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A PROPOSED RAIN ATTENUATION PREDICTION METHOD FOR FREE SPACE OPTICAL LINK BASED ON RAIN RATE STATISTICS

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ABSTRACT

Free Space Optics technology has gained acceptance in telecommunication industry mostly in enterprise campus network. However in tropical regions, rainfall is the dominant factor that degrades the FSO link performance and its availability. In this paper, a method is proposed to estimate the total path attenuation due to rain for Free Space Optical communication links for all percentage of availabilities and any path length. Path length reduction factor for FSO has been derived using reduction factors models developed for microwave under measurement in tropical climate. Regression analysis has been applied and model is derived using best fit curve. Comparison between derived and measured reduction factors has been made for validation. Derived reduction factor seems to have strong agreement with both models which were derived based on measurements. This method can provide estimation of total path rain attenuation for FSO for all percentage of time with any path lengths.

Keywords: FSO, rain attenuation, rainfall rate, reduction factor.

INTRODUCTION

Free Space Optics (FSO) is a wireless technology which uses laser as a medium of transmission between transmitter and receiver. This technology is a line of sight (LOS). It also considers being high speed wireless bridges in today's telecommunication industry. The FSO heads set prefers to be installed at roof top to prevent link outage. Among the advantages of FSO is that one could have a technology which provide the same speed of optical fiber within days. Others like: high secure compare with microwave technology, free licensing of bandwidth.

The main disadvantage in Free Space Optics technology is that it can easily be influence by atmospheric weather conditions like fog, haze, and rain [1]; also weather turbulence such as scintillation [2]. In temperate regions, fog has high impact on optical signal due to scattering and absorption of visible optical beams [3]; whereas in tropical regions, heavy precipitation is the dominant factor that degrading the FSO link performance and its availability [4]. Among the solutions have been proposed to compensate FSO problem is implement FSO link with back-up RF (Hybrid FSO/RF system). This solution can enhance the performance of FSO system and optimize the quality of FSO link [5]. Rain attenuation occurs due to non selective scattering or absorption of the optical wave [6]. Predicted rain attenuation as Equation (2) in general form is independent of wavelength [6,7]. Several prediction models were developed to predict the rain attenuation based on two methods namely: empirical method and physical method [8]. Empirical method provide the best fit of direct correlation on observed rain attenuation distribution and its corresponding rain rate distribution with 1 min integration time[9, 10]; This method is our concern in this paper. FSO specific rain attenuation models Table-1 are developed to predict rain attenuation for one kilometer distance only. For extrapolation to evaluate the performance of FSO for a distance beyond one kilometer, a total path attenuation prediction model is needed. ITU has recommended a model Equation (3) to estimate the total path attenuation for 0.01% for microwave [11] . The model can be applied for FSO if we develop reduction factor r for FSO. In this paper, the path length reduction factor r developed for FSO. Since path reduction factor depends on structure of the rain cell not the characteristic of propagating signal. The reduction factor developed for FSO based on two measured reduction factors used for microwave under tropical environment. The proposed reduction factor can provide an estimate of total path attenuation of Free Space Optics communications link for all percentage of time and distance higher than one kilometer. That can be useful for FSO designers to evaluate the performance for more than one kilometer FSO link.

SPECIFIC RAIN ATTENUATION OF FSO

To observe the impact of rain attenuation of Free Space Optics link, drop size distribution of rain and rain rate are needed. Specific rain attenuation or extinction coefficient in dB/km can be calculated by integrating all the drop sizes as follow [12]

$$\gamma = 4.343\int Q(D,\lambda,m)N(D)dD \qquad (1)$$

Where Q is extinction cross section (mm^2) and is a function of drop diameter D (mm), wavelength (mm) and the complex refractive index of water m.

Based on Equation (1) the general form of specific rain attenuation equation, Equation (2) derived using power law approach to obtain power law coefficient using curve fitting or point matching techniques to find the values of k and α. This making it in simple form and depends only on the rain rate as follow:

$$\gamma_R\,(dB/km) = kR^{\alpha} \qquad (2)$$

Over the years and up to recent time several power law models for specific rain attenuation for Free

Space Optics [13, 14, 15, 16, and 17] have been proposed in both temperate and tropical climate weather conditions. These models developed based on regression analysis and other methods of measured rain intensities (mm/hr) and rain attenuation (dB) in their respected areas. Table-1 shows the values of k and α for these models. Comparisons of specific rain attenuation models shown in Figure-1 Carbonnea and Japan models which recommended by ITU gave average attenuation compare with other models.

Table-1. K and α values of specific rain attenuation models of FSO.

Model	k	α	Country/Region
Carbonnea	1.076	0.67	France / Temperate
Japan	1.58	0.63	Japan / Temperate
Martine	0.231	0.7	Prague / Temperate
Samir	2.03	0.74	Malaysia / Tropical
Suriza	0.4195	0.8486	Malaysia / Tropical

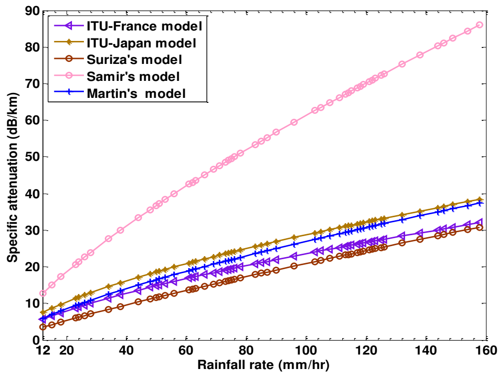

Figure-1. Comparison of specific rain attenuation of different FSO models.

METHODOLOGY

Rain rate measurements

A One year rain rate data measurement was collected by using tipping bucket rain guage (Casella) from 1 January 2011 to 30 December 2011. The cumulative distribution function (CDF) is shown in Figure-2. The highest rain rate was 168 mm/hr, whereas the lowest rain rate was 12 mm/hr. From Figure-2 the percentage of time exceeding 0.01% level is almost corresponding to 100 mm/hr.

Table-2. Rain gauge specification.

Item	Specification
Catchment area	200 cm^2
Resolution	0.2 mm per tip
Accuracy	1% up to 26 mm/hr
Output	Contact Closure
Contact rating	24 VDC 500 mA

Derivation of path length reduction factor

Due to inhomogeneous of rain while propagating along the path, the rain might not fall into the entire propagating path. Cause some portion of the link to be effected. This is so called effective path link, which define as the intersection between rain cell and path length. It is confirmed from this definition that the effective path length is smaller than total actual path.

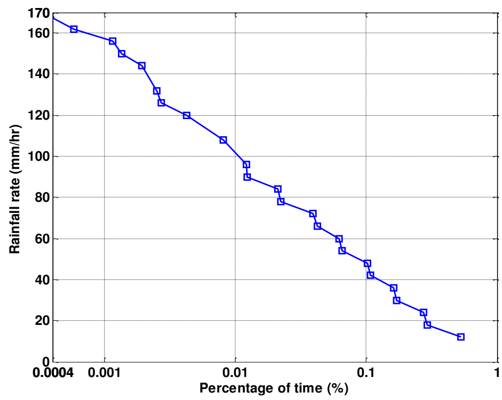

Figure-2. Cumulative distribution of rainfall data measured in Malaysia over a period of one year.

According to ITU recommendation, the total path attenuation exceeded for 0.01% of the time can be estimated by [11]:

$$A_{0.01\%}(dB) = \gamma_R d_{eff} = \gamma_R dr \tag{3}$$

Where; γ_R is the specific rain attenuation (dB/km) and d is total path length (km) and r is reduction factor.

There are many models has been developed to estimate the value of r in both temperate [18, 19] and tropical regions, even ITU has also recommended the value of r [11]. Among these models is [20] which is developed based on measured at seven different locations in Malaysia using 15 GHz frequency and for 0.01%. The value of r for this model can be estimated by:

$$r_{0.01} = \frac{1}{1 + \dfrac{d}{2.6379 R_{0.01}^{0.21}}} \tag{4}$$

Where R is rain intensity (mm/hr)

The other model [21] which also developed based on measured rain intensity and rain attenuation for a fixed distance of 2.29 km and 28.75 GHz under tropical climate in India but for all percentage of time. The value of r for this model can be obtained by:

$$r = 3.6435 R^{-0.377} \tag{5}$$

Based on the model [20], the value of r it depends on rain intensity and distance of path link. Whereas; model [21] it depends on rain intensity only. As the matter of fact, the r

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value should be less than one, but in model [21] the value of r showed to be greater than one at lower rain intensity < 30 mm/hr. That due to fact low rain intensity is widespread over the path length which represent uniform rain rates [21], in contrast high rain rates can be much localized [20].

In order to develop r for all percentage of time the model [21] needs to multiply by a factor so that can be fit with our local measurements of rain rate. Model [20] is developed based on Malaysia climate and it is a function of d as well, so the combination of these two models can produce a new model of reduction factor which can be suitable for all percentage of time and as a function of distance. Assume that a path link of 5 km distance, and given 100 mm/hr for 0.01% from measured data of Malaysia. Also we assume a single scatter of optical attenuation [22]. Based on this assumption the model [21] will give constant (C) value for all 5 km, whereas, [20] will let to variation of r (Δy) at each distance point. Dividing each Δy over C will let to a new function (Δx), by applying the regression analysis; the best fit curve gave an exponential function with the following expression:

$$\Delta x = 1.4912\, e^{-0.102x} \qquad (6)$$

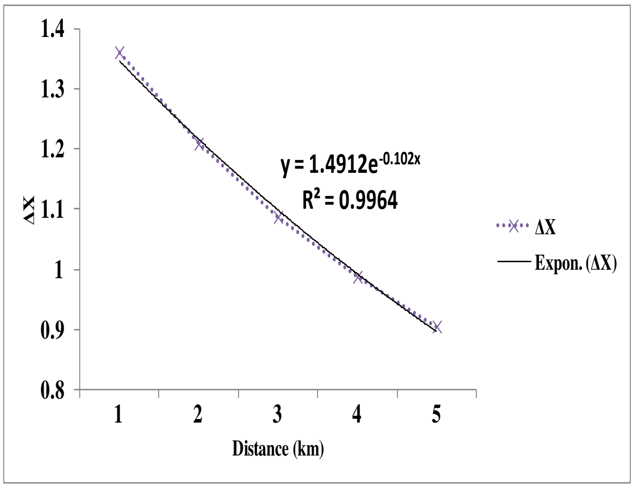

Figure-3. Exponential equation of best fit curve of Δx.

With coefficient of determination $R^2 = 0.9964$ as shown in Figure-3.

By multiplying Equation (5) & Equation (6) will give a new reduction factor as follow:

$$r_{\%p} = 5.433187 R_{\%p}^{-0.377} \exp(-0.102d) \qquad (7)$$

Proposed rain attenuation prediction method

Now by substitute Equation (7) into Equation (3); the final form of the total path attenuation of FSO due to rain will be as:

$$A_{\%p}\,(dB) = \gamma_R\, 5.433187 R_{\%p}^{-0.377} \exp(-0.102d)\, d \qquad (8)$$

The above equation can be used to estimate the total path attenuation due to rain for Free Space Optical link for all percentage of time and distances more than one kilometre.

ANALYSIS FOR VALIDATION

In order to validate the proposed reduction factor model; we Compare it with two measured reduction factors models developed for a tropical climate. Suriza model [17] has been employed to calculate the specific rain attenuation for comparison purposes.

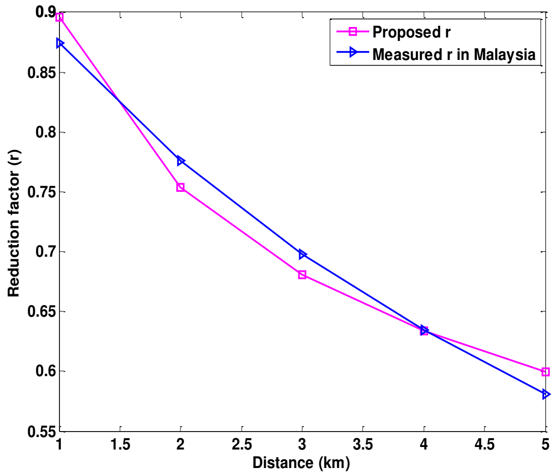

Figure-4. Comparison of r measured in Malaysia and r predicted by proposed model.

The values of r predicted by proposed model are close to measured r in Malaysia as shown in Figure-4.

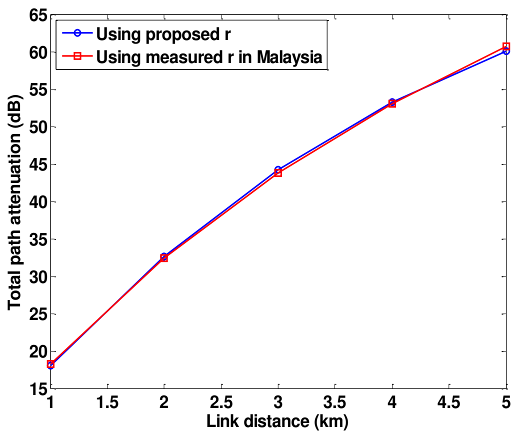

Figure-5. Comparison of total path attenuation for 0.01% using r measured in Malaysia and proposed r.

The total path attenuation using measured r in Malaysia is in close agreement with proposed r as shown in Figure-5.

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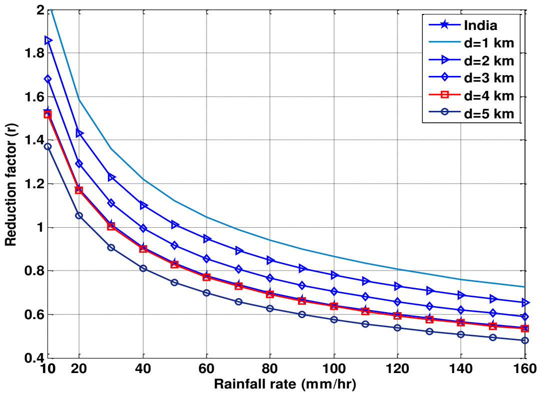

Figure-6. Path reduction factors measured in India & those proposed as a function of rainfall for different distances.

The proposed *r* which developed based on 100 mm/hr at Figure-6 is match with measured *r* in India which developed for 51.04 mm/hr at fixed distance 2.29km, the matching observed to be at d = 4 km. In other words, if we almost double of 51.04 mm/hr will be at 4 km distance which is also agree with the proposed *r*.

CONCLUSIONS

Rainfall is the dominant factor that degrades the FSO link performance and its availability in tropical regions. In this paper, a method is proposed to estimate the total path attenuation due to rain for Free Space Optical communication links for all percentage of availabilities and any path length. The method is developed using prediction method proposed by ITU-R and two reduction factor models proposed for microwave links based on tropical measurements. The proposed method can be applied as a useful tool to estimate the total path rain attenuation for FSO for any outages and path lengths while rain rate statistics are available.

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