Characterization of Millimeter Waves RoFSO Link Under the Effect of Rain

Manisha Samal, M. Vishnu Kartik, Sanya Arora, and Sanmukh Kaur

Abstract Free-space optics, being an optical wireless communication, uses the concept of light propagation in free space for data transmission between two points and is progressing as competitive and efficient alternative to optical fiber links or RF system. Being a favorable optical wireless communication technology, radio over free-space optics (RoFSO) has proved to be of great significance in various applications in telecommunication including 5G networks. High speed and data rate, large bandwidth, low consumption of energy, and unlicensed spectrum are some of the advantages of this technology. As the technology is based on an unguided medium, atmospheric weather affects the transmission of data through the FSO wireless communication. Varying climatic depletion factors including cloudiness, downpour, and haze conditions attenuate the transmitted signal and degrade its quality. Rain is considered as the significant cause of constriction causing degradation in the transmission of signal. This paper mainly focuses on the characterization of attenuation in a millimeter waves RoFSO link for 5G applications. Received signal quality has been evaluated in terms of Q factor and eye diagram patterns under different downpour conditions.

Keywords Weather conditions · RoFSO · Attenuation · Free-space optics · Q factor · Mm waves

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1 Introduction

Among the technological advancements taking place in the field of telecommunication, FSO, being an optical wireless communication, uses the concept of light propagation in free space for data transmission between two end points thereby becoming fair and efficient alternative to fiber optic links or radio frequency (RF) transmission systems [1–3]. Being a favorable optical wireless communication, radio over free-space optics (RoFSO) has been proved to be of great importance in various applications in telecommunication field for instance high speed, high bandwidth data link availability, and low consumption of energy. The RoFSO system basically comprises of radio over fiber and free-space optics system. The radio frequency along with the optical signal goes through modulation process in this RoFSO link. This optical wireless FSO technology gives numerous points of interest, which includes providing high data rate and bandwidth, low cost and power, immunization of radio frequency interference, and high security [4–6]. Be that as it may, atmospheric weather affects the transmission of data through the FSO wireless communication. Varying climatic depletion factors including cloudiness, downpour, and haze attenuate the transmitted signal quality. Rain is considered the significant cause of constriction causing degradation in the transmission of signal. Scintillation, absorption, and scattering are several other natural phenomena contributing to the degradation of FSO performance [7–9]. The variations in both the intensity and phase of the transmitted optical signal are a result of atmospheric turbulence which reduces the link performance [10]. RoFSO innovation expels RF spectrum overcrowding in wireless. RoFSO gives a wireless connection for the farthest mile association existing amid two end points in the region of troublesome physical connection for providing broadband services. This paper mainly focuses on the characterization of attenuation in a millimeter waves (MM waves) RoFSO link for 5G applications. Received signal quality has been evaluated in terms of maximum Q factor and eye diagram patterns under different downpour conditions.

2 System Design

The RoFSO framework is designed by using optisystem 17. This design comprises transmitter, FSO channel, and receiver. The target of the design is to generate modulated RF signal and the resulting RF signal and the optical carrier generated from CW laser is modulated and is then fed to FSO channel. The transmitter section comprising of user bit sequence generator, NRZ modulator, CW laser, Mach–Zehnder modulator, and DPSK sequence generator. The bit sequence generator generates the data rate at 10 Gb/s. Then, the duo-binary phase shift keying (DPSK) modulated scheme is utilized for extending the spectral efficiency of the framework. The signals coming from the DPSK modulator is then sent to M-ray pulse generator for converting into M-ray pulse and afterward is modulated using 60 GHz RF carriers [3]. The output RF

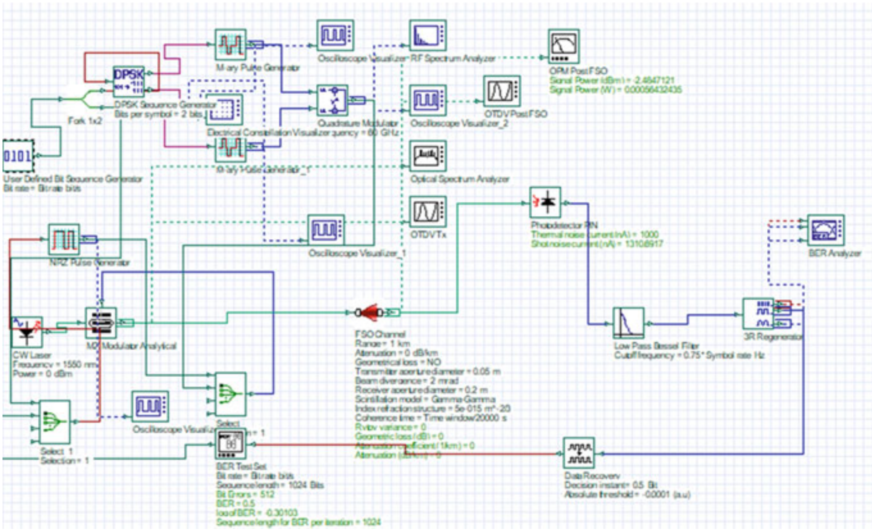

Fig. 1 A block diagram of RoFSO link

signal is modulated with optical carrier (laser), i.e., CW laser with frequency 193.1 THz by the Mach–Zehnder modulator (MZM) and is then fed to FSO channel under the downpour climate conditions. The laser diode has a wavelength of 1550 nm. For the FSO channel, the range is set up to 1 km as a default value. The signal transmits through FSO, transmitter power being 0 dBm and divergence angel being 2 mrad. The receiver comprises of a PIN photodetector with 1 A/W responsivity, and 10 nA dull is utilized for detection of the optical signal prior to transmission through the filter headed by the PIN photodetector. A low-pass Bessel filter cuts off the higher frequency components and thereby filters noises from the received signal. The bit error rate (BER) analyzer has been used to analyze the BER or Q factor of the received signal (Fig. 1; Table 1).

3 Rain Attenuation

The optical signal transmitted through atmosphere suffers from rain attenuation. Impact of rain is an essential factor that influences the optical communication link. Volume of rain drops being expansive causes refraction and reflection and thereby causes scattering. The precipitation expansion results in linearity expansion in attenuation. The normal size of raindrops increments with the precipitation, and this remains within the order of mm. Estimation of particular constrictions from the optical association with the rain rate *R* mm/hr by [11]

$$\alpha_{\text{rain}} = 1.076\text{R}^{0.67}, \text{dB/km} \tag{1}$$

R being the rain rate.

Table 1 Simulations parameters

Parameter	Value
Bit rate (Gbps)	10
Range (km)	1
Wavelength (nm)	1550
Modulation Scheme	DPSK
Responsivity (A/W)	1
Input Power (dBm)	−10 to 0
Sequence length (bits)	512
Samples per bit	64
Samples rate (GHz)	3200
Beam divergence (mrad)	0.5–3.5
Dark current (nA)	10
Cut off frequency (GHz)	2.4

The attenuation for laser power in the weather is represented by the Beer's law as:

$$\tau_{(L)} = P_{\text{receive}}/P_{\text{total}} = e^{-\alpha L} \tag{2}$$

L is the link range provided in meters, $\tau_{(L)}$ stands for the transmittance at a distance L, P stands for the laser power (Watt) whereas α is the scattering coefficient (km^{-1}).

4 Simulation Results

The objective of the paper is to study characterization of MM waves RoFSO link under the effect of rain. The Q factor is calculated for different downpour or rain conditions (clear air, light rain, moderate rain, and heavy rain).

Figure 2 depicts the Q factor versus range plot in different downpour conditions. With the increase in range, the Q factor value reduces. Q factor is highest in clear air shown in brown curve. The Q factor for clear air condition is 1316, for light rain is 986, for moderate rain is 467, and for heavy rain is 241.7 at a range of 1000 m. Least Q factor is in heavy rain shown in blue curve. As seen in the figure, communication is not possible beyond the range of 2 km under heavy rain conditions.

Figure 3 depicts Q factor versus power plot in different downpour conditions. With the increase in power, there is increase in the value of Q factor. Q factor is highest in clear air condition at 0 dBm shown in brown curve. The Q factor for clear air condition is 1264, while 986 for light rain, 467 for moderate rain, and 241.7 for heavy rain at a power of 0 dBm. Least Q factor is for heavy rain shown in blue curve. In the case of heavy rain condition, transmitted signal power should be more than −3 dBm for acceptable value of BER at the receiver.

Fig. 2 *Q* factor versus range plot in different rain conditions

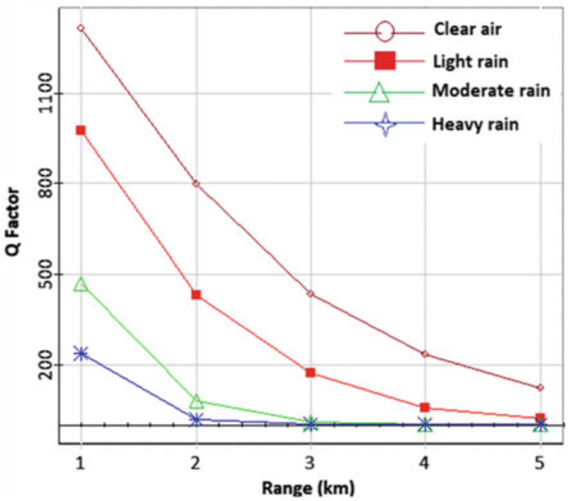

Fig. 3 *Q* factor versus power plot in different rain conditions

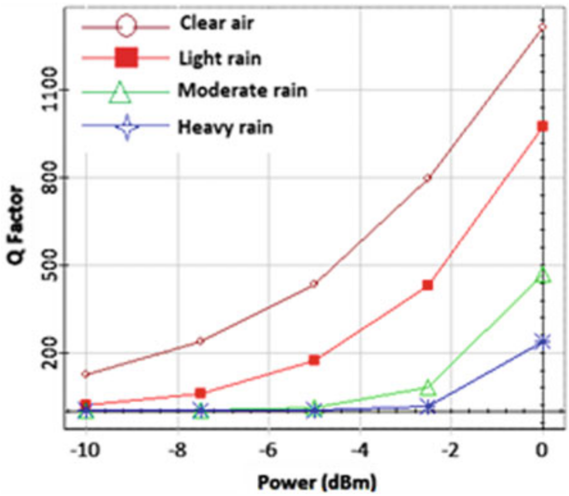

Figure 4 depicts *Q* factor versus bit rate plot in different downpour conditions. With the rise in data rate, *Q* factor reduces. *Q* factor is highest in clear air condition at 1 Gbps shown in brown curve. The *Q* factor for clear air condition is 1315, while 1015 for light rain, 464 for moderate rain, and 229 for heavy rain at data rate of 1 Gbps. Least *Q* factor is for heavy rain shown in blue curve.

Figure 5 depicts *Q* factor versus beam divergence plot in different downpour conditions. With the increase in beam divergence, *Q* factor reduces. *Q* factor is highest for clear air at 0.5 mrad shown in brown curve. The *Q* factor for clear air condition is 1329, while 1010 for light rain, 465 for moderate rain, and 232 for heavy rain at 0.5 mrad. Least *Q* factor is for heavy rain shown in blue curve.

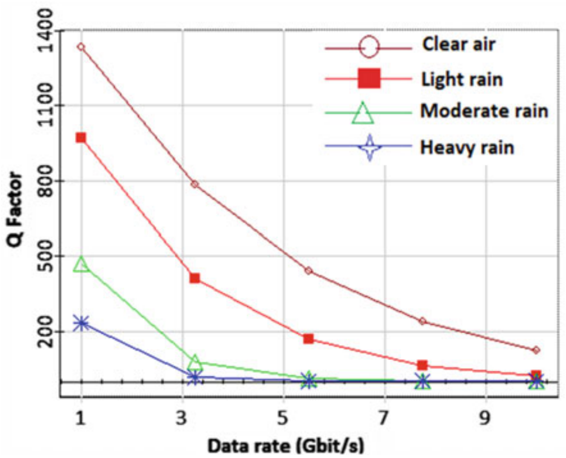

Fig. 4 *Q* factor versus data rate plot in different rain conditions

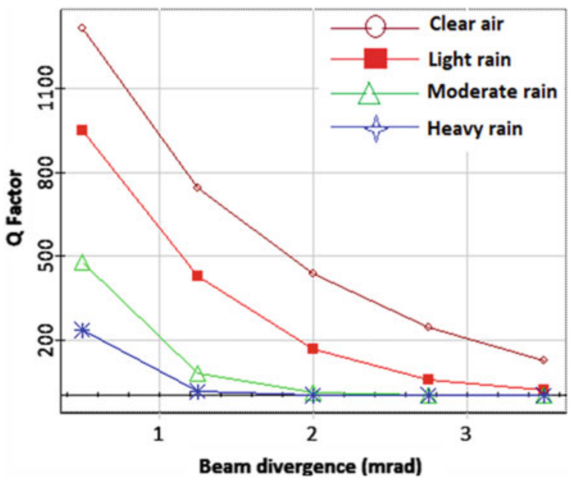

Fig. 5 *Q* factor versus beam divergence plot in different rain conditions

Figure 6 shows the eye diagram of received signal for a transmission of 10 Gbps data rate with RF of 60 GHz over 1Km of FSO length. The observed *Q* factor for heavy rain conditions at 1 km length is 25.05.

Figure 7 shows the eye diagram of received signal for a transmission of 10 Gbps data rate with RF of 60 GHz over 2.91 km of FSO length. The observed *Q* factor for heavy rain conditions at 2.91 km length is 3.68.

Table 2 represents the transmission of 10 Gbps signal by 60 GHz RF modulation through FSO. In clear air weather condition, maximum link length is 36.02 km with *Q* factor 6.29. In light rain weather condition, maximum link length is 7.61 km with *Q* factor 6.76. In moderate rain weather condition, maximum link length is 2.52 km with *Q* factor 6.36. In heavy rain weather condition, maximum link length is 1.66 km with *Q* factor 6.05.

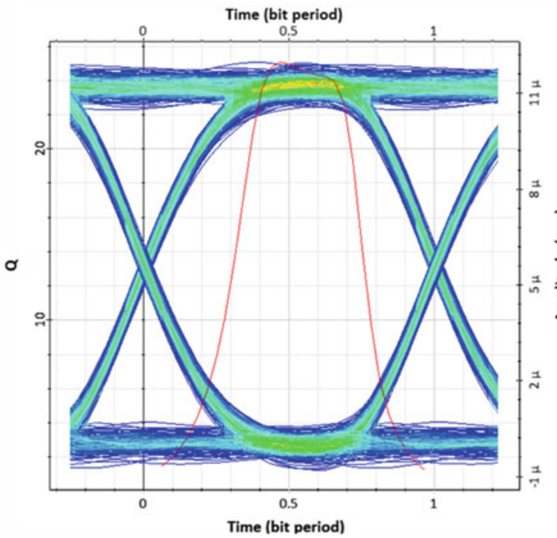

Fig. 6 Eye diagram for heavy rain conditions at a range of 1 km and data rate of 10 Gbps

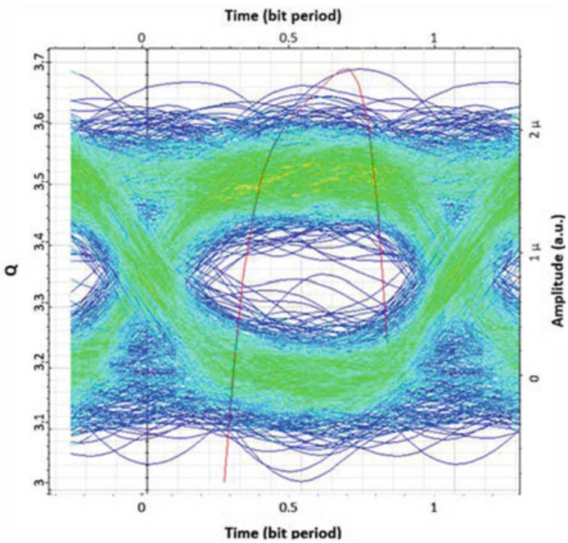

Fig. 7 Eye diagram for heavy rain conditions at a range of 2.91 km and data rate of 10 Gbps

5 Conclusion

In this paper, the simulation study of RoFSO link under the effect of rain has been performed. The MM waves RoFSO framework has been successfully designed and simulated for 5G applications. Received signal quality has been evaluated in terms of Q factor as a function of transmitted power, beam divergence, data rate, and transmission range under different downpour conditions. Our examinations demonstrate

Table 2 10 Gbps transmission at max link length

Weather condition	α db/Km	C_n^z	RF (GHz)	Max link (km)	BER	Q factor
Clear air	0.43	5×10^{-14}	60	36.02	$1.5528e^{-010}$	6.29
Light rain	1.98	0.6×10^{-14}	60	7.61	$6.74797e^{-012}$	6.76
Moderate rain	5.34	0.5×10^{-14}	60	2.52	$7.82742e^{-015}$	6.36
Heavy rain	9.28	0.4×10^{-14}	60	1.66	$7.15249e^{139}$	6.05

that the signal experiences degradation with the increase in the value of attenuation in heavy rain as well as with FSO range. In the case of heavy rain condition, transmitted signal power should be more than −3 dBm for acceptable value of BER at the receiver. The maximum link length for heavy, moderate, and light rain conditions comes out to be 1.66, 2.52, and 7.61 km, respectively.

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