may face rain rates up to 300 mm/h especially in monsoon seasons. Whereas, k and α values predicted by the Japan model is based on measurements taken from a maximum rain rate of 90 mm/h, which is significantly lower compared to average maximum rain rates in tropical countries [9]. Both models did not take into consideration the higher rain intensities which occur in tropical countries, thus the estimated k and α given by these models cannot be applied to tropical regions such as South East Asia [9]. The k and α values predicted by Marshal Palmer and Joss distributions were generated based on DSD method. As it is well known that this method is applicable to microwave systems, but it can also be applied to FSO systems [9]. As it is clearly suggested by [22] implementing DSD technique in tropical regions resulted in severe prediction error.

3. Methodology

In order to obtain the power law parameters, an experimental setup as in Fig. 1 was developed. The setup consists of one FSO transmitter (FSO TX), and one FSO receiver (FSO RX) separated along a test channel link C with link distance of l km. The attenuation of the channel between the FSO TX and FSO RX is a function of rain intensity, R. The channel is observed for a period of N hours with a sampling period of T_s hours. The collected data is saved to a local database for analysis based on MATLAB software. From the duration of data collection, a total of $M = N/T_s$ data is collected. M data spaces consist of rainy days observations O_r, and clear days observations $O_C(O_r \cup O_C = M)$. Each observation, O consists of the transmitter power, P_{tx}, the received power P_{rx} and the instantaneous rain intensity at the observed instant, $O = [P_{\text{rx}}, P_{\text{tx}}, R]$. In order to estimate the k and α values precisely, only channel observation during heavy rain is considered. The channel rain

Table 2
Rain attenuation prediction model for FSO.

Attenuation model/author	Location	Type of environment/rain rate R (mm/h)	Expression
Joss/Bouche	Switzerland	Temperate/drizzle or light rain $R < 3.8$	$0.509R^{0.63}$
Joss/Bouche	Switzerland	Temperate/mean rain $3.8 < R < 7.6$	$0.319R^{0.63}$
Joss/Bouche	Switzerland	Temperate/heavy rain (storm) $R > 7.6$	$0.163^{0.63}$
Marshal–Palmer/Bouche	Canada	Temperate/rain	$0.365^{0.63}$