Carrier Class Availability Prediction for Hybrid FSO/RF System in Heavy Rainfall Regions Based on ITU-R Models

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***Abstract*—Availability is considered as the main parameter of evaluating a Hybrid FSO/RF link quality. An accurate carrier class availability prediction of Hybrid FSO/RF is needed. In tropical regions, among different weather influences, rain plays a major role. Precipitation decrees are available for frequencies above 10 GHz. In this paper we will analyze the effect of rain on Hybrid FSO/RF to find the optimum operating frequency to back-up the FSO link besides tradeoff between speed of RF and link availability of FSO in tropical environment; we will also provide better prediction of link availability. ITU-R specific rain attenuation of FSO and RF models has been used for the analysis. From the results, a 30 GHz and below are suggested to be used as a back-up of FSO link to achieve carrier grade availability under the impact of rain.**

***Index Terms*—Carrier grade availability, heavy rain attenuation hybrid FSO/RF, ITU-R specific rain attenuation models.**

I. Introduction

Free Space Optics is a wireless technology which uses laser as a medium of transmission between transmitter and receiver. This technology is a line of sight (LOS) where transmitter and receiver should be on mountain or at the roof top of buildings.

FSO has many advantages such as high bandwidth, easy to install where you can install transmitter and receiver beside a window and within days, free licensing of frequency, cost effectiveness where no digging is needed and very high security where the signal cannot be hacked.

The big challenge facing this technology and considered a disadvantage is that FSO especially in long distances can easily be affected by weather conditions like fog, haze, rain and scintillation [1], [2]. In temperate regions, fog is consider the main factor which influences the performance of FSO link availability [3], [4]; whereas in tropical regions heavy rainfall rate is expected to be the limiting factor for FSO link availability. These weather conditions limit the distance of FSO and decrease the link availability [5]. In order to compensate this problem we need to have a comprehensive FSO system; one of the solutions is to implement FSO link with a back-up RF (Hybrid FSO/RF system). FSO/RF system can enhance the performance of FSO system and optimize the link quality such as the availability of FSO performance; by using FSO/RF the availability can increase from 99.99% (enterprise class) to 99.999% (carrier class) [2]. In this paper, the availability is calculated using link budget of FSO system and microwave. As the rain attenuation of Hybrid FSO/RF is independent of wavelength, the analysis will be based on rainfall rate [6]. ITU-R specific rain attenuation models for FSO and RF are used for the analysis. The effect of rain attenuation on the availability of Hybrid FSO/RF is analyzed by examining the distance of different RF frequencies. A recommendation of optimum operating frequency for tradeoff of FSO availability is suggested.

Over the years, FSO technology has gained acceptance in telecommunication industry mostly in enterprise campus network. This paper provides recommendations to local telecom service provider about possible availability figures of carrier and enterprise class that can be useful for the deployment of Hybrid FSO/RF link as the last mile solution, back-up for fiber optic and other applications. Fig. 1 below shows the proposed approach of the link availability prediction used in this paper.

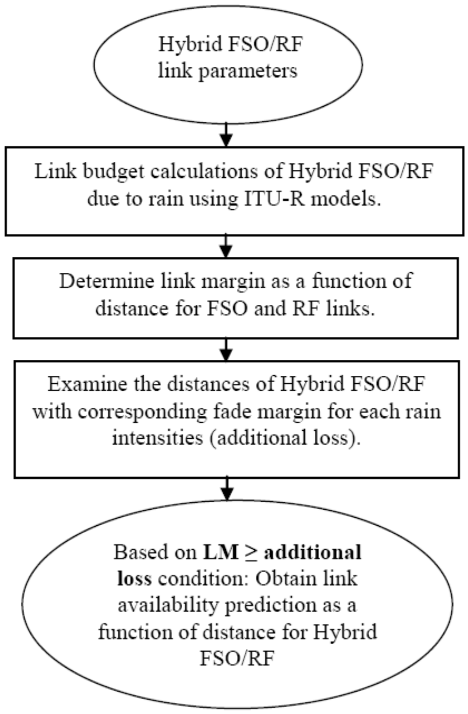

Fig. 1. Flow chart of proposed approach.

II. FSO Link Budget

A. Geometric Loss

Light beam is expanding as it travels from point of origin outwards. The beam usually adopts a cone shape and a

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divergence angle determines how much the beam spreads as it travels through air. Thus, this will lead to the fact that a big portion of the light will miss the receiver aperture at the receiver side and will be considered as a loss. This loss is referred to as a geometric loss or attenuation. Geometric attenuation has three main parameters which can help in optimizing the performance of FSO link which are minimizing divergence angle and link distance, increasing the receiver aperture area. The divergence angle and receiver aperture area are related to the design of FSO.

Mathematically, geometrical attenuation can simply be derived from Fig. 2 below. The portion of light which misses the receiver aperture is shown.

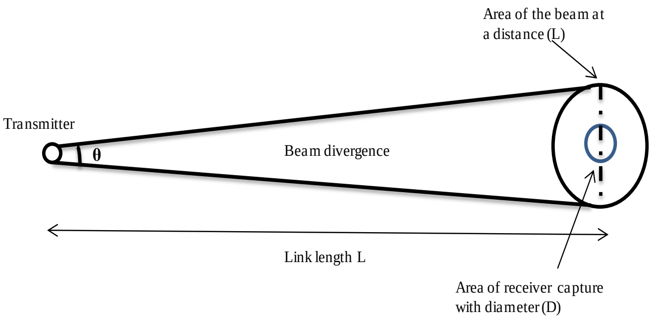

Fig. 2. Propagation of the light beam.

$$\text{GeomAtt} = \frac{Area\ of\ the\ beam\ at\ a\ distance\ (L)}{Area\ of\ receiver\ capture\ with\ diameter\ (D)}$$

So, simply by dividing these two circle areas as:

$$= \frac{\pi\left(\frac{L\theta}{2}\right)^2}{\pi\left(\frac{D}{2}\right)^2} = \frac{\frac{\pi}{4}(L\theta)^2}{\frac{\pi}{4}(D)^2} = \left(\frac{L\theta}{D}\right)^2 \quad (1)$$

The geometric attenuation can be in dB as follows:

$$\text{GeomAtt } (dB) = 10 \log\left(\frac{L\theta}{D}\right)^2$$

$$\text{GeomAtt } (dB) = 20 \log\frac{L\theta}{D} \quad (2)$$

B. Rain Attenuation

In regions with heavy rainfall rates such as tropical areas, rain is the main atmospheric attenuation parameter. One of the models which estimates attenuation due to rain for FSO links in tropical areas is:

$$A_p = W + A_{1\text{km}} \times L \times r_1 + 2 \quad (dB) \quad (3)$$

A_p is the overall rain link attenuation for % of the year for path length, L, W, loss due to water on the FSO transceiver window, $A_{1\text{km}}$, the rain path attenuation, r_1, normalized reduction factor. The additional 2 dB is taking into account the smoke haze and scintillation effects. The above model is an experimental model proposed in Singapore by [7].

C. FSO Link Margin

The concept of link margin of FSO link can be shown clearly in Fig. 3. The condition of link availability of Hybrid FSO/RF is $LM \geq$ additional loss. Also, from this condition the maximum distance of Hybrid FSO/RF can be achieved when link margin = 0.

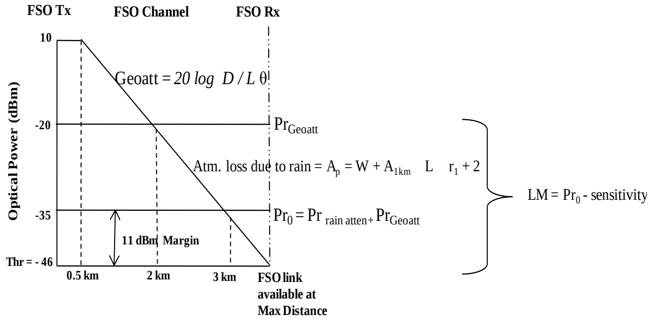

Fig. 3. An example of FSO link margin diagram.

III. Microwave Link Budget

A. Free Space Loss

The total transmission loss of a microwave link can be calculated using the following formula [8].

$$\text{Attenuation}_{dB} = 92.45 + 20 \log F_{\text{GHz}} + 20 \log D_{\text{km}} + e_{dB} \quad (4)$$

e is excess attenuation (dB) due to rainfall.

B. Rain Attenuation

Again the additional attenuation in microwave will be due to rain. The ITU-R specific attenuation model for rain of a microwave line of sight is used to determine the attenuation due to rain [9].

IV. Link Availability of Hybrid FSO/RF

The estimate availability figure calculated based on existing commercial Hybrid FSO/RF parameters is shown in Table I. In (3), ITU-R Japan model ($A_{1\text{km}} = 1.58R^{0.63}$) is employed for FSO channel to calculate $A_{1\text{km}}$ parameter [10]. The reason we use this model is because of the measurement conducted to develop this model up to 80 to 90 mm/hr rain rate which gives close figure of rain rate in heavy rainfall regions. To calculate the fade margin as a function of distance we used the rain rate of region N of Table I. in ITU-R PN.837-1 with corresponding percentage of time [11]; and specific rain attenuation model of RF. The simulations have been done for many different frequencies to find the optimum operating frequency to back-up FSO link. Fig. 4 and Fig. 5 show the fade margin as a function of distance of Hybrid FSO with lower back-up frequencies 10 & 25 GHz. 10 GHz gives carrier class availability for distance more than 5km. 25 GHz gives carrier class availability for a maximum up to 800m distance.

A. FSO/10 & 25 GHz

The reason 10 GHz can go up to a long distance is due to the fact that frequencies below 10 GHz are not affected only by rain but all weather conditions, whereas above 10 GHz are attenuated due to rainfall and atmospheric absorption. In high frequencies the wavelength will be shorter than the raindrop size causing absorption and scattering.

TABLE I: Hybrid FSO/RF Systems Parameters Used in Calculations

Channels	Transmit Power	Sensitivity	Divergence ang. / Antenna Gain	Receiver Ape. / System loss
FSO	28 dBm	-34 dBm	2.7 mrad	0.2 m
RF	26 dBm	-96 dBm	22 dB	2 dB

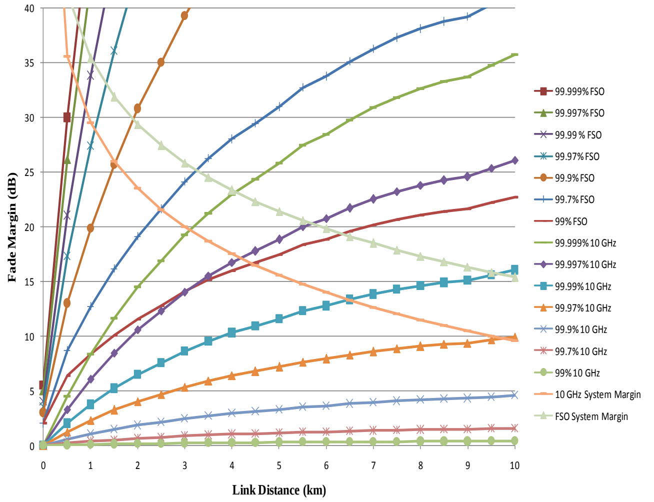

Fig. 4. Fade margin as a function of distance of Hybrid FSO/10 GHz.

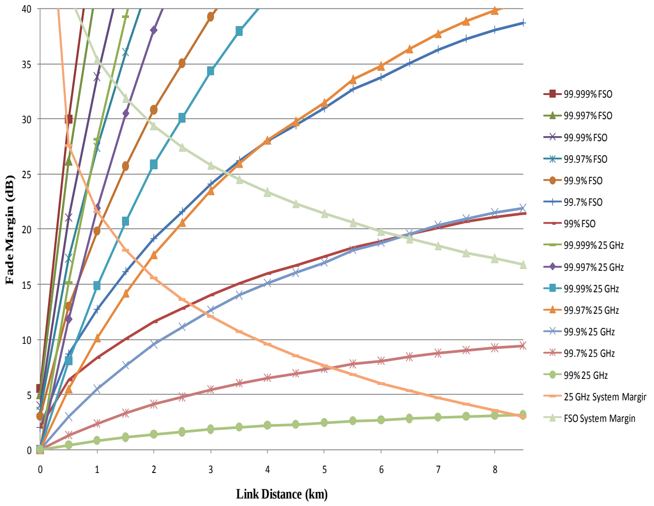

Fig. 5. Fade margin as a function of distance of Hybrid FSO/25 GHz.

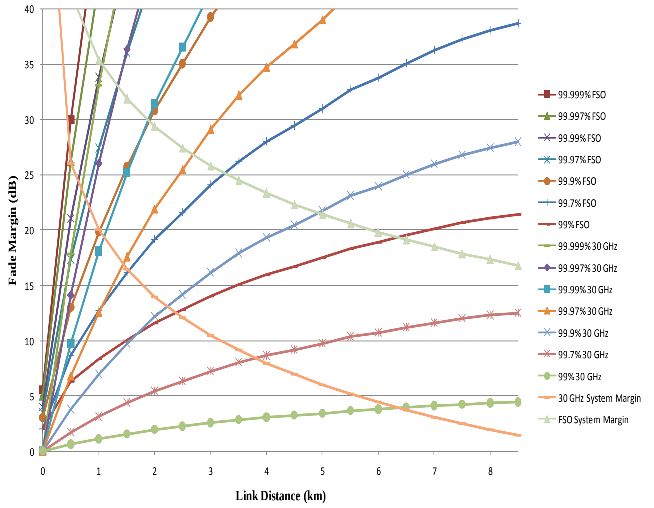

Fig. 6. Fade margin as a function of distance of Hybrid FSO/30 GHz.

B. FSO/ 30 GHz

Fig. 6 shows FSO link with the optimum choice of 30 GHz back-up. 30 GHz can provide carrier class availability over a distance of almost 750m only.

It can also provide long distance if the availability is not the priority.

C. FSO/ 40 & 60 GHz

Fig. 7 and Fig. 8 show the fade margin as a function of distance of Hybrid FSO with higher frequencies of 40 GHz and 60 GHz. These two frequencies can operate within only a few hundred meters for carrier class availability.

Enterprise class availability for 10, 25, 30, 40 & 60 GHz back-up can operate over long distances as shown in Fig. 9, whereas in Fig. 10 carrier class availability with good enough resolution for Hybrid FSO/RF is shown. In the case of FSO outage, the transition or switching can be done at 30 GHz back-up to provide carrier class availability with consideration of data rate.

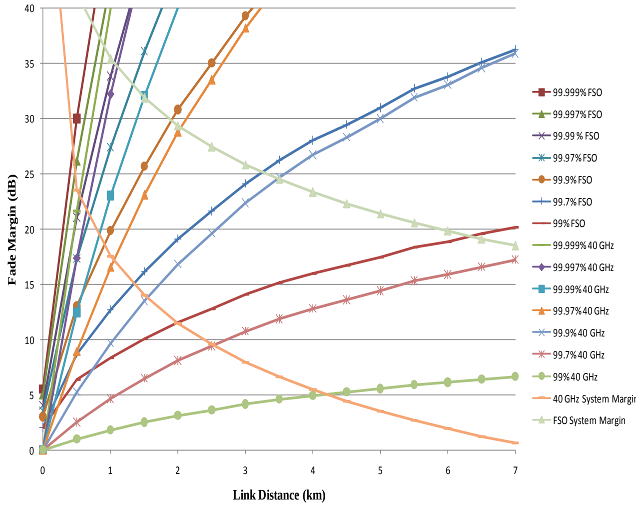

Fig. 7. Fade margin as a function of distance of Hybrid FSO/40 GHz.

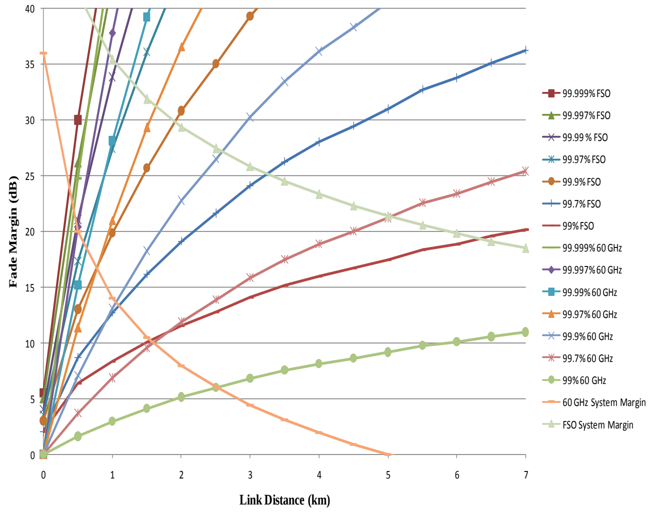

Fig. 8. Fade margin as a function of distance of Hybrid FSO/60 GHz.

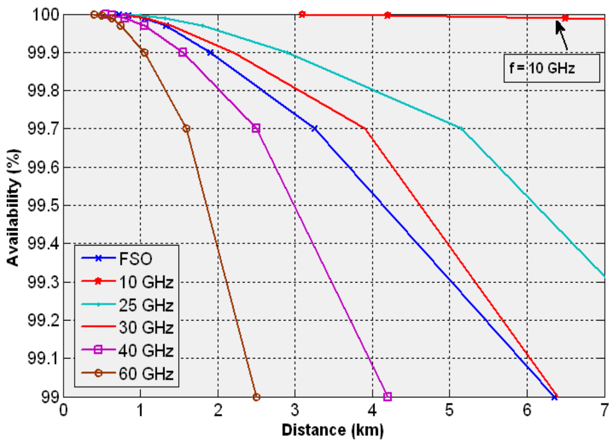

Fig. 9. Enterprise class availability of Hybrid FSO/RF.

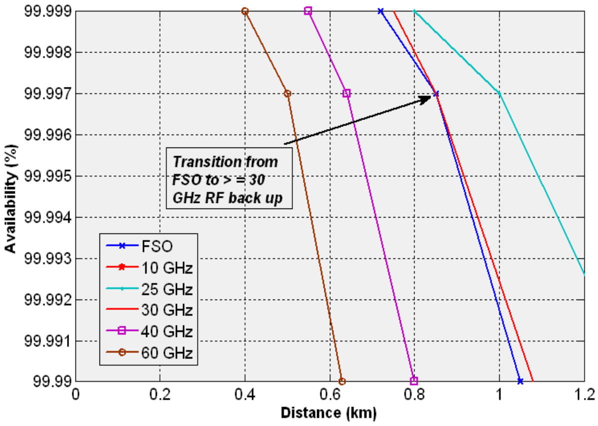

Fig. 10. Carrier class availability of Hybrid FSO/RF.

V. Conclusion

Availability in general depends on the internal parameter of Hybrid FSO/RF system such as divergence angle, receiver aperture of FSO and antenna gain of RF. Also, it depends on the weather in particular. To achieve carrier class availability of Hybrid FSO/RF under the impact of heavy rainfall climate in tropical regions, a 30 GHz is considered the optimum operating frequency to tradeoff between speed (data rate) of RF and availability of FSO at a distance of almost 750m only. In the case of enterprise class availability or data rate is not the priority; frequencies below 30 GHz are recommended to be used for long distances (few kilometers).

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