

Simulation and Performance Analysis of Free Space Optical Systems using Multiple TX/RX and Polarized CO-OFDM techniques under Atmospheric Disturbances

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Abstract— Free Space Optical (FSO) communication is an optical communication technology in which optical data transmitted wirelessly from one place to another. High security, faster installation, licence free spectrum are its main advantages. The atmospheric conditions like haze, fog, snow etc affects the performance of FSO system. Using some techniques like Spatial Diversity, Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) with dual polarization, it is possible to reduce the effects of atmospheric disturbances. This paper analyzed the performance of Multiple TX/RX FSO system and CO-OFDM FSO system under clear, haze and fog conditions using Q factor, Bit Error Rate (BER) etc. The simulations are done using a commercial optical system simulator named OptiSystem 12.0 by Optiwave.

Keywords— FSO, Spatial Diversity, MIMO, OFDM, CO-OFDM, Dual Polarization, OptiSystem 12.0

INTRODUCTION

Free-space optics (FSO) is one of the new optical communication technology which makes it possible to obtain the wireless optical communication with high data rate. This technology reduces the difficulty while laying optical fibers [10]. Wide license free spectrum, easy installation, secure transmission are its key advantages. Lasers and LEDs (Light Emitting Diodes) are used as sources. For long distance and short distance communication lasers and LEDs respectively are widely used. Terrestrial and outer space communications are its practical applications [8]. This technology finds application where a temporary link is needed, be it for a conference or ad-hoc connectivity in the event of a collapse of an existing communication network [12]. The energy beams are collimated and sent through clear air or space from the source to the destination, rather than guided through an optical fiber. If the energy source does not produce a sufficiently parallel beam to travel the required distance, collimation can be done with lenses. At the source, the visible or IR energy is modulated with the data to be transmitted. At the destination, the beam is intercepted by a photodetector, the data is extracted from the visible or IR beam (demodulated), and the resulting signal is amplified and sent to the hardware. FSO systems can function over distances of several kilometers. As long as there is a clear line of sight between the source and the destination, communication is theoretically possible. Even if there is no direct line of sight, strategically positioned mirrors can be used to reflect the energy. The beams can pass through glass windows with little or no attenuation. Although FSO systems can be a good solution for some broadband networking needs, there are limitations. Most significant is the fact that rain, dust, snow, fog, or smog can block the transmission path and shut down the network [9]. Diversity is one of the methods to provide high quality services by sending several copies of the same signal. It gives reliability to the transmission. CO-OFDM have provided high data rate and high capacity in the optical communications. These two techniques can be used to mitigate the effects of atmospheric disturbances on FSO systems.

SPATIAL DIVERSITY AND CO-OFDM TECHNIQUES

Spatial Diversity

Spatial diversity is one of the possibilities of including diversity based on the availability of multiple antennas at the transmitter or the receiver shown in Fig.1. It is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. The use of multiple antennas allows to exploit the spatial dimension of the wireless channel and to provide reliability by simultaneously transmitting the same signal through the new degrees of freedom provided by this spatial dimension. The transmitter section and receiver sections of this system contains multiple lenses which provide the diversity. Multiple beams from the transmitters are send to different paths using lenses. Beams after propagation through the channels get attenuated due to the atmospheric disturbances. The attenuation faced by each path will be different and all the multiple copies of the transmitted signals are then received at the receiver section using lenses [7].

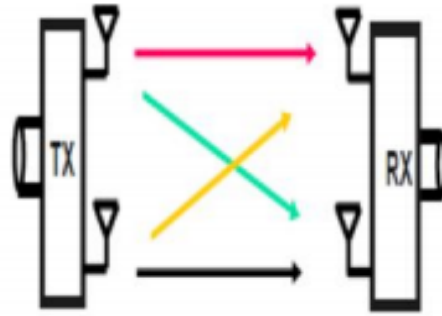


Fig.1 Spatial Diversity

CO – OFDM (Coherent Optical Orthogonal Frequency Division Multiplexing)

Coherent Optical OFDM (CO-OFDM) means OFDM data which is modulated to light frequency and then detected in coherent manner. Though OFDM has been standardized in wireless communication (e.g. IEEE 802.11) for a long time, the CO-OFDM was proposed around 2008 and is a relatively new concept for optical fiber transmission. Such a novel modulation format combines two powerful techniques in optical communications, coherent detection and OFDM. This modulation format holds the promise of delivering high electrical and optical spectral efficiency, receiver sensitivity, and optical dispersion resilience. A direct up conversion CO-OFDM architecture is shown in Fig.2. In this, transmitter and receiver uses two optical modulators and two optical detectors for modulating and demodulating both in phase and quadrature components of a signal [11].

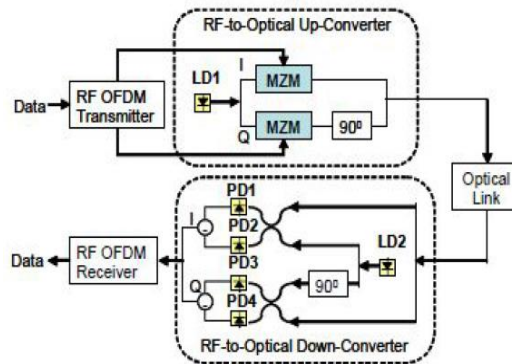


Fig.2 CO-OFDM direct up conversion architecture

DESIGN AND SIMULATIONS

FSO System using Multiple TX/RX technique

The fundamental elements that form a FSO system are the FSO transmitter, a FSO channel and the FSO receiver. Here TX and RX represents transmitter and receiver respectively. Transmitter includes the PRBS (Pseudo Random Bit Sequence) generator, NRZ pulse generator, a laser source and MZM (Mach Zehnder Modulator) [1]. In the simulation shown in Fig.4, data generated by the PRBS generator at a data rate of 20 Gbps is encoded and light modulated using MZM where laser source acts as the carrier source with wavelength 1550 nm and power 20 dBm. This modulated light is amplified using optical amplifiers before transmission to a range of 40 Km. The gain of the amplifier is set as 20 dB. Amplified signal is then directly send to the receiver through free space optical channel

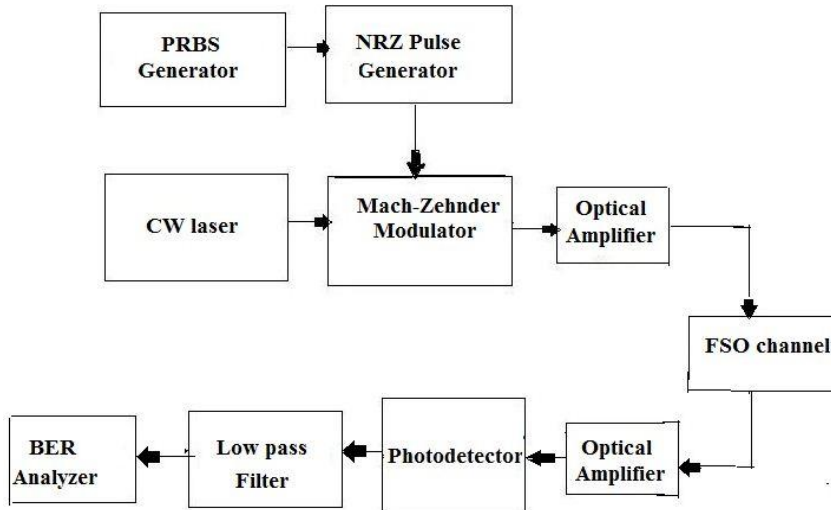


Fig.3 Block diagram of 1 TX/1 RX FSO system

Actually free space optical channel is a subsystem of two telescopes with FSO channel between them. The apertures of transmitter and receiver are set to 5 cm and 20 cm. The beam divergence is 2 mrad. In practical cases there is attenuation in the received signal due to atmospheric conditions of the channel. It is possible to set the attenuation losses in the FSO. Typical attenuation values of three conditions clear, haze and fog are 0.43 dB/Km, 4.3 dB/Km and 43 dB/Km respectively [15]. Initially, the attenuation value is set as 0.43 dB/Km (clear). The optical signals from the FSO channel are received by photodetector APD.

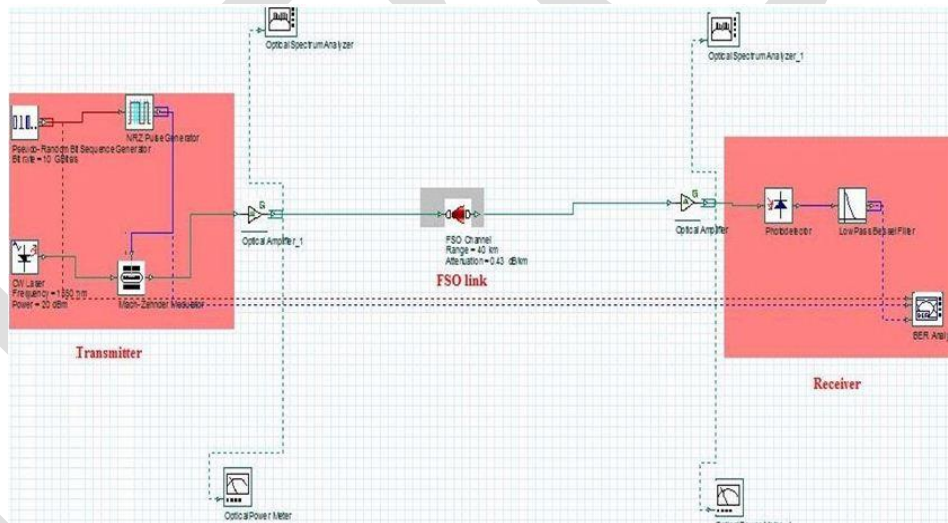


Fig.4 Simulation layout of 1 TX/1 RX FSO system.

A low pass Bessel filter is used to filter the signal from noise [5]. This simulations uses three visualizers namely optical power meter, optical spectrum analyser and BER analyser. Optical spectrum analysers provide the facility to analyse the optical spectrum. Optical power meters gives the power received in both dBm and Watts. BER analyzer automatically calculates the BER value, Q factor and display eye diagram. In the simulation shown in Fig.5, instead of one FSO channel, four channels are used. Fork is used for duplicating the input beam to all the channels.

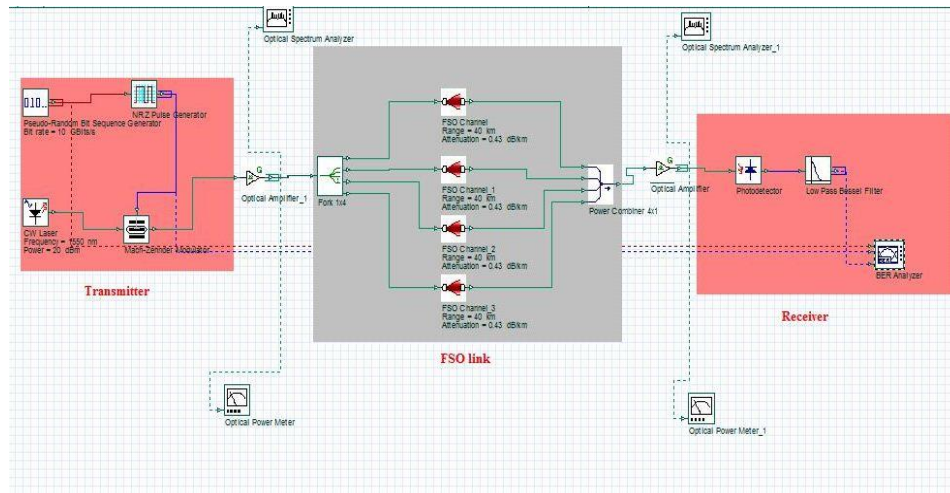


Fig.5 Simulation layout of 4TX/4 RX FSO system.

FSO System using Polarized CO-OFDM technique

A basic CO-OFDM FSO system can be divided into five parts respectively Radio Frequency (RF) OFDM transmitter, electro-optical (RF to Optical) up converter, optical free space link, optical electrical (Optical to RF) down converter, and RF-OFDM receiver. RF-OFDM transmitter consists of constellation mapper, OFDM modulator converts the signal to OFDM modulated RF. This OFDM modulated signals are then converted to light signals using Mach Zehnder modulators [2]. Light signals from modulators are then transmitted through free space channels. The transmitted light signals are then received at the optical to RF down converters and undergoes coherent detection. Data signals at several Gigabits/s are generated using 4 QAM sequence generator having 2 bit per symbol. QAM data signals are then OFDM modulated by means of OFDM modulator using 104 sub-carriers and FFT size of 128 to generate high speed OFDM analog data signals. These OFDM analog signals at this data rate are modulated with light carrier generated by a continuous wave laser having wavelength of 1550 nm and power of 20 dBm.

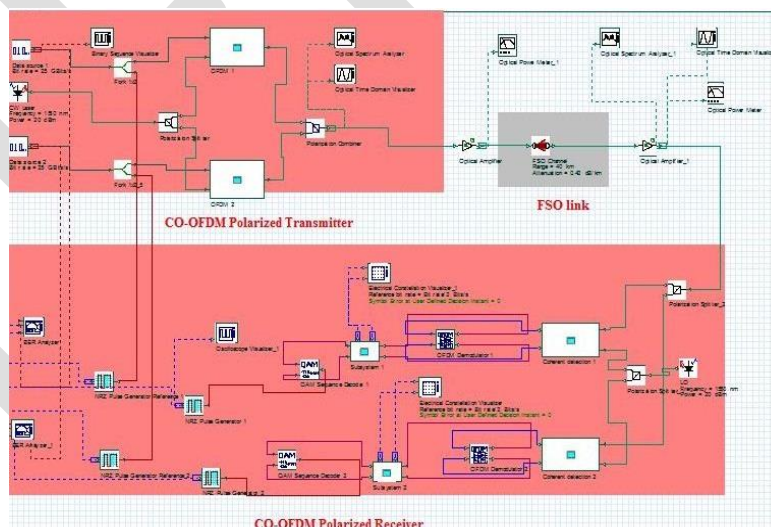


Fig.6 Simulation layout of polarized CO-OFDM FSO system.

Polarization splitters are used at the transmitter section in order to split the light to horizontally and vertically polarized light. These two orthogonally polarized lights are used for the light modulation of OFDM signals. Then both lights are combined with polarization combiner before transmission into the atmospheric channel. This method is used to cancel the effects of attenuation i.e., when horizontally polarized and vertically polarized light passed through the same channel, it will be counteracted by each other. Continuous wave laser light is split into two orthogonal polarization using polarization splitter and is used to modulate two groups of OFDM

analog signals by means of two MZM modulators(for each group) [4]. This QAM-OFDM treated analog data signals are directly transmitted over an optical span. At the receiver base station, the signal is retrieved successfully using four PIN photo-detectors which are derived by local oscillator having same wavelength ie, 1550 nm as that of transmitter to realize coherent detection. Simulation layout of polarized CO-OFDM FSO system is shown in Fig.6.

RESULTS AND DISCUSSIONS

Multiple TX/RX FSO system

Simulations of both 1 TX/1 RX and 4 TX/4 RX FSO systems with a power of 10 dBm, range of 1 km and bit rate of 10 Gbps are analysed under three conditions clear, haze and fog. Fig.7 represents the FSO system under clear condition. 4 TX/4 RX show a better performance with high Q factor and low BER.

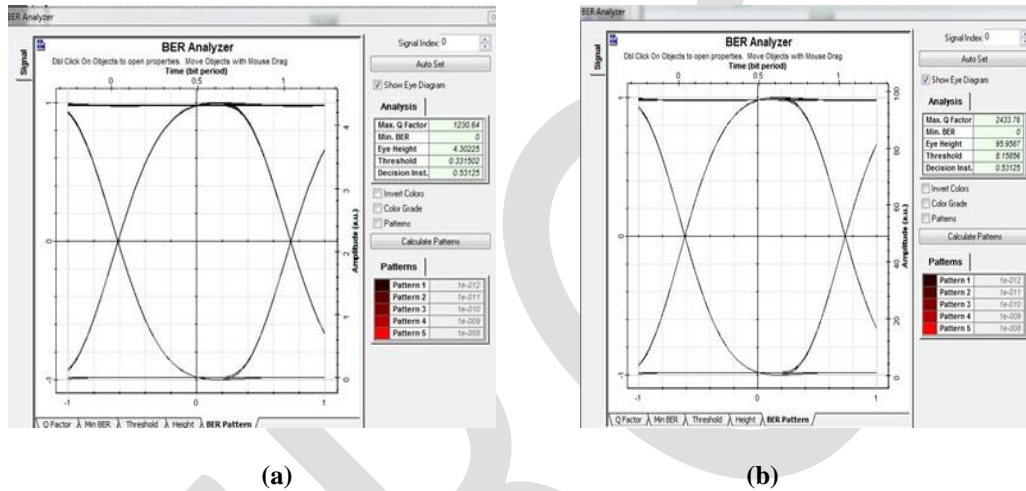


Fig.7 Eye diagram of (a) Single TX/RX and (b) Multiple TX/RX FSO system under clear condition.

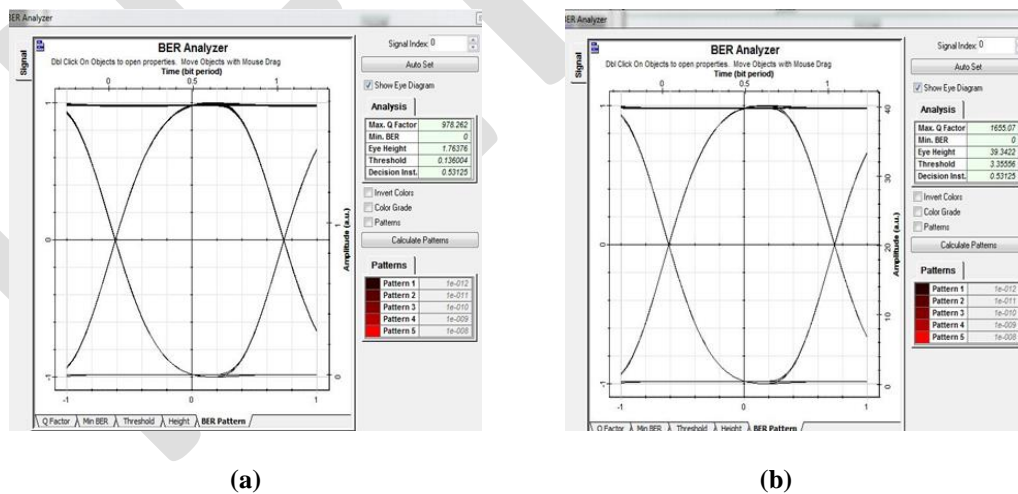


Fig.8 Eye diagram of (a) Single TX/RX and (b) Multiple TX/RX FSO system under haze condition.

Eye diagrams of both FSO systems under haze and fog are shown in Fig.8 and Fig.9. It is seen that in this case also the 4 TX/4 RX FSO system performed better. The most important challenge faced by FSO system is fog [14]. Its attenuation is taken as 43 dB/km. In FSO system under fog with same other conditions, it is seen that Q factor of 1 TX/1 RX FSO system is only 8.29 while that of 4 TX/4 RX is 29.37.

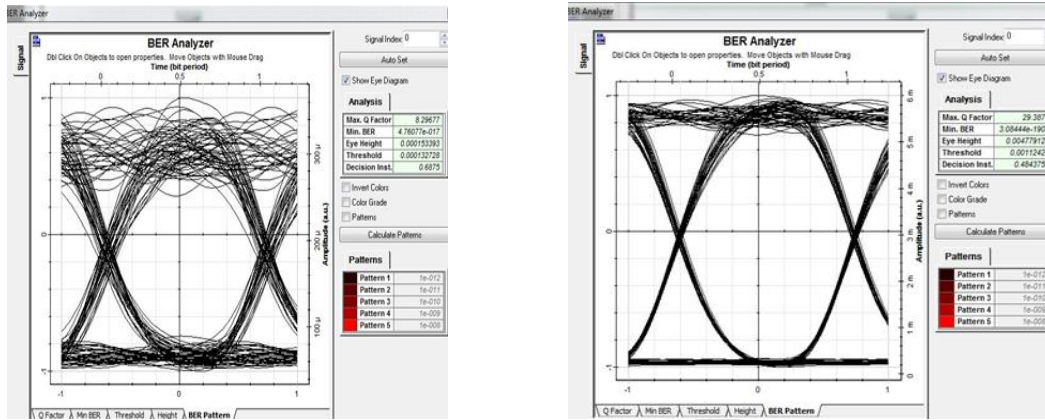


Fig.9 Eye diagram of (a) Single TX/RX and (b) Multiple TX/RX FSO system under fog condition.

Polarized CO-OFDM FSO system

The system is analysed under clear, haze and fog with a input power of 10 dBm, bit rate of 10 Gbps, and at a range of 1 Km. The eye diagrams of this system under clear, haze and fog conditions are shown in Fig.10. This system exhibits a better Q factor and low BER under these atmospheric conditions. The attenuation effects from these disturbances are minimized by the CO-OFDM modulation with polarization.

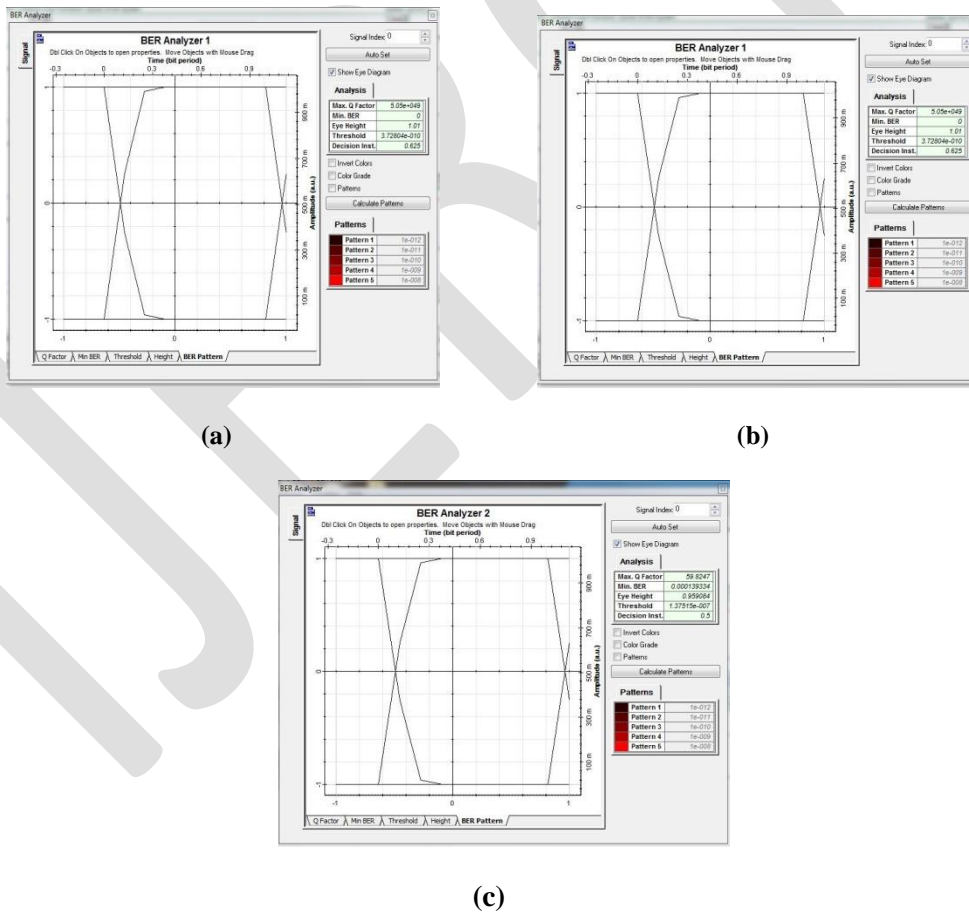


Fig.10 Eye diagram analysis of a polarized CO-OFDM FSO system under (a) clear (b) haze and (c) fog condition.

CONCLUSION

Free Space Optics is a promising communication technology in the near future. Due to the atmospheric disturbances, there is distortion of signals at the receiver. But by using new techniques it is possible to reduce the atmospheric effects on the optical signal. Use of spatial diversity and CO-OFDM with dual polarization in the FSO system increased the efficiency of systems under different disturbances. Eventhough Q factor of FSO system decreases on increasing attenuation, the 4 TX/4 RX shows a higher Q factor so better performances. Similarly CO-OFDM system with dual polarization reduces the attenuation effects on the optical signals propagating through the atmosphere.

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