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Analysis Study of Rain Attenuation on Optical Communications Link

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Abstract: This paper presents the attenuation due to rain on the free space optical communication systems. The work has compared the rain attenuation predicted by Marshal and Carbonneau models. The performance is also done for receiver signal power, link margin, data rate and signal to noise ratio. The data rate 100Mb/s can be achieved for distance about 800m. The two rain models have difference behavior for distance larger than 300. On the other hand the receiver signal power, link margin, data rate and signal to noise ratio decreases with increasing distance and rain attenuation.

Keywords: Attenuation, rain Attenuation, Free Space, Optical Communications.

I. Introduction

There is growing interest in the telecommunication community towards the use of Free Space Optics (FSO) links for short and very short path applications requiring the availability of very large bandwidth. In fact, the advantages of FSO communications over classical microwave links and fiber systems are low equipment cost, and flexible, license free installation [1]. Laser beam propagation in the atmosphere is severely affected by aerosol scattering and atmospheric turbulence which limit the path length for a given link availability; these effect are much worse than in the case of microwave relay links. Specifically, impairments are due to (i): air turbulence that produces beam spreading, beam wander, scintillation and degradation of the coherence of the wave front [2], and (ii): hydrometeors (rain and snow) and suspended water particles (fog represents the worst meteorological situation for FSO) that introduce extra losses due to scattering [3].

II. Rain attenuation 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 [4]. The most commonly used raindrop size distributions that have been proposed are Marshal and Palmer [5]. 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

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

Where a & b are power law parameters equal to 0.365, 0.63 respectively. 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 [6]. 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 [7]. The empirical method is based on correlation between observed attenuation distribution and corresponding observed rain-rate distribution measured at 1 minute integration time [8, 9]. While the physical method is an attempt to use the physical behavior involved in the attenuation process. The another model is proposed by Carbonneau, this model predict is

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

Carbonneau's model proposed values to predict a & b based on measurement done in france [10]. However the measurement done was for very low rain intensities compare with rain intensity in tropical region.

III. Communication Link Model

We now consider three types of communication links: the receiver signal power, link margin, and data rate. In addition, we performed a signal to noise ratio calculation.

1. Receiver Signal Power

We shall consider the situation of optical propagation between points underwater. Consider a laser transmitting a total power P_T at the wavelength 10600nm. The signal power received at the communications detector can be expressed as [11]

$$P_{\text{rec}} = P_{\text{trans}} \frac{D^2}{g_{\text{div}}^2 L^2} \cdot 10^{-\gamma \cdot L/10} \tau_{\text{trans}} \tau_{\text{rec}} \quad (3)$$

Where D is the receiver diameter, θ is the divergence angle, γ is the attenuation factor (dB/m), τ_{trans} , τ_{rec} are the transmitter and receiver optical efficiency respectively.

2. Link Margin

Another important parameter in optical communications link analysis is "Link Margin", which is the ratio of available received power to the receiver power required to achieve a specified BER at a given data rate. Note that the "required" power at the receiver P_{REQ} (watts) to achieve a given data rate, R (bits/sec), we can define the link margin LM as [11]:

$$LM = [P_T \lambda / (N_b R h c) * [D^2 / (\theta^2 L^2)] * 10^{-\gamma L / 10} \tau_{trans} \tau_{rec}] \quad (4a)$$

Or can be written as

$$LM = [\lambda / (N_b R h c) \cdot P_{rec}] \quad (4b)$$

Where N_b is the receiver sensitivity (photon/bits) or (dBm), R is a data rate, h is a plank constant and c is the light velocity.

3. Data Rate

Given a laser transmitter power P_{trans} , with transmitter divergence of θ , receiver diameter D , transmit and receive optical efficiency τ_{trans} , τ_{rec} the achievable data rate R can be obtained from [12]

$$R = \frac{P_T \cdot \tau_{trans} \cdot \tau_{rec} \cdot 10^{-\gamma L / 10} D^2}{\pi (\theta / 2)^2 L^2 E_p N_b} \quad (5a)$$

Or can be written as

$$R = \frac{4 \cdot P_{rec}}{\pi \cdot E_p N_b} \quad (5b)$$

Where $E_p = hc/\lambda$, is the photon energy at wavelength.

4. Signal to Noise Ratio (SNR)

The electrical power of the received optical signal is proportional to the mean squared avalanche photodiode APD current, which can be written as [13]

$$\langle i_{APD}^2 \rangle = (R_0 P_{rec} M)^2 \quad (6)$$

and

$$R_0 = \frac{\eta q \lambda}{h c} \quad (7)$$

where R_0 denotes the primary sensitivity of the APD, M is the APD gain, η is the quantum efficiency, q is the electron charge. The noise contributions (i.e., the mean-square values of the APD current) are shot noise:

$$\sigma_{sig-noise}^2 = 2q(R_0 P_{rec}) M^{x+2} B \quad (8)$$

Surface leakage current noise:

$$\sigma_{surface}^2 = 2q I_L B \quad (9)$$

multiplied dark current noise:

$$\sigma_{dark,m}^2 = 2q(I_D) M^{x+2} B \quad (10)$$

And Johnson noise:

$$\sigma_{johnson}^2 = \frac{4kT B F_T}{R_{eq}} \quad (11)$$

where I_D is the bulk dark current, I_L is the surface leakage current, $F(M) \approx M^x$ ($0 \leq x \leq 1$) is the excess noise factor, k is the Boltzmann constant, B is the equivalent noise bandwidth, R_{eq} is the equivalent circuit resistance, F_T is the noise figure of the electric circuit, and T is the system temperature. The SNR for the optical communication system is thus given by

$$SNR_{APD} = \frac{(R_0 P_{rec} M)^2}{2q(R_0 P_{rec} + I_D) M^{x+2} B + 2q I_L B + 4kT B F_T / R_{eq}} \quad (12)$$

IV. Simulation results

Simulation by matlab carried out to show the effect of rain attenuation effect employing Marshal and Carbonneau model on free space optical communication system (FSOWCS). The performance of (OWC) system can be evaluated by the receiver signal power, link margin, data rate and signal to noise ratio.

We have investigated the high quality and the best performance of rain attenuation effect on optical communication link system for two models. The investigating based on the modeling equations analysis and the assumed set of the operating parameters are shown in table (1).

Table (1): Proposed operating parameters for optical communications links

Operating parameter	value
wavelength	10600 nm
Transmitter power	50mw
Transmitter divergence angle	1.5mrad
Transmitter efficiency	0.5
Receiver efficiency	0.5
Receiver sensitivity	-20dBm
Receiver diameter	10cm
Bulk dark current, ID	0.05 nA
The APD gain	100
The excess noise factor, x	0.5
Electrical band, B	25MHz
Surface leakage current, I _L	0.001A
System temperature, T	290K
Noise figure, F _T	3dB
Equivalent resistance, R _{eq}	50kΩ

Simulations were performed to compare the value of rain FSO specific attenuation under Marshal and Carbonneau models. Fig. (1) shows this comparison, and from, it can be inferred that the models is not closer behaviour, accordingly Marshal model is better than Carbonneau model because it suffers less attenuation.

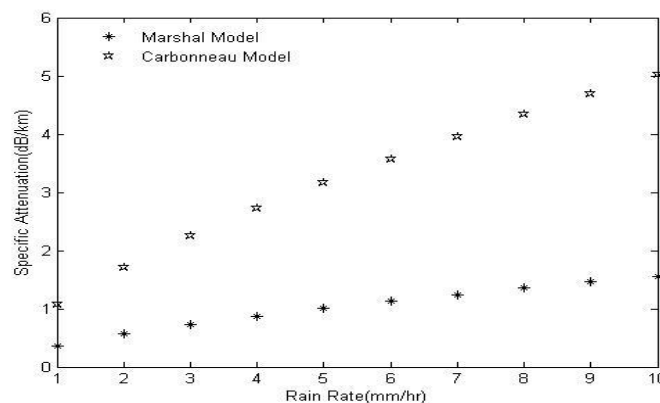


Fig. (1) Specific attenuation of the rain for the two models

The received power is achieved for rain attenuation at a link distance less than 1000m under different rain attenuation models as shown in fig. (2). The received signal power decreases with increasing rain rate for both Marshal and Carbonneau rain models. It is also observed that received signal power decreases with increasing distance under the same conditions. Also observed that the Marshal & Carbonneau curves have closer behavior for low distances but differ for distance larger than 300m under the same rain rate.

The link margin for receiver sensitivity -20dBm is achieved for data rate 100Mb/s operating under rain models (Marshal, Carboneau) at a distance 1000m. The link margin increases with decreasing rain rate for both rain models and decreases with increasing distance as shown in fig. (3). Also noted that the link margin have a close behavior curves for low distance.

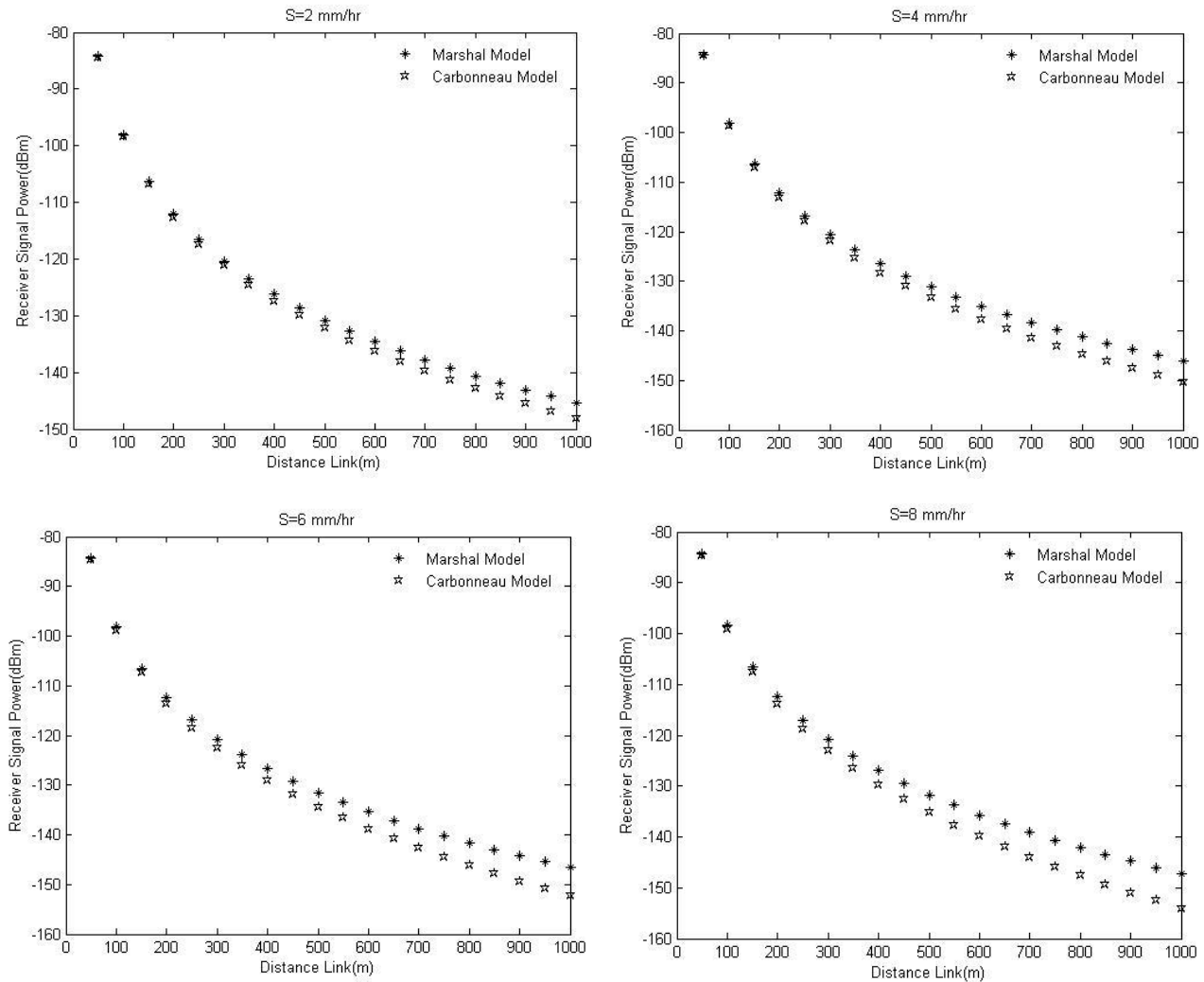
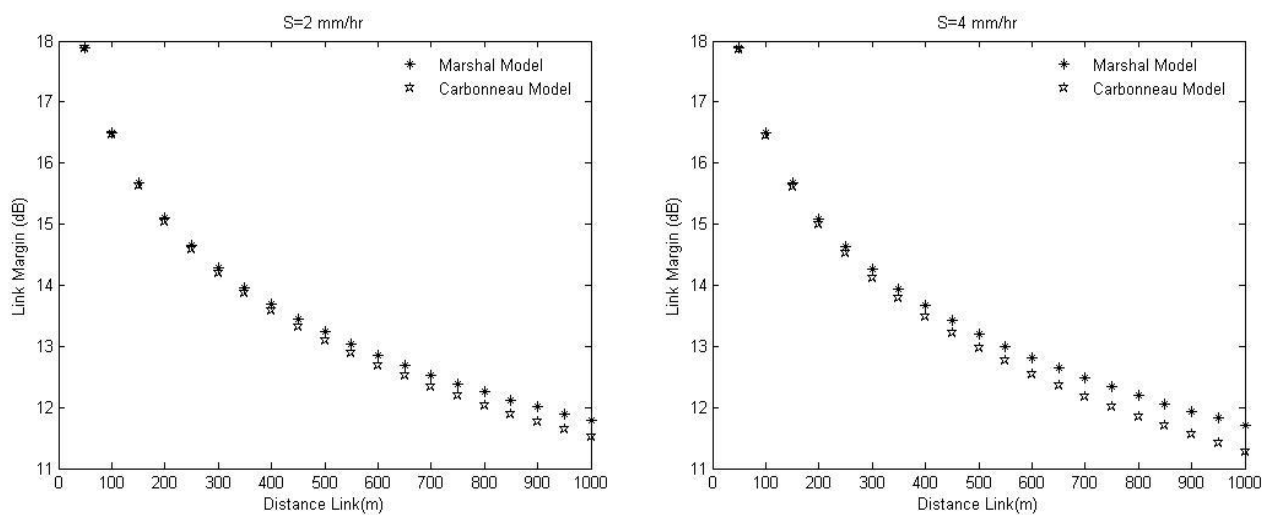


Figure (2) receiver signal power versus distance for rain attenuation under different rain rate



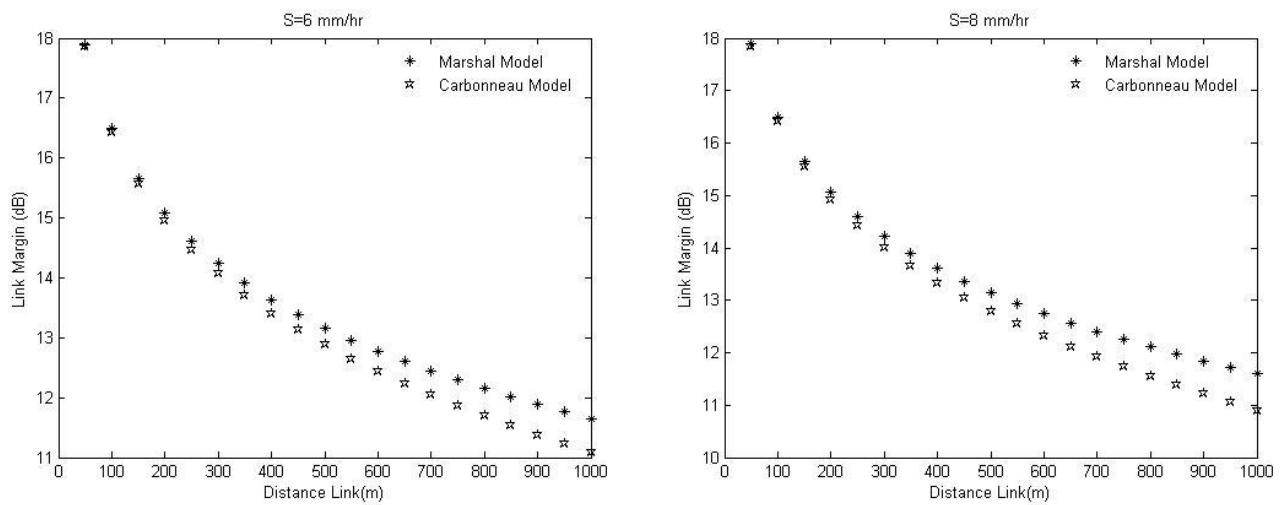


Figure (3) link margin versus distance for rain attenuation under different rain rate

The range equation can be used to generate the communication data rate versus link range for varying rain rate under rain attenuation models. Receiver sensitivity -20dBm which is equivalent to 327000 photons/bit. The data rate decreasing with increasing rain rate as shown in Fig (4), As can be seen a maximum data rate of 100 Mb/s can be achieved for a range large than 800 m under rain rate attenuation models. The signal no noise ratio(S/N) is increases with decreasing rain rate. It is also observed that the signal to noise ratio (S/N) for rain attenuation models have very close behavior curves for low distance. As well as high (S/N) has presented low rain rate compared with another values of rain rate.

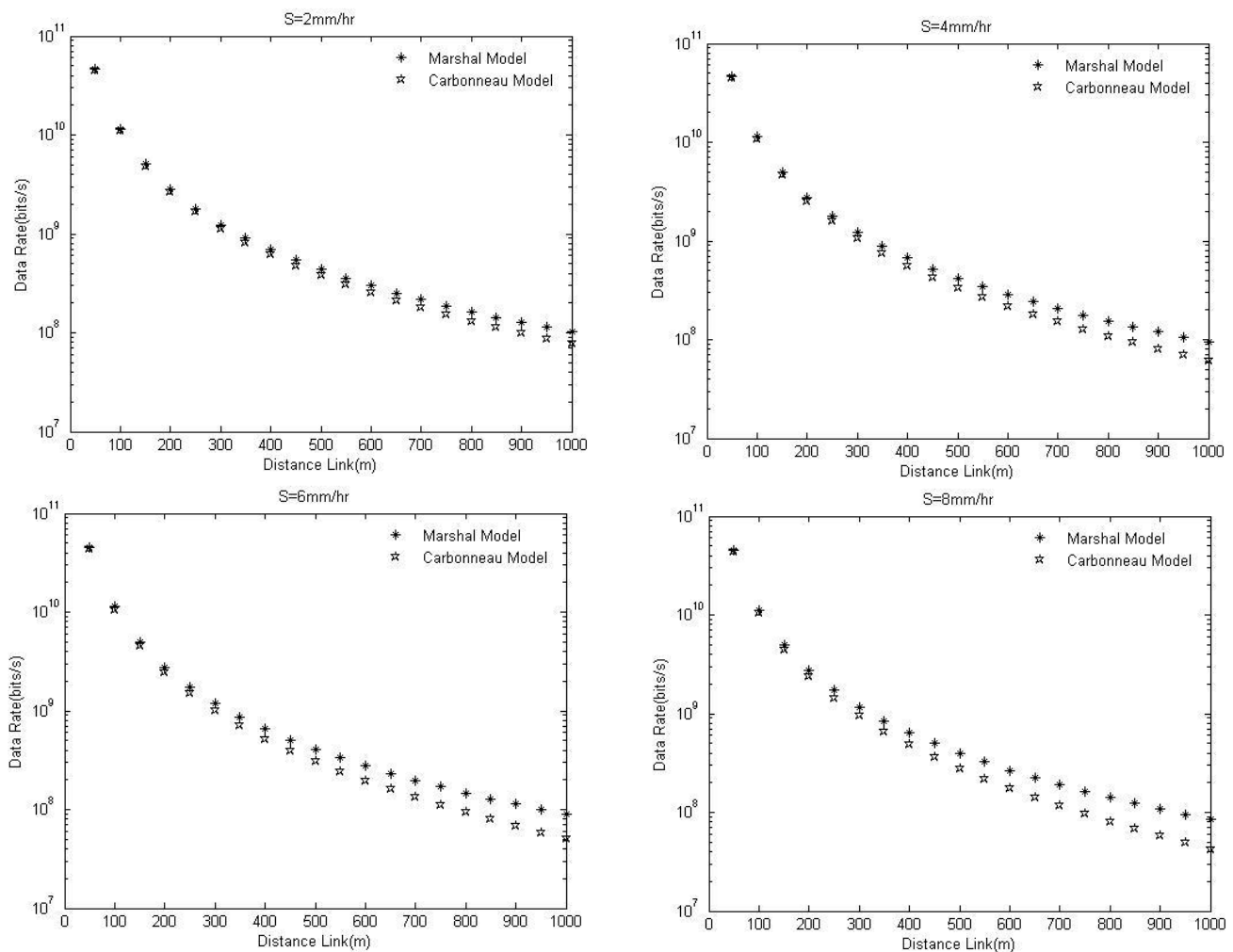


Fig. (4) Data rate versus distance for rain attenuation under different rain rate

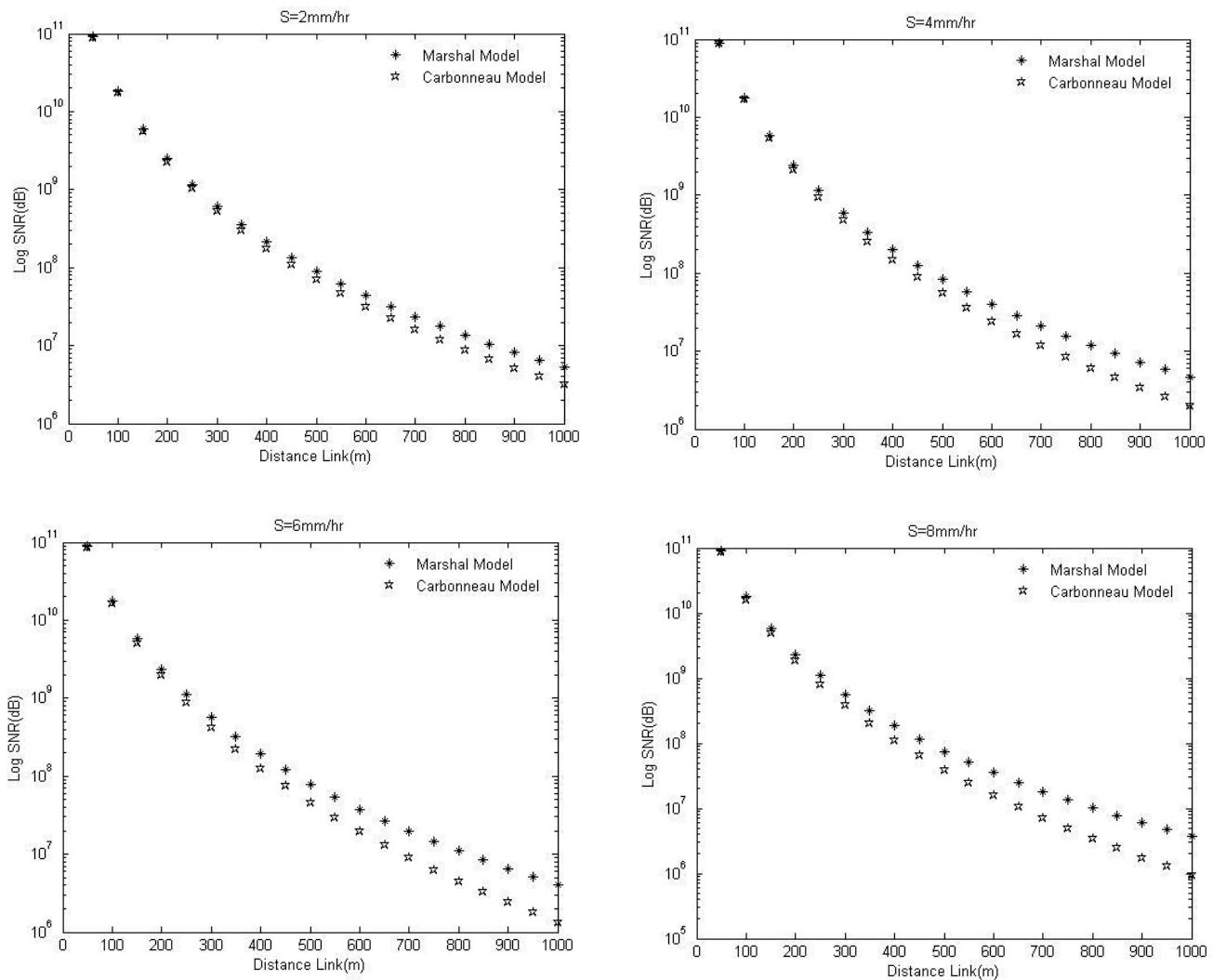


Fig. (5) Signal to Noise ratio versus distance for rain attenuation under different rain rate

V. Conclusion

This investigation presents the simulation results of the effect of rain on a FSO link. The analysis focuses on Marshal & Carbonneau Models which explain the effect of rain on FSO. These models have presented to observed effects on receiver signal, link margin, data rate and signal to noise ratio for distance approximate to 1000m. Simulation found that the rain attenuation affect for marshal model less than for Carbonneau model because in marshal model used empirical expression based on fitting data, while Carbonneau model used physical method based on measurements data. On the other hand the two rain models have very close behavior for distance less than 300m. the receiver signal power, data rate, link margin and signal to noise ratio decreases with increasing rain rate for the two models under study.

VI. References

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