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Free Space Optical Communications Performance Under The Effect of Rain Attenuation in Canada

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ABSTRACT
Free space optical communication (FSO) is an optical communication technique that propagates the light in free space. Free space systems are affected through the channel by atmospheric phenomena's like rain, fog and snow which reduce the link performance. In this paper, we study the effect of rain attenuation on FSO performance in Canada using different types of modulations like on-off keying (OOK), pulse-position modulation (16-PPM), and differential phase shift keying (DPSK) The effect of selective combining (SC) diversity is also included in this study. We evaluated the system performance under three different rain regions in Canada. The results indicate that the signal-to-noise ratio (SNR) and bit-error rate (BER) will severely degrade with a high rain as compared to the low rain rate. The BER for DPSK outperforms the other types of modulation schemes that were used in this research. The SC diversity gave a marginal improvement with the increase in link distance.
Keywords: Free Space Optical Communications, Rain Attenuation, on-off keying Modulation, and Selective Combining Diversity.

I. INTRODUCTION

Free space optical communication is a line of sight technology that transmits information by laser light through an atmospheric channel. FSO communication system seems to be one of the promising technologies for addressing the problem of huge bandwidth requirements and "last mile bottleneck". It has gained significant importance owing to its unique features: large bandwidth, license free spectrum, high data rate, easy and quick deployability, less power and low mass requirement [1-2].

The basic principle of FSO transmission is similar to fiber optic communication except that unlike fiber transmission, the modulated data is transmitted through unguided channel instead of guided optical fiber. The main constituents of an optical fiber communication link are transmitter consisting of optical source, an optical cable and a receiver consisting of a photo-detector. Photo-detector is the first element of the photo receiver circuit which interprets the information contained in the optical signal. They demodulate the optical signal that are subsequently amplified and processed to obtain the actual information signal. For such applications, photo detectors must have high sensitivity, high responsivity and minimum noise. For high-bit rate long-haul fiber optic communications, the avalanche photodiode (APD) is frequently the photo-detector of choice owing to its internal gain, which provides a sensitivity margin relative to PIN photodiodes [3].

Weather conditions of the FSO unguided channel are the main challenge where they directly affect the performance by attenuating the signal either through scattering, absorption, or scintillation.FSO has to deal with different atmospheric conditions that could dramatically impair the system performance like fog, heavy rain, snow, dust, and haze which increase the power loss and deteriorate the bit-error rate (BER).Several studies [4-6] were conducted to show the different atmospheric channel impairments such as fog, snow and rain. In this study we will focus on the rain attenuation and its effect on the FSO performance. The International Telecommunication Union (ITU) has created a statistical model in which the Earth is divided into different "rain zones," where each zone corresponds to a certain level of rain rate. Our contribution in this research is to analyze FSO links based on the rain regions in Canada.

Some of the modulation techniques used for FSO is OOK, PPM, and DPSK modulation. OOK modulation offers bandwidth efficiency but lacks power efficiency. PPM achieves high power efficiency and improves the system performance at the expense of reduced bandwidth efficiency compared with other modulation schemes. DPSK is a relative phase modulation model, the information which is transmitted represented by the phase difference between the adjacent symbols. Under the same BER condition, the average power of NRZ-OOK is twice than DPSK. In this paper we will compare between the three different modulation techniques under different rain rates.

One of the possible mitigation techniques that can be used to combat rain attenuation is diversity combining techniques. In general, diversity refers to the availability of multiple copies of the desired signal at the receiver; however each one is affected by different channel characteristics. Hence, the signals which are received from each individual link can be directly combined using a diversity combiner. The diversity combiner measures the SNR of received signal from different branches and offers an enhanced SNR. The popular combining schemes used to improve the SNR are selection combining, maximum ratio combining (MRC) and equal-gain combining (EGC) [7].

The rest of the paper is organized as follows. In Section II, the system model is described. In Section III, the results are presented for different rain rates, and different types of modulations. Also the effect of SC diversity is presented. In section IV, conclusions are drawn.

II. SYSTEM 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. The most commonly used raindrop size distributions that have been proposed are Marshal and Palmer [8]. Marshal and Palmer distribution proposed renowned empirical expression by fitting their data and the Laws and Parsons data. The specific attenuation of wireless optical link for rain rate of R mm/hr is given by

$$\gamma(dB/km) = a \cdot R^{b} \quad (1)$$

Where a & b 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 a & b independent of polarization [9]. The modeling of rain attenuation prediction is done using empirical methods proposed by International Telecommunication Union- Radio communication sector (ITU-R) for FSO communication. The specific rain attenuation (dB/km) for a FSO link is given by [10-11].

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. The empirical method is based on correlation between observed attenuation distribution and corresponding observed rain-rate distribution measured at 1 minute integration time [12]. While the physical method is an attempt to use the physical behavior involved in the attenuation process. Another model is proposed by Carbonneau, this model predict is

$$\gamma(dB/km) = 1.076 \cdot R^{0.67} \quad (2)$$

Carbonneau's model proposed values to predict a & b based on measurement done in France [13]. However the measurement done was for very low rain intensities compare with rain intensity in tropical region. Recommendation ITU-R P.837 gives the rainfall rate, R_p (mm/h), exceeded for a given percentage of the average year, *p*, and for any location. In this study we will focus on rain regions in Canada as shown in Table(1)

Table (1)

Canada Rain regions	Rain rate (mm/h)
B	12
C	15
E	22

In free space optical communications, the received power P_r has the following expression

$$P_r = P_t \tau_{tx} \tau_{rx} \frac{D^2}{(\theta L)^2} 10^{\frac{-\gamma L}{10}} \quad (3)$$

where P_t is the transmitted power, τ_{tx} and τ_{rx} are the transmitter and receiver efficiency respectively. D is the receiver diameter, θ is the divergence angle; L is the link distance and γ rain attenuation factor.

The SNR for the optical communication system for APD detector is given by

$$SNR = \frac{(R_0 P_r M)^2}{2qBM^{x+2}(R_0 P_r + I_D) + 2qI_L B + {}^{4kTBF}/_{R_{eq}}} \quad (4)$$

where R_0 denotes the primary sensitivity of the APD, M is the APD gain, *x* is the excess noise factor, I_D is the bulk dark current, I_L is the surface leakage current, q is the electron charge, k is the Boltzmann constant, B is the equivalent noise bandwidth, R_{eq} is the equivalent circuit resistance, F is the noise figure and T is the system temperature in Kelvin.

The performance of FSO system will be measured by BER for three types of modulation OOK modulation, N-PPM, and DPSK modulation as shown below [14]

$$BER_{OOK} = \frac{1}{2} \operatorname{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \quad (5)$$

$$BER_{N-PPM} = \frac{1}{2} \operatorname{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR \cdot \frac{N}{2} \cdot \log_2(N)}\right) \quad (6)$$

$$BER_{DPSK} = \frac{1}{2} \operatorname{erfc}\left(\frac{1}{\sqrt{2}}\sqrt{SNR}\right) \quad (7)$$

III. SIMULATION RESULTS

In this section we will study the effect of different rain rates on the received power, SNR, and BER. Also, we will evaluate the performance of FSO system using different types of modulation techniques. The parameters assumed in this simulation are shown in Table (2).

Table 2

Parameters	**Value**
wavelength	1550 nm
Transmitter power	50 mw
Transmitter divergence angle	2 mrad
Transmitter efficiency	0.5
Receiver efficiency	0.5
Receiver sensitivity	- 20 dBm
Receiver diameter	0.1 m
Bulk dark current	0.05 nA
APD gain	100
Excess noise factor	0.5
Bandwidth	25 MHz
Surface leakage current	1 mA
System temp.	290 K
Noise figure	3 dB
Equivalent resistor	50 KΩ

Figure 1 shows the received power for the three rain regions in Canada; rain rate of 12 mm/h (rain region B),15 mm/h (rain region C),and 22 mm/h (rain region E) versus the link distance. The received power for these rain rates started in almost equal received power then the difference widen with the increase in link distance. The higher rain rate has a significant degradation on the received power as compared to lower rain rate.

The SNR versus the link distance for the three rain rates were shown in figure 2. The lower rain rate has a better SNR than the higher rain rate and the difference between rain rate 12 and 22 mm/h becomes 17 dB at a link distance equal to 1 km.

The BER for OOK modulation and 16-PPM modulation are investigated and the results obtained are shown in figures 3 and 4. In figure 3, the BER for OOK modulation with lower rain rate performs better than the BER for a higher rain rate. Also, the increase in the link distance will deteriorate the BER. For example at a link distance of 1 km the BER is 2.2×10^{-3} for a rain rate = 12 mm/h as compared to 2.5×10^{-2} for a rain rate of 22 mm/h. Figure 4 shows the BER for 16-PPM modulation with a lower rain rate gives a better BER as compared to the high rain rate.

In figure 5 we compare the OOK modulation and the 16-PPM modulation for a rain rate equals 22 (mm/h). It shows that the BER for 16-PPM is better than the BER for OOK modulation. The BER difference between both modulation techniques is almost the same for the same link distance.

The BER for DPSK modulation with two rain rates were shown in figure 6. We noticed that the BER at a link distance of 1 km degraded from 8×10^{-9} to 8×10^{-5} when the rain rate increased from 12 mm/h to 22 mm/h. The difference between the two rain rates will widen with the increase in L.

Figure7 shows the BER for three types of modulation that we used in this study at a rain rate of 22 mm/h, and we noticed that DPSK outperforms the other modulation schemes especially at low link distance and the BER difference between the different modulations schemed becomes narrower as the link distance increased. In figure 8, we showed the effect of using SC diversity with OOK and 16-PPM modulation in a rain rate = 22 mm/h. The BER with SC diversity has improved slightly as compared to the case without SC diversity especially at a link distance more than 0.5 km.

IV. CONCLUSION

In this paper, we investigated the effect of rain attenuation on the performance of FSO link. We considered three rain regions in Canada. We used the Carbonneau Model which explains the effect of rain on FSO. We observed the effects on received signal power, SNR, and BER for three different rain rates and three types of modulations. Results show that the received power and SNR degrades with the increase in rain rate due to the rain attenuation. In the case of a rain rate 22 mm/h the performance of the 16-PPM is far better than the OOK modulation. The BER of DPSK outperforms the OOK and 16-PPM under the same rain rate. We have shown that SC diversity slightly improves the BER for the high rain rate region, and it is therefore recommended that SC diversity used to mitigate rain attenuation effects on FSO.

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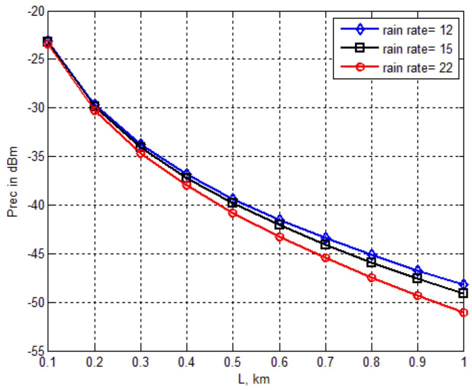

Figure.1 Received power for rain rate 12, 15 and 22 (mm/h)

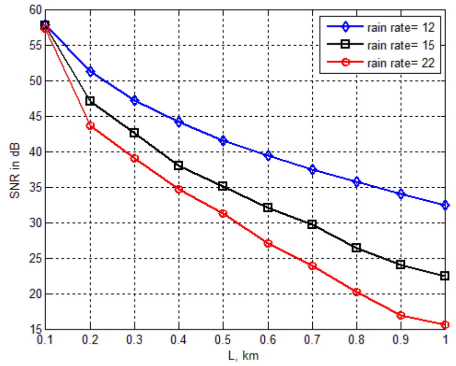

Figure.2 SNR for the rain rate 12, 15 and 22 (mm/h).

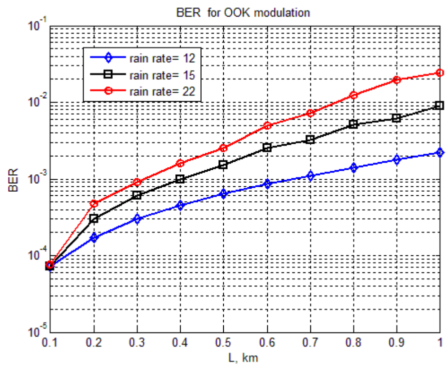

Figure.3 BER using OOK modulation for different rain rates.

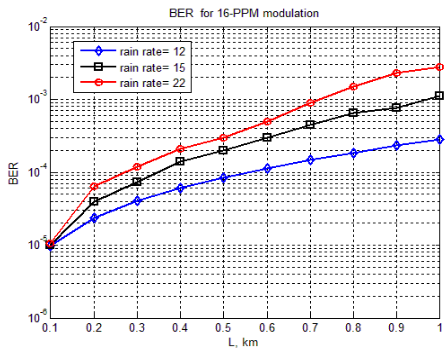

Figure.4 BER using 16-PPM modulation for different rain rates.

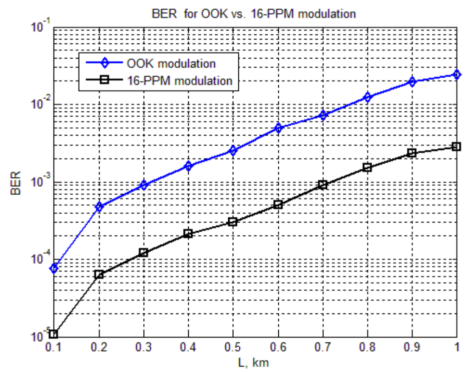

Figure.5 BER for OOK modulation vs. 16-PPM modulation for rain rate= 22 mm/h.

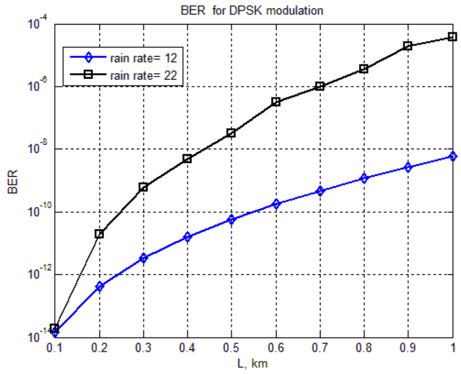

Figure.6 BER of DPSK modulation with two rain rates.

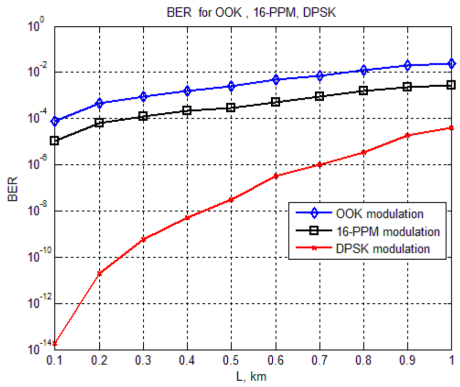

Figure.7 BER for different types of modulations at a rain rate= 22 mm/h.

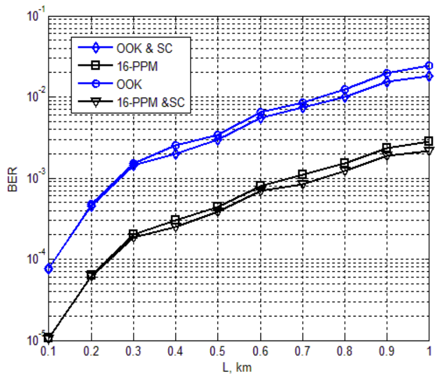

Figure.8 BER for OOK, 16-PPM with SC diversity at a rain rate= 22 mm/h.