Free Space Optical Link Connection Availability Estimation in Rain Data for Kathmandu Valley

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Abstract: Free Space Optical (FSO) link provides fast, high-capacity communication link without use of fiber. It is thus, inexpensive, fast to deploy, and suitable for tough terrains. However, its performance is hindered by local weather condition, making any FSO system's performance location dependent. This work analyses the effect of rainfall in FSO link, FL155E, based on rainfall data collected in Kathmandu valley. This work estimates the link connection availability based on empirical CDF analysis of rain data and attenuation due to rain for selected link range. Data has been borrowed from Department of Hydrology and Meteorology (DHM), Nepal, and in 1-hour interval basis accumulated rainfall value. The simple assumption is that the rainfall intensity is flat over the 1-hour interval. The result shows that the connection availability of FL155E system is 99.9% for link range below 1500 meters. Up to 2000 meters, availability of connection still remains 99%. The limitation in calculation of availability for range below 1500 is due to unavailability of higher resolution data. Another limitation is the turbulence effect is not considered in case of rainfall, which may increase the total attenuation in the link.

Keywords: FSO, Availability, Rain Attenuation

I. Introduction

Free Space Optical Communication (FSOC) is a wireless optical communication technology offering bandwidth in similar order that of fiber. It is flexible, fast [1] and has cost effective deployment, operates in high-speed license-free band which can offer data rate comparable to fiber optics [2]. It can address any needed connectivity in optical networks such as core, edge, and access [3].

However, its dependency on local weather condition presents an uncertainty in performance when deploying in a particular location. For more accurate estimate, local weather data can be utilized to estimate connection availability and its performance.

II. Framework, Methods and Tools

A. *Link Margin Calculation*

According to ITU standard calculation of link margin is provided as shown by equation (1).

$$M_{link} = P_e - S_r - A_{geo} - A_{rain} - A_{sys} \dots\dots\dots\dots..(1)$$

Where, M_{link} is link margin (dB), P_e is transmitted power, S_r is receiver sensitivity, A_{geo} is geometric loss, A_{rain} is rain loss and, A_{sys} is internal system loss. For selected system the link margin available after considering rain effect can be calculated using equation (2).

$$M_{link} = M_{def} - A_{geo} - A_{rain} \dots\dots\dots\dots..(2)$$

Where M_{def} is given system margin in system specification. The system specifications for selected Flightlight system FL155E is given in Table 1, and its block diagram representation is provided in Fig. 1.

B. *Rain Loss Calculation*

Rain attenuation in optical beam is due to non-selective scattering and absorption. Attenuation due to rain is thus wavelength independent, and it can be calculated using equation (3).

$$\gamma_{rain} = k \times {R_{rain}}^{\alpha} \dots\dots\dots\dots..(3)$$

The values of k and α parameters are different for different climatic regions [4] [5] [6] [7]. Thus, this also injects location dependencies in FSO. There are numerous studies done, on different climatic regions, to fit the power law equation to find the value of k and α.

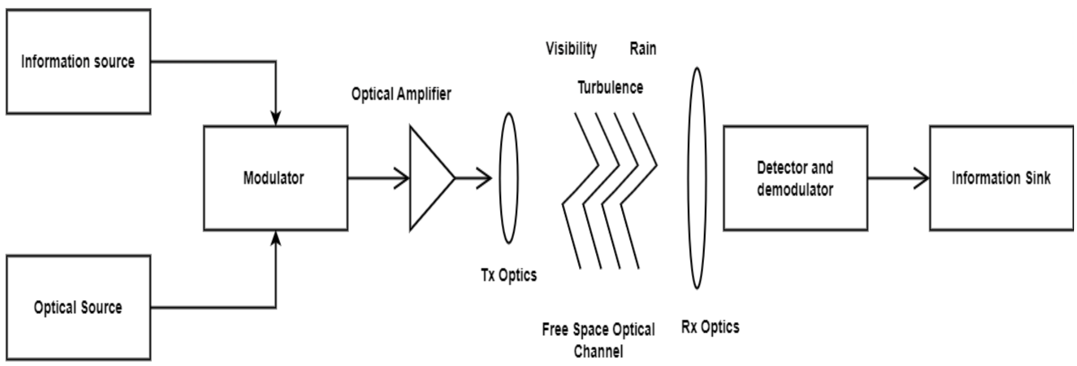

Fig.1: FL155E System Block

TABLE I: FL155E SYSTEM SPECIFICATIONS

System Model	Light Haze/Light Rain (3dB loss)	Thin Fog/Heavy Rain (10 dB loss)	Moderate Fog/Monsoon (30dB loss)
FL155E	2.9km	1.5km	700m

Kathmandu falls under temperate climate with Hot summer and Dry winter, and selected model for the rain loss analysis is Japan model. The parameter value for k and α in Japan model are 1.58 and 0.63 respectively. This provides A_{rain} for estimating availability for selected link range.

C. *Geometric Loss Calculation*

Geometric loss can be quantified as per ITU-standard [8] given by equation (4).

$$G_{loss} = \frac{\frac{\pi}{4}(d\theta)^2}{Receiver\ aperture} \ldots\ldots\ldots\ldots\ldots..(4)$$

In dB scale, $[G_{loss}] = 10log\ (G_{loss})$

For selected system, G_loss is assumed to be zero dB at reference location l_r = 700 meters, then the geometric loss in terms of link range is calculated using equation (5).

$$[G_{loss}] = 20\ log\ log\ (l)\ - 20\ log\ log\ (l_r)\ \ldots\ldots\ldots\ldots(5)$$

III. DATA ANALYSIS AND RESULTS

A. *Data*

A two years-long rainfall data from DHM is collected, which is from Automatic Weather Station (AWS) station situated in Tribhuvan International Airport (TIA). An empirical CDF plot is developed based on which exceedance probability for given rainfall attenuation is calculated. The plot of rain attenuation value and its respective exceedance probability is shown in Fig 2.

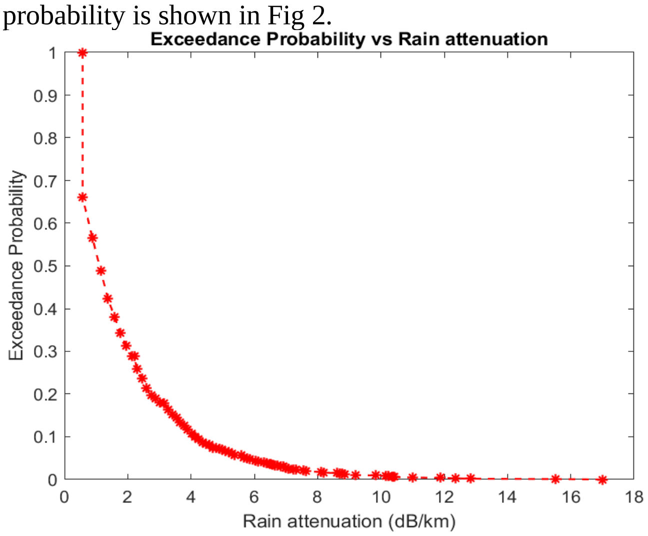

Fig. 2: Empirical Exceedance Probability of Rainfall Attenuation

B. *System Link Margin*

Using system specification and expression for geometric loss calculation, available fade margin for weather attenuation can be calculated as function of link range. The available fade margin is the room available for rain attenuation which should not be exceeded for FSO link connectivity to be available. For FL155E system and other Flightlight systems (FL155EW and FL-G) the available margin after geometric loss is shown in Fig.3.

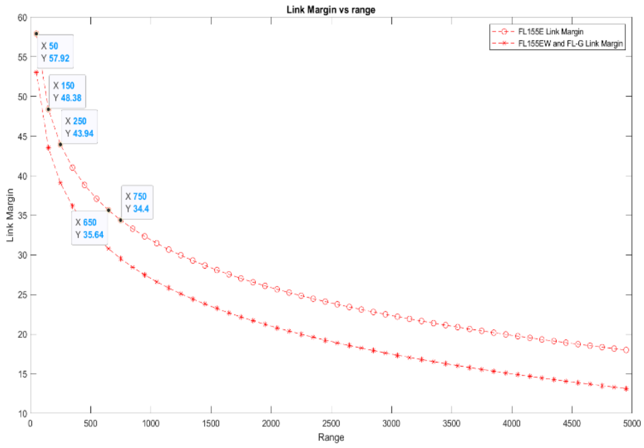

Fig. 3: Geometric Attenuation vs Link Range for FL155E, FL155EW and FL-G Systems

C. *Data Analysis Tools and Techniques*

The analysis is done by writing codes in MATLAB implementing all models of calculation and procedural steps in getting the result.

D. *Analysis Results*

For availability greater than 99%, exceedance probability of value 10^{-2} required at maximum. The associated attenuation and exceedance probability for the value below 10^{-2} is tabulated in Table 2.

Based on this analysis, the availability considering rainfall only can be empirically calculated. The intersection point of availability curve with available margin curve gives maximum link range for the selected availability value.

Fig. 4 shows the curve of availability and system margin for FL155E system after geometric loss is accounted. Table 3 shows the respective link range and the link margin needed to maintain FSO link connectivity, and availability of the link with provided link margin at selected link range.

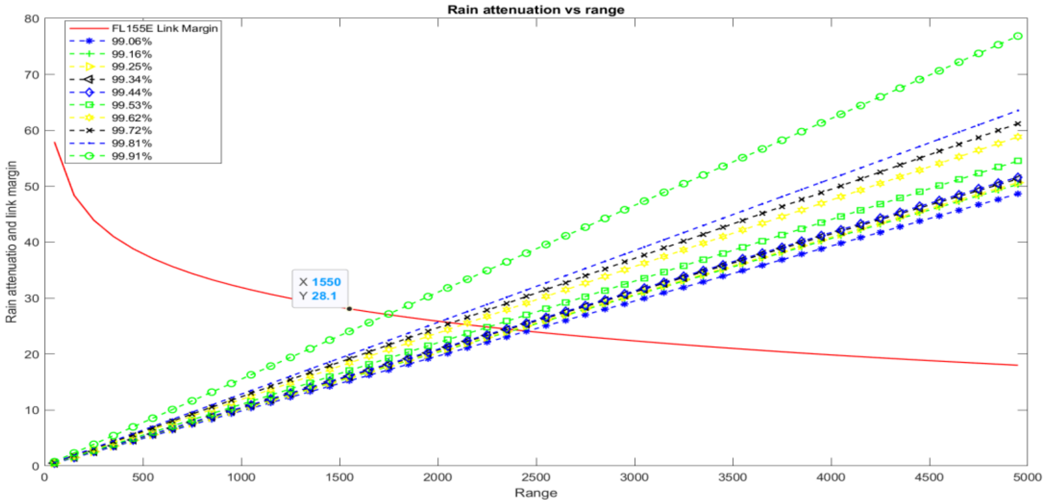

Fig. 4: Availability and Link Margin Curve for Rain Attenuation

TABLE II: RAINFALL ATTENUATION (DB/KM) AND ITS EMPIRICAL CUMULATIVE PROBABILITY

Rainfall attenuation (dB/km)	Cumulative probability	Exceedance Probability
9.828	0.99061	0.00938
10.165	0.99155	0.00844
10.232	0.99249	0.00750
10.364	0.99343	0.00656
10.430	0.99437	0.00562
11.012	0.99530	0.00469
11.883	0.99624	0.00375
12.364	0.99718	0.00281
12.835	0.99812	0.00187
15.524	0.99906	0.00093

TABLE III: LINK RANGE FOR FL155E SYSTEM AND ITS AVAILABILITY IN RAIN EVENT

Link range	Availability	Link Margin
<1500 meters	99.91%	>28.38 dB
2000 meters	99.81%	25.88 dB
3000 meters	97.65%	22.36 dB
4000 meters	93.06%	19.86 dB
5000 meters	86.68%	17.92 dB

IV. CONCLUSION AND FUTURE WORKS

Since, the DHM data is not sufficient enough, the calculation doesn’t have higher resolution to show the availability greater than 99.9% in rainfall condition. Also, the collected data is from AWS situated in TIA, where it collects the local environmental parameter. Inclusion of synoptic data is omitted in the analysis.

However, assuming that for link range below 1500 meters, the availability of the system in rainfall events remains at 99.9%, then for link range above 1500 meters the system availability in rainfall event can be tabulated by observing the intersection point of link margin with each rainfall attenuation curve for respective empirical availability value. Then the availability for different link range is tabulated in Table 3.

The analysis can be improved by adopting appropriate statistical modeling of rainfall pattern, and also by using higher resolution rain data. Further, this result can serve as preliminary estimation of availability for analyzing performance of FSO in rainy condition. It will help in quantifying a tentative attenuation value for rain event where, the performance of an FSO system can be characterized in terms of BER/SNR.

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