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Design and Analysis of Free Space Terrestrial Optical Network Using SAC-OCDMA and BPSK Modulation

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***Abstract*- This manuscript elaborates performance of terrestrial free space optical network with Spectral Amplitude Coding (SAC) Optical Code Division Multiple Access (OCDMA) technique. An orthogonal code named as Modified Random Diagonal (MRD) code is assigned to each of the users to minimizes the effect of Multiple Access Interference (MAI) with increased users. This work implements the direct detection technique with Binary Phase Shift Keying (BPSK) modulation. Erbium Doped Fiber amplifier (EDFA) has played the vital role in boosting of the optical signal directly in the optical domain so as to serve huge users with longer link length. The analysis is carried out using OptiSystem 16.0 simulator where the effect of no of users, data rate, transmission distance, weather condition, beam divergence, transmitter and receiver aperture on the Bit Error Rate (BER), Quality factor (Q factor), Received power are carefully observed using BER analyser and Eye Diagram analyser. The optical signal undergoes high attenuation during rainy conditions which can be avoided by decreasing the beam divergence. The role of transmitter and receiver aperture on received power are also clearly presented with the aid of eye diagrams. The reported work though implements 8 users in the system model, yet shows the simulation results for maximum 5 users. The maximum number of users to be supported for various data rates under different propagation conditions are yet to be reported. Thus, we have designed the MRD code for 25 users and used this new code to investigate the maximum number of simultaneous users that can be supported for an acceptable BER at a given link length and for a given data rate. Our EDFA gain is also low which is desirable. Since high gain requires high pump power and more active length in semiconductor PUMP laser.**

***Index Terms*- BPSK, FSO, MRD Code, OCDMA, SAC, NRZ.**

I. INTRODUCTION

Over the last two decades, wireless communication has achieved huge popularity for many personal and organisations by fulfilling their needs in an attractive way because of its novel characteristics such as flexibility, mobility, easy installation and cost effectiveness [1]. But the present days increasing demand for high capacity can be fulfilled by integrating optics, offering massive bandwidth, with wireless communication that results optical wireless communication. Optical wireless communication along with Code Division Multiple Access (CDMA) provides huge services with extremely enhanced security. In contrast to traditional microwave, Optical CDMA system based on optical fiber or free space optics could allow large transmission capacity, enhanced security with high data rate [2-3]. The OCDMA system can be classified into temporal or spectral according to the way optical signal is encoded [4]. The temporal OCDMA performs encoding in time domain. The spectral encoding can be achieved by varying either the amplitude or phase or polarization of spectral components of broad band optical source in frequency domain in accordance with the signature code. This results Spectral Amplitude Coding (SAC), Spectral Phase Coding (SPC), and Spectral Polarization Coding respectively [5]. Further, the OCDMA can be of One dimensional (1D), Two dimensional (2D) or Three dimensional (3D). In 1D, either time or frequency of broad band source is varied in accordance with signature code. While in 2D, both time and frequency are varied. Similarly, in 3D, more no of optical fibers are implemented to transmit 2D signal [6]. The short code length limits the flexibility in addressing of the codes, while long code lengths are considered

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disadvantageous in implementation. This is because either very wide bandwidth optical source or very narrow bandwidth filters are required [7].The Phase Induced Intensity Noise (PIIN) are mixed and incident upon a photodiode. They are originated from the intensity noise caused by the phase noise of the incoherent light fields due to spontaneous emission [7]. Similarly, leakage signals like residual reflections inherent within optical fiber components (e.g. circulator) can develop phase induced intensity noise (PIIN). They may be a few orders of magnitude more than the shot-noise [8]. The Multiwavelength OCDMA systems suffer severely from beat noise which is produced from the beating of pulses of the same wavelength in square-law detection [9]. The error probability of optical CDMA depends upon the signal to noise ratio which in turn function of code length, code weight and properties of transmission medium [10]. The dominant degrading factor i.e. Multiple Access Interference (MAI) along with Optical Beating Interference (OBI) limit the number of users whereas GVD limits the system's transmission length. Different types of codes have been proposed for SAC-OCDMA are Prime Code, Modified Double Weight (MDW) code, Modified Frequency Hopping (MFH) code, Walsh code and Random Diagonal (RD) code etc. [11]. In general, there are two basic detection techniques: namely, coherent and incoherent [12]. While coherent detection refers to the detection of signals with knowledge of the phase information of the carriers, incoherent detection refers to the case without such knowledge [12]. The incoherent and coherent systems respectively consist of unipolar and bipolar sequences in the signature code. The hardware complexity of incoherent system is reduced since it does not need phase synchronization. The detection can be of direct detection or differential detection which further may be either AND subtraction or complementary subtraction type. The direct detection scheme whereby only one pair of decoder and detector is required, the differential detection technique requires two pairs of decoder and detector. The complementary differential detection where the individual received signal is divided further into two branches at the receiver can effectively reduce MAI [13]. As opposed to complementary subtraction technique, the direct detection technique, can effectively reduce MAI with RD and MRD code. This is because the information is adequately recoverable from any of the clean chips (bit one) that do not overlap with any other clean chips from other code sequences [14]. The Modified Random Diagonal (MRD) code with direct detection can support huge users with least cross correlation [15]. The high cost of reconfiguring and maintaining in wired networks makes wireless an economical and flexible [16]. For high speed data transmission in open space between different satellites, Inter-satellite Optical wireless communication (IsOWC) is widely used [17]. The necessity of Line of sight (LOS), attenuation and dispersion due to scattering are major factors that could affect an FSO system [18]. The wireless optical systems are power limited due to the limitation on power consumption and eye-safety requirements [19]. Various Optical amplifiers required to boost optical signal strength are of three categories: Power amplifiers, Inline amplifiers and Preamplifiers [20]. The multiwavelength pulse position modulation (MWPPM) based OCDMA over FSO can mitigate intensity fluctuation and pulse broadening that improves system probability error [21]. The Space Division Multiplexing is another type of technique that allows multiple modes to propagate and provides higher capacity and a wide coverage area to facilitate a more number of users [22]. The OCDMA over FSO is studied using Khazani–Syed (KS) code with spectral direct decoding (SDD) technique and compared with the FSO system employing intensity modulation/direct detection (IM/DD) technique [23].

The reported work [1-2] implements 8 users in the system model, yet simulation results are reported for maximum 5 users. The maximum number of users to be supported for various data rates under different propagation conditions remains to be

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investigated. Thus, we have designed the MRD code for 25 users and used this new code to investigate the maximum number of simultaneous users those can be supported for an acceptable BER at a given link length and for a given data rate. Our EDFA gain is also low which is desirable. Since high gain requires high pump power and more active length in semiconductor PUMP laser. The proposed system is also investigated to exhibit quite improved BER with large beam divergence of 2 mrad in comparison to systems reported in literature [1-3,21-23]. Since obtaining highly focused beam is also a matter of challenge. The performances of the proposed system have been compared with 6 reported works and improvements in terms of a number of performance metrics like BER and Q factor etc. are observed.

The organization of this manuscript is as follows. Section II describes design of MRD code. Section III presents description on proposed system. Section IV describes simulation results and Section V concludes the proposed work.

II. DESIGN OF MODIFIED RANDOM DIAGONAL CODE (MRD CODE)

The MRD code belongs to Zero Cross Correlation Code (ZCC) [15]. An MRD code is denoted as (N, W, λc). Here, N is the code length, W is the code weight and λc is in-phase cross correlation. The no of user, K, is same as the no of rows. The in-phase cross correlation of the code is defined as [15]:

$$\lambda_c = \sum_{i=1}^{N} X_i Y_i \tag{1}$$

Where, X and Y are two code sequences.
The code used in [15] is modified to serve 25 users in our case as per the following:
For k=5, the MRD code

$$Z = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 \end{bmatrix} \tag{2}$$

Similarly, for k=8, the MRD code

$$Z = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{bmatrix} \tag{3}$$

The signal to noise ratio (SNR) is specific to a given code and medium dependant. For MRD code, it can be defined as [15]:

$$\mathrm{SNR} = \frac{R^2 P^2 \frac{W^2}{N^2}}{\frac{4KTB}{R_L} + 2P\,WEB\frac{R}{N}} \tag{4}$$

where, R = Responsivity of photo diode, P = Effective power of broad band optical source at receiver, W = Code weight, N = Code length, R_L= Load resistor, E = Electronic charge, B = Electrical bandwidth of receiver.

The bit error rate (BER) of Optical CDMA using a Gaussian approximation can be defined as [1,12]:

$$p_e = \mathrm{BER} = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{\mathrm{SNR}}{8}}\right) \tag{5}$$

where SNR is signal to noise ratio. It is code, medium as well as receiver design dependent.

III. PROPOSED SYSTEM DESCRIPTION

The proposed system models an optical terrestrial network over free space using SAC-OCDMA principle. Fig. 1 describes the block representation of SAC-OCDMA transmitter and receiver over free space.

It is implemented and simulated using Opti System 16.0 simulator. At first random binary data sequence is converted into Phase Shift Keying (PSK) form. This signal modulates the optical carrier intensity, coming from Continuous

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Wave (CW) laser. The power combiner then combines all of the modulated signals and an optical signal boosting unit called Erbium Doped Fiber Amplifier (EDFA) deployed to rise optical signal directly in optical domine before feeding the signal to the FSO channel.

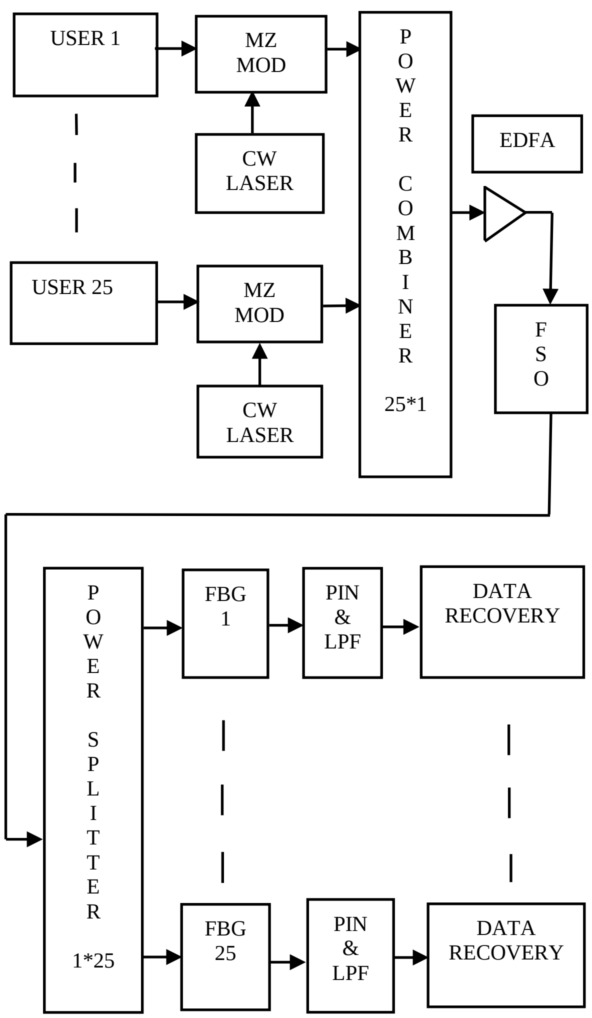

Fig.1. Block representation of terrestrial OCDMA network over free space

At the receiver end, the received signal is splitted into 25 parts and each of the receivers get optical power of equal proportion. The FBG, with intended receiver's signature code, decodes the splitted signal optically. A PIN diode converts decoded light signal into corresponding electrical form, called photo current to ensure optical to RF conversion. This signal is then fed to Low Pass Filter (LPF) with subsequent thresholding for recovery of transmitted binary signal.

IV. SIMULATION RESULTS AND ANALYSIS

The layout is simulated in 25 users' scenario using BPSK modulation and MRD code. The receiver is investigated for different data rates, beam divergence, transmitter aperture, receiver apertures, atmospheric conditions like clear climate, moderate rainy etc. are taken into consideration.

Table 1: Parameters considered for SAC-OCDMA with BPSK modulation over FSO

Parameters	Values
No. of users	25
Transmission distance	1 km - 15 km
Data rate	1Gbps -10 Gbps
Transmit power	0 dBm
Transmitter aperture	3 cm, 5 cm
Receiver aperture	20 cm, 25 cm
Beam divergence	1 mrad, 2 mrad
Attenuation	Clear weather (1 dB/km) Moderate rain (3 dB/km)
EDFA Gain	25 dB
Photo diode	PIN
Dark current	10 nA
Responsivity	1 A/W

Table 2: A comprehensive comparison of performance metrics of work published in literature and the proposed system

Reference No	No.of users	Link length (km)	Data rate (Gbps)	EDFA gain (dB)	BER	Q factor
[1]	8	3.5	10	30	10^{-40}	-
[2]	5	15	2.5	30	10^{-25}	-
[3]	8	8	10	30	10^{-25}	10
[21]	32	2	1	-	10^{-7}	-
[22]	10	11	10	-	10^{-11}	6.4
[23]	2	1	2.5	-	10^{-9}	-
Proposed system	10	15	10	25	10^{-45}	13
	15	15	5	25	10^{-15}	7.6
	25	15	1	25	10^{-15}	15

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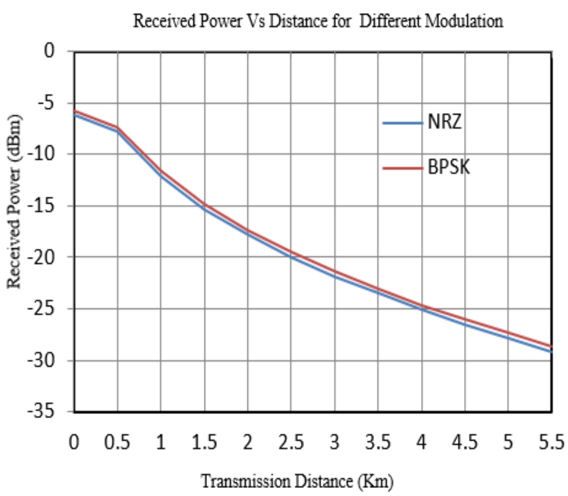

Fig.2. Variation of received power w.r.t distance for 3 users ,10 Gbps ,1 dB/km in FSO for different modulations

The received power at the front end of the receiver is a bit more incase of BPSK based OCDMA in comparision to NRZ based OCDMA as observed from Fig. 2.The rest paremeters cosidered in both systems are kept to be same.

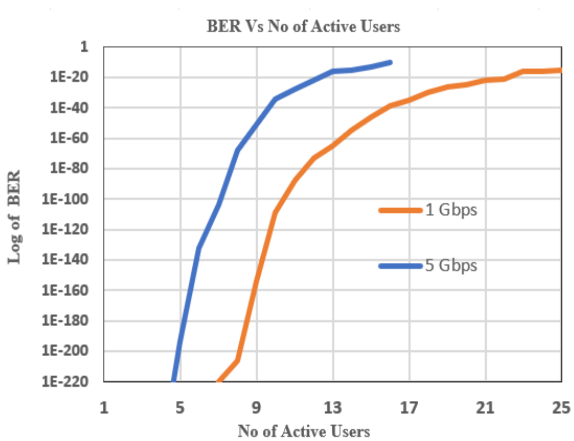

Fig.3. Variation of BER w.r.t users, 15 km, 2 mrad, 1 dB/km

Fig. 3 shows the role of active users on the BER value in an optical free-space terrestrial network employing OCDMA technique. For BER threshold value of 10^{-15}, this OCDMA network can supports 25 and 15 users at 1 Gbps and 5 Gbps data rates respectively.

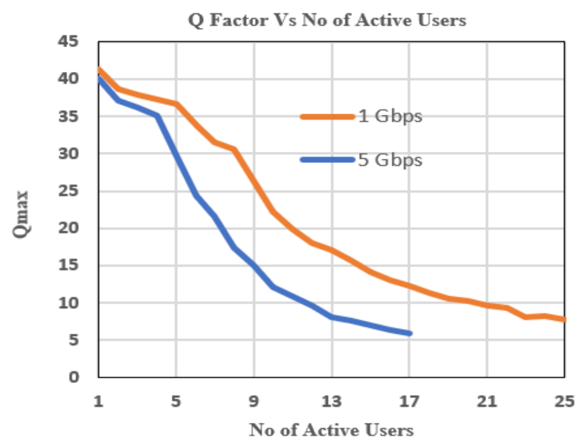

Fig.4. Variation of Q factor w.r.t active users,15 km,2 mrad,1 dB/km,0 dBm

Fig.4 describes the plots for Q factor w.r.t active users at 1 Gbps and 5 Gbps. It can be seen that the quality factor of the system decreases with active users as well as data rate. However, for BER value of 10^{-15}, the Q factors at 1 Gbps and 5 Gbps are still found to be 15.63 and 7.67 respectively.

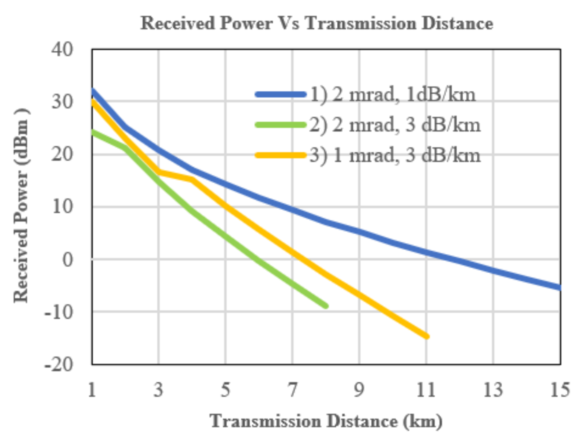

Fig.5. Received power as function of transmission distance for different weather conditions and beam divergences

Fig.5 addresses the dependency of received power on the transmission distance in clear and moderate rainy climate. The Optical signal undergoes heavy rain attenuation as shown by Plot '2' compared to clear climate shown by plot '1'. This attenuation can be compensated by decreasing the beam divergence that results more focused beam shown by plot '3'.

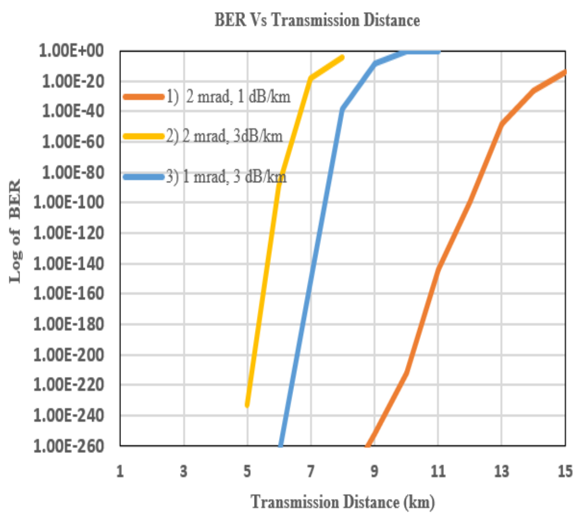

Fig.6. Variation of BER w.r.t transmission distance for different weather conditions and beam divergences

The BER value of the system is 10^{-15} and 1 in a clear climate and moderate rainy time as shown by plot no 1 and plot no 2 respectively in Fig.6. However, a slightly decreased beam divergence can compensate the rain loss and improves the system BER as presented by plot no 3.

The degradation of Q factor of the proposed optical terrestrial system is not significant for distances nearly up to 5 km which is approximately 38. Also, even at 15 km, the Q factor is found to be 9 which could be considerable as observed from Fig.7.

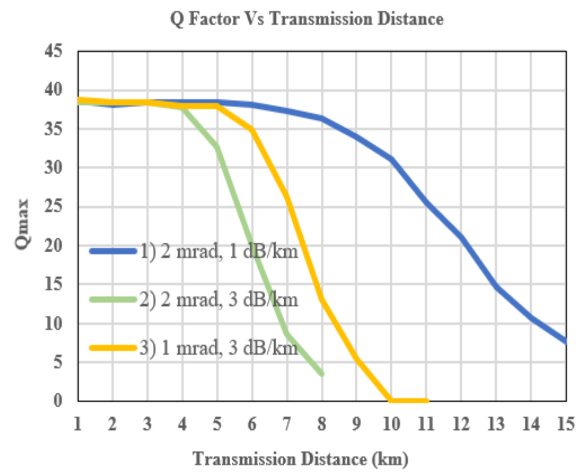

Fig.7. Variation of Q factor w.r.t transmission distance for different weather conditions and beam divergences

The proposed system is also investigated with the aid of eye diagrams as reported below.

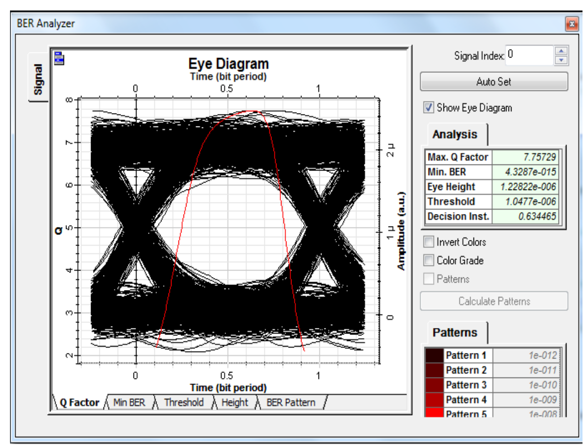

Fig.8. Eye diagram of OCDMA, 25 users,15km,2 mrad,1 dB/km,1 Gbps,0 dBm

Fig.8 represents the eye diagram of OCDMA network in a 25 user' scenario that covers 15 km distance under clear climate at a data rate of 1 Gbps. Here, the beam divergence, input optical carrier power, transmitter aperture and receiver aperture are considered to be 2 mrad,0 dBm,5 cm and 20 cm respectively.

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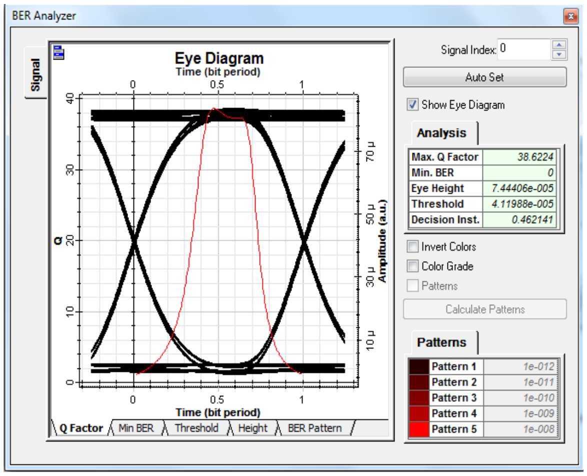

Fig.9. Eye Diagram of OCDMA, 3 users,15 km, 2 mrad,1 dB/km,1 Gbps,0 dBm

Fig.9 depicts the eye diagram of OCDMA that is similar to Fig. 8 with the exception that it is consider in a 3 user scenario.More eye opening is the result of less MAI by less users.

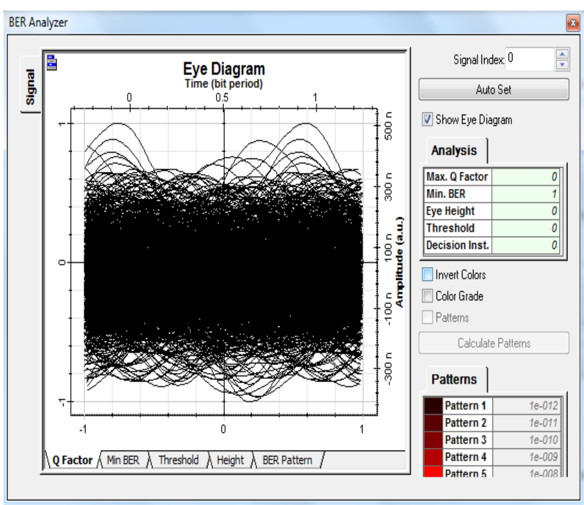

Fig.10. Eye diagram of OCDMA, 25 users,15 km,2 mrad,3 dB/km,1 Gbps,0 dBm

The optical signal propagating in rainy climate with atmospheric attenuation of 3dB/km,keeping rest parameter to be same as for Fig. 8, results closed eye with very high BER of 1 as detected in Fig. 10.

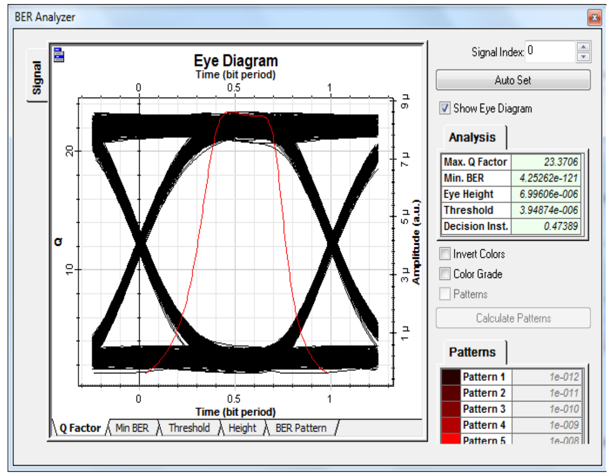

Fig.11. Eye diagram of OCDMA, 25 users,15 km,1 mrad,1 dB/km,1 Gbps,0 dBm

The decrease in beam divergence to 1 milli radian results less loss which in turn increases the height of eye opening as shown in Fig. 11.

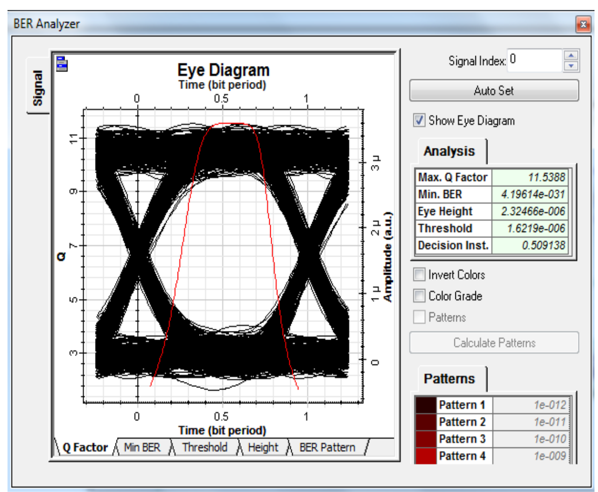

Fig.12. Eye Diagram of OCDMA 25 users, transmitter aperture 3 cm,15 km,2 mrad,1 dB/km,1 Gbps,0 dBm

A more focused optical signal at receiver end can be seen by deploying transmitter with less aperture in dimension.This results a bit more increase in eye openining with less BER as depicted in Fig.12 in comparison to Fig.8.

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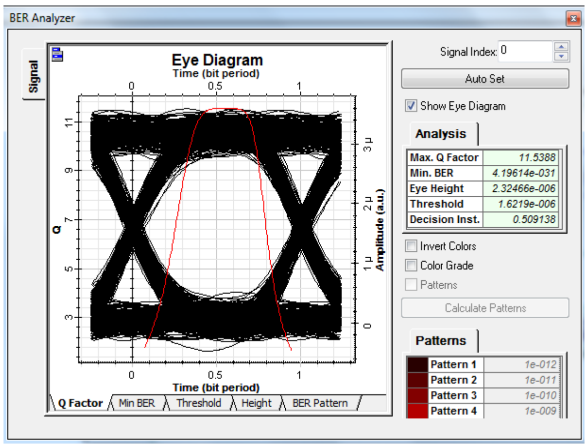

Fig.13. Eye Diagram of OCDMA 25 users, Receiver Aperture 25 cm,15 km,2 mrad,1 dB/km,1 Gbps,0 dBm

The FSO receiver with slightly larger aperture i.e. 25 cm can gather more optical power which results increase in eye opening with less BER as shown as in Fig. 13.

V. CONCLUSION

An Optical CDMA network over free space is investigated in a 25 users' scenario with 15 km link length using BPSK modulation. For acceptable BER value of 10^{-15}, OCDMA network can support 25 and 15 no's of users at 1 Gbps and 5 Gbps respectively with free space link length of 15 km. For BER value of 10^{-15}, the corresponding Q factors at 1 Gbps and 5 Gbps are found to be 15.63 and 7.67 respectively. Similarly, at 10 Gbps data rate, the system can support 10 users with link length of 15 km and BER value to be 10^{-45}. The BER value of the system is highly dependent on the transmission distance. Its value is 10^{-15} and 1 in a clear climate and moderate rainy with beam divergence of 2 mrad. However, a decreased beam divergence to 1 mrad can compensate the losses due to rain that improves the BER to 10^{-10}.

OCDMA over FSO are preferrable in high speed LAN networks like building to building, ship to ship communication. It has also given importance for earth to satellite and satellite to earth communication to service a large geographical area. Further research could develop some multi dimensional novel coding techniques that could exhibit low cross correlation even with increased code length. This feature would support huge users with least MAI to meet real field needs. The future investigation may introduce OCDMA systems with QPSK and QAM like advanced modulation techniques in order to provide good quality service.

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