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Simulation and Analysis of 2D Wavelength/Time Addition Modulo Temporal Length (W/T AML) code for OCDMA System

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***Abstract* - In one dimensional optical orthogonal codes, as the number of users increase, the code length to the code weight grows rapidly. In two dimensional OCDMA codes the length of the codes reduces and hence improves the BER performance. In this paper we present the design of a new improved family of two dimensional Wavelength/Time Addition Modulo Temporal Length (W/T AML) code. AML codes have high auto correlation and low cross correlation value in the comparison of other optical orthogonal CDMA codes. The performance is analyzed using various input parameters e.g. bit rate, received power with respect to the number of users on the basis of BER (Bit Error Rate) and Quality factor and eye diagram.**

Keywords - Code Division Multiple Access (CDMA), Multiple Access Interference (MAI).

I. INTRODUCTION

As the traffic is bursty in Local Area Networks (LANs), there is always a demand of high speed and large capacity communication. To meet these demands various multiple access techniques are being used. Due to enormous capacity of optical fiber, the communication capacity which depends on carrier capacity, also increases [1]. As the carrier frequency increases, the available transmission bandwidth also increases and therefore the information capacity of the communication systems also increases [2]. In long haul and high speed communication systems where users share the same transmission media, the OCDMA plays an important role [4]-[5]. In OCDMA each user is assigned a unique signature code which is modulated by the data of the corresponding user. The signals from all the users are combined on to a single optical fiber which is further broadcasted to each user in the network. Single-user decoding is processed by correlating the aggregate signal and the signature sequence of a particular user. When the output of the decoder is in autocorrelation, the receiver detects the signal sent to it. On the other hand, when the decoder is in cross correlation, the receiver does not receive the signal. Means, for OCDMA systems, codes should have maximum autocorrelation and minimum cross correlation property. With the increase in number of users the Multiple Access Interference (MAI) also increases which is the main cause of performance degradation in OCDMA networks. So the cross correlation must be kept minimum for maintaining low probability of error. Various codes have been proposed for the OCDMA networks. In one dimensional (1-D) codes , the length of the codes increases with the increase in number of users and thus the bit rate decreases for a given chip width. To remove the problem of 1-D codes in OCDMA, 2-D codes have been proposed such as Frequency Hopping (FH), Time-Space (T/S) and Wavelength-Time (W/T). The FH codes are not suitable to be used in OCDMA systems because of the optical beat noise appearing between the frequency slices at the photo detector (receiver) [10]. But the W/T codes reduce the length of codes as well as increase the number of simultaneous users. The design of Optical Orthogonal Codes (OOC) is based on folding of Optimum Golomb rulers [6]-[8]. In this paper we have described the construction of a new family two dimensional codes, named Wavelength/Time Addition Modulo Temporal Length (W/T AML) codes, which have nearly ideal auto correlation and cross correlation properties for asynchronous OCDMA networks. The design of T/S Single Pulse per Row (SPR) incoherent asynchronous OCDMA network is given by [3]. AML codes are Single-Pulse-per-Row and this code is designed using the operation of addition modulo of integer.

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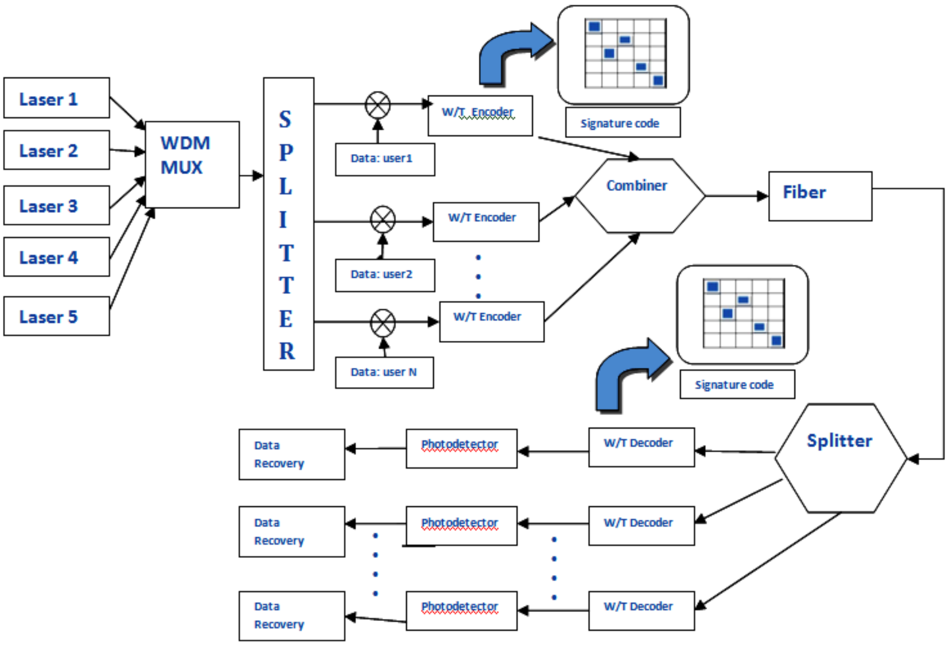


Fig. 1. Block Diagram of OCDMA system

II. DESIGN OF CODE

1-D codes can be characterized by N (L_t, W, λ_a , λ_c) where

- N is the number of codes
- L_t is the temporal length of the code
- W is the weight of the code(number of ones in the code)
- λa is out of phase autocorrelation peak
- λc is Cross correlation peak

The autocorrelation of one dimensional code x(t) is defined as:

$$Z_{x,x}(l) = \sum_{n=0}^{L_T-1} x_n\, x_{(n+l) \bmod L_T} \qquad (1)$$

$Z_{x,x}(l)$ satisfies

$$Z_{x,x}(l) \begin{cases} = W & \text{if } l = 0 \\ \leq \lambda_a & \text{if } 1 \leq l \leq L_T - 1 \end{cases}$$

The cross correlation of one dimensional code x(t) and y(t) is defined as:

$$Z_{x,y}(l) = \sum_{n=0}^{L_T-1} x_n\, y_{(n+l) \bmod L_T} \qquad (2)$$

$Z_{x,y}(l)$ satisfies $Z_{x,y}(l) \leq \lambda_c$ if $0 \leq l \leq L_T - 1$

The autocorrelation of 2-dimensional codes x(t) is defined as:

$$Z_{x,x}(l) = \sum_{m=0}^{R-1} \left(\sum_{n=0}^{L_T-1} x_{m,n}\, x_{m,(n+l) \bmod L_T} \right) \qquad (3)$$

$Z_{x,x}(l)$satisfies

$$Z_{x,x}(l) \begin{cases} = W & \text{if } l = 0 \\ \leq \lambda_a & \text{if } 1 \leq l \leq L_T - 1 \end{cases}$$

The cross correlation of 2-dimensional codes x(t) and y(t) is defined as:

$$Z_{x,y}(l) = \sum_{m=0}^{R-1} \left(\sum_{n=0}^{L_T-1} x_{m,n}\, y_{m,(n+l) \bmod L_T} \right) \qquad (4)$$

$Z_{x,y}(l)$ satisfies $Z_{x,y}(l) \leq \lambda_c$ if $0 \leq l \leq L_T - 1$

W/T AML codes are a family of an T/S SPR codes which are represented by:

N (L_t, R, P, W, λ_a, λ_c), Where

- L_t is the temporal length,
- R is the number of rows (equal to number of spatial channels)
- P is the number of pulses per row = 1 in the case of AML codes
- W is the weight of the code=R×P
- λa is out of phase autocorrelation peak
- λc is Cross correlation peak

A W/T AML code is represented by non-zero column number in rows from 0,1…..,R-1.

Time $\longrightarrow$

$$\begin{bmatrix}0\\1\\2\\3\\4\end{bmatrix} \quad \text{represents} \quad \begin{bmatrix}1\,0\,0\,0\,0\\0\,1\,0\,0\,0\\0\,0\,1\,0\,0\\0\,0\,0\,1\,0\\0\,0\,0\,0\,1\end{bmatrix} \; \lambda \downarrow$$

Depending on the type of integer taken for L_t the number of W/T AML codes can be obtained for L_t=W in two cases:

- When L_t is prime no.
- When L_t is composite no.

THEOREM 1 : When L_t is a composite number, L_t=W, λa=0 and λc=1, the number of W/T AML code that can be constructed is equal to the smallest prime no. of L_t.

THEOREM 2 : When L_t is a prime number, L_t=W, λa=0 and λc=1, the number of W/T AML code that can be constructed is equal to L_t.

The location of the ones in a W/T AML code C_i is characterized by one of the elements j of the group of integers modulo L_t (element j is called the generator of the code) as :

$$R_0\,(j) = 0 \qquad \text{for } j = 0,1 \ldots\ldots, L_T - 1$$

$$R_i\,(j) = \left(R_{(i-1)}\,(j) + j\right) \bmod (L_T),$$

$$1 \leq l \leq L_T - 1$$

where

$$C_i = \begin{bmatrix} R_0 \\ R_1 \\ \vdots \\ R_{L_T-1} \end{bmatrix}$$

and R_0, $R_1 \ldots R_{L_T-1}$ represent the position of ones in the rows 0, 1…,L_{T-1}. W/T AML codes are SPR code and so the out of phase autocorrelation is zero. In this code the distance between ones in the respective rows of any two codes are distinct, and this is applicable for all the rows.

Example:

W/T AML codes for L_t=5 and W=5 can be represented as :

Code 1, Code 2

$$\begin{bmatrix}0\\1\\2\\3\\4\end{bmatrix} = \begin{bmatrix}1\,0\,0\,0\,0\\0\,1\,0\,0\,0\\0\,0\,1\,0\,0\\0\,0\,0\,1\,0\\0\,0\,0\,0\,1\end{bmatrix}, \begin{bmatrix}1\,0\,0\,0\,0\\0\,0\,1\,0\,0\\0\,0\,0\,0\,1\\0\,1\,0\,0\,0\\0\,0\,0\,1\,0\end{bmatrix},$$

Code 3, Code 4

$$\begin{bmatrix}1\,0\,0\,0\,0\\0\,0\,0\,1\,0\\0\,1\,0\,0\,0\\0\,0\,0\,0\,1\\0\,0\,1\,0\,0\end{bmatrix}, \begin{bmatrix}1\,0\,0\,0\,0\\0\,0\,0\,0\,1\\0\,0\,0\,1\,0\\0\,0\,1\,0\,0\\0\,1\,0\,0\,0\end{bmatrix}$$

There may P^2 possible overlaps in any one row, if any two W/T codes of the same family having equal number of pulse per row, P. So, the total number of overlaps for all the rows R is RP^2.Then for W/T code the probability of overlap is Rp^2/L_t. Since in W/T AML code P=1, it is R/L_t. In the transmission pattern of on-off keying, the user data is transmitted by each information bit '1' which is encoded into desired address codeword and when the transmitted bit '0' is set ,transmitter does not construct any optical pulse.

In case of W/T AML code, the overlap probability of on-off keying is $R/2L_t$ or conversely the probability of no overlap is ($1-R/2L_t$).Assuming that either there is complete overlap or no overlap, the probability of error/bit P_e is given by

$$P_e = \frac{1}{2} \sum_{i=Th}^{N-1} \binom{N-1}{i} \left(\frac{R}{2L_T}\right)^i \left(1 - \frac{R}{2L_T}\right)^{N-1-i} \qquad (5)$$

III. SYSTEM SIMULATION

This OCDMA system is simulated by simulation tool, Optisystem™ version 13. For the OCDMA system based on W/T code, the transmitter and receiver sections are shown in Fig 2 and Fig 4 and their input parameters are shown in table I and table III. In transmitter section, Pseudorandom Bit Sequence (PBRS) generator is used to generate random data, CW (Continuous Wave) laser is used as an optical source, and Mach- Zehnder Modulator to modulate the carrier signal generated by PRBS generator. Five different wavelengths range from 1549.2nm to 1552.4nm with wavelength spacing 0.8nm are multiplexed by WDM (Wavelength Division Multiplexer) from the laser array.

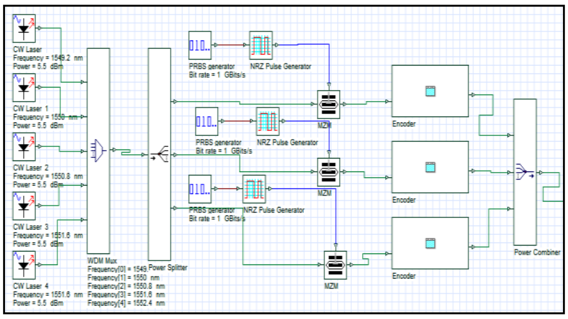


Fig. 2.Transmitter

Table I : Transmitter design parameters

Components	Parameters	Values
CW Laser	Wavelength	1549.2nm
	Wavelength Spacing	0.8nm
	Power	5.5dBm
	Line Width	10 MHz
	Initial Phase	0 degree
Pseudo Random Bit Sequence (PRBS)	Bit Rate	1,1.25Gbps
Mach-Zehender Modulator	Excitation ratio	30dB

A unique code through encoder is assigned for each user as shown in Fig 3. It consists of optical filters, time delays, splitter and combiner. The splitter splits the carrier signal into 5 wavelengths and optical filters selects five specific wavelengths from the carrier signal to produce the encoded bit sequence. With the help of the time delay in the encoder the selected pulses of specific wavelengths are placed in appropriate time slots and these five pulses are combined by the combiner to construct the encoded signal. The combined encoded data is passed through single mode optical fiber (SMF) of length 50 km. The OCDMA is designed which considers all practical impairments. The table II represents time delay at 1Gbps.

Fig. 3. Encoder

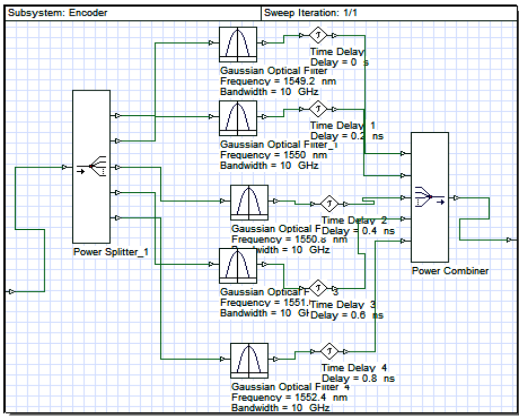


Table II : Time delay at 1 Gbps

Chip period	For 1 Gbps bit rate (in ns)
T1	0
T2	0.2
T3	0.4
T4	0.6
T5	0.8

The optical signal is passed through the receiver section followed by decoder and photo detectors with low pass filter. The information signal transmitted by the transmitter is extracted by the receiver. The decoder consists of optical filters and inverts time delays with respect to the transmitter which decodes to a particular code as the corresponding encoder.

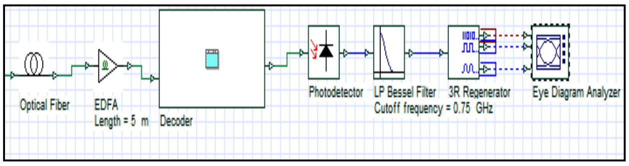


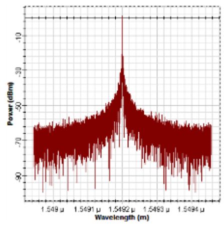
Fig. 4.Receiver

Table III. Receiver design parameters

Component	Parameter(s)	Value
Photodetector	Dark current	10nA
	Centre frequency	1552.5nm
Low pass Bessel Filter	Cutoff frequency	8Ghz
	Insertion loss	0db

IV. RESULT

In Fig 5 the output of CW Laser at 1549.2nm is shown and in Fig 6,output of five multiplexed laser sources are shown. Each user data modulate the multiplexed laser array signal and then encoded by the code designed in section II. Then encoded signal from all the users are combined and passed on to the fiber. At the receiver the decoder extract the optical data of a particular user with the help of their corresponding code. The photo detector detects the optical signal and convert it back to the electrical signal.



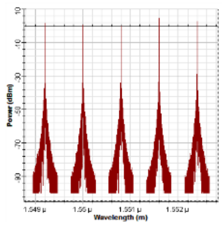


Fig. 5. Laser Output Fig. 6.Multiplexed Laser array output

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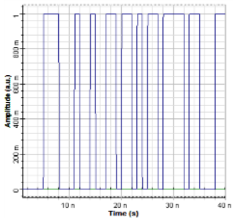
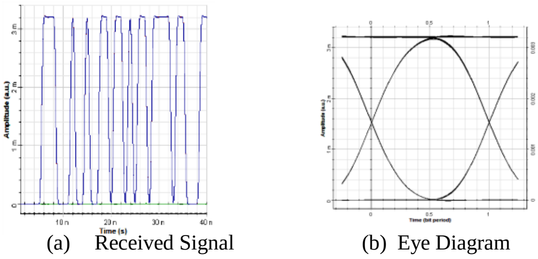
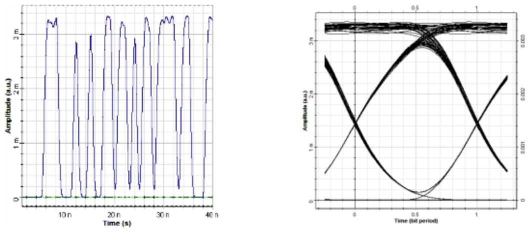


Fig. 7. Transmitted signal



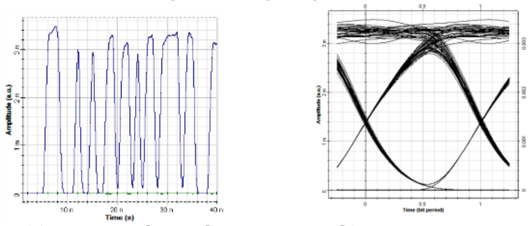
(a) Received Signal (b) Eye Diagram

Fig. 8. Timing Diagram for 1 user



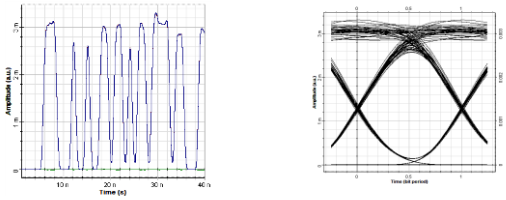
(a) Received Signal (b) Eye Diagram

Fig. 9. Timing Diagram for 2 user



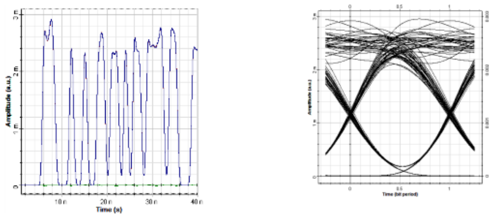
(a) Received Signal (b) Eye Diagram

Fig. 10. Timing Diagram for 3 user



(a) Received Signal (b) Eye Diagram

Fig. 11. Timing Diagram for 8 user



(a) Received Signal (b) Eye Diagram

Fig. 12. Timing Diagram for 16 user

The timing diagram at 1 Gbps for 1,2,3,8 and 16 users are shown in Fig 8-Fig 12. Fig 7 represents the transmitted signal and Fig 8-Fig12(a) represents the received signal when number of simultaneous users are 1,2,3,8 and 16 respectively. It has been revealed that as the number of users increase from 1 to 16, the amplitude start decreasing and also the signal get dispersed in time. Fig 8-Fig12 (b) represents the eye diagram for 1,3,8 and 16 simultaneous users. It is noted that as the number of users increases, the noise is also added and eye height start decreasing which result in decrement of SNR.

The simulation design of the system shows different values at different OCDMA matrix parameters like Bit Error Rate , Quality Factor, and Received Power with respect to the fiber length and number of users.

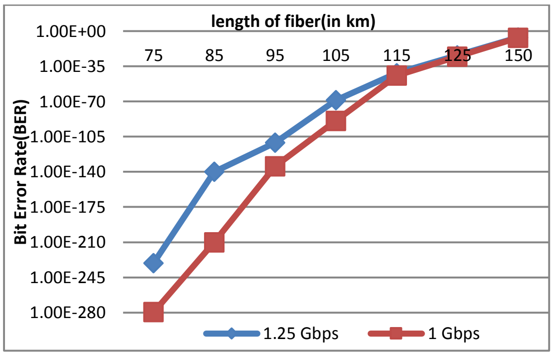


Fig. 13. BER vs. fiber length at 1 and 1.25Gbps data rate

Fig 13 represents the comparative analysis of Bit Error Rate (BER) vs. length of the fiber. It has been observed that the BER increases as the length of the fiber increases. Also, we can analyze that at 1.25 Gbps, the BER is more than at 1 Gbps.

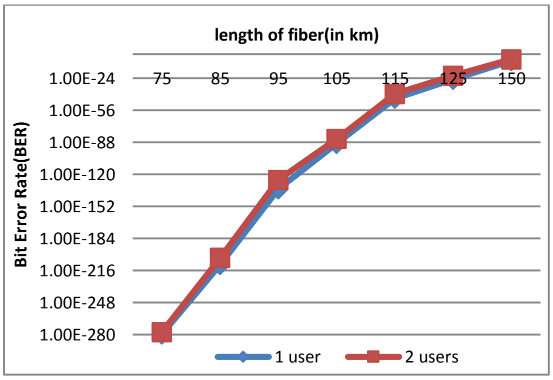


Fig. 14. BER vs. fiber length for 1 and 2 users

The combined results between BER and length of fiber for different number of users are shown in Fig 14. From the graph, it can be analyzed that there is a distinguishable different in BER for increasing path length for different number of users.

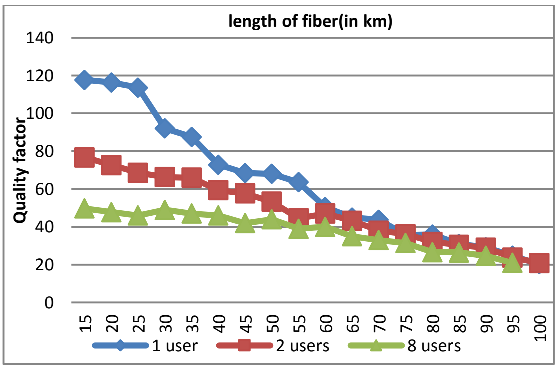


Fig. 15. Quality factor vs. length of fiber for 1,2 and 8 users

The results for Quality Factor vs. length of fiber for different number of users have been shown in Fig 15. It can be analyzed that the Quality Factor decreases as the path length increases. Also the Quality Factor for different length of fiber degrades as the number of users increases.

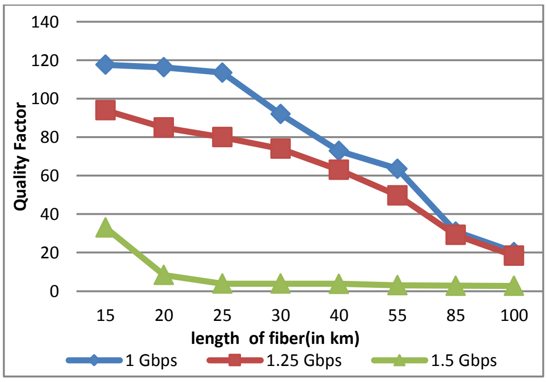


Fig. 16. Quality factor vs. length of fiber at 1, 1.25 and 1.5Gbps

The Fig 16 shows the graph between Quality Factor vs. path length for various data rates. The analysis shows that the value of Quality Factor degrades as the data rate increases. For an increase in the length of fiber also, the Quality Factor decays.

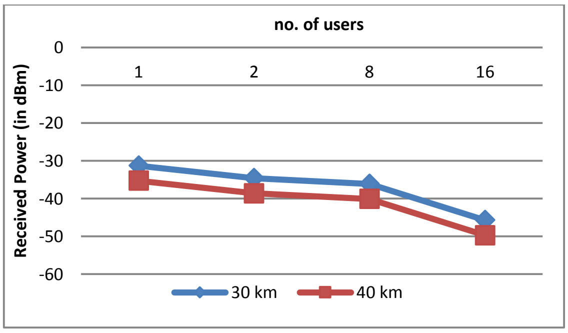


Fig. 17. Received power vs. number of user for different length of fiber

The Fig 17 gives the comparative analysis between received power and the number of users for different length of fiber. The received power weakens with the increase in the number of users. It gets deteriorate when the length of fiber increases.

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