IMPLEMENTATION AND PERFORMANCE EVALUATION OF MIMO TECHNIQUE FOR HIGH DATA RATE WIRELESS OPTICAL COMMUNICATION SYSTEM IN TURBULENT ATMOSPHERE

Ali Q. Baki[1], Dr. Shehab A. Kadhim[2], Dr. Salah Aldeen A. Taha[3]

[1,3]Laser & Optoelectronics Engineering Dept., University of Technology, Iraq

[2]Laser & Optoelectronics Research Center, Ministry of Science & Technology, Iraq

ABSTRACT

The data rate on the order of gigabits per second of Free Space optical communication (FSO) system in turbulent channel suffers random fluctuations in the intensity and phase of the received signal. For mitigation of this effect, multiple input multiple output (MIMO-FSO) system performance with spatial diversity overatmospheric turbulence channels was considered in this work. Obtained results demonstrate that MIMO performance mitigation techniques have high link availability and reliability of FSO system under wide range of atmospheric turbulence conditions.Data rate enhances results are achieved without any bandwidth or power expansions and the bit error rate (BER) at the receiver is maintained below 10^{-9}. We assume intensity modulation and on-off keying with NRZ type and present the BER performance of single-input single-output (SISO-FSO), (2Tx × 2Rx) and (4Tx × 4Rx) (MIMO-FSO) configuration systems with (155 Mbps) over this channel model. Both techniques of FSO systems (SISO and MIMO techniques) have been implemented experimentally through two approaches, laboratory and real field prototypes. It has been observed for (MIMO-FSO) link that increasing the system speed was almost linearly with the number of transmitting units.

Keywords: Data Rate of Communication, FSO, SISO, MIMO, Visibility, Atmospheric Turbulence.

I. INTRODUCTION

Free Space Optical (FSO) communications is the best practical solution to create abroad band three dimensional global communications grid among ground, airborne nodes and satellite due to its ease of deployment, huge available bandwidth, tolerance of bandwidth reuse and ingrained security at physical layer. In laser beam, the total loss due to absorption and scattering. However, atmospheric condition such as haze, fog, dust, smoke and rain turn the propagation environment into a multiple scattering medium and hence introduce laser pulse broadening in time and space. Intensity modulation and direct detection (IM/DD) FSO communication is a low cost and high bandwidth access technique, which has recently received significant attention and commercial interest for a variety applications so it's depended in this work [1].Hence, to exploit the huge potential of FSO at

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its best under all weather conditions, prudent measures must be taken in the design of transmitter and receiver. More specifically, multiple transmitters and multiple receivers can be used to combat the turbulence induced fading and to compensate for pulse attenuation and broadening caused by absorption and scattering, this technique is also known as a diversity technique.Moreover, the possibility for temporal blockage of the laser beams by obstructions is further reduced and longer distances can be covered through heavier weather conditions [2].

In digital communications, one is interested in the peak of received power waveform in order to recognize the signal from steady background radiation. In a receiver unequipped with appropriate countermeasure techniques, hence inter symbol interference occur because of overlapping pulse tails on adjacent symbol intervals, and thus limits the realize bit rate. As a result, the receiver should have a small Field Of View (FOV) and has to resort to Line Of Sight (LOS) photons. It has been shown that increasing number of lasers and detectors in a system, diversity gain can be achieved; an improvement in the reliability of the system can be had. This work focuses on the performance analysis of optical MIMO systems in various weather conditions environments [3].

1.1 Free Space Optical Communication System

Free space optical (FSO) communication is a hopeful solution for high data rate point to point communication system. An outdoor FSO link is essentially based on LOS, thus, its spatial isolation from potential interferers is sufficiently maintained by its narrow beam width profile, but the narrow laser beam width is the pointing and tracking requirements in the event of misalignment. This can be corrected using active tracking [4]. All FSO systems consist from three main stages:

1.2 Optical Source (Transmitter)

Light Emitting Diode (LED) and Laser Diode (LD) are the two basic source option for FSO systems. The choice between LEDs and LDs depends on the application and the configuration, adding to the cost. LED is use for short distance indoor applications that require degree of mobility[5]. Also, LED circuits are simple and LED do not require constancy against temperature changes. On the other hand, LD is often prefer for high speed directed LOS links in outdoor. LD can also use at higher modulation average than LED [6].

1.3 Optical Detector (Receiver)

The main types of a photodetector for FSO are; PIN photodiodes and APD[7]. A PIN photodetector is simple in structure and utilize but it is less sensitive than an APD. The increased power margin presented by APD delivers a system that is more robust to pointing inaccuracy and other losses [8].Hence, it should be noted that increase in the receiver aperture area will also increase the amount of background noise collected by the receiver. Therefore, diversity technique for mitigating the effect of turbulence in the atmosphere can operate on time, frequency and space. In this case, instead of single large aperture, an array of smaller receiver aperture is used so that multiple copies of the signal that are mutually uncorrelated can be transmitted either in time or frequency or space. This will improve the link availability and BER performance of the system. It also limits the need of active tracking due to laser misalignment [9].

1.4 Atmospheric Channel

As we know any communication system need medium to make a communication link and communication link has a direct effect on detector by limiting signal to noise ratio (SNR) and bit error rate (BER). There are two types of optical channel: optical fiber and free space or the atmosphere. The atmosphere is the mixture of gases and different particle of materials formed a multi layers surrounded the earth[10]. This nonhomogeneous fluid make a different types of losses that lead to make a limitation for communication system. A spatial diversity technique which uses multiple transmitter/receiver combination improves the link performance by reducing fading induced by atmospheric turbulence. This further improves the received power at the receiver[11].

II. ATMOSPHERIC CHANNEL MODELING

The refractive index varies randomly through the different turbulent eddies and causes phase and amplitude variations of the wave front. Turbulence can also cause the random drifts of optical beams and can induce beam focusing[12]. To design a high performance optical communication link for the atmospheric FSO channel several Probability Density Functions (PDFs) have been proposed for the intensity variations at receiver of optical system [13]. The fading strength depends on link length, wavelength of optical radiation and refractive index structure parameter c_n^2 of the channel. This model is mathematically tractable and characterized by the Rytov varianceσ_R^2. The turbulence induced fading is termed weak when σ_R^2<1 and this defines the limit of validity of the model [14]:

$$\sigma_R^2 = 1.23\, C_n^2 K^{7/6} \mathrm{L}^{11/6} \qquad (1)$$

Where $k = 2\pi/\lambda$ is the optical wave number, L is propagation distance.

The impact of PSF distortion is more severe on optical imaging systems, where the spatial impulse response determines the image resolution and quality [15]. When misalignment fading occurred, diversity gain is independent on numbers of transmitters and receivers but with atmospheric fading diversity gain is proportional to the numbers of transmitters and receivers. In this paper two main distribution models depended (Log-normal Distribution and Gamm-Gamma Distribution)to explain spatial diversity of the SISO and MIMO systems and diversity gain have been analyzed. Diversity gain is linearly proportional with number of paths from transmitter to receiver [16]. Log-normal distribution has been the most widely used as a statistical model for the random irradiance experienced over atmospheric channels when the strength of turbulence increases Gamm-Gamma Distribution model used because it cover all conditions weather [17].

2.1 Log-normal Distribution Model

The lognormal model assumes the log intensity of the laser light pass the turbulent atmosphere to be distribute normally. Thus the function of probability density of the received irradiance is given by [18]:

$$f(I) = \frac{1}{(2\pi\sigma_R^2)^{\frac{1}{2}} I} \exp\left\{-\frac{\left(In\left(\frac{I}{I_0}\right)+\sigma_R^2/2\right)^2}{2\sigma_R^2}\right\}, I \geq 0 \qquad (2)$$

Where (I) is the irradiance at the receiver and I_o signal irradiance without scintillation. According to this model diversity gain of MIMO FSO channels can be calculated with different scenarios based on the random displacements X' and Y' directions. Therefore, for MIMO channels with log-normal fading and no misalignment the diversity gain is linearly proportional with the number of transmitters and receivers. Furthermore in the presence of misalignment fading the logarithm of the outage probability is linearly proportional to log(SNR), but in the absence of misalignment fading the logarithm of the outage probability is linearly proportional to $\log(SNR)^2$ [19].

2.2 Gamm-Gamma Distribution Model

Gamma-Gamma distribution model of turbulence is based on such modulation process which assumes that the small scale and large scale effects are responsible for the changes occurring in the path of radiated light signal travelling through turbulent atmosphere. This model is a common model and it was supposed in this work [20].There is a statistical model that factorizes the irradiance as product of two independent processing random each of them with a Gamma PDF. The PDF of the intensity fluctuation is given by [14]:

$$f(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta)}{2}-1} K_{(\alpha-\beta)}\left(2\sqrt{\alpha\beta I}\right), I > 0 \qquad (3)$$

Where Γ(.) is the gamma function, $K_{\alpha\text{-}\beta}$ (.) is the modified Bessel function of the second kind and order α-β. α and β: are PDF parameters describing the scintillation experienced by plane waves, and in the case of zero-inner scale are given by equation (4 and 5) [6]:

$$\alpha = 1 \Big/ \exp\left[\frac{0.49\,\sigma_R^2}{\left(1+1.11\,\sigma_R^{\frac{12}{5}}\right)^{\frac{7}{6}}}\right] - 1 \;(4); \qquad \beta = 1 \Big/ \exp\left[\frac{0.51\,\sigma_R^2}{\left(1+0.69\,\sigma_R^{\frac{12}{5}}\right)^{\frac{5}{6}}}\right] - 1 \qquad (5)$$

It was observed for moderate to strong turbulence regime, Gamma-Gamma distribution provides the best fit to irradiance statistics. In case of aperture diameter larger than the coherence length of the atmosphere, the irradiance statistics appear to be log-normal.According to Gamma-Gamma distribution BER performance can be evaluated, the optimum decision metric for OOK is given by [20]:

$$P\left(r|on, I_{mn}\right) \lessgtr_{off}^{on} \mathrm{P}(r|off, I_{mn}) \quad (6)$$

Where r = (r_1, r_2...r_N) is the received signal vector.

The conditional bit error probabilities are given by:

$$P_e\left(off|I_{mn}\right) = P_e\left(on|I_{mn}\right) \qquad (7)$$

$$= Q\left(\frac{1}{MN}\sqrt{\frac{\bar{\gamma}}{2}\sum_{n=1}^{N}\left(\sum_{m=1}^{M} I_{mn}\right)^2}\,\right) \qquad (8)$$

Where N: the number of receiver, M: the number of transmitter. Therefore, average error rate can be expressed as:

$$P_{MIMO} = \int_I f(I) Q\left(\frac{1}{MN}\sqrt{\frac{\bar{\gamma}}{2}\sum_{n=1}^{N}\left(\sum_{m=1}^{M} I_{mn}\right)^2}\,\right) dI \qquad (9)$$

Where $f_I(I)$ is the joint pdf of vector I = (I_{11}, I_{12}. . . I_{MN}). On the other hand, the factor N is used to ensure that sum of the N receive aperture areas is the same as the area of the receive aperture of the SISO link [20].

III. ATMOSPHERIC ATTENUATION CALCULATIONS

In general attenuation is the reduction in the strength of the signal as it propagates through the medium. It is given as the ratio of the power of the transmitted signal to that of the received signal. The attenuation coefficient depends on four individual parameters and in a function of wavelength; these parameters are molecular and aerosol absorption coefficient, and molecular and aerosol scattering coefficients.The empirical formula to calculate attenuation coefficient is given by [2]:

$$\alpha(\lambda) = \frac{3.912}{V}\left(\frac{\lambda}{550}\right)^{-q} \qquad (10)$$

Where V is visibility range, λ is wavelength of the light and q is the size distribution coefficient of scattering related to size distribution of the droplets. For calculating the attenuation Kruse's model, Kim's models must be used for fog condition:

Kruse's Model:

Kruse model is widely used in the calculation to determine FSO equipment link budget. The attenuation coefficient, and Kruse model predict the attenuation for any meteorological conditions. Kruse model of particle size distribution is:

$$q = \begin{cases} 1.3 & \text{if } V > 50 \text{ km} \\ 1.6 & \text{if } 6\text{km} < V < 50 \text{ km} \\ 0.585\, V1/3 & \text{if } V < 6 \text{ km} \end{cases} \qquad (11)$$

Kim's Model:

The evaluation of the parameter q using Kruse model for visibility lower than 6km (0.585V1/3) was not collected in heavy fog. Thus, for visibility, V < 1 km, its significance is in doubt. Therefore, a recent study proposed another expression for the parameter q, which is called Kim model. It gives the particle size distribution q as:

$$q = \begin{cases} 1.6 & \text{If } V > 50 \text{ km} \\ 1.3 & \text{If } 6\text{km} < V < 50 \text{ km} \\ 0.16\, V + 0.34 & \text{If } 1\text{km} < V < 6\text{km} \\ V - 0.5 & \text{If } 0.5\text{km} < V < 1\text{km} \\ 0 & \text{If } V < 0.5\text{km} \end{cases} \qquad (12)$$

For tropical region which no fog attenuation to consider, only haze attenuation to be calculated, Kruse model is good enough since we do not need to consider for V <1 km.

IV. EXPERIMENTAL WORK

4.1 Laboratory Approach of MIMO-FSO Prototype

The aim of this work is study the effect of wavelength and beam divergence for both SISO and MIMO techniques with test their reliability under different weather effects. The lab chamber has been designed to generate and control different atmospheric conditions as smoke, fog and rain which is near as possible to real field atmosphere. This chamber has been set up to be in between transmitter and receiver at distance between 1 to 5 meters. This prototype (like any FSO system) consists from: transmitter, receiver and atmospheric chamber.

The transmitter unit is a LD which is commonly used in real field FSO systems with two wavelengths 650 nm and 850 nm to study the effect of wavelength in this system. One source has been used in SISO, while double sources launched in MIMO system with 5cm distance between them. The receiver unit is mainly composed of photo detector, amplifier, receiver optics and demodulator, in this work we used light power meter from Lambda Scientific company (MODEL: LLM-2) to measure the received power in each set up and each weather condition cases, the active area of this detector is 10mm.Different weather conditions generated in lab chamber like: fog, rain and smoke. This chamber have a dimension of (15 x 20 x35 cm).A fog has been generated by water steam (handmade water vaporizing) system and injected into the chamber, figure (1) shows the setup of the experimental FSO system.

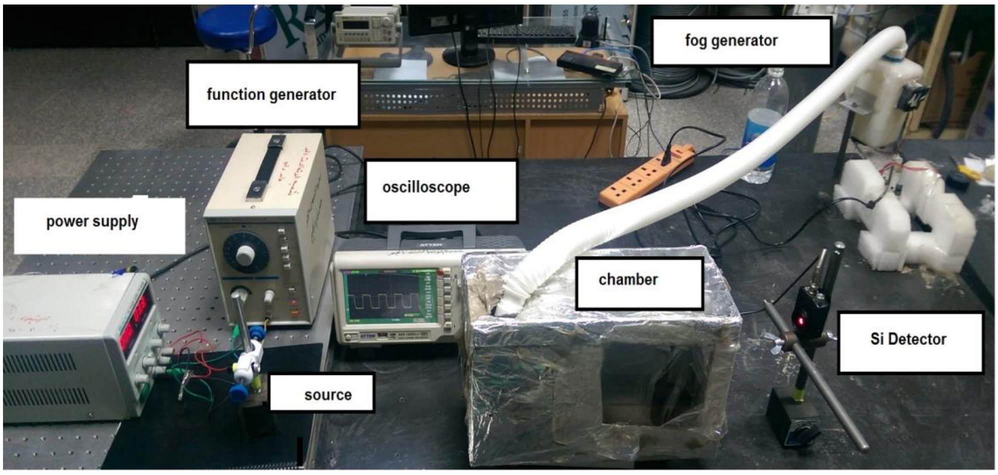

Fig. (1): The Experimental FSO setup

4.2 Real Field MIMO-FSO Prototype

In an earthly FSO, the communication system is typically located in the troposphere. All types of weather phenomena is located in troposphere so its play a very detrimental role for FSO communications in lower visibility range atmospheric conditions mainly due to rain, fog and snow.Flight Transport systems from LIGHT POINT Company (model: FSA 155) have been used, this system is designed according to an optimal design of MIMO-FSO communication system by lunching four semiconductor lasers in transmission unit and four optical detectors in receiver unit.According to the characteristics of FlightStrata, Vertical Cavity Surface Emitting Lasers (VCSEL) is very suitable to use in our MIMO-FSO system, this laser operate in an infrared wavelength 850nm [21].

The atmospheric chamber has been designed to control and simulate individual effects of (fog, smoke and rain) because it's impossible to work in real turbulence and also hard to determine their levels. This chamber is made from Perspex with dimensions (35 x 50 x 75) cm, the fog is generated by fog generator and the smoke by censer and the rain by home shower. Also the detector of this system is Si-APD which is more sensitive due to an internal amplification (avalanche) process.

To establish the FSO-MIMO system requirements the link head ought to connect to router board using optical fiber (optical fiber is used to keep high data rate of optical communication). This router board from MicroTik Company (model: RB2011 UiAs-IN) have been used in this system with CPU 600 MHz, and memory 64 MB. This router is a low cost multi-port device series and it is designed for indoor use, and available in many

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different cases, with a multitude of options. This router board considered as a heart of the system because its control and manage the input and output data between link head and data source [22]. Two data sources have been used in this work: desk top computer and camera (we use a camera to get live scene). Finally, the MIMO-FSO experimental setup is shown in figure (2).

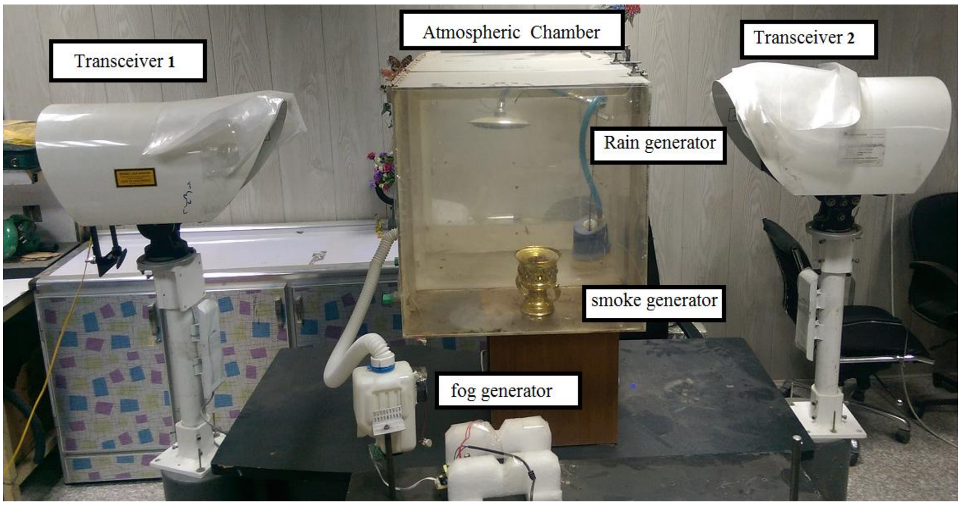

Fig (2): The photographic picture of the experimental setup

V. RESULT AND DISCUSSION

5.1 Results of Laboratory MIMO-FSO Prototype

The visibility have been calculated for each weather conditions by Kim model. Figure (3) shows the plot of total attenuation with visibility for 850nm and 650nm, its show clearly how the attenuation effect on the FSO system and show the priority of 650nm wavelength on 850nm.

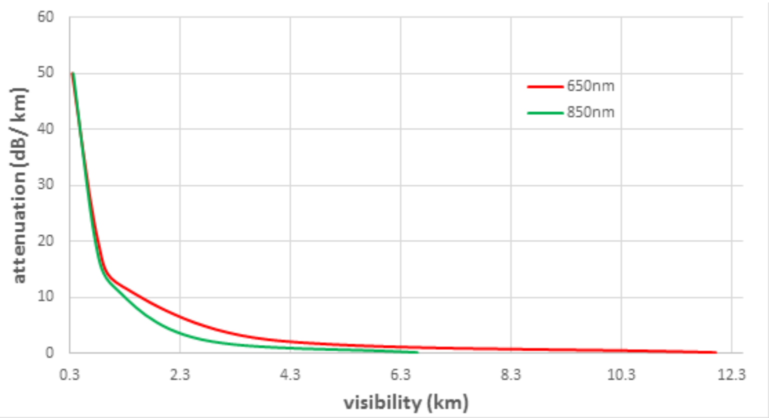

Fig (3): Attenuation verses visibility for two wavelengths

As it is shown above 650nm wavelength is better than 850nm also its easy install and control because it is visible beam so we chose it in this section of work. Also as it mentioned in chapter three, the output power was measured with different attenuation level by applying various weather condition. Then the attenuation was calculated by using Beer-Lambert law, after that theses attenuation values were plotted versus received power at 650nm wavelength for both SISO and MIMO techniques as it clear in figure (4). It is worth mentioning saying

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here, MIMO-FSO systems can significantly reduce the symbol error probability and provide diversity gain over SISO systems, so the MIMO technique is better than SISO technique.

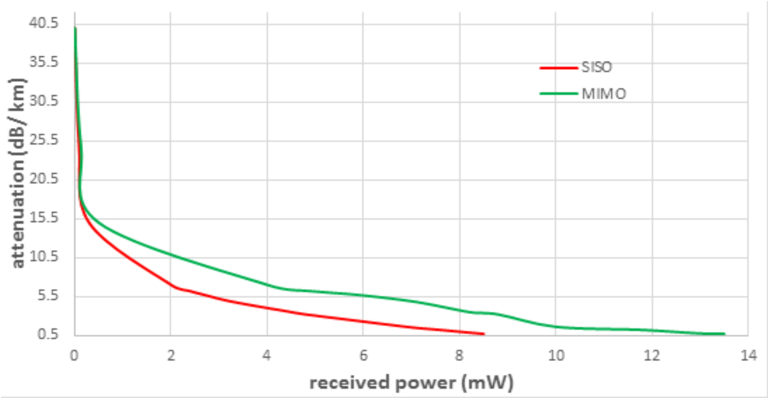

Fig (4): Attenuation verses received power for both SISO and MIMO

5.2 Results of Real Field MIMO-FSO Prototype

In the originally, FlightStrata155 is a MIMO system with four transmitter and four receiver. To study the effect of using SISO technique and MIMO technique from one side and number of transceiver from other side, we have blocked some of them gradually from 1Tx/1Rx, 2Tx/2Rx, 3Tx/3Rx and finally 4Tx/4Rx and observed the effectiveness on the communication link by watching WinBox software window which installed on the desktop computer. Then the same steps have been repeated with smoky and foggy weather conditions, and the attenuation effect has been noted by measuring the data rate and calculated the time which need to send information. It has been observed the increasing in number of transceiver in MIMO technique make a system get better performance but for engineering design and commercial calculation; $4T_X/4R_X$ is the optimal design for MIMO system which is in the ideal range (5Km).

This system have been interfacing with a desktop computer by use a network switch. In clear weather we noted there is no different in data rate when used 1Tx/1Rx, 2Tx/2Rx, 3Tx/3Rx and 4Tx/4Rx, but with smoky and foggy weather case when the number of transceiver is increase the data rate is increase and the time need for sent the file is decrease. Figure (5) and figure (6) shown the shot screen of the software with clear and foggy weather conditions sequentially. And these figures also shown fluctuated of the send and receive signals and their data rate.

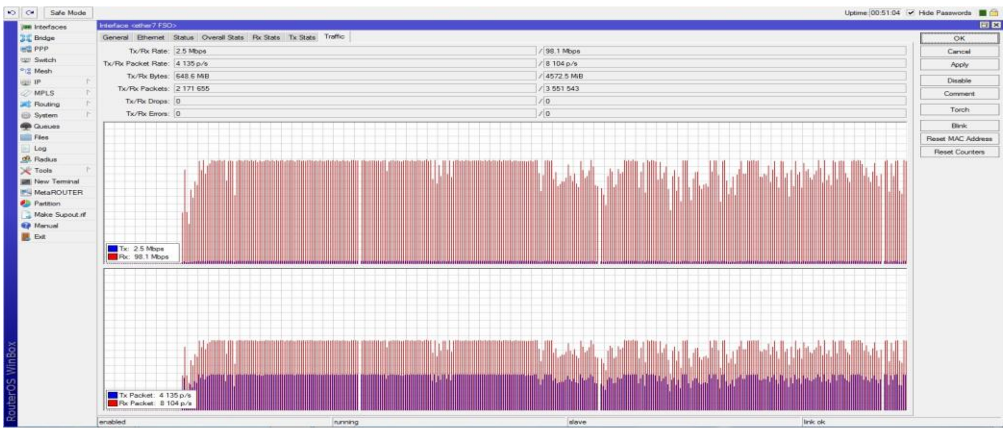

Fig (5): Winbox Program Window for MIMO System in Clear Weather

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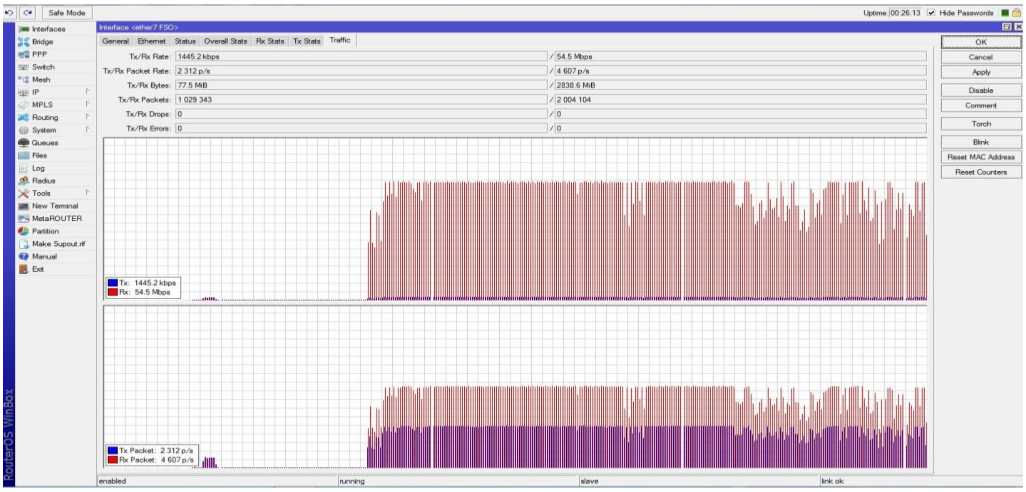

Fig. (6): Winbox Program Window for MIMO System in Foggy Weather

Its noteworthy Flightstrata155 is an industrial system and its for long distance (hundreds of meter) so to use it in laboratory field for short distance special attenuators have been use to compensation the long distance (in FSO communication the long distance mean more attenuation).All the measurement of real field system under variance weather conditions have been collected in table (1). Because we work in laboratory field the different in results between variance conditions weren't large but in real field the difference will be larger and shown clearly, in fact that isn't important point; the important point (which we get it) is the behaviors of the system in SISO and MIMO techniques under different attenuators effect.

Table (1): The Results of Time Duration and Data Rate for Different FSO Cases

Case		Data rate Mbps	Time spend to transfer the file (sec)
Clear weather	1Tx/1Rx	97	597
	2Tx/2Rx	98.2	587
	3Tx/3Rx	98	592
	4Tx/4Rx	98.1	590
Smoky weather	1Tx/1Rx	62.3	920
	2Tx/2Rx	72	795
	3Tx/3Rx	77.5	741
	4Tx/4Rx	80.6	723
Foggy weather	1Tx/1Rx	31	1775
	2Tx/2Rx	42.7	1287
	3Tx/3Rx	48.8	1128
	4Tx/4Rx	54.5	1025

VI. CONCLUSIONS

The main objective to study (MIMO-FSO) technology is to provide an effective wireless communication system. An effective communication system is that can transmit high data rate to a long distance with minimum bit error rate so that better channel capacity can be achieved. The performance evaluation conclusions of optical (MIMO-FSO) system shows:

1. MIMO-FSO system performance over a different atmospheric turbulence condition channel,it has been observed that increasing the system channel capacity was almost1 linearly with the number of transmitting units. Also the effectiveness of multi transmitters and receiver diversity helps in mitigating amplitude1 fading through overcome both amplitude and phase fluctuations. MIMO-FSO systems perform slightly better than an equivalent1 SISO-FSO system in the presence of log-normal amplitude attenuation.
2. For the MIMO-FSO system Analysis of the different atmospheric turbulence condition, it has been observed that when channel state over threshold condition; an improvement in (SNR) is directly proportional to the number of transmitter and receiver units' .The (SNR) and the unconditional (BER) were evaluated numerically for different system parameters. The degradation in system performance due to the channel effectiveness and improvement in receiver sensitivity was determined numerically. Optimum system parameters were determined for a given system BER, and we assume BER 10^{-9}. (MIMO-FSO) systems aresignificantly reducing the (BER), and provide diversity gain over SISO systems for different signal-to-noise ratio (SNR) values, considering amplitude and phase perturbations. By increasing the number of lasers and of receivers is able to achieve better performance from diversity gain.

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