Analysis of High Speed Mode Division Multiplexed Ro-FSO System using Gamma-Gamma Channel Model under Atmospheric Turbulences

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Abstract- Free space optical communication is prominent technique and premier alternative to RF communication. Nowadays, Researchers are giving attenuation to the hybrid radio over free space optical communication because of long reach and MDM also getting attention due to high capacity catering potential. In this research work, 2 x 40 Gbps-40 GHz RoFSO system is proposed using 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 (NRZ-DPSK). For the MDM, two Hermite Gaussian (HG) modes are used under the effects of different weather instabilities such as light, moderate and heavy fog. Input parameter such receiver antenna aperture diameter is varied and it is perceived that the increase in aperture diameter of receiver, Q factor and BER also improve. Results revealed that MDRZ performs best followed by NRZ-DPSK, RZ-DPSK, AMI and NRZ schemes.

Key words- FSO, RoFSO, MDRZ, HG modes, AMI, NRZ, DPSK

1. Introduction

Explosive internet demands all over the globe have made peer pressure on wireless services and Radio over free space optics (RoFSO) transmission systems emerged as a prominent alternative to Radio frequency services [1]. The increase in the bandwidth and capacity requirements leads to a shift from RF to optical communication. Ro-FSO systems carry overlaid radio signal over optical signal via free space transmission medium at high bit rates. Ro-FSO systems have many advantages over RF communication such as high speed of orders Gbps, wide bandwidth, unlicensed spectrum, high security, immunity to electromagnetic interference, power efficient, cost effective, easy installment and, last mile access [2]. FSO systems use line of sight communication and therefore does not need license for operation but link failure occurs if there are several obstruction in between transmitter and receiver such as buildings, birds etc. Despite the numerous advantages, FSO has some serious issues such as atmospheric condition has great deteriorative effect its performance. Different atmospheric turbulences are fog, haze, rain, sand storms, dust, haze etc which drastically affect the performance of Ro-FSO systems [3]. Optical eddies are the cause of refractive index change in the atmosphere and developed due to inhomogeneities of temperature and pressure of atmosphere. Beam wandering, beam spreading, scintillations are effects of atmospheric turbulences [4]. Fading effects in FSO can be estimated from different statistical models such as K model, lognormal Rician model, I-K model and Gamma-Gamma model etc [5]. Gamma-Gamma model is considered in Ro-FSO systems for weak to strong turbulences [6]. For the performance enhancements of Ro-FSO system, different approaches are investigated against fading effects like aperture averaging, adaptive optics, error control coding etc. Attenuation in Fog conditions is very high and in order to increase the power, either power of laser is increased or optical amplifier is employed. Input power can be increased upto limited values due to eye safety concerns and incorporation of amplifier increase complexity and cost of the system. Processing delay is observed in the error coding technique, and adaptive optics is very expensive [7]. Aperture averaging is simple and efficient technique in FSO to increase the quality of reception. In reported works, for the capacity enhancement multiplexing in phase [8], code [9], intensity [10], polarization [11], and wavelength [12], are demonstrated. Mode division multiplexing is perceived as highly competent technique for pacy networks because it can support data rates of order Tbps. MDM based Ro-FSO systems are demonstrated in [13] [14] [15] under the effects of atmospheric turbulences. In the performance of optical communication systems, modulation plays an important part and therefore in this work, different modulations in MDM-Ro-FSO are investigated. Investigated modulations are MDRZ, NRZ, RZ-DPSK, AMI, and NRZ-DPSK. In section 1, introduction about FSO, Ro-FSO, literature, problems in existing Ro-FSO systems is presented. System setup and results are discussed in section 2 and section 3 respectively. Concluding remarks are written in section 4 as conclusion of the work.

2. System Setup

For the accomplishment of proposed work, Optiwave Optisystem is used in this work. Figure 1 represents the Ro-FSO system incorporating MDM and modified duo-binary return to zero in Gamma-Gamma channel. Wavelength 1550 m is used for the two channels with different HG modes i.e. HG00 and HG01.

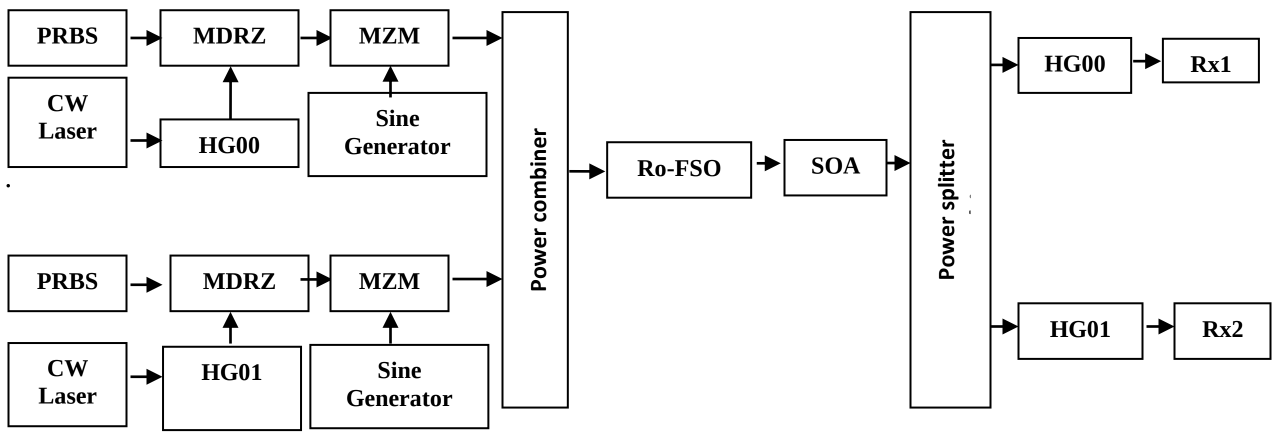


Figure 1 Block diagram of proposed MDM radio over FSO system

HG00 is assigned to first transmitter. Similarly, HG01 assigned to second transmitter and both channels modulated by MDRZ. MDRZ signal further modulated with 40 GHz RF signal to provide radio overlapped signal. Multiplexer is place to accommodate both the transmitters and fed to Gamma-Gamma FSO link model. Table 1 shows the simulation parameters of proposed work. After the transmission through FSO channel, de-multiplexer is placed to split one signal into two and mode selector is placed to filter specific mode according to the transmitted mode. Photo-detector PIN for the conversion of photons into electrons is performed and then low pass Bessel filter is placed to remove the noises in the converted signal. Re-time, Re-shaping and Re-amplification is done through 3-R regenerator and output sent to BER analyzer for final Q factor, BER.

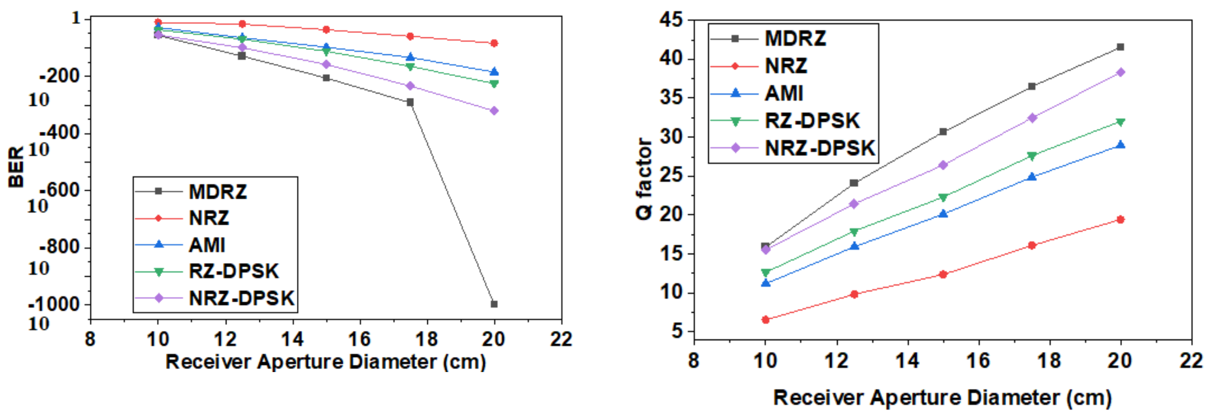
Table 1 Simulation parameters of proposed system

Parameter	Values
Data rate	40 Gbps
RF signal	40 GHz
Number of transmitter	2
Input power	0 dBm
Modulations	NRZ, MDRZ, AMI, RZ-DPSK, NRZ-DPSK

Modes	HG00, HG01
Wavelength	1550 nm
SOA injection current	0.5 mA
Transmitter receiver antenna	10 cm
Receiver aperture diameter	10-20 cm
Beam divergence	0.25 mrad
Atmospheric turbulences attenuation	Light fog 9 dB, medium fog 12 dB, heavy fog 16 dB
Scintillation	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

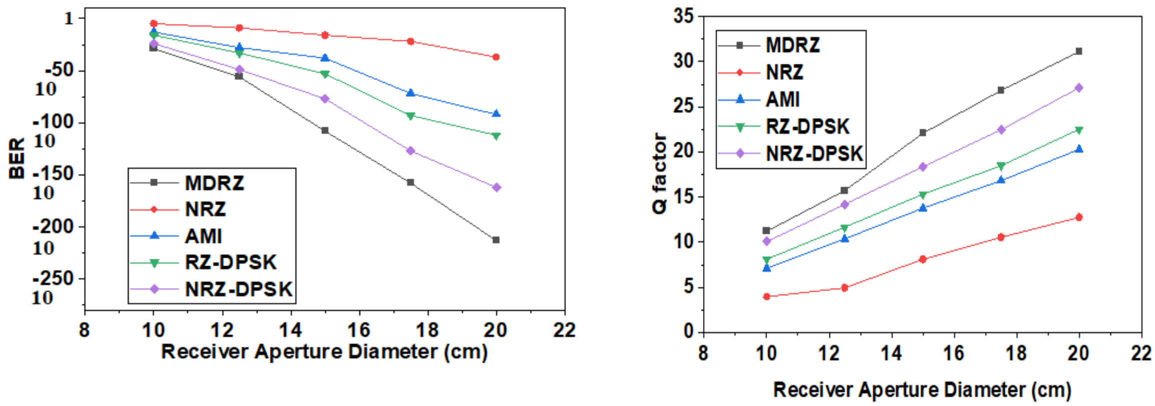
Proposed Ro-FSO system with different modulation formats is investigated at different input parameters such as FSO distance, receiver antenna aperture diameter, in terms of Q factor, BER, and SNR. Figure 2 (a) represents the performance of Ro-FSO channel under scintillation such as weak atmospheric turbulence in Gamma-Gamma model with variation of receiver antenna aperture diameter in terms of BER. Effect of weak turbulence is observed on MDRZ, NRZ, AMI, NRZ-DPSK, and RZ-DPSK under weak turbulence $C2_n = 5 \times 10{-}17 m^{-2/3}$. It is perceived that there is significant decrease in the BER with the increase in receiver antenna aperture diameter in all modulations because receiver can collect more signals. Results revealed that MDRZ performs best because of phase shifting operation between adjacent bits, more tolerance to nonlinear effects and also it is economical as it do not need balanced receiver. Performance of modified duo-binary return to zero is followed by NRZ-DPSK, RZ-DPSK, AMI and NRZ.



(a) (b)

Figure 2: Performance of different modulations formats under weak turbulence ($C^2_n = 5 \times 10^{-17} m^{-2/3}$) (a) in terms of BER (b) in terms of Q factor

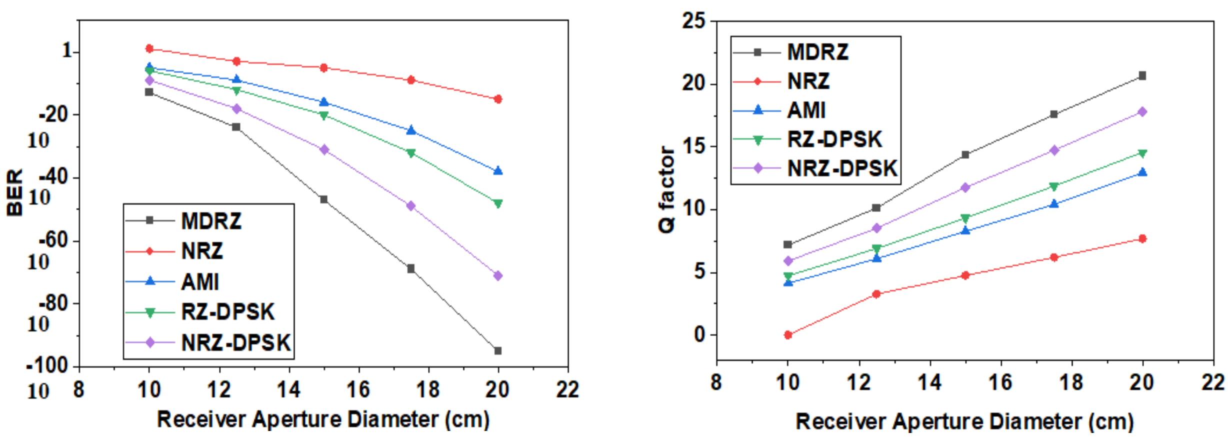
Similarly, performance of aforementioned modulations is evaluated in terms of Q factor under scintillation such as weak, moderate and strong atmospheric turbulence in Gamma-Gamma model with variation of receiver antenna aperture. Q factor versus receiver aperture antenna performance is shown in Figure 2 (b). It is perceived that Q factor is maximum in case of MDRZ. After the performance analysis under weak turbulences, the proposed system is analyzed under moderate atmospheric turbulences ($C2_n$ = 5 × 10−15$m^{-2/3}$). Figure 3 (a) shows performance in terms of BER when receiver aperture antenna diameter is changed and results revealed that MDRZ performs best but having more BER as compared to performance in weak turbulence. Figure 3 (b) depicts the performance in terms of Q factor and it is evident that more the receiver antenna aperture diameter, more is the Q factor. Performance trend of all the modulations is similar as under weak turbulences except the degradation in Q factor values.



(a) (b)

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

Further performance in terms of BER and Q factor moderate turbulence (C_{2n} = 5 × 10−15$m^{-2/3}$) 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.



(a) (b)

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

Figure 4 represents the performance of different modulation formats in the presence of strong turbulences (C2n = 5 × 10−13$m^{-2/3}$) for distance 20 km when receiver aperture diameter is changed from 10 cm to 20 cm. Results observed in terms of BER in Figure 4 (a) and it is evident that more receiver aperture diameter accommodated more signal an therefore provide enhanced BER. BER is minimum in case of MDRZ because of its spectrum efficiency and nonlinear effects tolerance. Figure 4 (b) represents the results in terms of Q factor for different modulation formats at 10 cm to 20 cm receiver aperture diameter. Q factor of NRZ is minimum due to broader carrier spectrum and unipolar nature which is very prone to nonlinear effects and dispersion. Phase shifting operation is in DPSK, but due to balanced receiver, shot and thermal noises are more. As a result performance of NRZ-DPSK and RZ-DPSK is bit lesser as compared to MDRZ modulation format. In this case, MDRZ again surpassed performance of all other investigated modulation formats. Therefore it is observed that MDRZ is optimal under strong atmospheric turbulences

Signal to noise ratio in optical communication systems should be high because it is ratio of the signal power received and noise power received. Figure 5 (a) shows the comparison in terms of SNR at different fog intensities i.e. light, medium and heavy fog. Attenuation of these fog intensities are different such as for light fog 9 dB/km, medium fog 12 dB/km and heavy fog 19 dB/km. It is perceived that due to single photo detector at the receiver to receive different phases, MDRZ provide lesser noise and therefore, highest SNR. With the increase in the intensity of fog, SNR decreases but proposed system performed well under fog conditions.

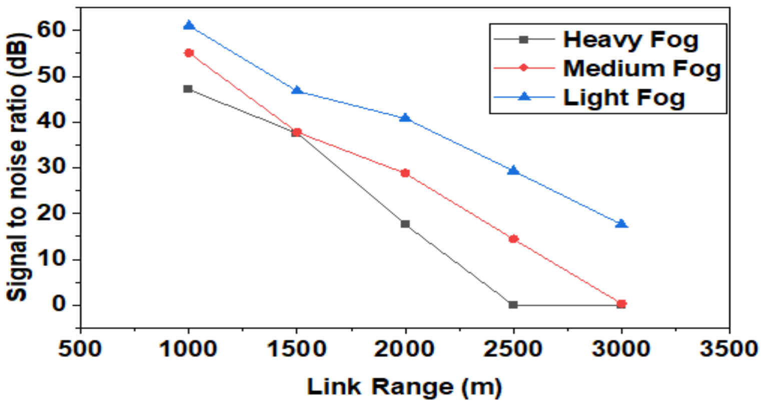


Figure 5 (a) Effect of FOG intensities on proposed MDRZ-MDM-FSO system in terms of signal to noise ratio

Figure 5 (b) depicts the total received power versus FSO link distance in case of MDRZ-MDM-FSO system. FSO link length varied from 1000 m to 3000 m under different fog conditions and it is observed that minimum power received in light fog followed by medium fog condition. Figure 6 shows the performance of proposed system under clear weather using HG00 and HG01 modes in terms of SNR. FSO link length is varied from 20 km to 45 km with the difference of 5 km and it is observed that performance of HG00 mode is better than HG01 mode. Proposed system successfully covered 40 km link distance within acceptable range of SNR.

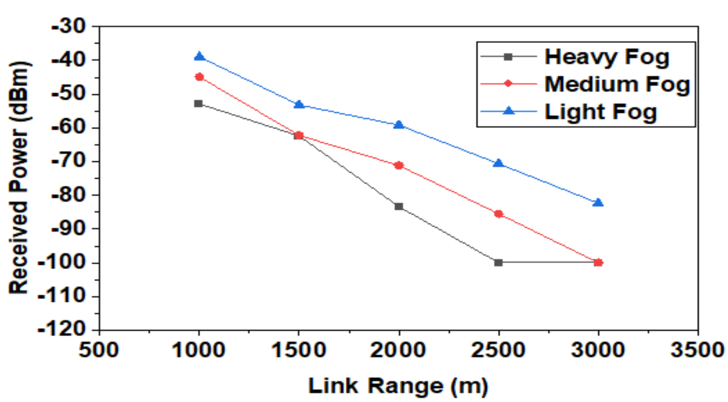


Figure 5 (b) Effect of FOG intensities on proposed MDRZ-MDM-FSO system in terms of total received power

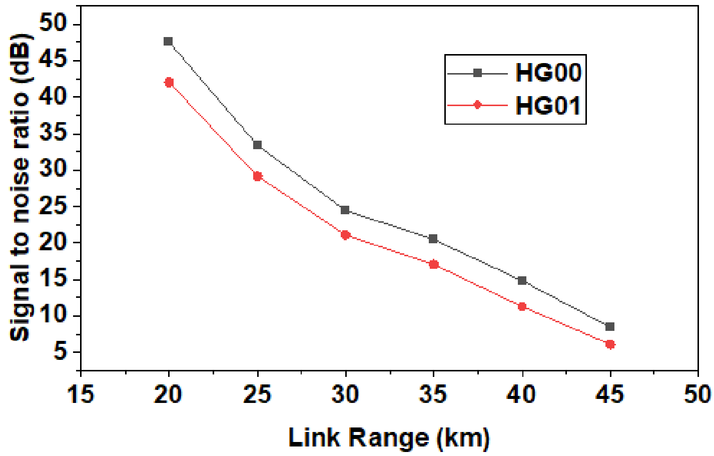
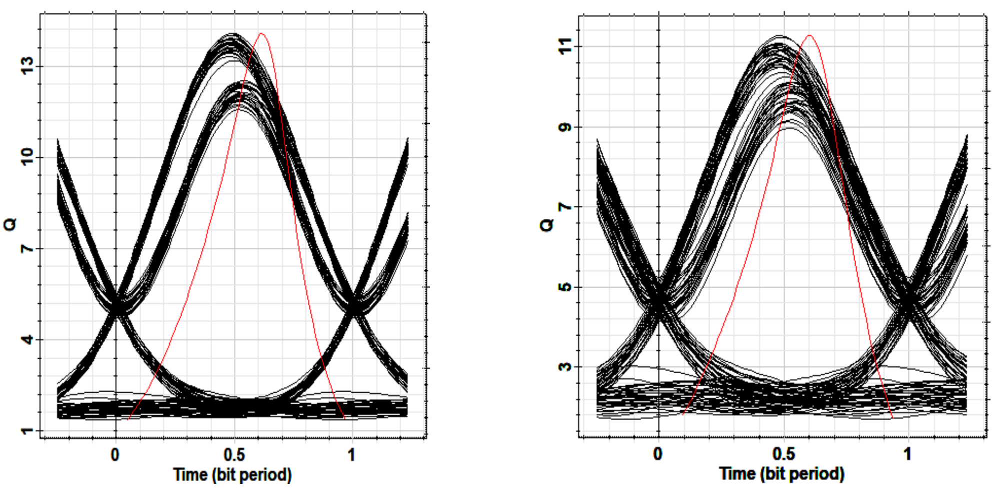


Figure 6 Performance of HG00 and HG01 mode in proposed system under clear weather

Figure 7 shows the eye diagrams of HG00 and HG01 modes in proposed work and it is observed that greater eye opening is observed for HG00 mode in MDRZ system because of lower multipath fading as compared to HG 01 mode.



(a) (b)

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

4. Conclusion

Radio over FSO system with the integration of mode division multiplexing is proposed in this work with the capacity of 2 x 40 Gbps integrated with 40 GHz RF signal. Performance comparison is performed under atmospheric turbulences and Gamma-Gamma model is considered. Comparison of different modulation formats such as NRZ, AMI, MDRZ, MRZ-DPSK, RZ-DPSK has been done at different receiver aperture antenna diameters to find out optimal modulation for Ro-FSO systems. It is observed that MDRZ performs best because of phase shifting operation between adjacent bits, more tolerance to nonlinear effects and also it is economical as it do not need balanced receiver. Increase in receiver aperture antenna diameters provides better performance. Shot and thermal noise increases with the increase in photo-detectors as happened in case of NRZ-DPSK and RZ-DPSK. Least performing modulation format is NRZ because of broad carrier spectrum and unipolar nature. HG00 mode is better than HG01 mode because of lesser susceptibility to multipath fading. System worked for 45 km under clear weather with Q factor 8.45 and under light fog is 3100 m, under medium fog is 2450 m and heavy fog is 2100 m.

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