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Comparison Different Modulation Schemes in SISO and MIMO FSO links to Obtain Maximum FSO Link

Ibrahim Mohamed
Omar Al-Mukhtar University

Reem Saleh
Omar Al-Mukhtar University

Abstract— **Proper Choose of modulation scheme in Free Space Optical (FSO) technique helps to improve FSO performance and this in turn helps to increase FSO link, so in this paper, the modulation schemes Return-to-Zero (RZ), Non Return-to-Zero (NRZ), Differential Phase-Shift Keying (DPSK) and Minimum Shift Keying (MSK) were compared under Bit Error Rate (BER) constrains. Firstly, for Single Input Single Output (SISO) – FSO link and then for 4*4 Multiple Input Multiple Output (MIMO) – FSO link, where both were set up in OptiSystem V.7 simulation, all at the very clear air, clear air, light haze and thin fog conditions. The results concluded that performance of NRZ-OOK was asymptotic to the performance of DPSK in SISO FSO and 4*4 MIMO-FSO, under very clear air, clear air, light haze and thin fog conditions.**

Index TermS: **free space optical, bit error rate, RZ – OOK, NRZ – OOK, DPSK, MSK.**

I. INTRODUCTION

FSO technology produced an alternative solution to the crowded microwave & RF links, where FSO is an effective element to achieve free space link according to the requirements of the modern era technologies due to it is advantages, such as large bandwidth, unlicensed spectrum and high data rate. The main drawback of FSO lies in the stability of FSO link is depended on weather condition such as rain, snow, fog, etc. [1-3]. Difference in local weather for each region makes many researchers analysis and evaluate the performance of an FSO link based on the data of the geographic area in which the FSO link to be installed, most researches have been tended to study the effect of fog on an FSO system, and that because the size of fog particles is close to the size of the wavelength of the carrier signal, this impedes the passage of light through fog particles causing in absorption and scattering light [4-6].

Modulation schemes have been able to catch the attention of the researchers as a solution of the FSO link drawback, where the perfect choice of the modulation schemes and the corresponding demodulation will lead to enhancing FSO link [7]. A lot of research has been going on in order to mitigate the FSO link drawback, by testing and analysis different modulation schemes. In this context, (690, 780, 850, and 1550) nm are wavelengths that were tested in [5] by using NRZ and RZ modulation schemes under fog and rain effects, with transmitter power 160 mW and PIN detector. The experimental results concluded that 1550 nm wavelength gave less BER than other wavelengths for RZ and NRZ modulation and RZ modulation gave BER lower than NRZ modulation. Singh and Kumar [3] tested the impact of direct and external modulation with transmitted power 8 dBm, 1550nm, data rate 2.5 Gbps and an Avalanche Photodiode (APD) detector at On Off Keying (OOK) modulation schemes, results included that external modulation gave better performance than direct modulation. Also OOK modulation schemes NRZ, Carrier Suppressed Return to Zero (CSRZ), Chirped Return to Zero (CRZ) and RZ were tested at external modulation, the results were divided into two parts, the first RZ is a best performance at long distance and the second NRZ being a best performance at short distance. In [2, 8] the researchers based on the comparison of some of the OOK modulation schemes to increasing the distance, and both used the MIMO technology with APD detector, where Israr et al. [2] analyzed the OOK modulation schemes of NRZ, RZ and CSRZ for MIMO - FSO technology with varying attenuation factor, the results included that RZ is a best for MIMO FSO technology for a short distance, whereas Nadeem et al. [8] analyzed the OOK modulation schemes of NRZ, RZ, and CSRZ for SISO - FSO technology and MIMO - FSO technology, the results included that RZ is the best modulation for SISO FSO technology and NRZ is the best modulation for MIMO FSO technology under little fog, light rain, moderate fog and heavy rain conditions. Parween and Tripathy [9] compared the optical analog link communication by Amplitude modulation (AM) and optical digital link by both NRZ, RZ modulation

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schemes for the range of a communication, Optical Fiber Cable (OFC) and FSO all with Erbium-Doped Fiber Amplifier (EDFA) of length 5m at transmitter and receiver sides . The results illustrate that FSO gave a longer range than OFC with NRZ modulation. The researchers in [7, 10] used hybrid modulation schemes to improve the performance of FSO technology. Tiwari et al. [10] used hybrid a Subcarrier Intensity Modulation (SIM), L-Pulse Position Modulation (L-PPM) and MSK to enhance FSO performance under different turbulence condition, the proposed system improved the performance of the FSO system under weak, moderate and strong turbulence. Liu et al. [7] proposed hybrid an L-PPM, MSK and SIM to enhance BER performance for FSO system, the results illustrate that the proposed hybrid modulation enhanced the BER performance, wherein every increase of L leads to an decrease of BER. Sathya and Robinson [11] tested the receiver sensitivity, BER and Q-factor with respect to link distance under rain conditions for both modulation schemes DPSK and MSK, the results shows that DPSK modulation gave a better BER performance than MSK modulation. Sarkar and Metya [12] proposed using an FSO link in the last, mile after sending MSK signals with 10Gbps over 100 km Dispersion Shifted Fiber (DSF) downlink and use the same DSF link in the uplink from the modulated MSK users under six weather conditions, finally, the proposed system gave an error free link under different weather conditions at the perfect range.

In this paper, different modulation schemes RZ - OOK, NRZ - OOK, DPSK and MSK were investigated under four weather conditions, firstly, for SISO-FSO link and then for the MIMO- FSO link to get to the maximum FSO link, by analyzing the BER performance, the maximum FSO link will be found when BER becomes 10^{-9}.

The local weather, especially fog, affects an FSO link, so the contribution of this paper was to analyze FSO link under influence very clear air, clear air, light haze and thin fog in the city of Al-Bayda, where the attenuations due to very clear air, clear air, light haze and thin fog, were 0.0703, 0.1580, 0.2557 and 1.33 dB/km, respectively. The analysis was conducted for choosing the proper modulation scheme that increases the FSO link distance.

This paper is arranged as the followings, section II introduces modulation schemes, section III provides an FSO system model, section IV illustrates simulation setup, section V presents results and discussion followed by conclusion in section VI.

II. FSO MODULATION SCHEMES

The main goal of modulating data is transmitting this data reliably over, because sent data without modulation maybe suffer from one or more of certain channel impairments such as noise, interference, attenuation, etc. [13]. There are several types of modulation schemes that are appropriate for FSO technology such as PPM, Pulse Amplitude modulation (PAM), OOK modulation, MSK modulation, DPSK modulation, Quadrature Phase Shift Keying (QPSK) modulation. [10, 14, 15]. Modulation schemes performance in FSO technology dependent on several parameters such as attenuation, bit rate, number of channels and transmission distance [8]. In this paper, modulation schemes RZ - OOK, NRZ - OOK, DPSK and MSK will be investigated under four weather conditions, and it can be presented in brief as follows:

A. RZ - OOK and NRZ – OOK

RZ and NRZ fall under OOK modulation, where OOK modulation widely employed in FSO technology due to it is simple, inexpensive, easy in an implementation. RZ - OOK is characterized by power efficient, but NRZ - OOK is simpler and cheaper than RZ - OOK. BER with RZ - OOK and NRZ - OOK schemes are given by (1) and (2**)**, respectively [9, 13, 14].:

$$BER_{RZ\text{ - }OOK} = 0.5\ erfc\ (\ 0.5\ SNR^{0.5}) \qquad (1)$$

$$BER_{NRZ\text{ - }OOK} = 0.5\ erfc\ (\ 0.535\ SNR^{0.5}) \qquad (2)$$

B. DPSK

DPSK overcome on disadvantage of Binary Phase Shift Keying (BPSK), who require to knowing the frequency and phase of the carrier at the receiver side, whereas in DPSK modulation is unnecessary to known that. BER with DPSK scheme is given by (3) [14]:

$$BER_{DPSK} = 0.5\ erfc\ (0.707\ SNR^{0.5}) \qquad (3)$$

C. MSK

MSK is one of the forms Continuous Phase Frequency Shift Keying (CPFSK), that has been used in many applications, where the frequency of its single carrier is changed continuously to avoid use the signals that having large spectral side lobes. BER with MSK scheme is given by (4) [11, 13]:

$$BER_{MSK} = erfc\ (SNR^{0.5}) \qquad (4)$$

III. FSO SYSTEM MODULE

Figure 1 illustrates a block diagram of simulation design.

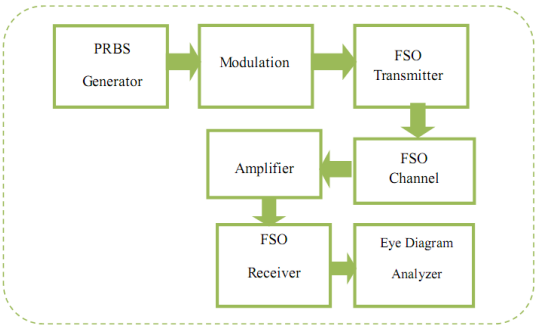

Figure 1. Block diagram of simulation design.

- PRBS Generator: Pseudo-Random Bit Sequence (PRBS) generator which its task lies in

generating bit sequence from the information signal.

- Modulation: Bit sequence is modulated in the modulation block, which its task lies in converting a bit sequence to an electrical signal. The modulation schemes implemented in this study are RZ-OOK, NRZ-OOK, DPSK and MSK.
- FSO transmitter: Transmitter block consists of a light source and the modulator, Continuous Wave (CW) laser is the type of light source was chosen in this study. In relation to the modulator, external modulator was applied in this study by using a Mach-Zehnder Modulator (MZM), MZM modulator has two inputs, one of them is supplied from CW laser as carrier signal and the other input is electrical signal was sent from the modulation block, MZM modulator its task lies in converting the electrical signal into an optical signal.
- FSO Channel: The type of channel in FSO technology is air, its task lies in transmitting light signal from FSO transmitter to FSO receiver. The number of channels in FSO technology is determined by determining the number of transmitters, in this study the performance of single channel SISO-FSO and multi - channel 4*4 MIMO-FSO, were analyzed.
- Amplifier: Tasks of the amplifier in the receiver side lies in increase the signal quality and receiver sensitivity, EDFA was used in this study.
- FSO Receiver: Receiver block consists of photo-detector, filter and 3R Regenerator, the task of the photo-detector lies in converting the optical signal into electrical signal, a filter is used to increase the power level and remove unwanted noise associated with the signal, 3R Regenerator task lies in regenerating the sent original bit sequence. PIN as a photo-detector and low pass Bessel filter were used in this study.
- Eye Diagram Analyzer: Its task lies in analyzing the bit sequence in terms of Q factor, eye height, or BER. In this study, the analysis was based on BER and to get to a maximum and the reliable FSO link, the BER should not exceed 10^{-9}.

IV. SIMULATION SETUP

In this paper, modulation schemes RZ - OOK, NRZ - OOK, DPSK and MSK were analyzed under very clear air, clear air, light haze and thin fog conditions, firstly, for SISO-FSO link and then for the MIMO - FSO link to get to a maximum FSO link under BER constraints. Both SISO - FSO and 4*4 MIMO - FSO were set up in OptiSystem V.7 simulation by using the parameters that illustrated in Table I. Figure 2, Figure 3, Figure 4 and Figure 5 illustrate SISO - FSO with RZ - OOK, NRZ - OOK, DPSK and MSK, respectively. And Figure 6, Figure 7, Figure 8 and Figure 9 illustrate MIMO -FSO with RZ -OOK, NRZ-OOK, DPSK and MSK, respectively.

Table I. parameters of simulation design

Parameters	Value
Data Rate (in Gbps)	2.5
Wavelength (in nm)	1550
Output Power (in dBm)	10
Beam Divergence angle(in mrad)	0.5
Transmitter Aperture (in cm)	2.5
Receiver Aperture (in cm)	37.5
Transmitter Loss (in dB)	1.8
Receiver Loss (in dB)	1.8
Additional Loss (in dB)	1
Attenuation (in dB/km) At very clear air condition At clear air condition At light haze condition At thin fog condition	 0.0703 0.1580 0.2557 1.33

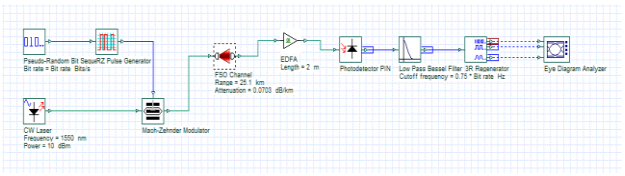

Figure 2. SISO - FSO with RZ - OOK

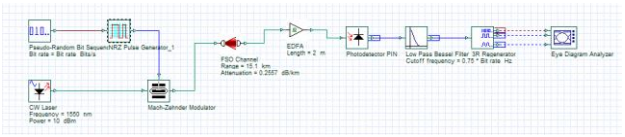

Figure 3. SISO - FSO with NRZ - OOK

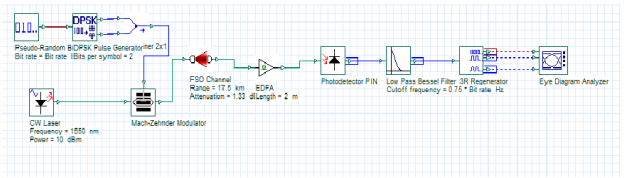

Figure 4. SISO - FSO with DPSK

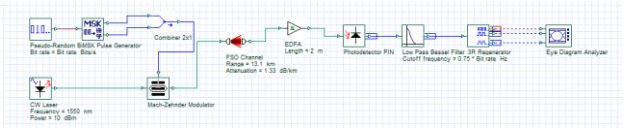

Figure 5. SISO - FSO with MSK

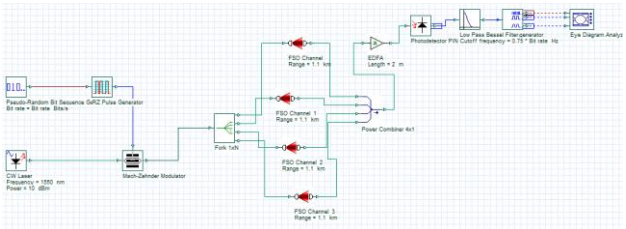

Figure 6. MIMO - FSO with RZ – OOK

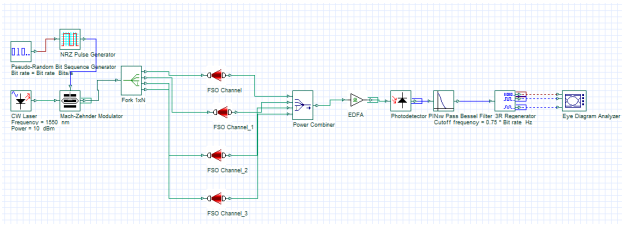

Figure 7. MIMO - FSO with NRZ - OOK

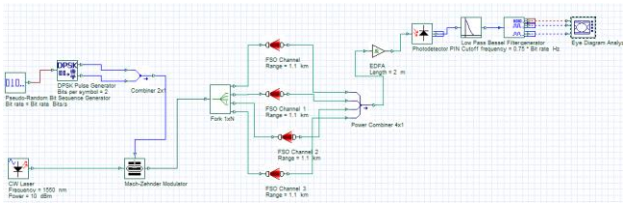

Figure 8. MIMO - FSO with DPSK

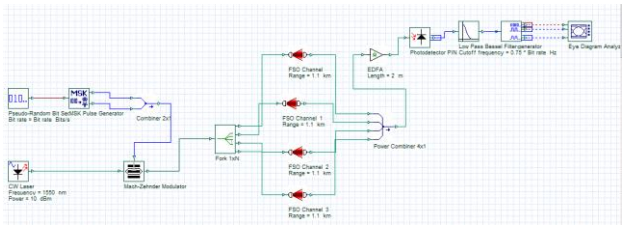

Figure 9. MIMO - FSO with MSK

V. RESULTS AND DISCUSIONS

A. Results and Discusions for SISO – FSO System

Figure 10, Figure 11, Figure 12 and Figure 13 illustrates the relationship between LOG BER and link range in SISO - FSO with a change in modulation schemes RZ - OOK, NRZ - OOK, DPSK and MSK at the very clear air, clear air, light haze and thin fog conditions, respectively.

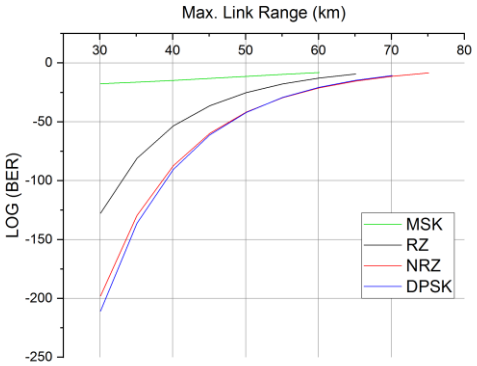

Figure 10. Relationship between LOG BER and link range in SISO - FSO under very clear air

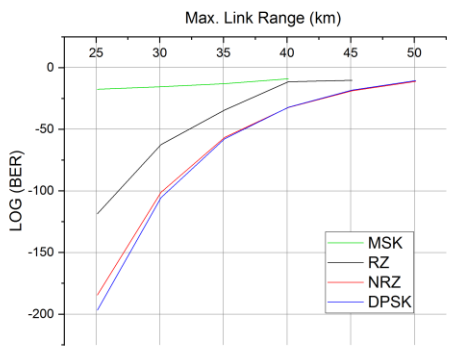

Figure 11. Relationship between LOG BER and link range in SISO - FSO under clear air

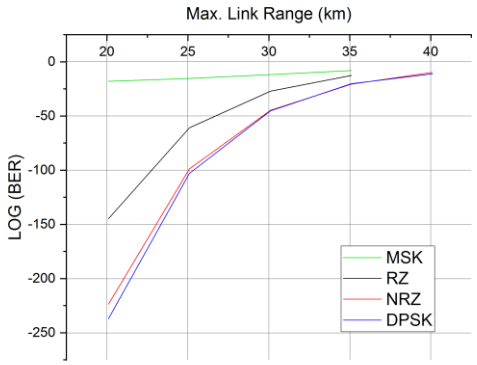

Figure 12. Relationship between LOG BER and link range in SISO - FSO under light haze

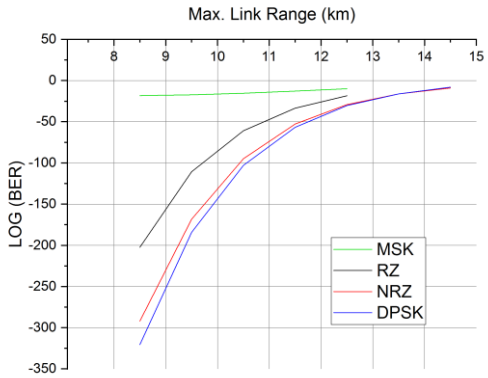

Figure 13. Relationship between LOG BER and link range in SISO - FSO under thin fog

The results concluded that performance of NRZ - OOK was asymptotic to the performance of DPSK and the both gave maximum SISO - FSO link than other modulation schemes, where maximum SISO - FSO link with NRZ - OOK were (75,50,40 and14. 5) km at very clear air, clear air, light haze and thin fog conditions, respectively, and were with DPSK (70,50,40 and14. 5) km at very clear air, clear air, light haze and thin fog conditions, respectively.

B. Results and Discusions for MIMO – FSO System

Figure 14, Figure 15, Figure 16 and Figure 17 illustrates the relationship between LOG BER and link range in 4*4 MIMO - FSO with a change in modulation schemes RZ - OOK, NRZ -OOK, DPSK and MSK at the very clear air, clear air, light haze and thin fog conditions, respectively.

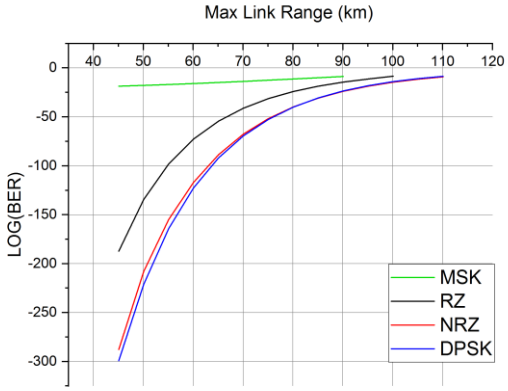

Figure 14. Relationship between LOG BER and link range in MIMO - FSO under very clear air

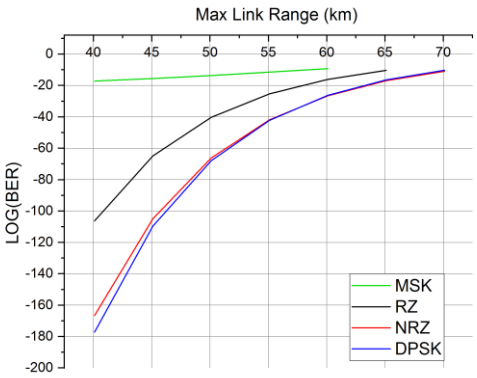

Figure 15. Relationship between LOG BER and link range in MIMO - FSO under clear air

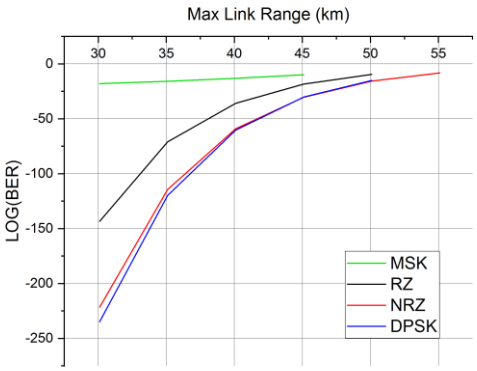

Figure 16. Relationship between LOG BER and link range in MIMO - FSO under light haze

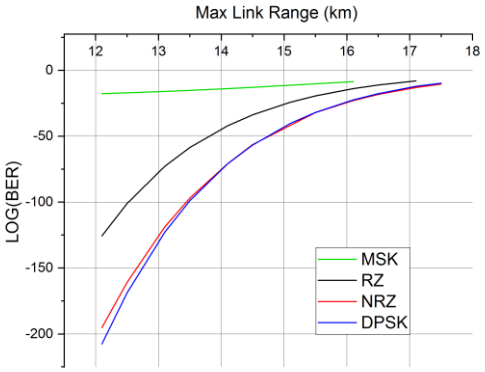

Figure 17. Relationship between LOG BER and link range in MIMO - FSO under thin fog

The results concluded that performance of NRZ - OOK was asymptotic to the performance of DPSK and the both gave a maximum 4*4 MIMO - FSO link than other modulation schemes, where maximum 4*4 MIMO - FSO link with NRZ - OOK were (110,70, 55 and17. 5) km at very clear air, clear air, light haze and thin fog conditions, respectively, and were with DPSK (110,70,50 and17. 5) km at very clear air, clear air, light haze and thin fog conditions, respectively.

VI. CONCLUSION

The results of the comparison in the SISO - FSO and MIMO - FSO links between the modulation schemes RZ - OOK, NRZ - OOK, DPSK and MSK, that was conducted under the effect of the very clear air, clear air, light haze and thin fog conditions which illustrated that the maximum FSO link in SISO - FSO and in MIMO – FSO were occurred at NRZ - OOK and DPSK. And if we take into account that the NRZ - OOK is simpler, cheaper and easier in an implementation than DPSK, we can say that NRZ - OOK will be preferred in this study, where maximum SISO- FSO link with NRZ - OOK were (75,50,40 and14. 5) Km at very clear air, clear air, light haze and thin fog conditions, respectively, and the maximum 4*4 MIMO - FSO link with NRZ - OOK were (110,70, 55 and17. 5) Km at very clear air, clear air, light haze and thin fog conditions, respectively, in the end, it can be said that in this study the maximum possible link has been reached under the BER constraints of the FSO technology at 4*4 MIMO-FSO with NRZ - OOK modulation.

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