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Performance analysis of 1.6 Tbps Optical Code Division Multiple Access system using Multi-Diagonal Code

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ABSTRACT

The rapid expansion of multimedia services could lead to improve the network accessibility with multiple users simultaneously. The technological development in asynchronous communication considered system performance as one of the major issues. Simultaneous accessing of channel from the multiple stations is one of the techniques. Traditionally multiple access for the channel is playing an important role in multiple asynchronies communication. Optical Code Division Multiple Access (OCDMA) is one of the advanced techniques used in accessing the asynchronous network due to its inherent capability. OCDMA provides dynamic bandwidth support for multimedia services. In this paper OCDMA system is designing using Multi Diagonal (MD) code and Direct Detection (DD) code to improve the Bit Error Rate (BER), Q-factor. The designed system is used to compare with MD code and Modified Congruence Quadratic (MCQ) code to determine the performance improvement for multiple users.

Keywords*— OCDMA, MD, MCQ, BER, Q-factor, Multiple access, Direct Detection (DD)*

1. INTRODUCTION

Optical Code-Division Multiple-Access (OCDMA) is having an inherent capability to support asynchronous access for the networks to provide the dynamic allocation of bandwidth, and multimedia services [1]. Multiplexing of channel is an incorporate with different single channels [2]. Optical spread spectrum used to fulfil the band width requirement and these spectrums are stable for operation [3-4]. The TDM, WDM, FDM are the multiple accessing techniques used in metro networks [5]. OCDMA systems support especially for local area networks to access asynchronous network applications [6]. OCDMA performance parameters are analyzed by data rate, simultaneous multiple users, Trans-receive power, and the code type used. The code types and the data rates represent the number of users can directly access the network [7]. The systems affected by different noises such as thermal noise, shot noise, dark current, and multiple-access interference (MAI). The practical design code sequence is essential the effect of MAI on the total Power received [8]. Spectral amplitude coding for optical code-division multiple-access is used to reduce the effect of MAI with fixed in- phase cross co-relation [9]. Few popular codes for the SAC-OCDMA networks are Optical Orthogonal (OOC) code [10], prime code [11], Enhanced Double Weight (EDW) code [13], Modified Frequency-Hopping (MFH) code [14], Khazani–Syed (KS) code [12], Modified Double Weight (MDW) code [17], etc.

The drawback of the existing codes are:
(a) Length of the code sequence is more
(b) The code construction is limited by the code parameters. The cross-correlation increases with weight number
(c) Codes don't support for high data rate and multiple simultaneous users

Considering the drawbacks of the existing codes an MD code is designed with the grouping of diagonal matrix. The advantages of the designed codes are:
(a) Less cross-correlation to avoid interference.
(b) The parameters like wavelength and number of users are chosen flexibly.
(c) Simple design and overlap occurred in spectral characteristics.
(d) Due to the high data rate it makes the network possible to serve more users.

2. MULTIPLE ACCESS TECHNIQUES

Multiple access means multiple users to share the allotted spectrum in an effective manner. Multiple station can access a service within the time. Multiple access techniques are: Time-Division Multiple Access (TDMA), Frequency-Division Multiple Access (FDMA), Code-Division Multiple Access (CDMA).

TDMA: The system allotted the time slot for each user to transmit and receive the data. If the time slot is not available the user must wait for its slot. Depending on the number of users the time slots also varied, more user resulting to high latency. In the networking Local Area Network (LAN) many stations were connected. Some of the stations are ideal during accessing. The ideal state of the station does not use the bandwidth. Hence band width during the communication is waste.

FDMA: The user is allotted a frequency bands in the channel. Hence, limited user can access the network simultaneously. Many of the allotted channels are unused when bandwidth is utilized. The transmitter light source at transmitter and filters at the receiver are the frequency tuner over the channel. The designing of the system with low cost is the major issue in FDMA. The performance of the designed system is limited in resource usage.

CDMA: The technique of spread spectrum communication have been used to improve radio spectral usage efficiency in radio communication systems. Unlike in TDMA, FDMA, in CDMA specific time slot or wavelength channel does not allocate to each user. A unique identity code is designed for the multiple user to access the network asynchronously. The bit error in CDMA allow the user actively participate in the data transmission regardless of the users. CDMA is more suitable for multiple access situation in the asynchronous LAN. Due to high carrier frequency magnitude than microwave frequencies the management of phase stability of the oscillators in the trans-receiver is difficult [9].

The DD method involves receiver to detect energy of the optical pulse. The system is an incoherent, the data modulated by the intensity envelop of the carrier. DD avoids the transmission of negative pulse through the channel, the channel is labelled only unipolar. Hence it prevents designing of bipolar for multiple users. The difference between positive and negative values generates the new codes. CDMA codes were designed for the unipolar optical channel to avoid the interference from other users. The light pulses of the unipolar (1, 0) codes are spread carefully with time and frequency. In data processing the receiver system makes the decision as to indicate whether a "1" or "0" bit is sent.

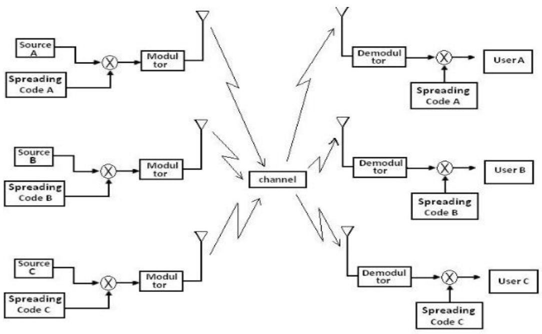

Fig. 1: Block diagram of OCDMA system

Figure 1 shows the block diagram of OCDMA system. OCDMA system provides the support to access the asynchronous network with high data rate due to its inherent capability. The code is provided to each user to access the network with any instant of time regardless of the active users. The system mainly effected by noises like thermal noise, dark noise, short noise etc. The Multiple Access Interference (MAI) is called as controller to minimize interference and reduce the loss of power received. The proposing OCDMA system provides the solution to design the better codes, minimize the limitations in the performance of the system.

3. LITERATURE REVIEW

According to the literature survey optical CDMA is one of the hot topic for the research improvement: The proposed optical orthogonal code generated and error probability performance analysis using auto- correlation and cross- correlation properties with unequal constraints for a fixed system resources [1]. The performance is significantly improved in the system. The parameters analyzed are diversely supported for the Quality of Services (QoS), improvement of different multimedia services with different users. The focus of the analysis to make the improvement in bandwidth for the services.

The proposed a novel methodology to incorporate the multiple grouping code channel to a single channel without affecting the other codes [2]. The system delay is affected by electrical driving optical switch with specific optical devices. Multi-channel drop is a complex phenomenon that support single unit channel multiplexing without disturbing the neighboring codes.

The developed strategical method to access asynchronous multiple channel to local area network using spread spectrum technique. The bandwidth requirement is fulfilled using optical co-relation [3]. Number of users increased by using the property of co-relation and optical incoherent. To reduce the bandwidth for the detector monostable multivibrators are used to provide the triggering. The optical system can provide substantial improvements in the capacity of the CDMA system.

The proposed an incoherent method based on wavelength or time to support for the system 1.25Gs/U for 16 users while maintain the wavelength < 10-11. The proposed method shows the beat noise occurred between signal and multiple interference and its effectiveness to the performance [7]. The proposed system can able to generate 8-wave length in continues wave source with 100 pulse with repetition ratio of 1.25GHz.

The architecture of transmitter and receiver for tunable chirped fiber Bragg gratings is designed. The proposed coding method suppress the noise effectively to improve the system performance, the effective power is larger >-10dBm [14]. The auto co-relation constructed series of new code families with fixed in phase of cross co-relation value of 1. The BER compared with hadmand code to analyze the performance.

4. CONSTRUCTION OF MD AND MCQ CODE

4.1 Construction of MD codes

To construct MD code the parameter assumed as: N is the code length, w is the code weight, K is the number of Subscriber or users and λ_C is the Phase cross-correlation.Formulation of the cross-correlation the linear algebra and the identity matrix of size N X N is used. Consider a square matrix with unit matrix with its main diagonal as one and others are zero. The unit matrix can be represented as:

$$Ti,1 = \begin{bmatrix} 1....0 \\ . \\ .0....1 \end{bmatrix} \tag{1}$$

Step 1: Construct a sequence diagonal matrix of the W and K assume W and K are positive values, then set value I, JW.

i= 1, 2, 3…n ;

jw= 1, 2, 3, 4,… W to represent the diagonal matrix.

Step 2: The MD sequences are computed for each diagonal matrix basing on the relations as:

$$S_{i,j} =: \begin{Bmatrix} (i_n + 1 - i);\ j_w \ even\,\mathrm{int}\ eger \\ i;\ j_w \ odd\ \mathrm{int}\ eger \end{Bmatrix} \tag{2}$$

The diagonal matrix of each individual component notated as:

$$Si,1=\begin{bmatrix}1\\2\\3\\.\\.\\N\end{bmatrix} Si,2=\begin{bmatrix}N\\.\\.\\3\\2\\1\end{bmatrix} Si,3=\begin{bmatrix}1\\2\\3\\.\\.\\N\end{bmatrix} \ldots Sin=\begin{bmatrix}1\\2\\3\\.\\.\\N\end{bmatrix} \quad (3)$$

The equation can be generalized as:

$$Ti,1=\begin{bmatrix}1\ldots.0\\.\\.0\ldots.1\end{bmatrix}_{KxK}$$

$$Ti,2=\begin{bmatrix}0\ldots.1\\.\\.1\ldots.0\end{bmatrix}_{KxK}$$

$$Ti,w=\begin{bmatrix}1\ldots.0\\.\\0\ldots.1\end{bmatrix}_{KxK} \quad (4)$$

Step 3: The total combination of diagonal matrix K×N matrix.as:

$$MD=[T(i,1):T(i,2):\ldots\ldots.T(i,w)]_{KxN} \quad (5)$$

$$MD=\begin{bmatrix}a_{1,1}\ldots.a_{1,2}\ldots\ldots.a_{1,N}\\a_{2,1}\ldots a_{2,2}\ldots\ldots a_{2,N}\\.\\a_{in,1}\ldots a_{in,2}\ldots\ldots a_{in,N}\end{bmatrix} \quad (6)$$

In the basic matrix given by Eq. (5), the rows determine the number of users.

The number of subscribers may be expressed as:

$$N = K\times W \quad (7)$$

4.2 Construction of MCQ codes

Kostic & Titlebaum (1994) proposed Quadratic Congruence (QC) code for ideal cross-correlation for prime number p. A series of new (p^2+p, p+1, 1) code families for each 'p' (when p>2) can be obtained by padding another similar group with QC code. These codes are called Modified Quadratic Congruence (MQC) codes. The MCQ code generated for the sequences and Sequence of binary numbers when p = 5, d = 1 and b = 2 are:

MQC Sequences	Sequence of Binary Numbers
0 0 014412	10000 01000 00001 00001 01000 00100
1 0 144103	01000 00001 00001 01000 10000 00010
4 0 101441	01000 10000 01000 00001 00001 01000
1 3 422433	00001 00100 00100 00001 00010 00010
4 3 04030	00010 10000 00001 10000 00010 10000

The important properties of MQC codes are: the first property is code sequence has p^2+p elements that can be divided into (p+1) groups and each group contains one 1's and (p-1) 0s. The second property is in-phase cross-correlation between any two sequences is equal to 1. Consideration of these two properties MQC codes is much better than Hadamard codes for optical CDMA systems design.

5. SYSTEM ARCHITECTURE

OCDMA transceiver system design based on direct detection technique:

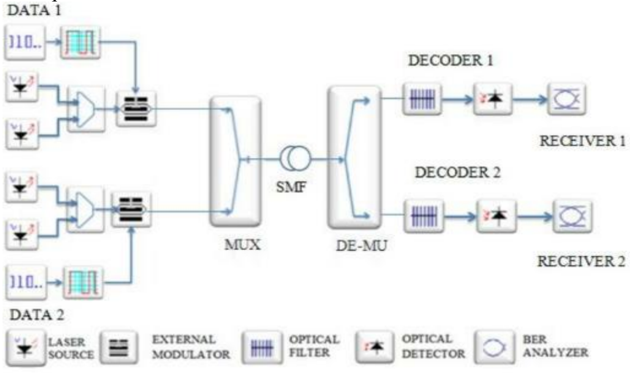

Fig. 2: System architecture for direct detection technique

OCDMA system architecture for direct detection technique is as shown in figure 2. Input data given in terms of digital sequence to the modulator. The optical signal generated from the laser source is fed to operational amplifier. The data sequence is modulated with optic signal at the external modulator after amplification.

The generated signal from the modulator is transmitting to the multiplexer and channel. At the receiver side, the signal will be demodulated and passed to the detector. At the receiver optical filter is adopted to remove the unwanted signals. Optical detector shows the original data after decoded the input signal. BER analyzer measures the bit error rate of the signal received.

6. SYSTEM PERFORMANCES ANALYSIS

Photo current:

$$I=R\int_0^\infty G(V)dv=\frac{RP_{SR}W}{N} \quad (8)$$

Probability standard deviation:

$$\sigma^2=\frac{P_{SR}WRBe}{N}+\frac{4K_bT_nB}{R_L} \quad (9)$$

Average SNR:

$$SNR=\left[\frac{\frac{P_{sr}WR^2}{N}}{\frac{P_{SR}WRBe}{N}+\frac{4K_bT_nB}{R_L}}\right] \quad (10)$$

BER parameter:

$$BER=Pe=1/2erfc\left(\sqrt{SNR/8}\right) \quad (11)$$

7. NUMERICAL ANALYSIS

The parameters are assumed for the analysis:

Table1: Typical parameter used in the analysis

Symbol	Parameter	Value
R_b	Data bit rate	320 Gb/s
ΔV	Line width	49947MHz
f	Frequency	193.5 THz

P_{sr}	Broadband effective power	-5DBm
Ꝛ	Photo detector quantum efficiency	0.748
SNR	Signal to noise ratio	59.125
BER	Bit error rate	6.3419*10^-5

1. **Data bit rate(R_b):**

Link data rate=1.6 Tb/s

$$\text{For four users} = \frac{1.6\text{Tb/s}}{4} = 400 \text{ GB/s} \quad (12)$$

2. **CW laser:**

$$\frac{\nabla v}{\nabla \lambda} = \frac{C}{\lambda^2}$$

For $\nabla\lambda = 0.4\text{nm}$ gives (13)

$\nabla v = 49947\text{MHz}$

3. **Frequency**:

$f = C/\lambda$; if λ=1550nm (14)

Gives f=193.5 THz

4. **Broadband effective power**:

$P_{sr} = 0.3162\text{W}$ (15)

Psr = - 5DBm

5. **Quantum efficiency of Photo-detector:**

$$Ꝛ = \frac{\eta e\lambda}{hc} = \frac{0.6*1.6*10^{-19}*1550n}{6.625*10^{\wedge}-34*3*10^{\wedge}8} = 0.748. \quad (16)$$

6. **Multi Diagonal code (MD):** In order to generate the MD code consider K=5 and W=3. Then i=1,2,3,4,5 i_n+1=6, and j_w=1,2,3.

$$D = \begin{bmatrix} 1\,0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,1\,0\,0\,0 \\ 0\,1\,0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,1\,0\,0 \\ 0\,0\,1\,0\,0\,0\,0\,\ 0\,0\,1\,0\,0\,0\,1\,0 \\ 0\,0\,0\,1\,0\,0\,0\,0\,0\,0\,1\,1\,0\,0\,1 \end{bmatrix}_{3X15} \quad (17)$$

Modified Quadratic Congruence (MQC) Codes:

Sequences and Sequence of binary numbers when p = 5, d = 1 and b = 2

Sequences	Sequence of Binary Numbers (MQC codes)
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4 0 101441	01000 10000 01000 00001 00001 01000
1 3 422433	00001 00100 00100 00001 00010 00010
3 4 304030	00010 10000 00001 10000 00010 10000

7. **Signal to Noise Ratio (SNR):**

$$SNR = \left[\frac{\left(\frac{P_{sr}WR}{N}\right)^2}{\frac{P_{sr}WRBe}{N} + \frac{4K_bT_nB}{R_L}}\right]$$

$$= \frac{\left(\frac{0.748*0.0003162*3}{15}\right)^2}{\frac{1.6*10^{-19}*1.67*0.748*0.0003162*3}{15} + \frac{4*1.38064*10^{-23}*300*1.67}{R_L}} \quad (17)$$

SNR=59.125

8. **Bit Error Rate (BER)**

$$\text{BER} = P_e = \frac{1}{2}\, erfc\left(\sqrt{\frac{SNR}{8}}\right) \quad (18)$$

$$= \frac{1}{2}\, erfc(2.71)$$

BER=6.3419*10^-5

8. SIMULATED RESULT AND DISCUSSION

The simulation diagram of MD code for 3 users as shown in Fig. 3. The opti-system version 7.0 software is used for simulate the schematic. Opti-system is one of the comprehensive software to design networks, enables users to plan, test and verify, and simulate optical links in the layer of modern optical networks. The OCDMA system is designed to check the errors and the eye diagram for the system is designed, compared and verified.

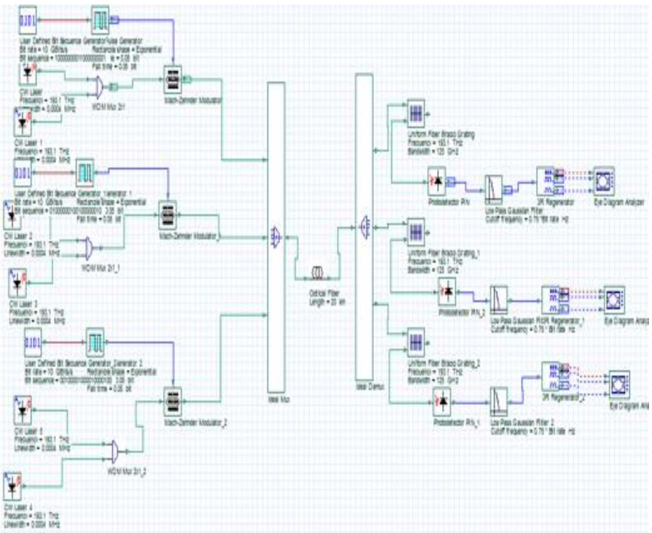

Fig. 3: Simulation diagram of MD code (3-users)

The continuous wave laser generates the carrier light signal and two signals are modulated for WDM 2x1 MUX. To control the amplitude of the optical wave the carrier and input signal is combined with mach zehnder modulator. The input waveguide is separated into two waveguide interferometer arms. At the transmitter side apply the voltage at one of the arm, a phase shift is induced for the wave passing through that arm.

All signals were transmitted and combined by the ideal mux, later the signal is passed to the optical fiber. At the receiver, the uniform fiber Bragg grating system receive the signal and reflects the particular wavelengths of light and transmits all other systems. Photo detector detects the corresponding wavelength of light. The low pass filter removes the unwanted signal and 3R regenerator generates the original signal. The eye diagram analyzer measure the values of BER, Q-factor, threshold value etc.

The system performance is analyzed by the BER and the eye patterns. To decode optical signals fiber Bragg grating and avalanche photo detector have been involved. The noise produced at the receivers has been conventional treated as be random and not correlated. The dark current 5 nA and the thermal noise coefficient 1.8×10–23 W/Hz have been taken respectively for each of the photo detectors.

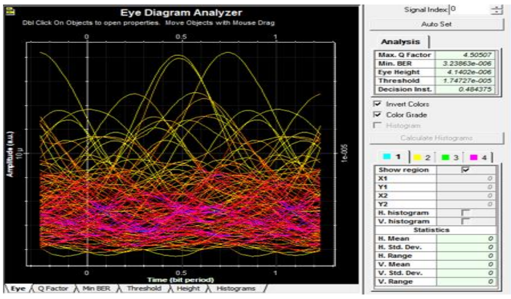

Fig. 4: The first channel at 320 GB/s 20km and -5 dBm for 3 users

In the first channel the BER and Q- factors are improved compered to MCQ code**.** The BER of the first channel is 0.00032 and Q-factor is 4.505 as shown in figure 4.

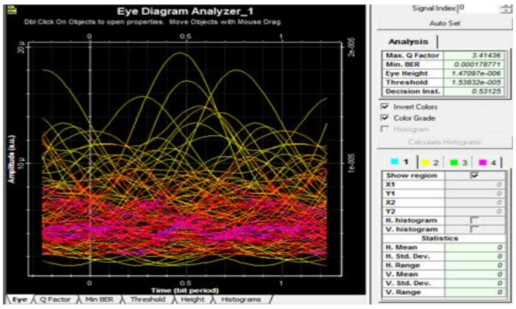

Fig. 5: The second channel at 320 GB/s 20km and -5 dBm for 3 users

In the second channel the BER and Q- factors are improved compered to MCQ code**.** The BER of the first channel is 0.000178 and Q-factor is 3.14 as shown in figure 5.

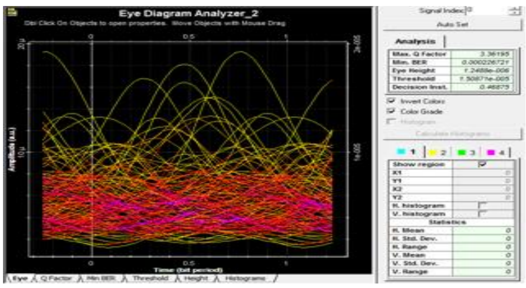

Fig. 6: The third channel at 320 GB/s 20km and -5 dBm for 3 users

In the Third channel the BER and Q- factors are improved compered to MCQ code**.** The BER of the first channel is 0.0002 and Q-factor is 3.36 as shown in figure 6. All the above results show the code comparison of three users simultaneously access the channel.

Table 2: Code comparison for 3 users

Channel	MD codes		MQC codes	
	BER	Q-factor	BER	Q-factor
1	0.00000323863	4.50507	0.000192602	3.51688
2	0.000178771	3.41436	0.000412171	3.32684
3	0.000226721	3.36195	0.000468087	3.28865

The code comparison of MD codes with MCQ code for the five users tabulated in table 2. Compared to MCQ code the bit error rate and Q-factors improved in proposed method for MD code analysis.

9. CONCLUSION

Modelling, simulating and analysis of a SAC-OCDMA system for 1.6 Tb/s is designing using MD code has been successfully verified. Due to the property of minimal cross-correlation, Multi Diagonal code, the design of encoder/decoder system is simple. Using direct detection technique, the decoder is designed provided that the code avoids overlapping appeared for the spectra linked to multiple users. The designed system achieves the lowest *BER* (0.00000323863), when compared with other OCDMA codes (MCQ). The system optimizes the parameters for obtaining higher data rates, multiple simultaneous users.

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