ANALYSIS OF RAIN EFFECTS ON TERRESTRIAL FREE SPACE OPTICS BASED ON DATA MEASURED IN TROPICAL CLIMATE

SURIZA A.Z., ISLAM MD. RAFIQUL, WAJDI AL-KHATEEB AND A.W. NAJI

Electrical and Computer Engineering Department,
International Islamic University Malaysia,
Jalan Gombak, 53100 Kuala Lumpur, Malaysia.

rafiq@iium.edu.my

ABSTRACT: Free Space Optics (FSO) shows a great alternative as the solution for last mile problem where fiber optics is unavailable due to deployment time and cost constraint. However, the feasibility of using FSO system as communication link very much depends on local weather. Since tropical region experiences heavy rainfall, rain with high intensity is expected to affect the FSO link severely. Few prediction models have been proposed by ITU-R based on France and Japan's measurement. This paper has compared rain attenuation predicted by models and data measured in Malaysia over Free Space Optical links for one year period. Prediction models are clearly unable to predict attenuation measured in tropical climate.

ABSTRAK: Wayarles optik menjadi alternatif sebagai satu penyelesaian kepada masalah kesesakan terutama diakhir sesuatu talian dimana ianya tidak dapat diselesaikan dengan menggunakan gentian fiber akibat daripada kekangan masa pemasangan dan masalah kewangan. Walaubagaimanapun, kejayaan untuk menggunakan wayarless optic ini amat bergantung kepada keadaan cuaca di sesuatu tempat. Di rantau tropika hujan lebat sentiasa dialami, oleh itu hujan dengan kepadatan tinggi adalah dijangkakan lebih memberi kesan kepada talian wayarles optic ini. Beberapa model yang telah dicadangkan oleh ITU-R berlandaskan kepada pengumpulan data yang dibuat di Perancis dan Jepun. Kertas kajian ini akan membandingkan antara model-model yang telah digunapakai dengan data yang dikumpulkan di Malaysia selama setahun. Jelasnya model yang telah digunapakai tidak dapat digunakan secara berkesan di rantau tropika.

KEYWORDS: *free space optics; rainfall rate; rain attenuation*

1. INTRODUCTION

In telecommunication infrastructure, backbone network and last mile access is required to have efficient telecom and internet connectivity. With the existing connectivity gap, Free Space Optics (FSO) provides an excellent alternative. FSO technology promise point-to-point, high speed communications links. It is a technology which offers the speed of fiber with the flexibility of wireless. Available communication system like fiber which is the most reliable solution for optical communications is one of the backbones in most cities. However, the cost to digging and laying down the fiber cable are huge. Furthermore, the time of deployments is also economically too expensive. It is also quiet difficult to relocate fiber cable once it is already been deployed [1,2].

However, local weather condition is the foremost limitation of FSO link availability. The attenuation in atmosphere is unpredictable and can cause the attenuation from a few dBs to hundred of dBs per kilometer distance. In temperate region, the availability of FSO link is limited by fog and heavy snow [3]. In tropical region like Malaysia, rainy events can be experienced throughout the year. Therefore, rain is an important factor of attenuation and distortion signals in receiver systems [4]. Heavy rain is expected to be the limiting factor for FSO link availability. Recently, few prediction models have been proposed by ITU-R based on France and Japan's measurement. The rain attenuation on FSO links and corresponding rainfall intensity has been measured at IIUM for a period seven month from March 2011 to September 2011. This paper has compared attenuation predicted by models and those measured over Free Space Optical links in Malaysia.

2. RAIN ATTENUATION PREDICTION MODEL

Rain attenuation prediction is normally referred as "specific attenuation" which means attenuation per unit length. In Terahertz wave system like FSO, rain attenuation is particularly severe and greatly dependent on various models of raindrop-size distribution [5]. The most commonly used raindrop size distributions that have been proposed are Marshal and Palmer [6]. Marshal and Palmer distribution proposed renowned empirical expression by fitting their data and the Laws and Parsons data.

Rain specific attenuation is represented by power law; refer to equation (1).

$$A = kR^{\alpha} \qquad (1)$$

where R is the rain rate in mm/hr, k and α are power law parameters. The power law parameters depend on frequency, rain drop size distribution and rain temperature. For the purpose of calculating the attenuation, it is adequate to assume that raindrops have spherical shape. This assumption makes k & α independent of polarization [7]. To model rain prediction attenuation in tropical weather condition, an approach adopted by ITU-R is used. It is based on the relationship between the equally probable experimental rain rates and received level signal [8]. In ITU-R methods, it is recommended that the rainfall needs to be measured at interval of 1 minute in order to determine the rain rate [9].

Analysis on the effect of rain on FSO link can be done by knowing the rain attenuation on FSO links and corresponding rainfall intensity. The modeling of rain attenuation prediction can be done using two methods, namely empirical method and the physical method [10]. The empirical method is based on correlation between observed attenuation distribution and corresponding observed rain-rate distribution measured at 1 minute integration time [11, 12]. While the physical method is an attempt to use the physical behavior involved in the attenuation process.

The prediction model that has been recommended by ITU-R [13] is as in Table 1 and other models that have been used for FSO rain attenuation prediction is as in Table 2 [6].

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

Model	Origin	Author	k	α	Note
Carbonneau	France	ITU-R [17]	1.076	0.67	Temperate region
Japan	Japan	ITU-R [17]	1.58	0.63	Temperate region

Table 2: Rain attenuation prediction model for FSO.

Attenuation	Relation
Drizzle or light rain (Joss) (R<3.8 mm/hr)	$0.509\ R^{0.63}$
Mean rain (Joss) (3.8 < R < 7.6 mm/hr)	$0.319\ R^{0.63}$
Strong rain (storm) (Joss) (R < 7.6 mm/hr)	$0.163\ R^{0.63}$
Rain (Marshal and Palmer)	$0.365\ R^{0.63}$

Charbonneau's model proposed values to predict the k & α based on measurement done in France [14]. However the measurement done was for very low rain intensities compare with rain intensity in tropical region. The 5 mm/hr rain rate is taken as the highest rain rate in measurement and is considered exceptional in the United Kingdom (UK) [14]. However, in tropical region the highest rain intensity measured above 200 mm/hr. For Japan's model, the measurement seems to be conducted up to 80 to 90 mm/hr rain rate. The most of the data concentrated below 50 mm/hr which is much lower than measured in Malaysia. Both models, the higher rain rate is not in the consideration for determining values of k and α.

k and α values of Marshal-Palmer and Joss distributions are developed by considering measured drop size distribution. In [15], it is mentioned clearly that the use of drop size distribution established for other countries may result in the prediction error when applied in tropical region. Even though the analysis is done for microwave system but the application on drop size distribution is applied also in FSO. Therefore, the aim of this paper is to investigate rain attenuation prediction model for FSO under tropical weather condition using method recommended by ITU-R with 1 minute integration time.

3. MEASUREMENT SETUP

Rainfall data is measured using tipping bucket type rain gauge located at rooftop of block E1, Faculty of Engineering, IIUM, Malaysia. The block diagram of the tipping bucket rain gauge and the data logger are as shown in Fig. 1.

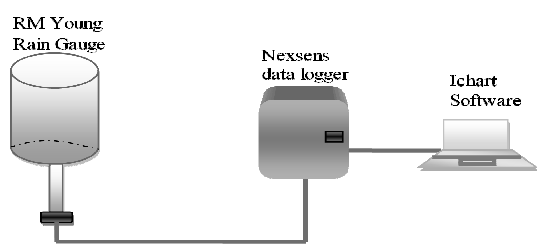
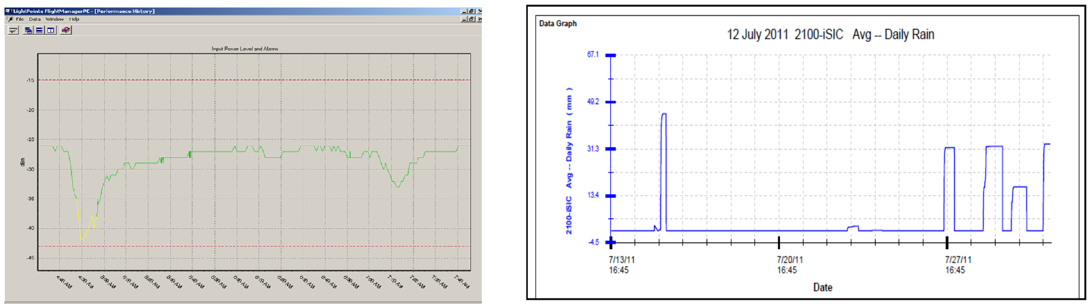


Fig. 1: Rain gauge and data logger block diagram.

The data is being logged into the data logger before being transmit to the monitoring device. Rainfall amount is logged by data logger [16] to the monitoring software with 1 minute integration time. From the collected rain data, rain events are extracted and rain intensity of mm/hr is calculated.

The FSO link is installed between Faculty of Engineering Block E1 and Mahallah Ruqayyah in line of sight. Since the transmission of the FSO link is sending and receiving signal, the term to describe it is transceivers. The distance of both transceivers is 800 m.

On both sides of transceivers there are four transmitters and four receivers. All are operated in 850 nm wavelength optical signals [17]. The management point of the link head is connected to PC interface via multipatch fiber cable to the monitoring device. The data point of the link head is connected to media converter as the source of the data transmission. The other side of the transceiver is loop backed using fiber cable. The effect of rain on the FSO link, as shown in Fig. 2, is monitored and the result for both rain event and FSO power received level is analyzed and synchronized to find the link attenuation and rain intensity at the time the rain occurred.



(a) (b)

Fig. 2: The effect of rainfall on FSO link (a), and rain data taken from rain gauge (b), taken on 29 July 2011 between 4.40AM to 7.40AM.

4. RESULTS AND ANALYSIS

Throughout the measurement, 96 raining events were collected and out of it 73 heavy raining events are considered for analysis. The other 23 observed raining events are discarded due to two obvious reasons. There are 18 events where rain gauge collected rain intensity but the FSO link was unavailable. And other 5 events measured low rain intensity which has no effect to the FSO link.

All measured rain intensities and attenuation on FSO link were synchronized based on the 1 minute's integration time. For every rainy day and amount of rain is extracted out from the measured data. Each rain event is compared to FSO link's received power level and the attenuation level due to the rain is extracted for each minute. The collected data was not considered for one year period, hence it is not adequate to represent statistical distribution. But the analysis is focused on to derive relationship between rain and its effects on FSO signal. Therefore, it is obvious that considering 73 events are adequate to produce correct results. A sample calculation of percentage of exceeded for is calculated and plotted. A sample graph for a month data is as shown in Fig. 3.

The same process is done for measured received power level (dBm) of FSO link that attenuate due to the rainfall rate at the same time and the same date as the rain events with 1 minute integration. From the data, the attenuation due to rainfall is extracted and percentage of time exceeded is calculated and plotted as in Fig. 4. The measured rain intensity and corresponding rain attenuation on FSO link is estimated for equally probable at different percentage of time exceeded.

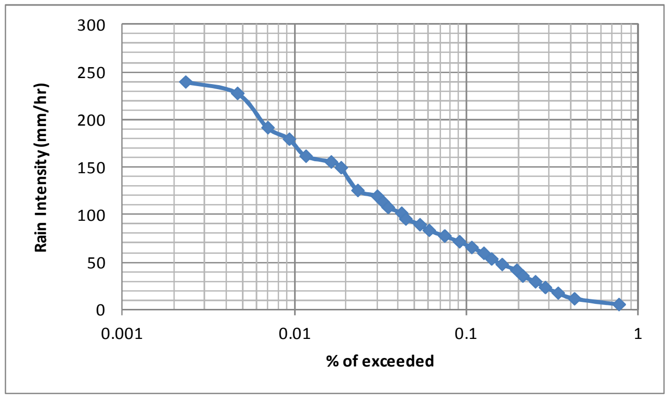


Fig. 3: One month rain intensity (mm/hr) as a % of time exceeded measured on July 2011.

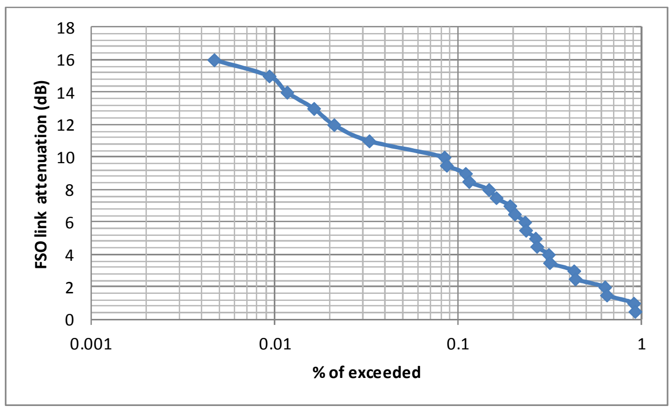


Fig. 4: One month rain attenuation on FSO link (dB) as a % of time exceeded measured on July 2011.

The same process is repeated and done for all 73 measured rain events. The measured rainfall data against the attenuation of the link is plotted. The predicted rain attenuation using rain rate obtained from measurement and k and α values proposed by Carbonneau, Japan's model, Marshal-Palmer and Joss are estimated and compared with measured attenuation. The predicted and measured values are presented in Fig. 5.

It is obvious from the result in Fig. 5, the prediction models which are proposed by Marshal-Palmer and Joss based on rain drop size distribution underestimate measured attenuation at all rain intensities. On the other hand, model proposed by Carbonneau, overestimate the measured attenuation for entire rain intensities. The differences are more than 10 dB/Km for higher rain rates; since the Carbonneau model just considered very low rain intensity to develop k and α. Hence these values seriously mislead the prediction for tropical region where intensity of rain is much higher than 10 mm/hr, most of the raining event.

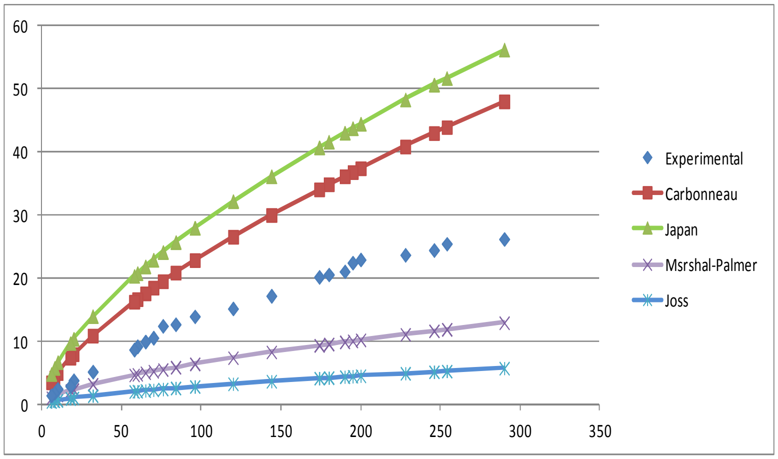


Fig. 5: Comparison of measured rain attenuation and that predicted by prediction models using measured rain intensity.

Model proposed by Japan overestimate the measured data even higher than that proposed by Carbonneau model. The prediction goes more than 20 dB/Km for higher rain intensity which shows severe error. This model also estimate k and α values based on rain intensity much lower than 100 mm/hr. Attenuation on free space optics occurred mainly due to scattering which seems not to increase exponentially with intensity of rain. That's why the regression coefficients proposed based on very low rain intensity are unable to predict attenuation on FSO in tropical region's high intensity rainfall.

5. CONCLUSION

Free space optics is severely affected by rain and it is a challenge to design a reliable FSO link in tropical region. In order to investigate the effects of rain on FSO, a link was installed in the Faculty of Engineering, International Islamic University Malaysia's Kuala Lumpur campus. Real time rain intensity and corresponding attenuation on FSO link was measured concurrently for one year period. Measured result was with that predicted by models proposed by ITU-R based on France and Japan's measurement. Both models overestimate the measurement severely. On the other hand, models proposed by other researchers based on drop size distribution of rain underestimate the measurement. Hence it is recommended to study rain effects more details for designing FSO links in tropical climate.

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