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Optimization of WDM-FSO link using Multiple Beams under different rain conditions

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***Abstract*– Free Space Optics (FSO) has received much attention in recent years as a cost – effective, licence free and wide-bandwidth access technique for high data rates applications. Single beam FSO and multiple beam FSO system is designed and analyzed to produce the best system capable of tackling the effect of atmospheric weather conditions. Hybrid wavelength division multiplexing (WDM)/multi-beam free-space optics (FSO) is a promising technique to overcome atmospheric attenuation due to medium and heavy rain in tropical regions, that provide a significant improvement in the link distance, received optical power, and Q-factor.**

This paper describe design and simulation of hybrid Wavelength Division Multiplexing (WDM) based multi beam Free Space Optical (FSO) link for different rain conditions and analyses the performance of the system by using parametric optimization. In this paper, a hybrid sixteen channel 2.5 Gb/s WDM multi-beam FSO network having sixteen wavelengths with standard channel spacing of 100 GHz (0.8 nm) is proposed. Comparing the results with WDM FSO system with WDM multi-beam FSO system, there is a major improvement in the received optical power, and Q-factor, under different rain conditions. It was realized that four-beam FSO system can operate successfully for a link distance of 2540 m at BER of 10^{-9} with a received optical power of -30.022dBm for heavy rain and link distance of 3030 m at BER of 10^{-9} with a received optical power of -29.806dBm for medium rain, providing the fact that multi beam FSO is sensitive even to very low optical power.

Index Terms— atmospheric attenuation, BER, FSO, optical networks, Q-factor WDM/multi-beam FSO.

I-INTRODUCTION

Free space optics (FSO) is a promising communication technology for various types of services in all-optical access network. Free space optical communications is a technique by which one transmits a modulated beam of visible or infrared light through the atmosphere and it is a direct line-of-sight communication system, thus, no laying of fiber optic cables are needed, no expensive rooftop installations are required, and further no security upgrades are required. The development of FSO system is feasible at 1550 nm wavelength because of low attenuation window and availability of component with high speed semiconductor laser technology [4].

The concept of the multi-beam FSO system is the replacement of the single-beam by multiple lasers beam. WDM (Wavelength Division Multiplexing) is a multiplexing technique in which the multiple optical signals are multiplexed on a single medium using different wavelengths On the other hand, Hybrid WDM/multi-beam FSO is a promising technique to overcome atmospheric attenuation due to different rain conditions and to fulfil the growing demand for increased communication bandwidth [2]. In this paper, OptiSystem7.0 is used as simulation tool to simulate the link for the data-rate of 2.5 Gb/s with input power 7.7 dBm.

This paper is organized as follow: Section II describes atmospheric effect on FSO System. Section III describes system design and analysis. Section IV describes simulation results followed by conclusion.

II- ATMOSPHERIC EFFECT ON FSO SYSTEM

In tropical country, rain dominates the total attenuation coefficient. The attenuation due to rainfall is also called as non-selective scattering. System performance can degrade due to the atmospheric conditions such as rain, dust, snow, fog/smog. Geometric losses and atmospheric attenuation are the main causes of degradation but there are other factors also like scintillation, turbulence and multipath fading [3]. Fog and heavy snow are the weather condition of temperate regions and heavy rain is of tropical region. Rain is the major attenuation factor in environment for light ray that’s why FSO link is very much affected. Large drops of rain scattered the optical beam and effect is known as scattering. There are

factors that affect the link performance and results in degradation of received power and Q-factor.
The received power is

$$P_{Received} = P_{transmitted} \frac{d_r^{\,2}}{(d_T+\theta R)^2} 10^{-\alpha\frac{R}{10}} \quad \text{--- (1)}$$

Where,
d_r –receiver aperture diameter in cm
d_T- transmeter aperture diameter in cm
θ_R- beam divergence angle in mrad
R- link range
α- atmospheric attemuation coefficient

III. SYSTEM DESIGN AND ANALYSIS

A. FSO system

The block diagram simple FSO system is shown below in Figure 1.The FSO transmitter consist of PRBS (Pseudo Random Bit Sequence) Generator which generates random binary sequence for the system to transmit. Then NRZ pulse generator is used to convert the binary sequence to the electrical signal. The CW(Continuous Wave) laser is used to transmit the input signal with wavelength 850nm or 1550nm.Then,Mach-Zehnder Modulator does intensity modulation of laser output, which is optical signal for given power, according to the NRZ pulse generator output.In the receiver part, to detect the optical signal we use APD photodiode, which generates electrical signal according to incident optical beam. Then low pass Bessel Filter is used to filter the noise from signal, followed by 3 R regenerator to Retiming, Reshaping and Regenerating the original signal.BER Analyser is used to measure the Q-factor and minimum BER, etc.

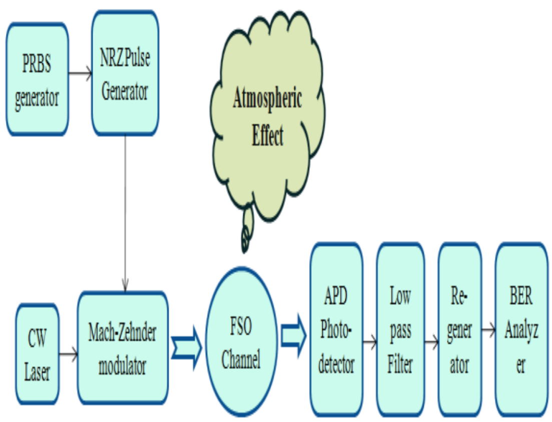


Fig. 1: Block diagram of simple FSO system.

The performance of the link can be severely affected by atmospheric effect like heavy rain or snow. These factors produce intensity variations, at the receiver side of the communication link, which translates into a lower channel capacity and higher BER.

B. WDM-FSO System

WDM is a multiplexing technique, which carry more than one optical signal on a single medium. However the FSO system is a well-studied topic, the appearance of WDM technique has become a new study in communication area. A WDM system is designed to overcome the challenge of FSO signal degradation due to atmospheric attenuation which is shown in Figure 2. WDM has higher capacity so high data rate with longer link distance is also possible. Several single beams FSO WDM transmission system has been successfully demonstrated, even though more than one wavelength is used to increase the data rate.

Implementing Hybrid WDM multi-beam FSO system could result in an increase in the number of end users (EUs) which is capable of accessing high data rate at low price. In this paper, 16 channels WDM-FSO is implemented.

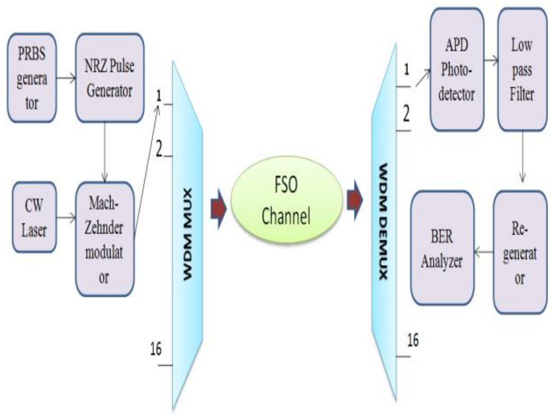


Fig. 2: Block diagram of WDM-FSO system

C. Hybrid WDM/multi-beam FSO system

The hybrid WDM-multi-beam FSO network is proposed to provide a significant improvement in the link distance, received power and BER. Here, the performance evaluation and applicability of four beam FSO system, in medium and heavy rainy condition is further explored and investigated using WDM multiplexing.

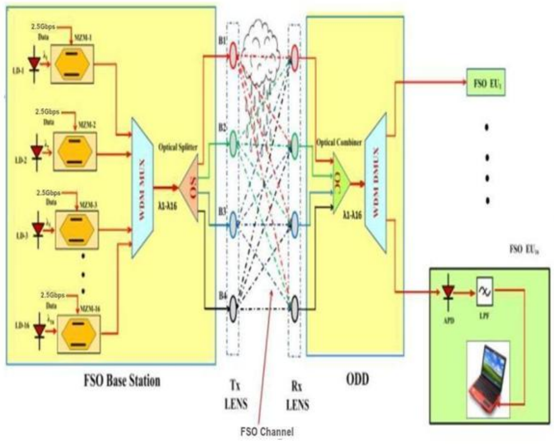


Fig. 3: Block diagram of Hybrid WDM/multi-beam FSO system.

here,
LD: Laser Diode
MZM: Mach-Zehnder Modulator
WDM: Wave Length Division Multiplexer
APD: Avalanche Photo Detector
FSO: Free Space OpticsEU: End User
OS: Optical Splitter
OC: Optical combiner
LPF: Low Pass Filter

The Hybrid WDM/multi-beam FSO system is designed for 16 channels with one optical splitter and one optical combiner. And base station (BS) consists of 16 transmitters which produce optical carrier signals at different wavelengths ranges from 1538nm to 1550nm with channel spacing of 100GHz (0.8nm) following the ITU-T G standard.

D. Design Parameters

For link optimization of hybrid WDM multi-beam FSO system, there are 16 subsystems. Each subsystem consists of PRBS generator, followed by NRZ pulse generator. A CW laser is used with input power 7.7 dBm. The output of NRZ pulse generator and CW laser is followed by Mach Zehnder Modulator. After that, an optical amplifier is used to enhance the signal strength.

These signals are then optically multiplexed using WDM MUX into one downlink signal carrying 16 wavelengths (1550, 1549.2, 1548.4 ....1539.6, 1538.8, and 1538) nm. The multiplexed signal is spitted into four beams (B1, B2, B3 and B4) using an Optical Splitter (OS). The four beams are sent through FSO Channel having some attenuation and geometrical losses. The large value of receiver aperture is taken in the simulation due to higher attenuation. For heavy rain, attenuation is 19.2 dB/km and for medium rain, it is taken as 15.5 dB/km. And these spitted signals are then combined through Optical Combiner. Then a WDM DEMUX having same specifications of WDM MUX is used to demultiplex all the signals. These signals are then sending to respective EUs. EU is provided by an APD photo detector with a gain of 3 and sensitivity of 1A/W, followed by a low pass Gaussian Filter. And 3R regeneration is used to reshaping, retiming and regenerating the signals.BER analyzer and optical power meter is used to measure all the parameters for optimizing the link.

TABLE 1: SYSTEM SPECIFICATION

PARAMETER	VALUE
Data Rate	2.5Gb/s
Wavelength	1550nm
Power	7.7 dBm
Gain	35dB
Number of input ports	16
Bandwidth	10GHz
Channel Spacing	0.8 nm
Range	1000 to 3500 m
Transmitter Aperture diameter	10cm
Receiver Aperture diameter	30cm
Gain	3
Responsitivity	1 A/W
Dark current	10 nA

There are two system designed in this paper: System I consist of 16 channels WDM-FSO without multi-beam and System II consist of 16 channels Hybrid WDM –FSO with multi-beam.

Comparison is done between these system using parameters: received optical power (dBm) and Q-factor. Also, a comparison is shown for medium rain and heavy rain. Using this, maximum achievable link range is determined for light rain and medium rain condition. Here, the link range is optimized till the targeted value of minimum BER is achieved as 10^{-9}.

Figure 4 shows the layout of 16 channels WDM-FSO system without multi-beam. Figure 5 shows the layout of 16 channel hybrid WDM/multi-beam FSO system.

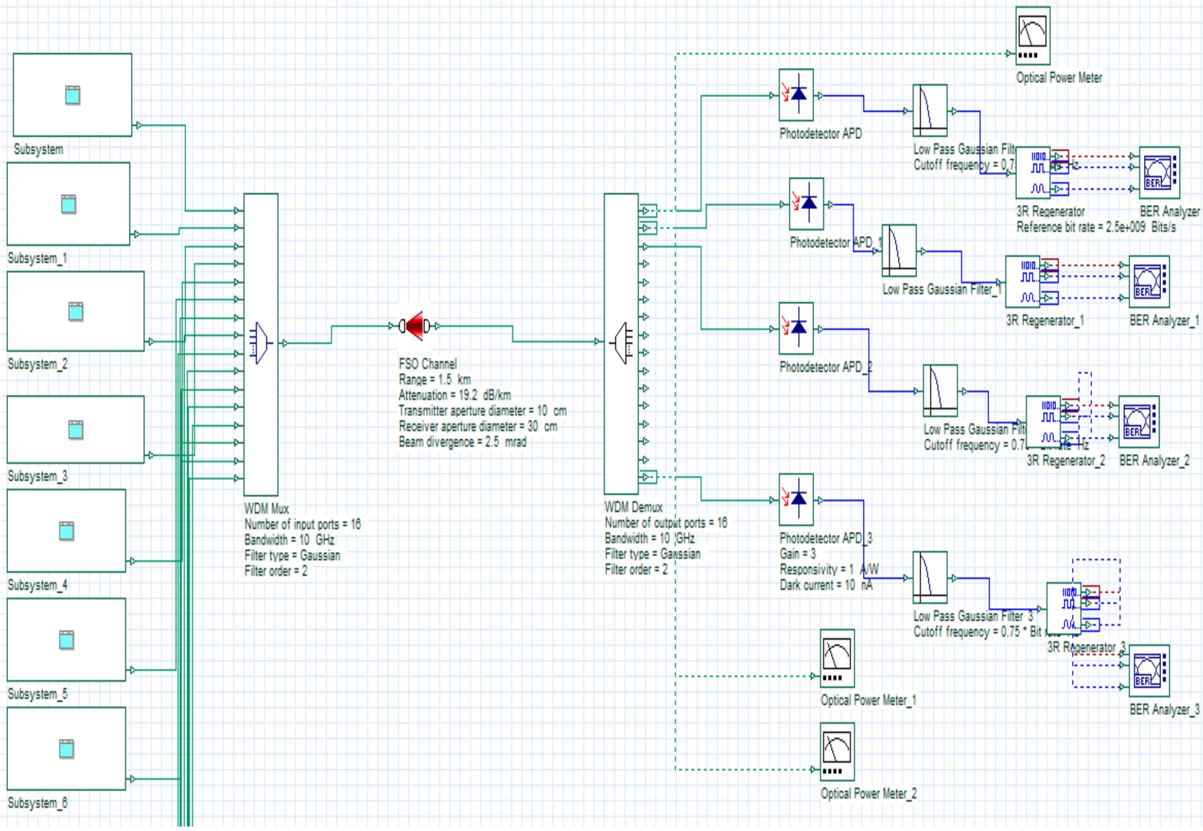


Fig. 4 Layout of System-I (16 channels WDM-FSO system without multi-beam)

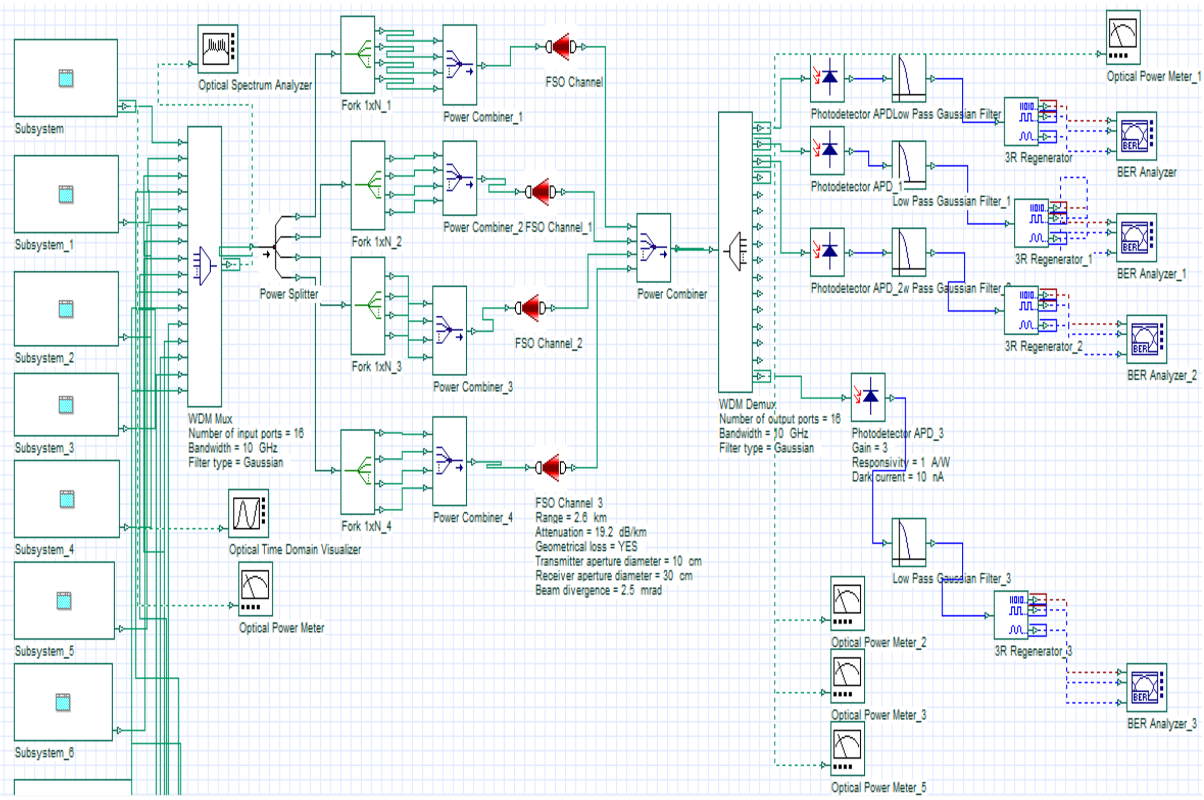


Fig. 5 Layout of System-II (16 channels WDM-FSO system with multi-beam)

IV. RESULT AND DISCUSSION

While analyzing the performance of both the system at heavy rain condition, it is observed that Q-factor of System II is much better than System I as shown in Figure 6.

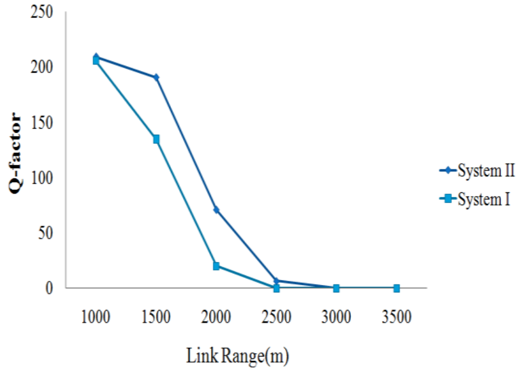


Fig. 6 Max Q-factor Vs Link Range

Also the received optical power in system II is more than that of System I as shown in Figure 7.

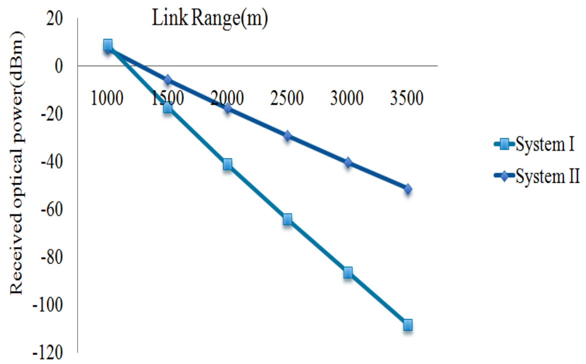


Fig.7 Received optical power Vs Link range

Figure 8 shows BER versus received optical power, in which power received sensitivity difference of the receivers at different FSO EUs for different wavelengths. It is clearly observed that Receiver-3 gives the best performance among all the receivers.

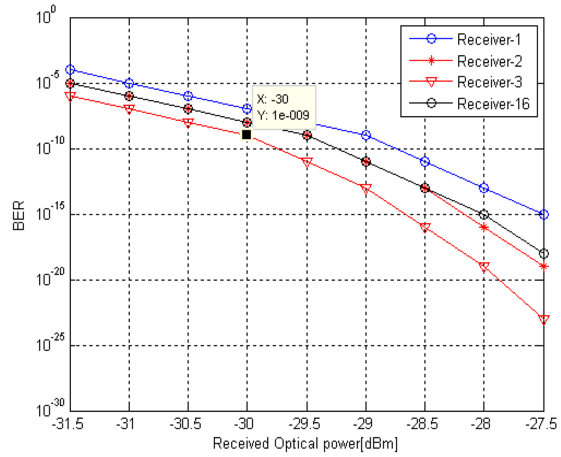


Fig. 8 BER Vs received optical power at FSO EUs

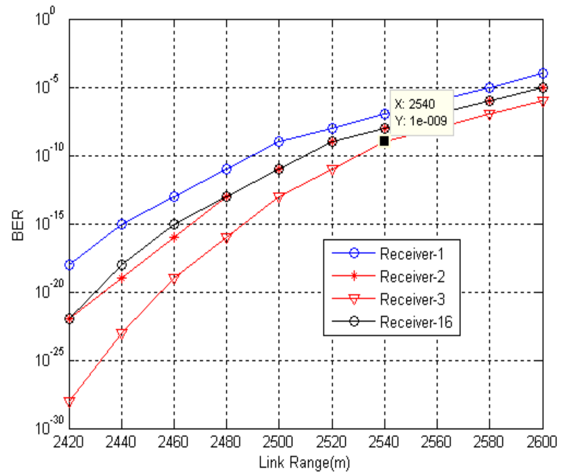
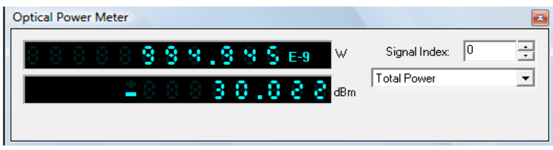


Fig.9 BER Vs Link Range at FSO EUs.

It is observed that for proposed system maximum distance achieved is 2540 m for heavy rain at minimum BER of 10^{-9}. Also repeat the whole process for medium rain,then the maximum distance achieved is 3030m. Here, received optical power for heavy and medium rain is shown in Figure 10.



a)heavy rain

b)medium rain

Fig. 10 Received power at optimized link range for a) heavy rain and b) medium rain

For medium rain, optimized link range is 3030 m and for heavy rain it is 2540 m at minimum acceptable BER of 10^{-9}.

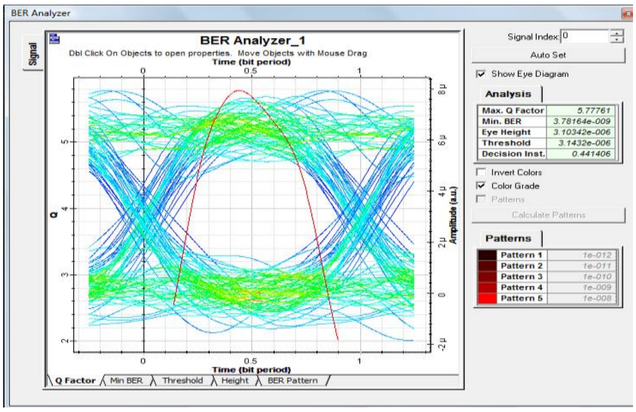


Fig. 11 BER Analyzer for heavy rain

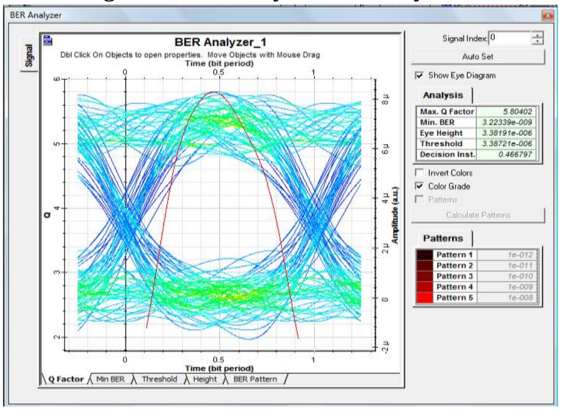


Fig. 12 BER Analyzer for medium rain

Figure 11 shows the BER analyzer for heavy rain at a optimized link range of 2540 m with Q-factor of 5.777 and minimum 3.78e-009. Figure 12 shows the BER Analyzer for medium rain at a optimized link range of 3030m with Q-factor of 5.80 and minimum BER of 3.22e-009.

V. CONCLUSION

In this paper, study of single and multi-beam WDM-FSO system is analyzed. The Hybrid WDM/multi-beam FSO system has provided a major improvement in received power, link range and quality factor.It concludes that for heavy rain maximum link distance of 2540 m and 3030 m for medium rain conditions with minimu acceptable BER of 10^{-9} with high data rate of 2.5Gb/s and an input power of 7.7 dBm. In future, increasing the capacity of the hybrid WDM/multi-beam FSO system can be studied and implemented to reach up to 32 channels WDM.

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