Optik 127 (2016) 10316–10321

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Availability analysis of free-space-optical links based on rain rate and visibility statistics from tropical a climate

Ahmed Basahel*, Islam Md. Rafiqul, A.Z. Suriza, Mohamad Hadi Habaebi

Electrical & Computer Engineering Department, Faculty of Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 29 April 2016
Received in revised form 23 August 2016
Accepted 23 August 2016

Keywords:
Free-space optics
Rain attenuation
Visibility
Haze attenuation
Availability

ABSTRACT

Availability is one of the major parameters to measure the performance of Free Space Optics (FSO) communication link. In tropical climate, rainfall acts as a dominant factor that affects the FSO link availability; whereas haze has no significant effect compare with rain. But for longer FSO link distances, the effect of haze on the overall FSO link availability becomes serious and need to be considered. In this paper, availability of an FSO link is estimated under the impact of rain, haze and the combination of the two phenomena. The availability estimations based on predicted attenuation due to rain and haze using long-term statistical measurements of rain rate (mm/hr) and visibility (km) data measured in Malaysia. The effect of individual weather phenomena was demonstrated over FSO link ranges from 1 to 5 km. The combine effect of both rain and haze also has been analyzed using the cumulative distribution function (CDF) of predicted atmospheric attenuations. In tropical regions, for short FSO link distance, the influence of haze on the availability of FSO signal is negligible compare with rain; whereas for longer FSO distances, haze attenuation will reduce the overall link availability. This effect of haze needs careful consideration for the deployment of FSO systems especially in Malaysian tropical climates.

1. Introduction

Free-space optics (FSO) is no longer emerging technology rather it becomes implemented widely. Increasing demand of FSO is due to providing higher bandwidth, high security and licensed free compare with microwave [1]. FSO systems are most frequently used in terrestrial applications over distances up to several kilometers [2,3]. For telecommunications industry the two widely used availability standards are: carrier class availability which generally considered to be 99.999% (5-nines) and enterprise class availability in which 99% is considered as sufficient [4]. Thus, availability assessment based on local weather data provides a reasonable link distances for FSO systems. However, FSO systems are influence by different weather conditions such as rain, haze, fog, and snow [5]. Another factor that may affect the FSO link is scintillation. But the effect of scintillation can be resolve by using novel algorithms [6] or applying spatial diversity technique [7]. In a recent study, the FSO link can operate over a few kilometers link distance under clear weather conditions [8]. In temperate region, fog is a major concern on FSO link availability [9]. In tropical regions, heavy rainfall is the main factor which influences the optical signal. Meanwhile, haze induces by smoke, mist and other dry particles have low impact on the optical power compare with rain [10]. The particle size of rain and haze has similar size distribution with transmitted optical wavelength resulting in Mie

* Corresponding author.
E-mail addresses: ba_sahal@hotmail.com, basahel@gmail.com (A. Basahel).

http://dx.doi.org/10.1016/j.ijleo.2016.08.061

Table 1
Specific rain attenuation parameters of FSO.

Model	K	α	Region
Carb. (France)	1.076	0.67	Temperate
Japan	1.58	0.63	Temperate
Prague	0.231	0.7	Temperate
Malaysia (KL)	0.4195	0.8486	Tropical
Malaysia (Johor)	2.03	0.74	Tropical

scattering of optical signal [11]. This scattering will induce attenuation of optical received power, thus reduce the availability of FSO link for a given link distance [12]. In this paper, availability of FSO link in tropical climate has been predicted based on rain rate and visibility data measured in Malaysia. The atmospheric loss due to rain and haze were predicted using measured rain rate and visibility data respectively. The effects of individual hydrometeros of rain and haze as well as combine of both were analyzed. In tropical environment FSO links can be deploy over a few hundred meters link distance to achieve carrier class availability; whereas FSO links can operate over longer distances up to 5 km for enterprise availability.

2. Atmospheric attenuation

2.1. FSO specific rain attenuation models

To observe the effect of rain attenuation on the FSO signal, the rain rate is needed. Specific rain attenuation γ_R can be calculated in decibel scale by the following relationship [13]:

$$\gamma_R(dB/\text{km}) = kR^{\alpha} \tag{1}$$

where k and α are scattering coefficient and can be derived from experiments and measurements by adopting the power law approach [14]. For FSO, several models [15–18] were derived the values for k and α. Table 1 shows the values of k and α for each model. In this paper, model developed in Malaysia (KL) [17] has been selected in the prediction of rain attenuation because it has been developed based on experiment conducted in tropical climate over 800 m FSO link distance. For predicting rain attenuation for more than one kilometer FSO link distance, the total path attenuation for FSO is proposed in modified form and given by [19]:

$$A_{\%p}(dB) = 5.433187\, d(\gamma_R)(R_{\%p}^{-0.377})\exp(-0.102d) \tag{2}$$

where d is the total path length (km) and $R_{\%P}$ is the rain intensity (mm/hr).

2.2. Haze attenuation

Malaysia and neighboring countries had experienced several serious dens haze due to plantation activities involving biomass burning in the forests in Indonesia and parts of Malaysia. These forests fires induced dense haze that impair the visibility and cause a huge attenuation of optical signal; but other human activities such as open burning of waste and vehicle emissions will induce normal haze which is always occur most of the years [10]. In this article, normal haze is considered. Haze attenuation can be predicted by Beer-Lambert law as follow [20]:

$$\tau = e^{-\sigma d} \tag{3}$$

where σ (km^{-1}) is the scattering coefficient which derived from the definition of visibility and experimental data and given by [21]:

$$\sigma = \frac{|\ln(\varepsilon)|}{V}\left(\frac{\lambda}{\lambda_o}\right)^{-q(v)} \tag{4}$$

where ε is the contrast threshold (2%), $\lambda_\circ$ is the visibility reference (550 nm) and $q(v)$ is size distribution of the scattering particles. The value of $q(v)$ for high and moderate visibility are 1.6 and 1.3 respectively, and for low visibility as follow [11]:

$$q(v) = \begin{cases} 0.16V + 0.34 & \text{for } 1 < V < 6\text{km} \\ V - 0.5 & \text{for } 0.5 < V < 1\text{km} \\ 0 & \text{for } V < 0.5\text{km} \end{cases} \tag{5}$$

2.3. Combined effects of rain and haze attenuation

Based on our observations on measured data of rainfall rate and visibility; rain and haze are two weathers phenomena which independent of each other. Although Malaysia has rainy forest climate, the frequent occurrence of haze should be consider in order to obtain accurate availability predictions. Haze condition has slight impact on the overall availability and has to be taken into account. The overall availability of combine rain and haze conditions can be obtain by joint exceedance