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Simulation realization of 2-D wavelength/time system utilizing MDW code for OCDMA system

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Abstract. This paper presents a realization of Wavelength/Time (W/T) Two-Dimensional Modified Double Weight (2-D MDW) code for Optical Code Division Multiple Access (OCDMA) system based on Spectral Amplitude Coding (SAC) approach. The MDW code has the capability to suppress Phase-Induce Intensity Noise (PIIN) and minimizing the Multiple Access Interference (MAI) noises. At the permissible BER 10^{-9}, the 2-D MDW (APD) had shown minimum effective received power (*Psr*) = -71 dBm that can be obtained at the receiver side as compared to 2-D MDW (PIN) only received -61 dBm. The results show that 2-D MDW (APD) has better performance in achieving same BER with longer optical fiber length and with less received power (P*sr*). Also, the BER from the result shows that MDW code has the capability to suppress PIIN ad MAI.

1 Introduction

Optical Code Division Multiple Access (OCDMA) technology is one of the talented technologies to execute all-optical networks. It is a group of multiplexing and internetworking technologies that encodes/decodes signal through employing straightforward and cost-effective inactive optical component such as the signal multiplexing, routing and switching can be implement easily [1]. OCDMA can be realized in one-dimension (1-D) and two-dimension (2-D) encoding through spatial/spectral domain. The execution assessment of OCDMA framework in view of wavelength/time (W/T) code has been investigated by measuring the estimations of bit error rates for various number of active users [2]. The network capacity of the OCDMA is in high cardinality, compatible code with various bandwidth demands, throughput and acceptable at 10^{-9}-bit error rate (BER) [2, 3, 4]. The OCDMA systems undergo from assured noise such as phase induce-intensity noise (PIIN) shot noise and thermal noise [5]. Besides, multiple access interference (MAI) is the major performance degradation mainly when a large number of users are occupying in the OCDMA systems. Then, the most significant consideration is the code design for decreasing contribution at the MAI to the optical power receives [6]. In OCDMA systems, there are several techniques can be implemented to eliminate MAI. Spectral Amplitude Coding (SAC) is the one that can be used in this system. SAC schemes activate at bit rate, and as a result the condition for receiver bandwidth is tranquil [7, 8]. Here, the performance of 2-D MDW codes for OCDMA systems to achieve higher performance possible through suppressing PIIN and decreasing the MAI was analyzed [9, 10].

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2 Development of 2-D Modified Double Weight (MDW) code

2-D MDW codes are also signified by using the $M \times N$ matrix form. The 2-D MDW codes with M as a number of wavelengths, N as a temporary codes length, W as a weight, λ_a and λ_c are auto-correlation and cross-correlation values respectively. There are denoted by $(M\ x\ N, W, \lambda_a, \lambda_c)$. The j_{th} user's 2-D codes $C^j_{M,N}$, in equation (1), is a matrix of M row vectors $d^j_{k,N}$ related to the temporary spreading; $d^j_{1,N} = c^j_{k,1}, c^j_{k,2}, \ldots, c^j_{k,N-1}, c^j_{k,N}$ where $c^j_{k,i} \in \{0,1\}$ and k is the emitted wavelength of $k \in \{1,\ldots,M\}$ [5, 7, 9].

$$C^j_{M,N} = \begin{bmatrix} d^j_{1,N} \\ d^j_{2,N} \\ . \\ . \\ . \\ d^j_{M-1,N} \\ d^j_{M,N} \end{bmatrix} \quad (1)$$

The signals $r_{k,N}(t)$ are sum of the temporary spreading data of Fu user carried on the wavelength λ_k and expressed as $r_{k,N}(t) = \sum_{j=1}^{Fu} b^j_i(t) d^j_{k,N}$, where $b^j_i(t)$ is i_{th} user data bit of j_{th} and Fu is the number of users. The

M signals $r_{k,N}^{j}(t)$ are multiplexed and the total signal $R_{M,N}(t)$ transmitted on optical fiber is expressed as $M \times N$ [5, 7, 9].

$$R_{M,N}(t) = \begin{bmatrix} r_{1,N(t)} \\ r_{2,N(t)} \\ \cdot \\ \cdot \\ \cdot \\ r_{M-1,N(t)} \\ r_{M,N(t)} \end{bmatrix} \quad (2)$$

2-D MDW optical CDMA network are made of M (transmitter) and N (receiver). $A_{g,h}$ correspond to the code where $g \in (1,2,3,\dots,M-1)$ and $h \in (1,2,3,\dots,N-1)$. X_g and Y_k are spectral and spatial encoding respectively. Table 1 shows the 2-D MDW code projections [5, 7, 9].

Table 1. 2-D MDW Code Projections $k_1 = 4$ and $k_2 = 2$.

$X_{g,h}/Y_g$	[000011011]	[011000110]	[110110000]
$\begin{bmatrix}0\\1\\1\end{bmatrix}$	$\begin{bmatrix}000000000\\000011011\\000011011\end{bmatrix}$	$\begin{bmatrix}000000000\\011000110\\011000110\end{bmatrix}$	$\begin{bmatrix}000000000\\110110000\\110110000\end{bmatrix}$
$\begin{bmatrix}1\\1\\0\end{bmatrix}$	$\begin{bmatrix}000011011\\000011011\\000000000\end{bmatrix}$	$\begin{bmatrix}011000110\\011000110\\000000000\end{bmatrix}$	$\begin{bmatrix}110110000\\110110000\\000000000\end{bmatrix}$

$X = [x_0, x_1, x_2, \dots, x_{M-1}]$ and $Y = [y_0, y_1, y_2, \dots, y_{N-1}]$ are the code sequence of 1-D MDW codes. The 2-D MDW cross-correlation can be derived through four characteristic matrices of $A^{(d)}$, where $d \in (0,1,2,3)$ are defined as:

$$A^0 = Y^T X \quad (3)$$

$$A^1 = Y^T \bar{X} \quad (4)$$

$$A^2 = \bar{Y}^T X \quad (5)$$

$$A^3 = \bar{Y}^T \bar{X} \quad (6)$$

The cross-correlation between $A^{(d)}$ and $A_{g,h}$ can be defined as:

$$R^{(d)}(g,h) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} a_{ij}^{(d)}\, a_{(i+g)(j+h)} \quad (7)$$

Where $a_{ij}^{(d)}$ is $(i,j)_{th}$ of $A^{(d)}$ and $a_{(i+g)(j+h)}$ is $(i,j)_{th}$ of $A_{g,h}$; $g \in (1,2,3,\dots,M-1)$ and $h \in (1,2,3,\dots,N-1)$.

Table 2 shows the cross-correlation of the 2-D MDW code generated from $R^{(d)}(g,h)$. From the table, $R^{(3)}(g,h)$ has nonzero value when $g \neq 0 \cap h \neq 0$. Furthermore, when $g \neq 0$ and $h \neq 0$, the values of $R^{(0)}(g,h)$, $R^{(1)}(g,h)$, $R^{(2)}(g,h)$ and $R^{(3)}(g,h)$ indicates the specific relationships. Cross-correlation function is defined by using $R^{(3)}(g,h)$ to eliminate influence due to $A_{g,h}$ from $R^{(0)}(g,h)$, $R^{(1)}(g,h)$, and $R^{(2)}(g,h)$ when $\neq 0 \cap h \neq 0$. New derived 2-D MDW cross-correlation function is expressed as;

Table 2. 2-D MDW Cross-Correlation.

$X_{g,h}$	$R^{(0)}(g,h)$	$R^{(1)}(g,h)$	$R^{(2)}(g,h)$	$R^{(3)}(g,h)$
$g=0$, $h=0$	$k_1 k_2$	0	0	0
$g=0$, $h\neq 0$	k_1	k_1	0	0
$g\neq 0$, $h=0$	k_2	0	$k_2(k_1$-1)	0
$g\neq 0$, $h\neq 0$	1	1	k_1-1	k_1-1

$$R^{(0)}(g,h) - R^{(1)}(g,h) - \frac{R^{(2)}(g,h)}{(k_1-1)} + \frac{R^{(3)}(g,h)}{(k_1-1)} = \begin{cases} k_1 k_2, & \text{for } g = 0 \text{ and } h = 1 \\ 0, & \text{otherwise} \end{cases} \quad (8)$$

3 2-D Wavelength/Time (W/T) Signal-to-Noise Analysis

Phase-induced intensity noise (PIIN), shot noise and thermal noise are three types of noises that have to be considered in the performance analysis. To identify the thermal lights produces, the photodiode can be expressed as follows [9]:

$$< i^2 > 2eIB + I^2 B\tau_c + \frac{4K_b T_n B}{R_L} \quad (9)$$

The noise power of I_{PIIN}^2 can be expressed as below.

$$\langle I_{PIIN}^2 \rangle = \frac{B_r \Re^2 P_{sr}^2}{M\Delta f k_2^2 (MN-1)^2} \begin{bmatrix} k_1\, k_2\, (MN-1)^2 + \\ [k_2\, (W-1)(M-1)]^2 \end{bmatrix} \quad (10)$$

The short noise current can be written as follow:

$$\langle I_{short}^2 \rangle = 2eB_r \left\{ \frac{\Re^2 P_{sr}^2}{Mk_2(MN-1)} [k_1\, k_2 (MN-1) + 2k_1 (W-1)(N-1) + 2k_2 (W-1)(M-1) + 4(W-1)(M-1)(N-1)] \right\} \quad (11)$$

The thermal noise power is:

$$\langle I_{thermal}^2 \rangle = \frac{4K_b\, T_n\, B_r}{R_L} \quad (12)$$

Total photocurrent output from receiver I_r:

$$\langle I_r^2 \rangle = \left[\frac{\Re\, P_{sr}\, k_1}{M} \right]^2 \quad (13)$$

The signal-to-noise ratio (SNR) equation at receiver is developed as follows:

$$SNR = \frac{I_r^2}{\langle I_{PIIN}^2 \rangle + \langle I_{short}^2 \rangle + \langle I_{thermal}^2 \rangle} \quad (14)$$

Therefore, bit error rate (BER) can be expressed in terms of the signal-to-noise ratio (SNR) [9]:

$$BER(M) = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}} \right) \quad (15)$$

where $erfc$ is:

$$erfc(x) = \frac{2}{\sqrt{x}} \int_x^{\infty} e^{(-z^2)} dz \quad (16)$$

4 Simulation Results and Discussions

Table 3. Table of link parameters.

Parameters Used in Numerical Calculation	
PD quantum efficiency	η=0.6
Spectral width of broadband light source	$\Delta\lambda$ =30 nm(Δ =3.75 THz)
Operating wavelength	λ_0=1.55μm
Electrical bandwidth	B=311 MHz
Data transmission rate	R_b=622 Mbps
Receiver noise temperature	T_n=300 K
Receiver load resistor	R_L=1030 Ω
Boltzmann's constant	K_b=1.38x10^{-23} W/K/Hz
Electron charge	e=1.6021764x10^{-19} coulombs
Light velocity	C=3x10^8 m/s

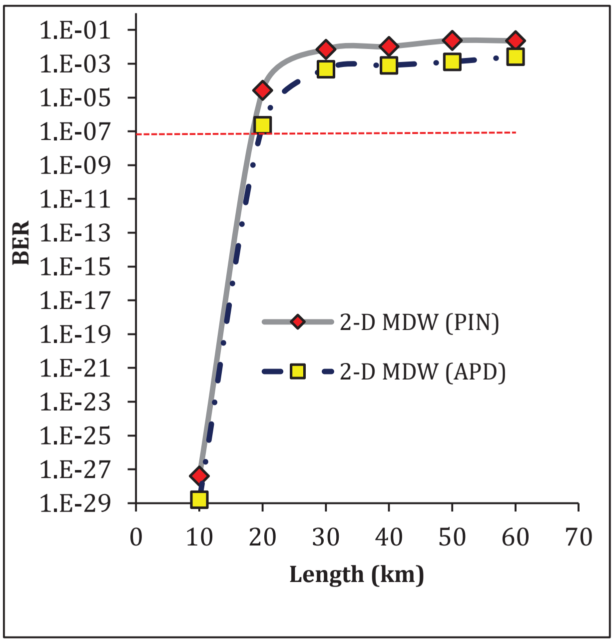

Fig. 1. BER versus optical fiber length for 2-D MDW codes.

Table 3 is the system parameters used to find the numerical results, while Figure 1 demonstrates the graph of BER versus optical fiber length in kilometer (km) for the 2-D MDW codes. In this simulation, 622 Mbps of bit rate is used. The number of length used is from 10 km until 60 km. According to the simulation and the result obtained, the graph increase for both bit rate due to the increasing of the optical fiber length. The system performances of BER 10^{-9} 2-D MDW (APD) at 19 km of fiber length have better performance compared to 2-D MDW (PIN) at fiber length of 18 km. This is because of the distance described by the number of dispersion and the signal loss.

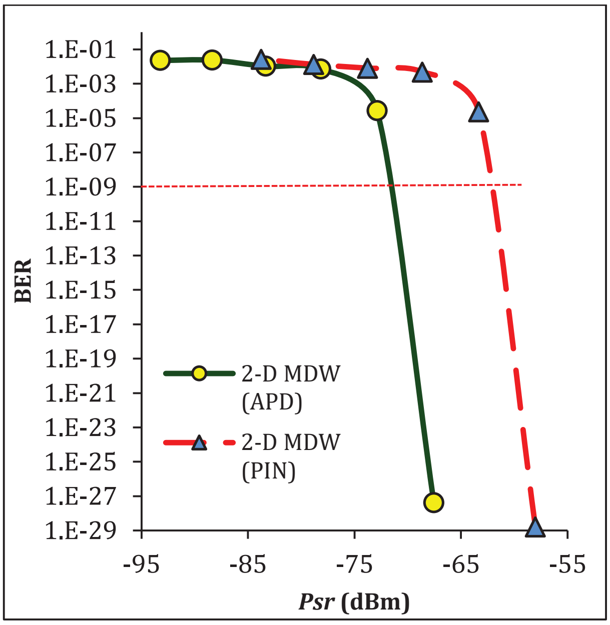

Fig. 2. BER versus effective received power (*Psr*) for 2-D MDW codes.

Figure 2 illustrates the curve of BER versus effective received power (*Psr*) for 2-D MDW codes. The values of effective received power (*Psr*) are varied from -95 dBm until -40 dBm. The number of bit rate used is 622Mbps. Then the length of optical fiber used is 10 km to 60 km. It can be seen that, 2-D MDW (APD) code requires -71 dBm more effective source power to achieve normal optical transmission requirements compared to 2-D MDW (PIN), which requires only -61 dBm. This situation occurs when the losses of fiber optic cable caused the *Psr* to decrease while the BER is increased.

5 Conclusion

From the numerical results, the *Psr* value for 2-D MDW (APD) codes is – 71 dBm while 2-D MDW (PIN) codes is -61 dBm. Therefore, photodiode APD are more effective compared to photodiode PIN because of photodiode APD are increase according their gain. In addition, the theoretical calculation demonstrates the number of BER 10^{-9} so, it's easily to suppress PIIN and eliminate MAI.

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