**Indonesian Journal of Electrical Engineering and Computer Science**
Vol. 4, No. 1, October 2016, pp. 125 ~ 132
DOI: 10.11591/ijeecs.v4.i1.pp125-132 

# Two Dimensional Tunable Optical-CDMA System

**Rajesh Yadav*, Gurjit Kaur**
Department of ECE, School of ICT, Gautam Buddha University, Greater Noida, U. P., India
*Corresponding author, e-mail: raj_opyadav@yahoo.co.in

***Abstract***

*In this work an experimental demonstration is proposed to implement the synchronous optical code division multiple access system using two dimensional wavelength hopping and time spreading optical prime code is presented. An optical CDMA system is configured on latest version of optisystem by optiwave for the 20 users (Prime Number = 5) connected in a network operating at a bit rate 10 Gbps each. Tunability is achieved by using a MATLAB based delay selector which serves as the source of control signal for optical delay lines. The encoded optical signal of each user has been assigned a particular mode. The resulting optical signal is then transmitted over parabolic index multimode optical fiber. The received signal can successfully be retrieved at the decoder, when the encoder and decoder are configured for the same user. The performance of Optical CDMA system is evaluated in terms of the autocorrelation and cross correlation function, BER, Q factor, eye diagram and compared with 1D code for a given prime number.*

***Keywords**: Optical CDMA, 2D Codes, Prime Codes, Autocorrelation, Cross-correlation*



## 1. Introduction

In recent time, Optical Code Division Multiple Access (O-CDMA) is an emerging technology for providing a reliable and scalable communication system. OCMDA support multiple user access over large bandwidth provided by the optical fiber. OCDMA is a suitable multiple access technique for access network and LAN because of its flexibility and scalability to the network topology [1, 2]. Optical CDMA has been studied by lot of researchers in past for many years because of fast and secure data transmission feature inherently lies in the optical fiber while efficient traffic management and zero access delay is offered by CDMA technique [3]. With the advancement in optical fiber and optical components the transmission over the fiber has also get improved considerably.

The performance of Optical CDMA system significantly depends upon the optical code and system configuration [4]. As in communication system, each subscriber communicates with others at same or different time. Thus each user is typically assigned a unique code and has a tunable encoder and decoder. The encoder and decoder must be tuned to that particular code in order to transmit the information successfully even though in the presence of other user in the system [5]. Researchers have proposed many coding techniques like 1D spectral phase encoding, 1D spectral amplitude coding, 1D time spread coding, 2D wavelength hopping and time spreading coding [6] etc.

The presented 2D tunable Optical CDMA system is computer program controlled, well-configured, reliable and cost effective. This is because of the superior designing using multimode fiber as well as the ability of controlling many users concurrently and since non interfering codes has been used. The features and feasibility of system are characterized in the paper as: the two dimensional prime code /prime code codeword is discussed in section 2. The structure of two dimensional encoder and decoder are explained in section 3. The experimental setup and results are presented in section 4. The performance of the 2D optical CDMA system has been compared with the 1D optical CDMA system for comparative analysis.The evaluation of result has been discussed in section 5. Conclusion has been summarized in section 6.

*Received May 3, 2016; Revised August 26, 2016; Accepted September 11, 2016*

## 2. Two Dimensional Optical Codes

The two dimensional optical CDMA system employ wavelength as the second dimension to the time coding thus provides significant improvement in the performance and flexibility in configuration [7]. In this paper, we have demonstrated the implementation of wavelength hopping and time spreading based two dimensional prime code/prime code optical codes as discussed [8, 9].

Consider a prime number P, and then obtain the prime sequence $S_x = (s_{x,0}, s_{x,1},\ldots\ldots, s_{x,y}, \ldots, s_{x,(P-1)})$, where x = 0, 1…, P-1 and y = 0, 1 ……., P-1. The elements of this prime sequence will be given by $s_{x,y} = \{x, y\}$ (mod P). Then, mapping of each prime sequence $S_x$ is done into the binary sequence according to the following rule given in equation 1.

$$c_{x,z} = \begin{cases} 1 & if\ z = s_{x,y} + y.P,\ for\ y = \{0,1,2,\ldots,P-1\} \\ 0 & elsewere \end{cases} \quad (1)$$

A binary prime code sequence of length $P^2$ can be constructed as:

$C_{x,z} = (c_{x,0}, c_{x,1},.. c_{x,z}, \ldots. c_{x,N-1})$ where x = 0, 1,……., P-1, $N = P^2$

The 2D prime codewords has code length $N = P^2$ and the cardinality of $|C| = P^2$. The number of available wavelengths (M) is P and the code weight (w) is P. The paper present the OCDMA system having 20 users (p = 5) having code weight 5 and code length 25 using 5 wavelengths. Thus for any two different codeword's either they have distinct wavelength hopping or have different time spreading.

In Optical CDMA, each user is assigned optical code sequence that serves as its address. Every data bit 1 will close the switch and pass one clock pulse of a data modulated optical signal, but nothing for a data bit 0. The generated optical pulse will have voltage corresponding to the data bit voltage. The transmitting encoder encodes each bit of data source with the address code sequence of its intended receiver. At the receiver end, the decoder can be tuned to any transmitting subscriber by tuning the optical delay lines using a MATLAB based delay selector which serves as the source of control signal. The data is then retrieved via correlation. The receiver then give a high auto correlation peak for correctly decoded data bit or a low cross correlation peak for wrong decoding [10]. The optical CDMA system is designed and tested on 14 version of optisystem by optiwave.

## 3. 2D OCDMA Encoder/Decoder Structure

In order to cater the need of growing number of subscribers and traffic demand, the networks will require robust system that can support higher data rate. In the designed OCDMA system setup the encoder and decoder structure of each user comprise of P x 1 WDM multiplexer, P tunable fibre optic delay lines, a delay controller and 1 x P WD de-multiplexer to encode and decode the transmitting bit pattern according to the user defined 2D optical prime codeword. The P is considered to be equivalent to the code weight of the optical prime code used. Each transmitting user consists of a data source, NRZ pulse generator, Optical pulse generator, wavelength division multiplexer (WDM), tunable optical delay lines, MATLAb based switch controller and wavelength division de-multiplexer. The data source generates a continuous stream of data bit. The data bit is first converted into a format suitable for electro-optic processing using NRZ pulse generator. The gating is performed by using the voltage of the data bit and to be modulated using amplitude modulator or on-off keying modulator.

Figure 1 shows the structure of the proposed optical encoder. The proposed tunable OCDMA encoder/decoder structure is based on the 2 × 2 optical switches act as tunable optical filters provides incoherent configuration [11, 12]. For the transmission of data bit one, the modulated optical pulses are launched at the input of the encoder where they are de-multiplexed into P pulses by the wavelength division de-multiplexer. The P distinct wavelengths are mapped along each time delay lines. Each wavelength incident onto the tunable time delay lines is assigned an independent delay which is determined by the optical code sequence of the selected user. The tunable time delay is constructed using the 2 × 2 optical switches followed by optical fiber delay lines. The opening and closing of the optical switches in series configuration are individually controlled by a binary signal. The binary signal for delay control corresponding to address codeword is generated by MATLAB based program. Software generated signal was used to have optimized delay signal that will independently steer the incident optical pulse components along arbitrary delays. Each switch is configured to operate in either of the two states. So the power content of the original optical pulse is divided among the P optical pulses of distinct wavelengths. These P optical pulses are delayed individually by their own tunable optical delay line, according to the location of binary ones in the address codeword of the intended destination. The short pulses of distinct wavelengths are positioned in the code sequence according to $s_{x,y}$ of the $y^{th}$ subsequence. At last these properly delayed P optical pulses are then multiplexed by the wavelength division multiplexing to form the desired address codeword.

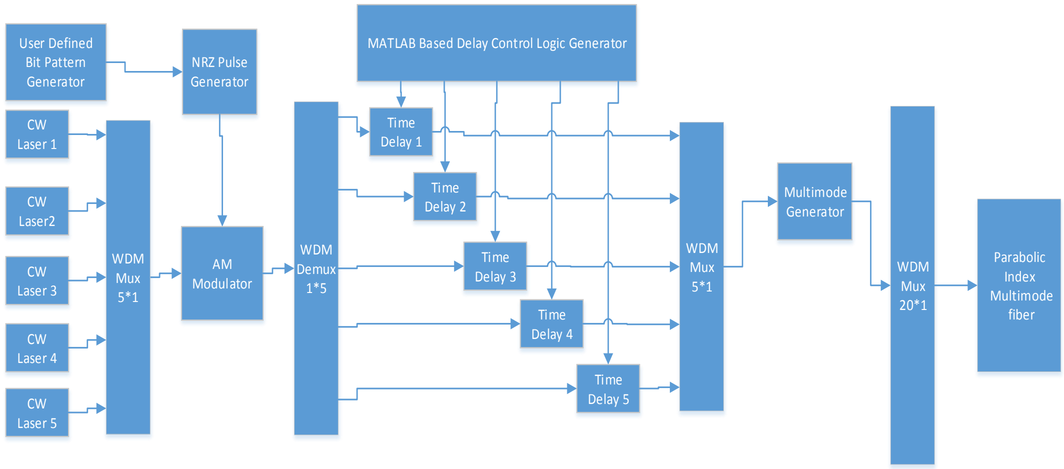



Figure 1. Tunable encoder structure for 2D OCDMA system

The resulting optical waveform has been assigned a particular mode using multimode generator. The encoded signal is then transmitted where it is combined with the encoded optical signal from other users and then they are transmitted over the network. The structure of tunable optical decoder is similar to that of the optical encoder, except that the inputs to the delay selection controller are now replaced with the desired time reversed sequence. The optical receiver structure consists of a photo detector to detect a threshold.

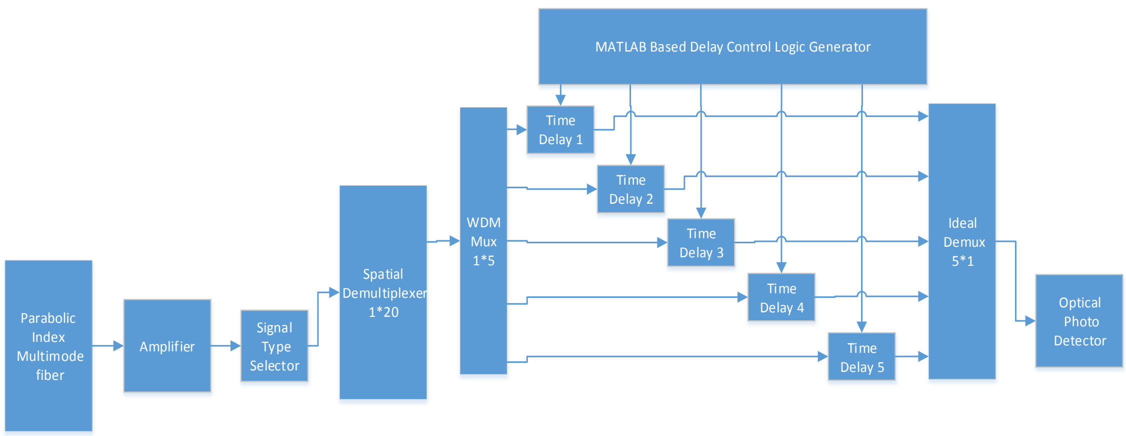



Figure 2. Tunable decoder structure for 2D OCDMA system

At the receiver end, the encoded signal is first directed to a spatial de-multiplexer to segregate the mode and the optical waveform is launched to the wavelength division de-multiplexer that will split the waveform into optical beams of distinct wavelengths. The resulting optical beam is routed towards a tunable delay lines, which maps them onto the delay lines tuned by control signal of the decoding Tunable OCDMA. In order to retrieve back the original signal, it is important that the receiver of tunable OCDMA system must be tuned with address code word similar to those of the transmitter tunable OCDMA. The decoded signal is coupled back into the multiplexer and routed to the photo-detector. When the code word of the encoder and decoder are identical, a high-peak auto-correlation waveform is resulted, which can be detected using a threshold detector. Otherwise, a low-amplitude cross-correlation function is detected, indicating a difference between the codewords of the encoder and the decoder. It will be considered to be the interference.

## 4. Simulation Setup and Result

The OCDMA system has been configured for 20 users having tunable encoder and decoder structure designed for two dimensional prime codes given by $(N, w, \lambda_a, \lambda_c) = (25, 5, 5, 1)$ has been simulated on 14 version of optisystem software by optiwave. The system has been driven by CW laser for a optical window of wavelength 1550 nm (193 THz).

Table 1. System Parameters

| Parameter | Value |
|---|---|
| Data Rate | 10 Gbps |
| Laser Employed | CW Laser |
| Line Width | 10 MHz |
| Input Power | 0.1 W |
| Wavelengths Used | 5, ($\lambda_1$ = 1549.3 nm, $\lambda_2$ = 1550.1 nm, $\lambda_3$ = 1550.9 nm, $\lambda_4$ = 1551.7 nm and $\lambda_5$ = 1552.3 nm) |
| Line Spacing | 0.8 nm |
| Fiber Type | Parabolic Index Multimode Fiber |
| Fiber Length | 50 km |
| Attenuation | 1,4 dB/km |
| Number of modes | 20 |
| Core Radius | 100 μm |
| Cladding Thickness | 10 μm |
| Refractive index | 1.45 |
| Photodiode | PIN Photodiode |
| Responsivity | 1 A/W |
| Dark Current | 10 nA |
| Width | 10 μm |
| Pol. X Mode Type | Fiber LP |
| Pol. Y Mode Type | Laguerre Gaussian |

A 6-bit non-return-to-zero (NRZ) bit pattern “010100” was generated by user defined bit pattern generator. Each bit assigned to a user is then represented by 25 bits that will take 2.5nS time interval. So for representing five bits we need 12.5ns. Table 1 present the value of system parameters chosen to simulate the two dimensional OCDMA system. The system has been configured for the ninth user as an active having a codeword employing “$\lambda_1$0000 $\lambda_2$0000 $\lambda_3$0000 $\lambda_4$0000 $\lambda_5$0000” and assigned mode (2, 1). Therefore, the wavelengths were coupled into the 2D encoder and steered away (substantially delayed) according to the user ninth codeword. Figure 3(a) shows the schematic of the input bit pattern (010100) applied on the ninth user of the 2D Tunable OCDMA system designed on optisystem. Here each bit is of interval 0.1nS. Figure 3(b) shows the encoded optical signal according to the codeword. Figure 3(c) represents the measured spectrum of the optical signal launched out of the encoder.

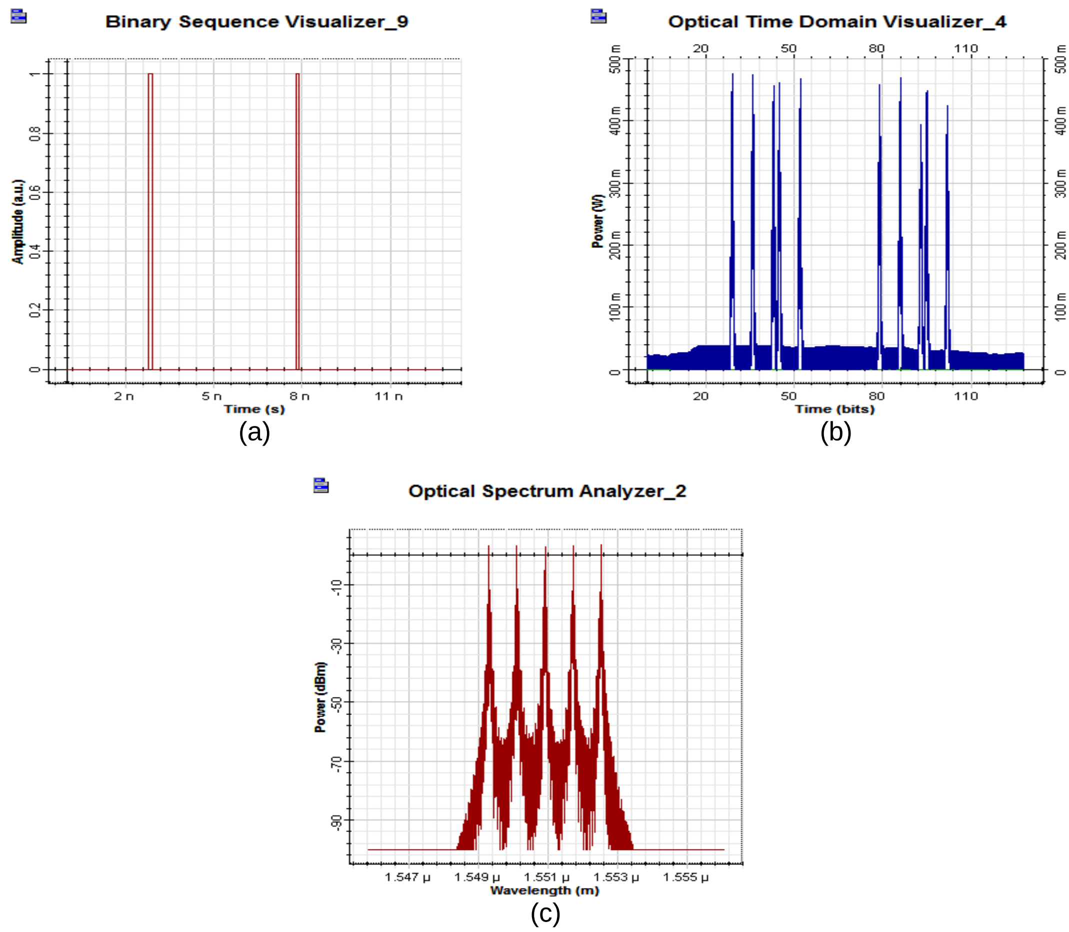



Figure 3. (a) Input bit pattern loaded on the 9th user (010100); (b) The encoded signal at the output of 9th user; (c) Represent the spectrum of the launched encoded optical signal

The encoded optical signal of all the active users has been assigned a distinct mode and then sent to the wavelength division multiplexer to route towards the network. The combined signal spectrum at the multiplexer output is shown by the Figure 4(a). Whereas figure 4 (b) and 4 (c) represent the combined output in time domain and visualization of spatial mode. The signal is transmitted over the parabolic index optical fiber and amplified.

At the receiver, the signal is passed through the spatial de-multiplexer using Bessel filter to segregate the optical signal on the basis of received mode. The resulting optical beam has been launched towards the decoder, which was loaded with the same delay control signal of the user 9th. Figure 5(a) shows the received signal with peak at the last bit of code sequence. Figure 5(b) represents the measured spectrum of received signal at five different wavelength centered at 1550.3 nm wavelength. Figure 5(c) and (d) shows the eye diagram and the Q factor of an error-free transmission respectively.

The optical signal was detected by a highly responsive photo detector and monitored using a digital oscilloscope. Figure 6(a) shows the received signal with a single high-peak autocorrelation function. A mismatch between the encoder and decoder will have a low-intensity output signal at the decoder end. To analyze this, the 9th user encoder of tunable OCDMA system was left unchanged while the decoder was reconfigured with a codeword assigned to 3rd user. In this case, a low-amplitude cross correlation output signal was resulted, as shown in Figure 6(b).

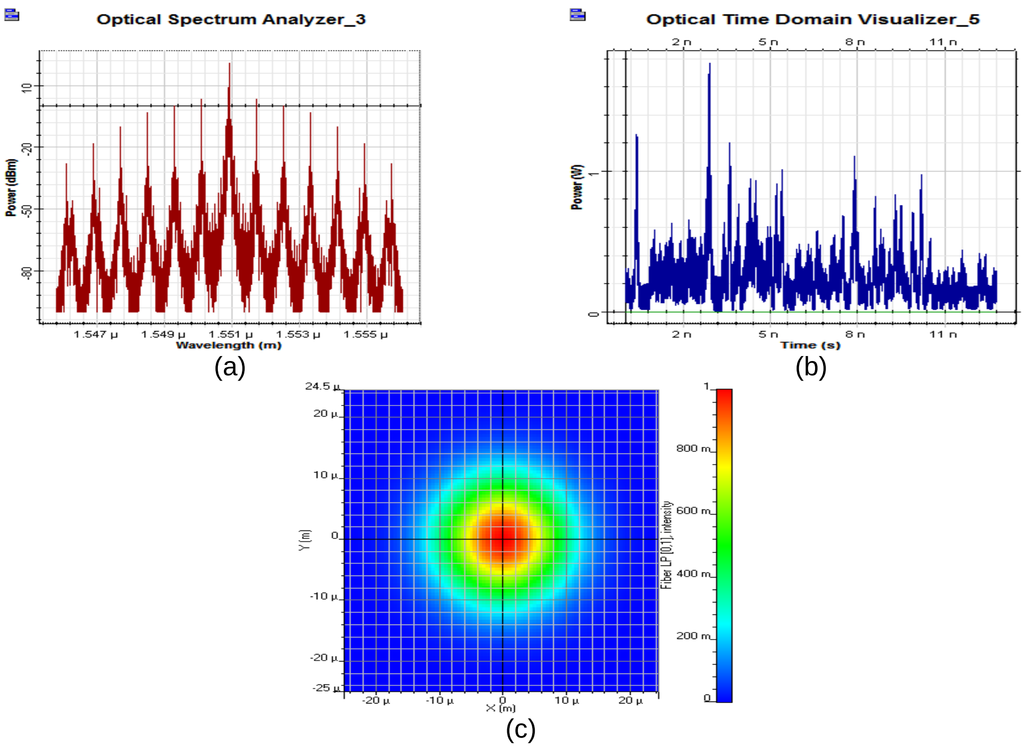



Figure 4. (a) Spectrum of the combined optical signal; (b) The spectrum of the launched encoded optical signal; (c) The spatial visualizer at the multiplexer output

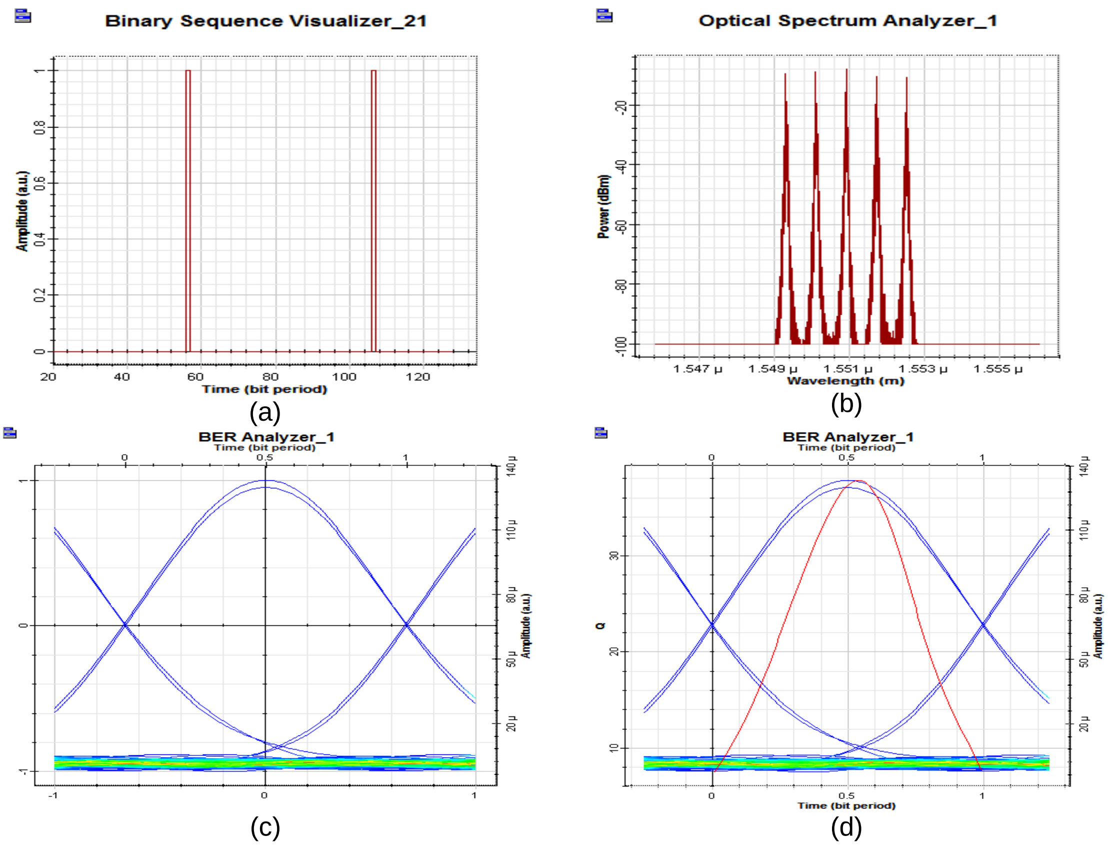
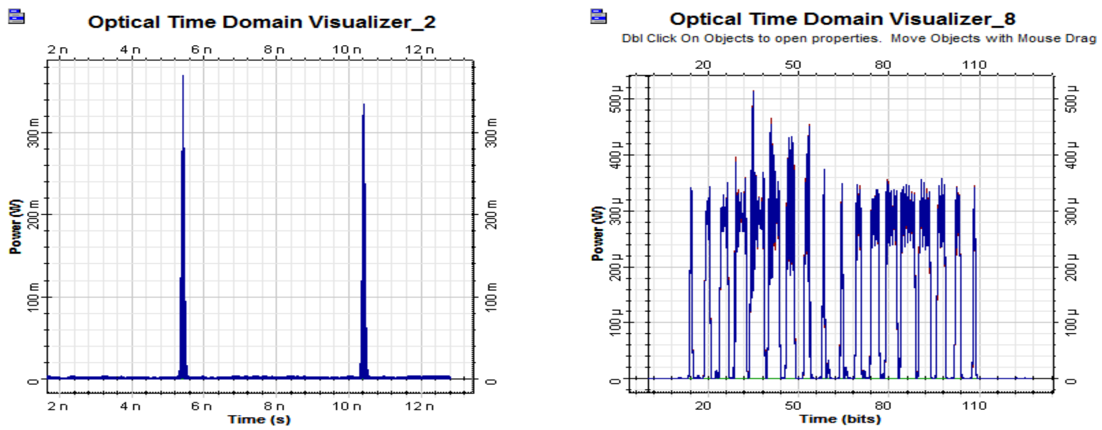



Figure 5. (a) Received optical signal bit pattern; (b) Measured spectrum of received signal; (c) Eye diagram of system; (d) Q factor of 2D Tunable OCDMA system




(a) (b)

Figure 6. (a) Received signal having a high-peak autocorrelation function; (b) Received signal representing a low-peak cross-correlation function

## 5. Discussion

The results presented in Table 2 demonstrate the performance of the proposed 2D tunable OCDMA encoder/decoder structures to encode and decode the information. Here we can see the proposed 2D system have better BER and Q factor then 1D system at 10 Gbps for 50 km of optical fiber for a given number of user (P = 5). It can be seen from the Figure 7 that the Bit Error Rate of 2D is good for a given number of users then 1D code at 10 Gbps.

Table 2. Bit error rate and Q factor for 1D and 2D code for prime number P = 5 at 10 Gbps for different user

| No. of User | 1D Code 10 Gbps BER | 1D Code 10 Gbps Q Factor | No. of User | 2D Code 10 Gbps BER | 2D Code 10 Gbps Q Factor |
|---|---|---|---|---|---|
| 1 | 7.90E-21 | 9.285 | 2 | 6.103E-78 | 18.571 |
| 2 | 3.57E-18 | 9.125 | 4 | 4.279E-67 | 17.116 |
| 3 | 7.12E-15 | 8.626 | 8 | 1.549E-58 | 15.069 |
| 4 | 9.48E-14 | 7.742 | 12 | 2.365E-51 | 14.893 |
| 5 | 7.27E-13 | 6.724 | 16 | 1.285E-45 | 13.917 |
| | | | 20 | 1.925E-29 | 10.156 |

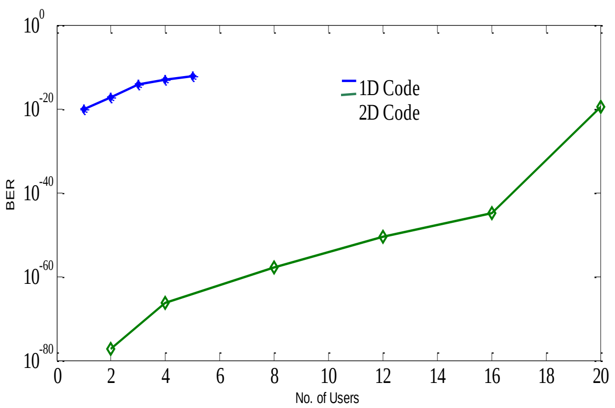



Figure 7. BER vs number of users for 1D and 2D codes at 10 Gbps transmission speed

The scalability of the proposed structure depends on the code used, active window size, and the control logic employed. The proposed 2D tunable OCDMA encoder/decoder structure is suitable for LAN and access networks applications because of its simplicity, compactness, cost effectiveness and software program based (MATLAB) tunablility along the time range. These capabilities enable future network upgrade to be performed with easiness. Moreover, to support high speed access networks the codeword generations should be independent of the transmitted data bit rate and the number of bits, which makes the configuration attractive [13]. The performance of the system can be improved by reducing the multiple access interference and can support more users [14]. Finally, an increase number of users can also be achieved by introducing the more dimensions and increasing the value of prime number.

## 6. Conclusion

The paper demonstrates an experimental setup of 20 users for two dimensional OCDMA system with wavelength hopping and time spreading prime code. Codeword's have been synthesized at the encoder and decoder using computer generated MATLAB program. The simulation result shows an error free transmission for all the twenty users at a bit rate of 10 Gbps using parabolic index multimode optical fiber for transmission length of 50 km. A high-peak autocorrelation function at the decoder has successfully been observed when the MATLAB program loaded on the decoder and encoder are matched. In "no match" scenarios, low-peak cross correlation functions have been detected and easily recognized from cross-correlation functions. Finally, an increase number of users can also be achieved by introducing the more dimensional code and by increasing the value of prime number.

## References


[1] Salehi JA. Emerging optical CDMA techniques and applications. *International J. Opt. and Photon*. 2007; 1(1): 15-32.

[2] Stok A, Sargent EH. The role of optical CDMA in access networks. *Communications Magazine, IEEE*. 2002; 40(9): 83-87.

[3] Prucnal P, Santoro M, Fan T. Spread spectrum fiber-optic local area network using optical processing. *Journal of Lightwave Technology*. 1986; 4(5): 547-554.

[4] Vannucci G, Yang S. Experimental spreading and de-spreading of the optical spectrum. *IEEE Transactions on Communications*. 1989; 37(7): 777-780.

[5] Yin H, Zhang G, Yang S. The Research of Tunable Optical Orthogonal Encoder/Decoder for Optical Code-Division Multiplexing Communication. *Journal-China Institute of Communications*. 1998; 19: 85-90.

[6] Tancevski L, Andonovic I. Wavelength hopping/time spreading code division multiple access systems. *Electronics Letters*. 1994; 30(17): 1388-1390.

[7] Kaur G, Gupta N, Sahota NS. *Performance comparison of W/T Matrix with Variable code parameters for OCDMA System*. In 2008 10th Anniversary International Conference on Transparent Optical Networks. 2008.

[8] Yadav R, Kaur G. Design and performance analysis of 1D, 2D and 3D prime sequence code family for optical CDMA network. *Journal of Optics*. 2016: 1-4.

[9] Yang GC, Kwong WC. Prime codes with applications to CDMA optical and wireless networks. Artech House. 2002.

[10] Yang GC, Kwong WC. Performance analysis of optical CDMA with prime codes. *Electronics Letters*. 1995; 31(7): 569-570.

[11] Prucnal PR, Krol MF, Stacy JL. Demonstration of a rapidly tunable optical time-division multiple-access coder. *IEEE Photonics technology letters*. 1991; 3(2): 170-172.

[12] Zhang JG, Picchi G. Tunable prime-code encoder/decoder for all-optical CDMA applications. *Electronics letters*. 1993; 29(13): 1211-1212.

[13] Prucnal P, Santoro M, Sehgal S. Ultrafast all-optical synchronous multiple access fiber networks. *IEEE Journal on Selected Areas in Communications*. 1986; 4(9): 1484-1493.

[14] Park S, Kim BK, Kim BW. An OCDMA scheme to reduce multiple access interference and enhance performance for optical subscriber access networks. *ETRI journal*. 2004; 26(1): 13-20.