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Performance Evaluation of a WDM/MIMO-Multibeam Free-space Optics for Multigigabit Access Networks in Sudan

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ABSTRACT

Free Space Optics (FSO) is regarded as the next generation high-speed wireless communication technology. The data rate, link distance and reliability of FSO systems are highly affected by a number of atmospheric phenomena such as rain, humidity, temperature and haze. In this paper, the characterization and optimization of terrestrial FSO system in Sudan has been carried out experimentally and theoretically. wavelength division multiplexing (WDM)/ multiple-input and multiple-output (MIMO) multi-beam FSO system having four wavelengths with standard downlink channel spacing of 0.8 nm (100 GHz) is proposed. The results reveal that four-beam MIMO FSO system can operate successfully for a link distance of 5 km with 1 Gb/s for each stream at BER of 10^{-12}.

Key words : FSO, MIMO, Multibeam, WDM.

1. INTRODUCTION

The existing radio frequency (RF) networks are saturated with the huge traffic that generated by the new broadband multimedia services and the increasing number of mobile users. Moreover, the RF spectrum is limited and it needs license to be used. In addition, traditional backhauling methods will run out of bandwidth sooner or later due to the aforementioned traffic demands. Using conventional FSO to solve these problems also has its limitations such as weather conditions and the limited bandwidth per wavelength. In the other hand, multiple-input–multiple-output (MIMO) is an indispensable technique for all the new wireless standards and systems that require high data rate. MIMO system is designed to improve transmission range/reliability and deliver higher data transmission rates than the single-input single-output (SISO) system [1].

Instead of using RF-MIMO signals, optical-MIMO signals can be used for the wireless transmission such as free-space optics (FSO) and infrared (IR) light. Optical wireless communication (OWC) systems rely on optical radiations to transmit information with wavelengths ranging from infrared to ultraviolet [2].

FSO comprises of many advantages. Among these lower cost related with the system, no RF license is required and exploit the enormous potential bandwidth of the OWC [3]. Using MIMO technique in these type of systems has revealed great potential to improve the system performance[4] [5].

An effective indoor optical wireless system is proposed in [5] using space-time block (STB) MIMO coding techniques coherently to provide gigabit level of indoor broadband communication. A straightforward extension of the SISO is proposed to provide 2×2 optical IR MIMO system. It is shown that coherent IR optical systems take advantage of the diversity gain offered by STB MIMO coding techniques.

FSO systems gain the advantages of MIMO technique by the use of multibeam. In the FSO multibeam system, the same signal is sent from different LDs all using the same wavelength or different wavelengths combined together using wavelength division multiplexing (WDM).

WDM is a multiplexing technique in which multiple optical signals are multiplexed on a single medium using different wavelengths. It is a technique to carry more than one optical signal with different wavelengths. Although the FSO system is a well-studied topic, the advent of the WDM technique and the high demand for broadband communications have become a new study in communication area [6]

Sudan lacks the basic fiber to the home (FTTH) infrastructure that found in the first world countries, due to its expensive implementation. In this paper hybrid WDM/MIMO Multibeam Free-space Optics is proposed as a cheap alterative for the traditional expansive FTTH deployment. Hence FSO does not require any changes in the existing infrastructure nor digging in the streets to be deployed. However, FSO is highly affected by the wither conditions which has been study in this research considering the best and the worst case scenarios. The strengths of this technology's inherent are its lack of use of in ground cable (which makes it much quicker and often cheaper to install), the fact that it operates in an unlicensed spectrum (making it easier from a political/ bureaucratic perspective to install), the fact that it can be removed and installed elsewhere (allowing recycling of equipment), and its relatively high bandwidth (up to 1 Gigabyte per second (Gb/s) and beyond.

This work proposes a simulation model of WDM for fiber less optical communication system which encircles propagation study on rain, temperature and haze attenuation effects in regions like Sudan considering four MIMO-Multibeams transmission.

2. LAYOUT OF WDM/MIMO-MULTIBEAM FSO SYSTEM

The block diagram of the proposed WDM/MIMO-Multibeam FSO system is shown in Figure 1. The basic concept and devices that have been used in designing the unidirectional WDM system are as follow (shown in Figure (2)): The transmitter which includes a Pseudo-Random Bit Generator, NRZ Pulse Generator, CW Laser, Mach-Zehnder Modulator; while, APD photo-detector and Low Pass Gaussian Filter at the receiver part. Measurement tools such as Oscilloscope, Optical Time Domain Visualize are used as well. There are four laser diodes (LDs) which produce optical carrier signals at different wavelengths (λ1, λ2, λ3 λ4) with transmitted power of 8 dBm. These downlink wavelengths are selected in 1550 nm band with channel spacing (Δλ) of 0.8 nm. This data is then optically multiplexed using WDM multiplexer into one downlink signal carrying the four wavelengths as shown in Figure 2. The four beams are sent to the FSO channel through transmitter optical lens. After the transmission distance there is another optical lens for reception which feeds the WDM demultiplexer with the received signal. The WDM demultiplexer separates the four wavelengths and sends them to the optical receivers.

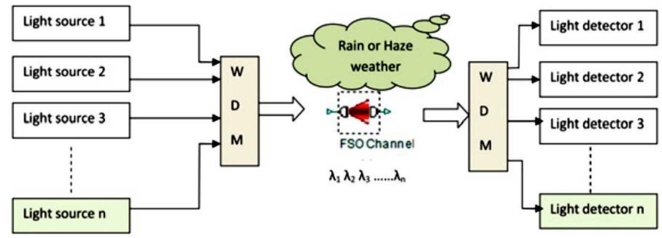

Figure 1: WDM for fiber less optical communication block diagram.

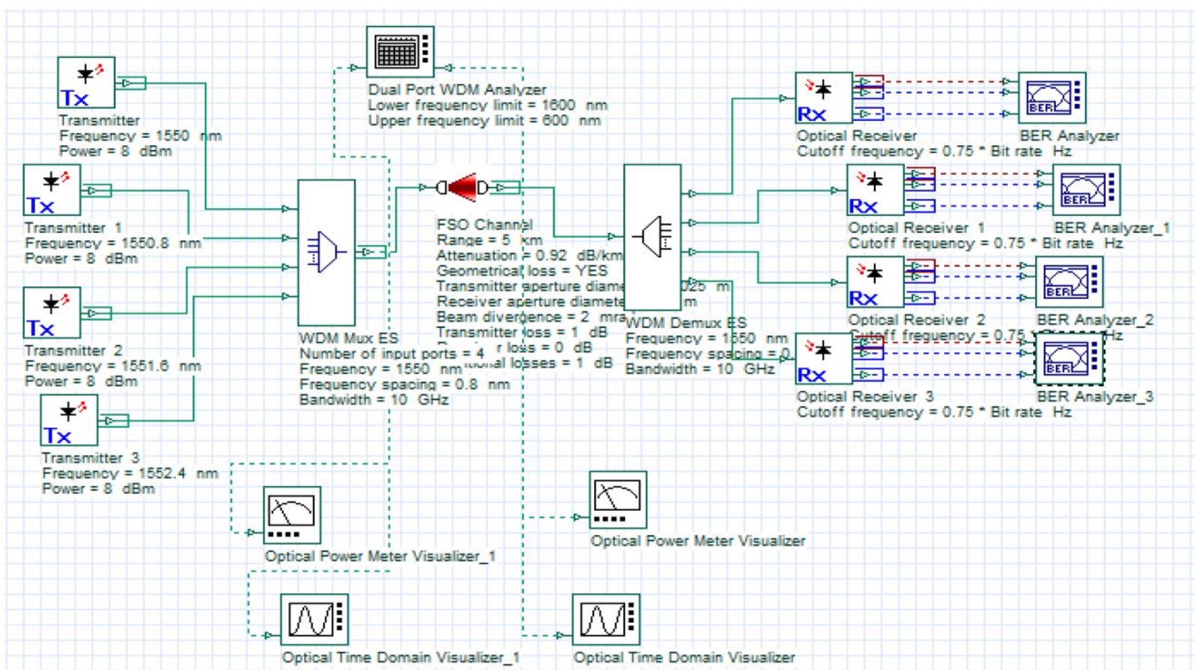

Figure 2: System Simulation Layout in Optisystem Software.

The quality of the received signal greatly depends on the conditions of the free space channel and the WDM system design. The values of the rain attenuation and geometrical loss were evaluated by [7] using expressions (1) and (2), respectively, given as

$$\gamma_{Rain} = k.R^{\alpha} = A_{atmos}, \qquad (1)$$

where

γ_{Rain} —rain attenuation (dB/km)

R—rain intensity (mm/h)

k and α —rain coefficients

k and α depend on the rain characteristics such as the frequency, rain temperature, raindrop size distribution, and polarization. Their values can be obtained from ITU-R P.838-3 [8].

$$A_{geo}(dB) = \frac{P_r}{p_t} = 10\log_{10}[N_{RX}(A_{RX})/\pi(\theta l)^2]\ \text{dB} \qquad (2)$$

where

$$P_r = 4A_{RX}\frac{P_t}{\pi(\theta l)^2}$$

P_r —received power

N_{RX}—number of receivers used

θ —beam divergence (mrad)

l —link distance (km)

These values are used to calculate the atmospheric attenuation for a period of the year. The geometric loss is calculated on the basis of specifications for FSO system. Furthermore, the values of atmospheric and geometric attenuation are used to simulate the performance of the system for link range of 5 km. The typical parameters used in the simulation of the proposed system are shown in Table 1.

The rain rate in mm/hr is an essential parameter for evaluating atmospheric attenuation in link margin equation for FSO, which is taken from trusted source shown below in Table 2 for Khartoum the capital city of Sudan [9]. Real time rain intensities and corresponding rain attenuation on the FSO link were measured concurrently for a period of one year. From the data collected, and values concerning power law for evaluation rain attenuation were estimated as 5.36 dBm and 0.92 dBm respectively using optimized calculation [8].

Table 1: Typical parameters used in the simulation of the proposed system

Parameter	Value	Unit
Link distance	5	km
Transmitted power (best case - worst case)	8 - 30	dBm
FSO MIMO-Multibeam system	4-beam	---
The first WDM Operating wavelength	1550	nm
Channel spacing $\Delta\lambda$	0.4, 0.8 & 1.6	nm
Multiplexer	WDM	----
Atmospheric loss (heavy rain fall - Normal rain fall)	5.36 - 0.92	dB/km
Data rate/wavelength	1	Gb/s
Bandwidth for each channel	10	GHz
Avalanche photo diode (APD) gain	3	---
APD dark current	10	nA
Receiver sensitivity (SR) @ 10^{-12} BER	-45	dBm
System loss (Insertion & other losses)	8	dB
Beam divergence θ	2	mrad

3. Results and Analysis

The WDM has many different channels spacing which specifies with filtering manufacturing, wavelengths, inter-symbol interference, cost, and proportional to the power received. The effect of channel spacing $\Delta\lambda$ on the performance of the proposed WDM/MIMO-Multibeam FSO network is shown in Figure 3. The proposed network is analyzed under different channel spacing $\Delta\lambda$ = 1.6, 0.8, and 0.4 nm. The channel spacing $\Delta\lambda$ of 1.6 has the best performace since the four wavelengths are widly separated and there is no any interfrace caused by the adjacent wavelengths. However, the communication of the three channel spacing values operates successfully with acceptable BER. Threre is a penalty of 1 dB when using the lowest spacing of 0.4 nm compared with the spacing of 1.6 nm.

The BER versus optical received power at the WDM/MIMO-Multibeam FSO system for the four wavelengths (λ1, λ2, λ3, λ4) is analyzed, as shown in Figure 4, which also shows power receiver sensitivity difference of the receivers for different wavelengths at a BER of 10^{-12} it is clearly a small value, which is roughly less than 1 dB. Where Figure 5 shows the eye diagram at the end-user receiver with acceptable eye opening to detect the received power signal at the receiver.

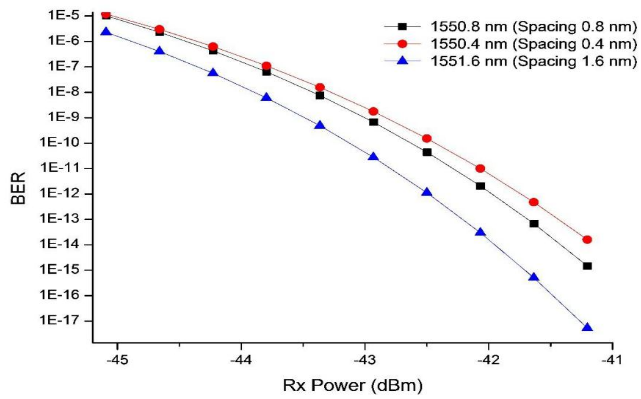

Figure 3: The received power for WDM with different channel spacing.

These values were used for calculating the atmospheric losses, and to simulate the WDM for fiber less optical communication system performance using OptiSystem software. OptiSystem is an advanced type of software tools which is used to design optical system and plan from component to system level, and visually presents analysis and states.

Table 2: Weather during the year in Khartoum

	Precipitation	Humidity	Dew point	Visibility
Jan	0.0	26%	2	14 km
Feb	2.8	19%	0	13 km
Mar	0.0	14%	-2	13 km
April	2.7	13%	0	13 km
May	3.2	17%	5	13 km
June	6.0	24%	10	12 km
July	7.7	41%	17	13 km
Aug	5.0	52%	20	14 km
Sep	5.7	43%	17	14 km
Oct	3.0	29%	12	14 km
Nov	0.0	25%	6	15 km
Dec	5.7	29%	5	15 km

Figure 6 demonstrates the relationship between BER and link distance, it shows that at BER 10^{-12} required by ITU-R, can be successfully achieved at a distance of 5 km, beyond this distance the system will not achieve the target BER.

Whereas Figure 7 shows the optimum optical received power R_x for when the attenuation increases. It is clear that with higher attenuation conditions we need a higher transmission power or a better receiver sensitivity in order to compensate for the power loss.

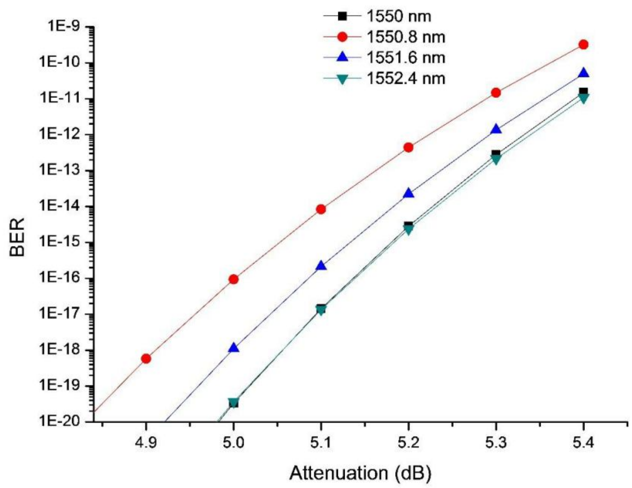

Figure 4: Variation of attenuation with BER for the four wavelengths.

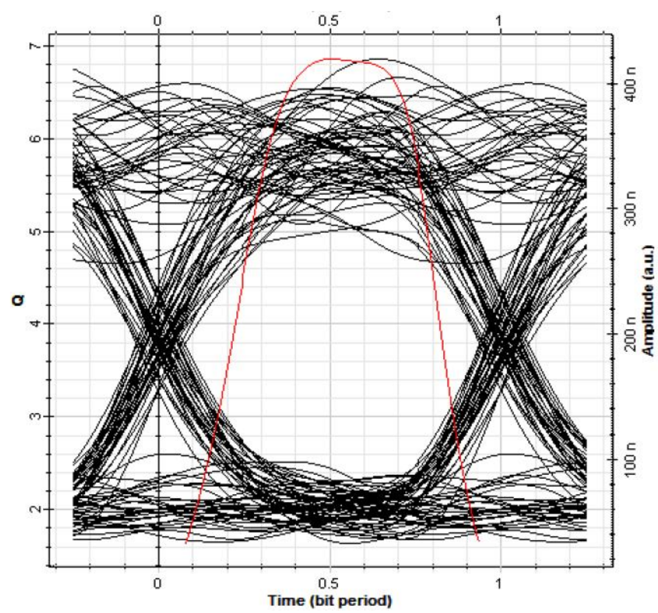

Figure 5: Eye diagram for the received signal.

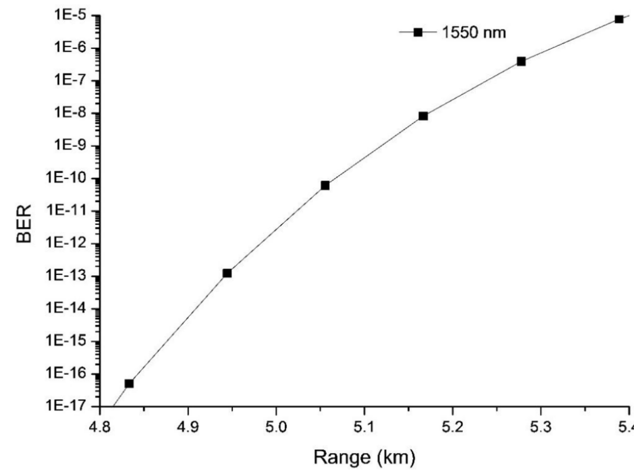

Figure 6: Variation of BER with link distance.

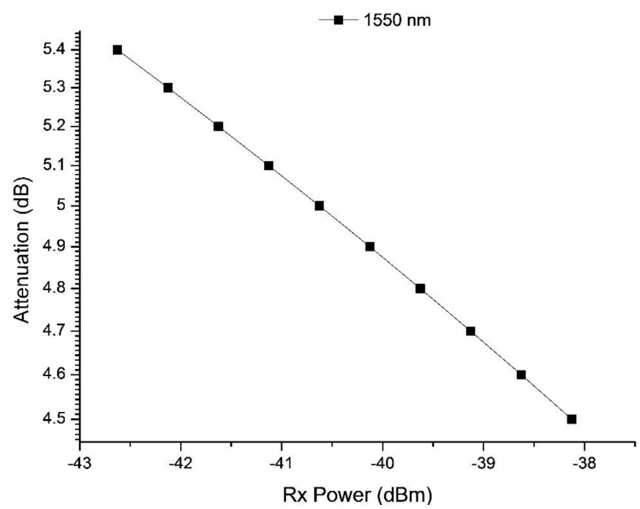

Figure 7: Optimum optical received power with the variation of attenuation.

4. CONCLUSION

The system is designed and analyzed to produce the best system capable of tackling the effects of weather. The performance evaluation and applicability of the system, is explored and investigated using WDM multiplexing. The study is carried out based on simulation and verified using on site attenuation and rain intensity measurements. It has considered the received power, geometrical losses and atmospheric losses due to rain. In Sudan, the main limiting factors for wireless optical communication link design are humidity, rain and haze. However, as long as there is a clear line of sight between the source and the destination and enough power received, FSO communication is possible. The performance of the system has been analyzed in this work for worst & best cases of attenuation of the weather, and the study concludes that after performing the most acceptable results were given by the FSO channel used in the system. It was realized that FSO channel can operate successfully for a link distance of 5 km at BER of 10^{-12} with the WDM four beam MIMO configuration. While considering the scalability, four users will access data at data rate of 1 Gbit/s which is considered sufficient as compared to one end user using single-beam technique. In the future, the number of MIMO-Multibeams can be increased to 16 beams to increase the data rate as well as studying the system for bidirectional transmission.

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