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Performance Analysis of MDM Ro-FSO System under Atmospheric Turbulences

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A B S T R A C T

In this research analysis, different modulation formats such as modified duo-binary return to zero (MDRZ), non-return-to-zero (NRZ), return-to-zero differential phase shift keying (RZ-DPSK), alternate mark inversion (AMI), and non-return-to-zero differential phase shift keying (RZ-DPSK) are proposed for the 2 x 40 Gbps-40 GHz RoFSO system (NRZ-DPSK). For the MDM, under the influence of various weather conditions such as light, moderate and heavy fog, two Hermite Gaussian (HG) modes are used. Various input parameters such as transmitter antenna, receiver antenna aperture diameter are varied and it is perceived to boost the increase in transmitter and receiver aperture diameter, Q factor and BER as well. Results showed that, followed by NRZ-DPSK, RZ-DPSK, AMI, and NRZ systems, MDRZ performs best.

Keywords: FSO, RF, Q factor, BER, SOA

1. Introduction

Explosive demands for the internet around the world have caused peer pressure on wireless networks and transmission systems for Radio over Free Space Optics (RoFSO) have emerged as a popular alternative to radio frequency services [1]. Increasing the demand for bandwidth and power, is leading to change from RF to optical communication. At high bit rates, Ro-FSO systems carry overlaid radio signal over optical signal via free space transmission media. Ro-FSO systems have several advantages over RF communication, such as high Gbps order speed, broad bandwidth, unlicensed spectrum, high protection, electromagnetic interference immunity, energy efficient, cost efficient, simple implementation and last mile access[2]. FSO systems use sight communication line and thus do not need an operating licence, however there is a link loss if there are many obstacles between the transmitter and the receiver such as houses, birds etc. Despite the numerous benefits, FSO has some serious problems, such as its efficiency has a great degrading impact on atmospheric conditions. Fog, haze, fog, sand storms, dust, haze etc. are different atmospheric turbulences which have a drastic effect on the performance of Ro-FSO systems[3]. Optical eddies are the cause of changes in the refractive index in the atmosphere and have been formed due to temperature and atmospheric pressure inhomogeneities. The results of atmospheric turbulence are beam wandering, beam scattering, scintillation [4]. From various statistical models such as K model, lognormal Rician model, I-K model and Gamma-Gamma model etc [5], fading effects in FSO can be estimated. For weak to heavy turbulence, the Gamma-Gamma model is considered in Ro-FSO systems[6]. Different methods are explored against fading effects such as aperture averaging, adaptive optics, error management coding, etc. for the efficiency improvements of the Ro-FSO method. In fog conditions, attenuation is very high, and either laser power is increased or optical amplifiers are used to increase power. Due to eye protection issues and amplifier incorporation, input power can be increased to minimal values, increasing the complexity and expense of the device. In the error coding technique, processing delay is observed and adaptive optics are very costly [7]. In FSO, aperture averaging is an easy and efficient technique to increase the reception efficiency. In the works published, code [9], strength [10], polarisation [11], and wavelength [12] are shown for phase multiplexing capability enhancement [8]. Mode division multiplexing for pacy networks is perceived as a highly skilled technique because it can accommodate Tbps order data rates. The effects of atmospheric turbulence are demonstrated in MDM-based Ro-FSO systems[13][14][15]. Modulation plays an important role in the efficiency of optical communication systems and different modulations in MDM-Ro-FSO are therefore investigated in this work. The modulations under investigation are MDRZ, NRZ, RZ-DPSK, AMI, and NRZ-DPSK.

Introduction to FSO, Ro-FSO, literature and problems in current Ro-FSO systems is discussed in section 1. In section 2 and section 3, respectively, the system configuration and outcomes are discussed. Concluding remarks are given in section 4.

2. System Setup

Optiwave Optisystem is used in this work to accomplish the suggested task. The Ro-FSO device that integrates MDM and modified duo-binary return to zero in the Gamma-Gamma channel is represented in Figure 1. For the two channels, wavelength 1550 m is used with separate HG modes, i.e. Around HG00 and HG01.

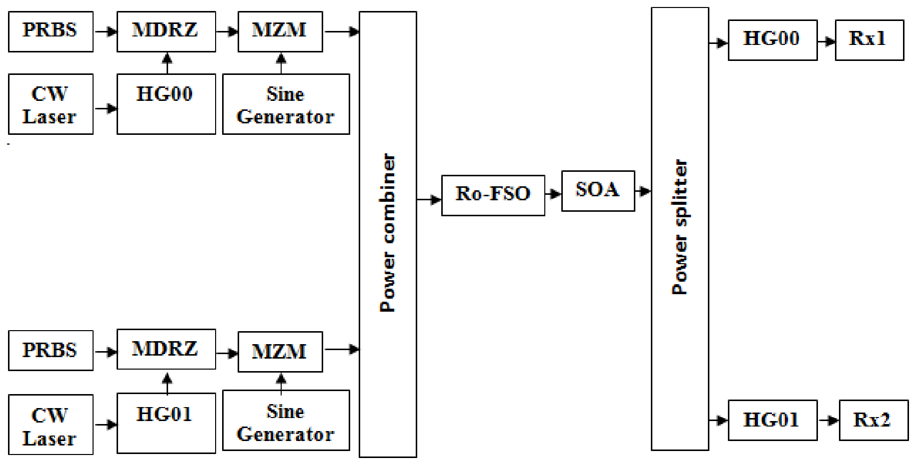


Figure 1 Representation of proposed system

Likewise, HG01 was allocated to the second transmitter and MDRZ modulated both channels. The MDRZ signal is further modulated with a 40 GHz RF signal to provide an overlapping radio signal. The multiplexer can handle both transmitters and is fed to the model of the Gamma-Gamma FSO link. The simulation parameters of the proposed work are shown in Table 1. The de-multiplexer is placed to split one signal into two after transmission through the FSO channel and the mode selector is placed to filter the relevant mode according to the transmitted mode. For the conversion of photons into electrons, the photo-detector PIN is carried out and then the low-pass Bessel filter is positioned to eliminate the noises in the transformed signal. Re-time, re-shaping and re-amplification are performed by the 3-R regenerator and output is sent to the final Q factor BER analyzer, BER.

Table 1 Simulation parameters of proposed system

Parameter	Values
Bit rate	40 Gbps
Frequency of RF signal	40 GHz
No. of transmitter	2
Launched power	0 dBm
Pulse shapes	NRZ, MDRZ, AMI, RZ-DPSK, NRZ-DPSK
HG mode numbers	HG00, HG01
Injection current of SOA	0.5 mA
Diameter of transmitter antenna	10 cm
Diameter of receiver antenna	10-20 cm
Beam divergence	0.25 mrad
Weather conditions	Light fog 9 dB, medium fog 12 dB, heavy fog 16 dB
Scintillation values taken	weak turbulence $C^2_n = 5 \times 10^{-17} m^{-2/3}$, medium turbulence $C^2_n = 5 \times 10^{-15} m^{-2/3}$ strong turbulence $C^2_n = 5 \times 10^{-13} m^{-2/3}$

3. Results and Discussions

The proposed Ro-FSO system with different modulation formats is tested in terms of Q factor, BER, and SNR at various input parameters such as FSO size, receiver antenna aperture diameter. Figure 2 (a) shows the scintillation output of the Ro-FSO channel, such as poor atmospheric turbulence in the Gamma-Gamma model with BER variance in the receiver antenna aperture diameter. Weak turbulence effects on MDRZ, NRZ, AMI, NRZ-DPSK, and RZ-DPSK are observed under weak C2n turbulence $C^2_n = 5 \times 10^{-17} m^{-23}$. With the increase in receiver antenna aperture diameter in al modulations, it is considered that there is a substantial decrease in the BER because receivers can gather more signals. Results showed that MDRZ performs better because of the phase shift operation between adjacent bits, more nonlinear effect tolerance, and it is also economical as it does not require a balanced receiver. NRZ-DPSK, RZ-DPSK, AMI and NRZ are accompanied by the output of the modified duo-binary to zero.

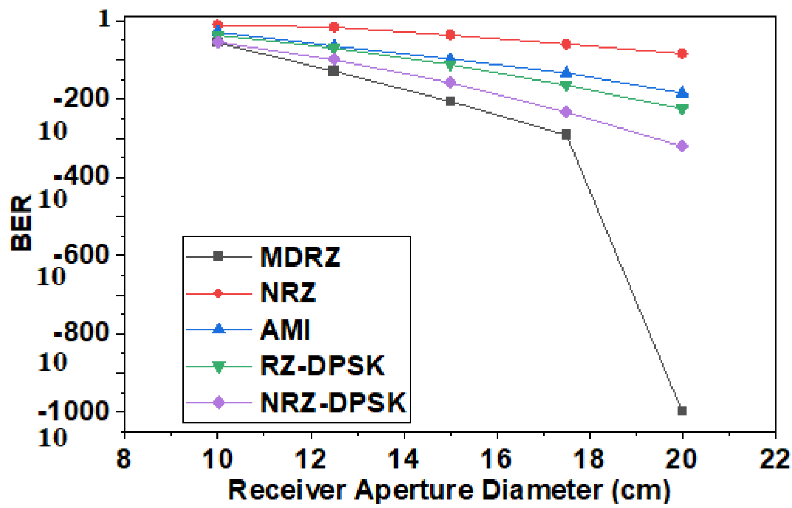


Figure 2 (a) Performance of under weak turbulence ($C^2_n = 5 \times 10^{-17} m^{-23}$) of different modulations formats in terms of BER

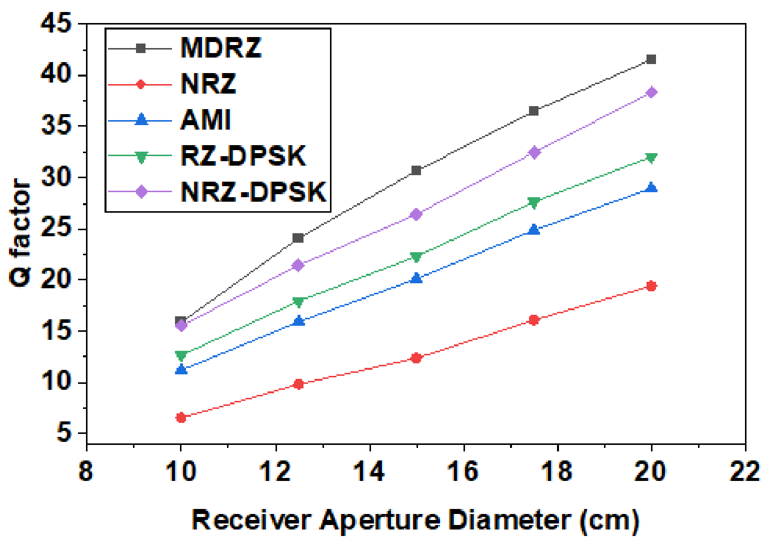


Figure 2 (b) Performance of under weak turbulence ($C^2_n = 5 \times 10^{-17} m^{-23}$) of different modulations formats in terms of Q factor

Similarly, in the Gamma-Gamma model with variation of the receiver antenna aperture, the output of the aforementioned modulations is evaluated in terms of Q factor under scintillation, such as weak, moderate and heavy atmospheric turbulence. Figure 2 shows Q factor versus receiver aperture antenna output (b). In the case of MDRZ, the Q factor is considered to be maximal. The proposed system is analysed under moderate atmospheric turbulence ($C^2_n = 5 \times 10^{-17} m^{-23}$) following the output review under weak turbulence. Figure 2 (a) shows BER efficiency when the receiver aperture antenna diameter is altered and the results show that MDRZ performs better but has more BER compared to low turbulence performance. Figure 2 (b) displays the Q factor output and it is apparent that the greater the diameter of the receiver antenna aperture, the greater the Q factor. Except for the deterioration in Q factor values, the output pattern of all modulations is close to that under weak turbulence.

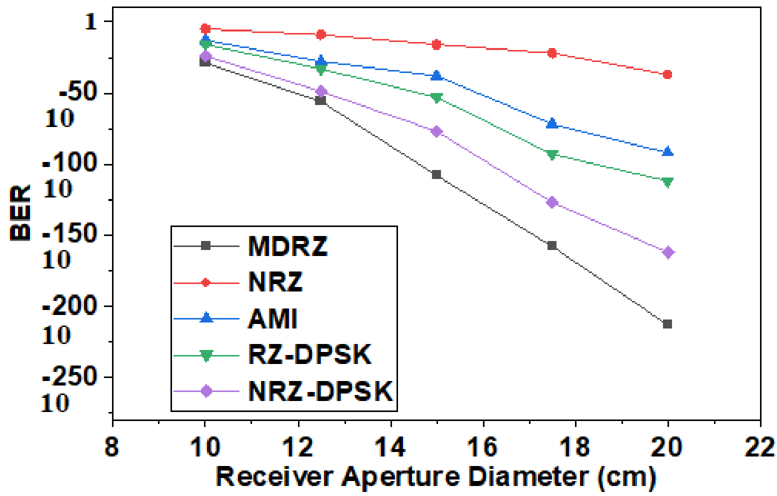


Figure 3 (a) Performance under moderate turbulence ($C^2_n = 5 \times 10^{-15}m^{-2/3}$) of different modulations formats in terms of BER

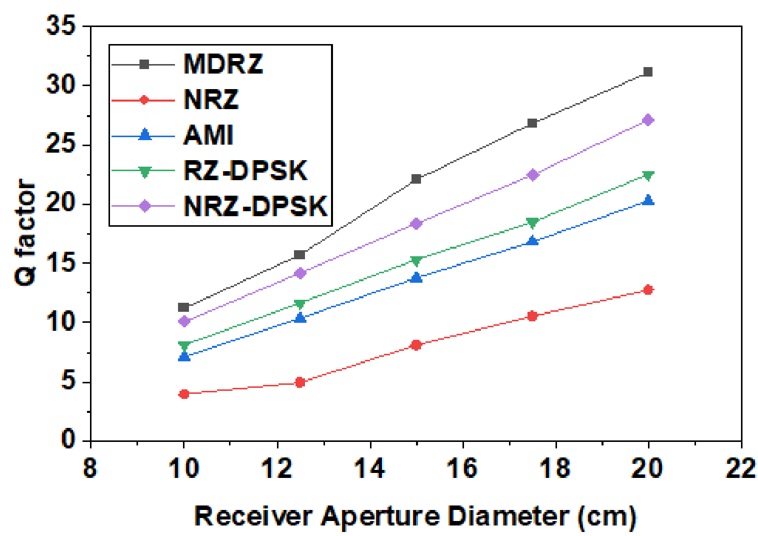


Figure 3 (b) Performance under moderate turbulence ($C^2_n = 5 \times 10^{-15}m^{-2/3}$) of different modulations formats in terms of Q factor

Further performance in terms of BER and Q factor moderate turbulence ($C_{2n} = 5 \times 10{-}15m^{-2/3}$) is presented in Figure 3. Performance trends are similar at varied receiver aperture diameters as observed under strong turbulences except the degradation. Therefore it is perceived that performance of MDRZ is optimal in terms of BER and Q factor.

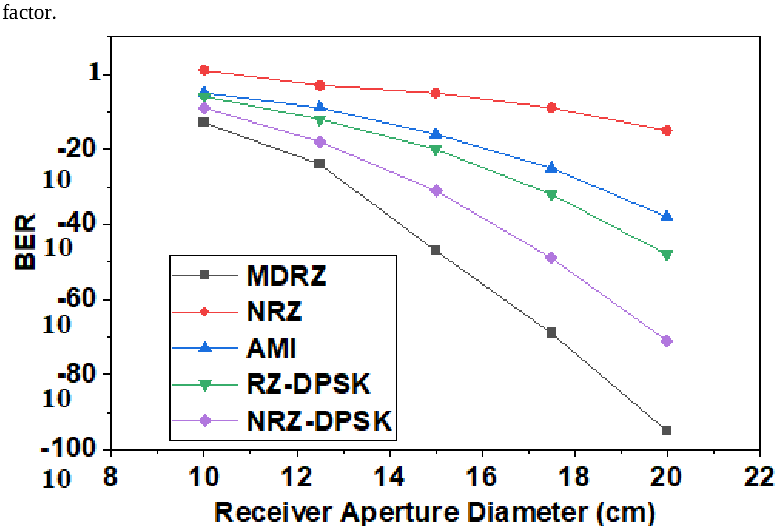


Figure 4 (a) Performance of different modulations formats under strong turbulence ($C^2_n = 5 \times 10^{-13}m^{-2/3}$) in terms of BER

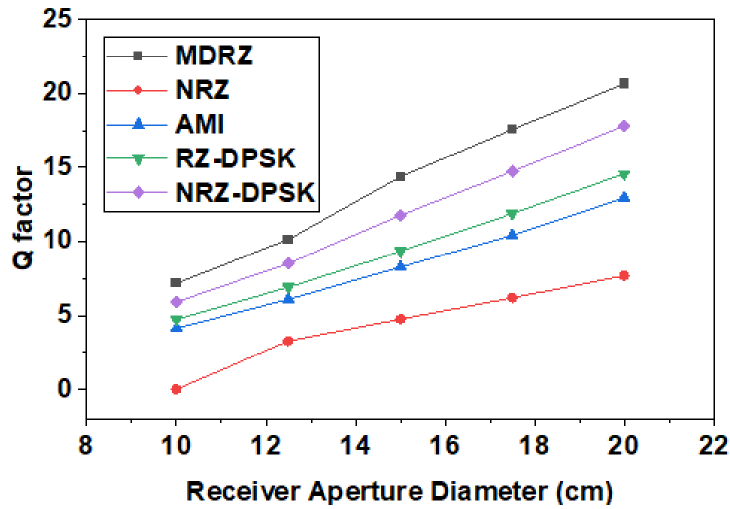


Figure 4 (b) Performance of different modulations formats under strong turbulence ($C^2_n = 5 \times 10^{-13} m^{-2/3}$) in terms of Q factor

In the presence of heavy turbulences ($C^2_n = 5 \times 10^{-13} m^{-2/3}$) for distances of 20 km when the receiver aperture diameter is changed from 10 cm to 20 cm, Figure 4 shows the output of different modulation formats. Results observed in Figure 4 (a) in terms of BER and it is clear that more receiver aperture diameter accommodated more signal and thus provides enhanced BER. In the case of MDRZ, BER is minimal because of its spectrum performance and tolerance of nonlinear effects. Figure 4 (b) illustrates the Q-factor results for various modulation formats with a receiver aperture diameter of 10 cm to 20 cm. Due to the wider carrier spectrum and unipolar nature, the Q factor of NRZ is small, which is very vulnerable to nonlinear effects and dispersion. Phase shifting behaviour is in DPSK, but there are more because of balanced receiver, shot and thermal noises. As a result, the output of the NRZ-DPSK and RZ-DPSK compared to the MDRZ modulation format is slightly lower. In this case, MDRZ once again exceeded the efficiency of all other modulation formats examined. It is therefore observed that under heavy atmospheric turbulence, MDRZ is ideal.

In optical communication systems, the signal-to-noise ratio should be high because it is the ratio of received signal power and received noise power. The comparison in terms of SNR with different fog intensities, i.e. light, medium and heavy fog, is shown in figure 5(a). The attenuation of these fog intensities varies, such as 9 dB/km light fog, 12 dB/km medium fog and 19 dB/km heavy fog. It is considered that MDRZ provides less noise and thus the highest SNR because of a single photo detector at the receiver to obtain various phases. SNR decreases with the rise in fog strength, but under fog conditions, the proposed system worked well.

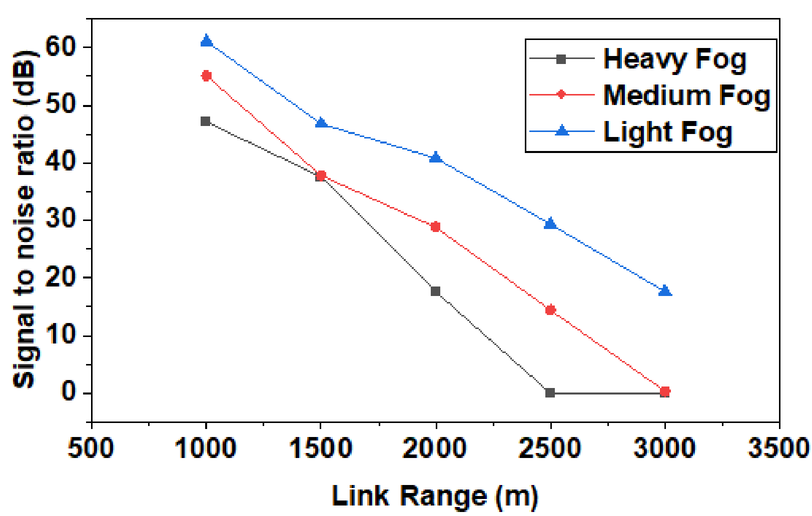


Figure 5 (a) SNR versus link range of proposed MDRZ-RO-FSO system

The signal to noise ratio should be high in optical communication systems because it is the ratio of the received signal power and the received noise power. The comparison in terms of SNR for different fog intensities, i.e. light, medium and heavy fog, is shown in figure 5(a). There are various attenuations of these fog intensities, such as 9 dB/km light fog, 12 dB/km medium fog, and 19 dB/km heavy fog. It is perceived that MDRZ provides less noise and thus optimal SNR because of the single photo detector at the receiver to receive various phases. SNR decreases with the rise in the strength of fog, but under fog conditions, the proposed system worked well.

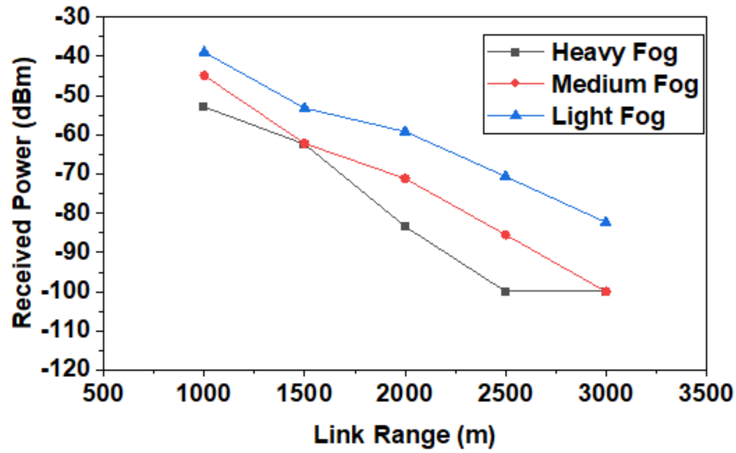


Figure 5 (b) Received power versus link range of proposed MDRZ-RO-FSO system

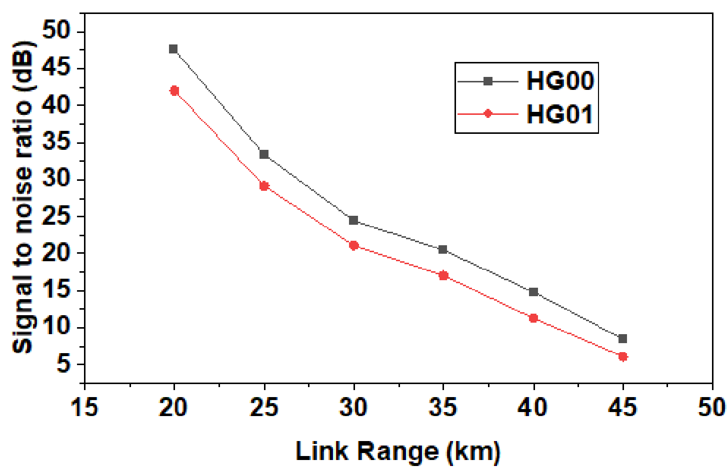
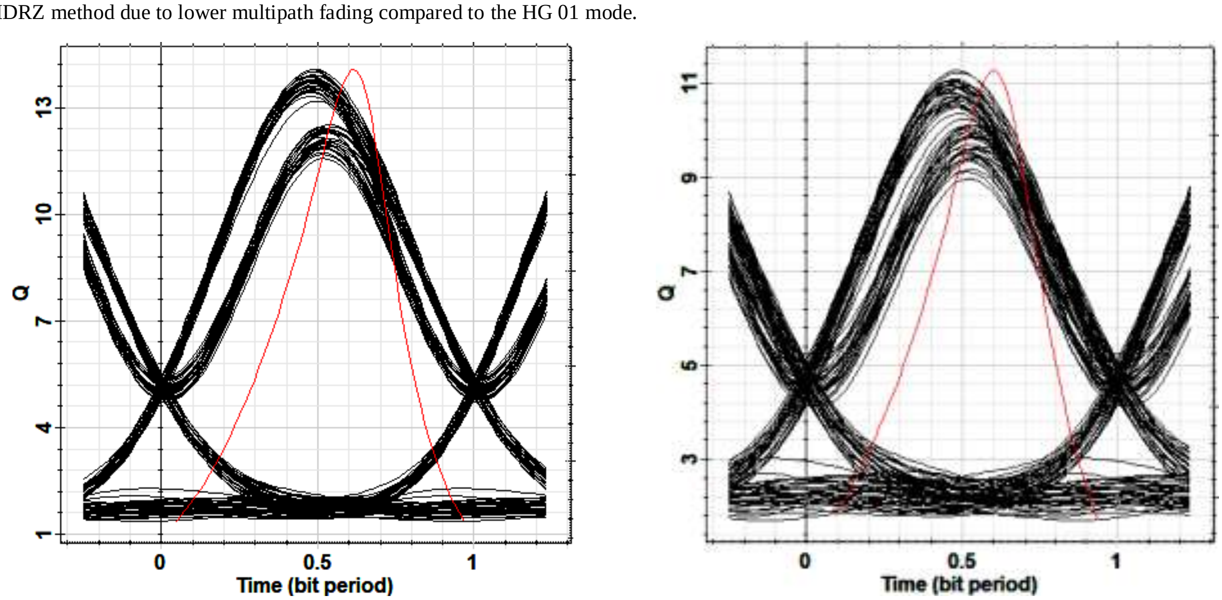


Figure 6 SNR versus link range for HG00 and HG01 mode

The eye diagrams of the HG00 and HG01 modes are shown in Figure 7 in the proposed work and greater eye opening is observed for the HG00 mode in the MDRZ method due to lower multipath fading compared to the HG 01 mode.



(a) (b)

Figure 7 Representation of Eye diagrams at 40 km distance for (a) HG00 (b) HG 01

4. Conclusion

In this work, the radio over FSO device with the integration of multiplexing mode division is proposed with a capacity of 2 x 40 Gbps integrated with 40 GHz RF signal. Under atmospheric turbulence, efficiency comparison is conducted and the Gamma-Gamma model is taken into account. In order to find optimum modulation for Ro-FSO systems, a comparison of various modulation formats such as NRZ, AMI, MDRZ, MRZ-DPSK, RZ-DPSK was carried out at different receiver aperture antenna diameters. It is noted that MDRZ performs better because of the phase shifting operation between adjacent bits, more nonlinear effect tolerance, and it is also economical as it does not require a balanced receiver. Better output is given by the increase in receiver aperture antenna diameters. As in the case of NRZ-DPSK and RZ-DPSK, shot and thermal noise increases with increases in photo-detectors. Due to the large carrier range and unipolar nature, the least performing modulation format is NRZ. Due to lower resistance to multipath fading, the HG00 mode is stronger than the HG01 mode. The system operated for 45 km with a Q factor of 8.45 under clear weather and 3100 m under light fog, 2450 m under medium fog and 2100 m under heavy fog.

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