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The Potential of 2-Dimensional Modified-FCC Code in Noise Reduction in OCDMA Network

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ABSTRACT

In this paper, the potential of new 2-dimensional code to reduce the multiple access interference (MAI) in OCDMA network is investigated. MAI is a phenomenon that occurs when multiple users transmit their signals simultaneously, and the signals will interfere with each other, resulting in degraded performance. In the meantime, the new 2-dimensional code known as Modified-FCC code is introduced which more efficient, helps reduce the impact of MAI and improves the overall system performance. The code was developed from great combination of 1-dimensional code using spectral/time method. The code performance was test using mathematical approach and simulation at different bit rate, power, and cardinality. As the bit rate increase as well as the code length increase, leading to higher bit error rate such as codelength M=6, BER = 10^{-69} while M= 64, BER = 10^{-6}. 2D Modified-FCC code may increase the cardinality with higher SNR as compared to other code which can accommodate more than 250 users even at long codelength. The wide eye pattern with BER 10^{-37}, prove that the 2D Modified-FCC have great potential in reducing the noises in the propose optical network system.

Keywords:

2D modified-FCC; MAI; PIIN

1. Introduction

OCDMA network has proven that it is capable in supporting many subscribers and at the same time can access users, and to have high data rate for each user with a low bit error rate. It was introduced in mid-80's where encoding and decoding operations are performed in optical domain as stated in Kaur *et al.,* [1] and Morsy *et al*., [2]. In OCDMA, each user will be provided with a unique code that is assigned to each transmitter.

When multiple send signal simultaneously user share same network, will introduce multiple access interference (MAI). MAI is the principal source of noise in OCDMA and is the limiting factor to system performance which presents unwanted signals appear as noise to the decoder or receiver side. The other noise should be consider is phase intensity induced noise (PIIN) because it's the main

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reason for performance degradation especially when broadband intensity light was used as a light source as reported by Rashidi *et al.*, [3].

The strength of OCDMA has been recognized with large potential on the networking as discussed details by Kerim *et al.*, [4]. However, it is faced with interference which degrades the system at the receiver section thus affecting the received signal. Introduce 2-dimensional code to fix the problem as well as increase the numbers of subscribers and simultaneous users. There are several 2-dimensional codes have been published by combining different 1-dimensional code from different families. Such codes with efficient detection schemes can effectively suppress the MAI and PIIN and it has been investigated by T. Sharma *et al.*, [5] then followed by [6-10]. Noise investigation has been study since 1 dimensional code was introduced and applied in the optical system. Unfortunately, one dimensional code has disadvantages such as long code length for a large system capacity, where a large bandwidth is used in spectral coding and ultrashort pulses have to be used in temporal coding which conclude by M. A. Morsy *et al.*, [6]. With the presence of many types of 2-dimensional code, its greatly suppressed MAI.

Two-dimensional code can be constructed by various combinations of time, spectral and spatial such as spectral/time, spectral/spatial and spatial/time domains as implemented various author in [12-15]. Spectral/time or wavelength hoping time spreading is the most popular scheme due to extra benefit result in higher transmission capability and more flexibility. M. Qadir *et al.*, [8] demonstrate that 2D-DZ using spectral/time code significantly reduces the contribution of interfering users by mitigating the effect of the cross-correlation functions at the receiving end and enhance system capacity. Cherifi *et al.*, [9] developed 2D SWZCC code using spectral/spatial to enhances the system performance by improving its capacity, reducing the signal-to-noise ratio, and increasing the data rate. As summary, by introduce variety schemes or techniques, the aim is to reduce or eliminate noise, therefore the signal transmission meets the requirement and reliable.

2. Methodology

As mentioned above, 2-D code has been introduced to that capable to reduce interference. Taking the numerous benefits offers by applying 2-dimensional code in optical system such as low interference, enhance security and many more, a new 2-dimensional Modified-FCC code has been introduced and developed for OCDMA which has potential to achieve higher performance through suppressing PIIN and reducing the MAI. 2-D Modified-FCC code was developed from the 1-dimensional Double Weight (DW) family and can be express in codeword (*MxN*, W, λ_a, λ_c) where *M* refer to code length and time *N*, weight *W*, λ_a is the autocorrelation and λ_c is cross-correlation.

These parameters were used in previous research paper [13-17]. The Modified-FCC code generation is using the equation as below:

$$A_{g,h} = Y_h^T X_g \tag{1}$$

The of 2D Modified-FCC code as depicted in in Figure 1.

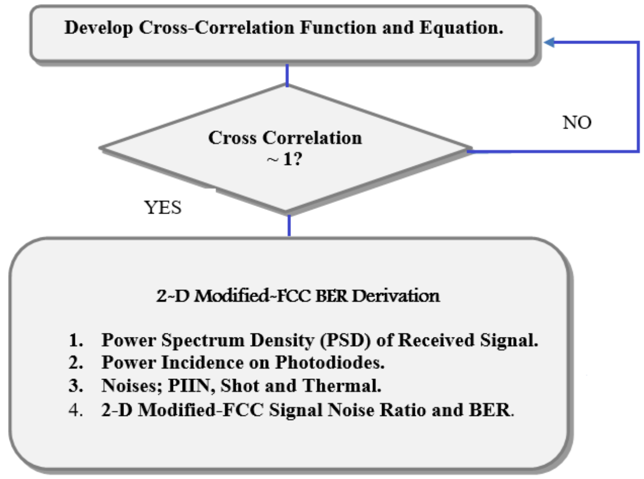

Fig. 1. The flow of 2-Dimensional Modified-FCC code Development

2.1 Coding Development and Noises Equation

Considering 1D MDW code {9,4,1} and 1-D EDW code {6,3,1}. MDW code was developed by Aljunid [10] is derived from DW code and proven has superior performance. While, EDW code has good properties such as ideal cross-correlation, simple encoder/decoder design, existence for every natural number, which can be any odd number greater than one [19,20].

Modified Double Weight Code for User =3

$$\begin{vmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \end{vmatrix}$$

Enhancement Double Weight Code for User = 3

$$\begin{vmatrix} 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{vmatrix}$$

Using Eq. (1), the resulting 2D code arrangement as shown in Figure 2.

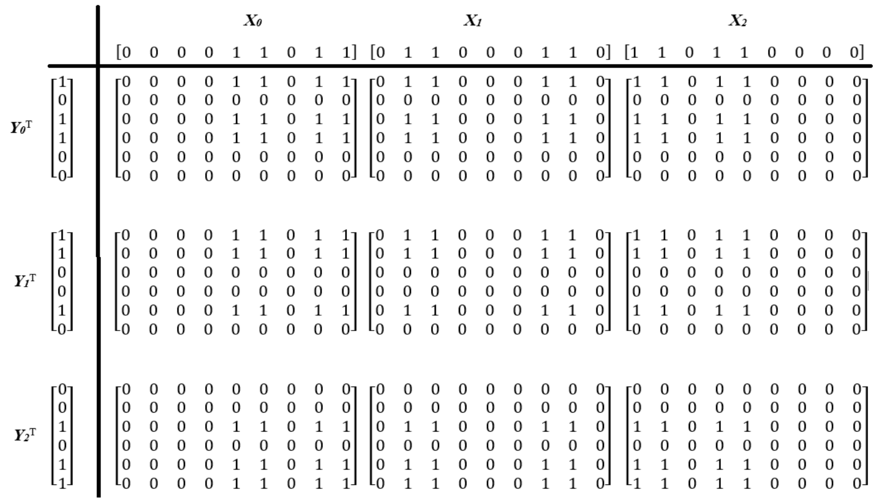

Fig. 2. Arrangement of 2 D Modified-FCC

Next, the correlation property of 2-D Modified-FCC can be derived by introducing the four characteristic matrices of $A^{(d)}$, where *d* is the subset of 0, 1, 2 or 3 $((d) \in (0,1,2,3))$ as proposed by Yang *et al.*, [7] four decoding matrices and four correlation functions are defined as follows:

$$A^{(0)} = Y^T X \text{ , } A^{(1)} = Y^T \overline{X} \text{ , } A^{(2)} = \overline{Y}^T X \text{ and } A^{(3)} = \overline{Y}^T \overline{X} \tag{2}$$

Here,$\bar{X}$ and,$\bar{Y}$ are denotes as the complementary of $X = [x_0, x_1, x_2, x_{M-1}]$ and $Y = [y_0, y_1, y_2, x_{N-1}]$ as shown in Figure 2. Then, the cross-correlation of 2-D code $A^{(d)}$ and $A_{g,h}$ can be expressed as:

$$R^{(d)}(g,h) = \sum_{i=0}^{M-1}\sum_{j=0}^{N-1} a_{ij}^{(d)} a_{(i+g)(j+h)} \tag{3}$$

MAI cancellation property can be expressed as:

$$\mathrm{R}^{(0)}(\mathrm{g},\mathrm{h}) - \frac{\mathrm{R}^{(1)}(\mathrm{g},\mathrm{h})}{\mathrm{K}_1-1} - \frac{\mathrm{R}^{(2)}(\mathrm{g},\mathrm{h})}{\mathrm{K}_2-1} + \frac{\mathrm{R}^{3}(\mathrm{g},\mathrm{h})}{(\mathrm{K}_1-1)(\mathrm{K}_2-1)} = \begin{cases} \mathrm{K}_1\mathrm{K}_2 & \text{for } \mathrm{g}=0 \cap \mathrm{h}=0 \\ 0 & \text{Otherwise} \end{cases} \tag{4}$$

Due to the cross-correlation property, it reduces the complexity of system development. Achieving low correlation values for 2-D OCDMA codes offers several benefits, including maximum orthogonality, high capacity, enhanced security, improved performance, and simplified decoding. These benefits make such codes desirable for efficient and reliable multi-user communication in optical networks. From the cross-correlation it can be assumed that Modified-FCC is characterized by the zero-cross correlation property. From Eq. (3), the next step is to formulate the signal-to- noise ratio (SNR) equation for the system. SNR is the noise level which appears in the system at the receiver part. To examine the SNR of the system, three types of noises; the PIIN, shot noise and thermal noise are taken into consideration. Using Gaussian approximation approaches, SNR can be expressed as inversion of the total of PIIN, Shot and thermal noise or in mathematical form:

$$SNR = \frac{I_r^2}{I_{PIIN}^2 + I_{SHOT}^2 + I_{THERMAL}^2} \tag{5}$$

General equation form of the photocurrent noise emitted from the photodiodes can be expressed as in Eq. (6) and the equation has been provided by Yeh [12], and Wei [13] where, I refer to average photocurrent produced from the photodiode and τ_c = the coherence time of the light source to the photodiode:

$$\langle i^2 \rangle = I^2 B\tau c + 2eIB + \frac{4K_b T_n B}{R_L} \tag{6}$$

The noises equation by considering the power spectral density of the received signal can be formulate as follows:

$$\langle i^2 \rangle = \left\{ \frac{B_r \Re^2 P_{sr}^2}{2M\Delta f k_2^2 (MN-1)^2} [[K_1 K_2 (MN-1)]^2 + 2(K_1 K_2)(MN-1)K_2(W-1)(N-1) + [K_2(W-1)(N-1)]^2 \right\} + \left\{ 2eB_r \frac{\Re P_{sr}}{Mk_2(MN-1)} \left\{ \left[K_1 K_2 (MN-1) + k_1 \left(\frac{1+K_2}{2} \right) (W-1)(M-1) + 2K_2(W-1)(N-1) + 4(W-1)(M-1)(N-1) \right\} \right\} + \left\{ \frac{4K_b T_n B_r}{R_L} \right\} \tag{7}$$

The average photocurrent output from the receiver is defined as:

$$I_r^2 = \left\{ \frac{\Re \mathrm{P_{sr}}}{\mathrm{MK_2}} [\mathrm{K_1}] \right\}^2 \tag{8}$$

From Eq. (7) and Eq. (8), the numerical analysis can be proceeded to calculate the BER to evaluate the performance of 2D Modified-FCC code. The bit error rate is an important metric for the performance characterization of a transmission channel. The minimum error rate is 10^{-9}, which means that, on the average, one error occurs for every billion pulses sent. From the above derivation, from SNR derivation, the BER can be written as:

$$BER = \frac{1}{2}\, erfc\left(\sqrt{\frac{SNR}{8}} \right) \tag{9}$$

3. Results

This section discusses the results from the mathematical analysis and simulation. There are important parameters should be considered for optical network. The performance is based on the bit error rate (BER) and the pattern of eye diagram. The threshold value for BER is set at 10^{-9} and the wide eye-opening means the system has higher resistant to the noise. The noise is analysed from the numerical result, and it is represented by the graph performance in this section. The code performance can be seen from the plot in Figure 3, it was test at input power -10 dBm at different codelength, M and fixed time chip, N . As the codelength increased, it also reflects the increments of cardinality, the BER is saturated at 155 Mbps. Look at 0.622 Gbps when M=6, N=4, the BER value is 9.22×10^{-61}, and at 2.5 Gbps the BER increase to 2.75×10^{-11}. As the codelength increases as well as bit rate increase the , its impact the BER performance become deteriorate.

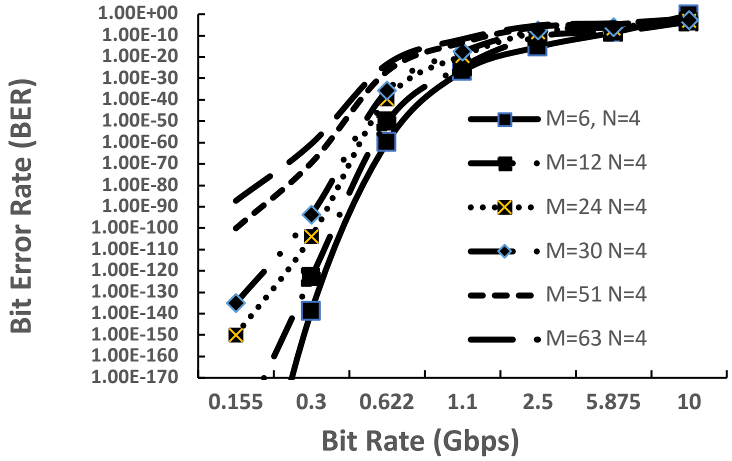

Fig. 3. BER versus Bit Rate at Different codelength, *M*

BER curves against received power P_{sr} for the range of -40 dBm to 0 dBm shows in Figure 4 considering combination of noises such as PIIN+shot, PIIN+ Thermal and PIIN+Shot+thermal. The test was done to investigate which combination may impact the system performance more significantly. It is shows that combination of PIIN and shot noise lowered the BER, thus meets the optical transmission requirement with the lowest P_{sr}= -31 dBm.

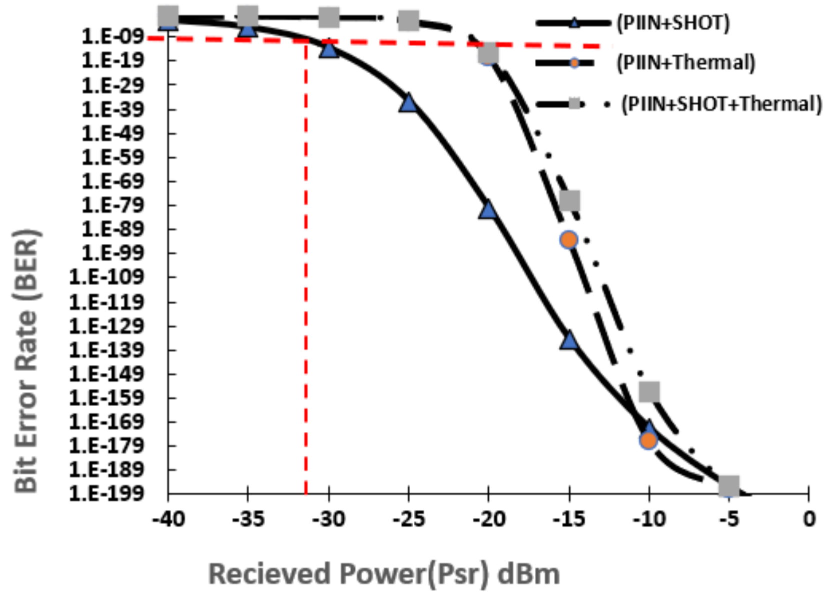

Fig. 4. BER versus Received Power considering combination of noises

The SNR curve for 2D Modified-FCC code decrease as number of user increase but signals remain at higher user compare to 2D MDW and 2D PDC code. The SNR for 2D MDW and 2D PDC code almost reach 0 as user increase. SNR shows that the signal is clear and easy to detect or interpret, while low SNR means that the signal is corrupted or obscured by noise and may be difficult to distinguish or recover. This is important factor at receiver part to recover the original signal from the corrupted.

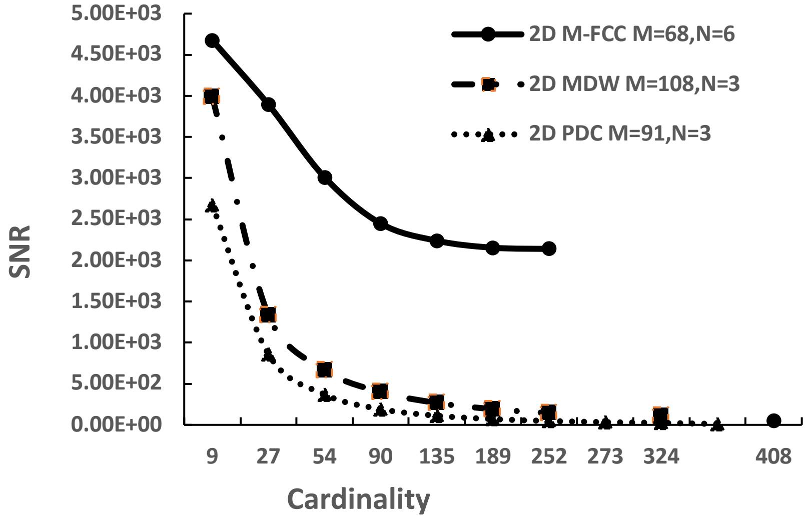

Fig. 5. SNR versus Number of User for 2D Modified-FCC compared to different type of 2D Code

The performance is further investigated by using Optisys, simulate for 9 users simultaneously. The wide eye opening with corresponding BER value 3.71x10^{-37} proved that the network system has higher resistance the noise.

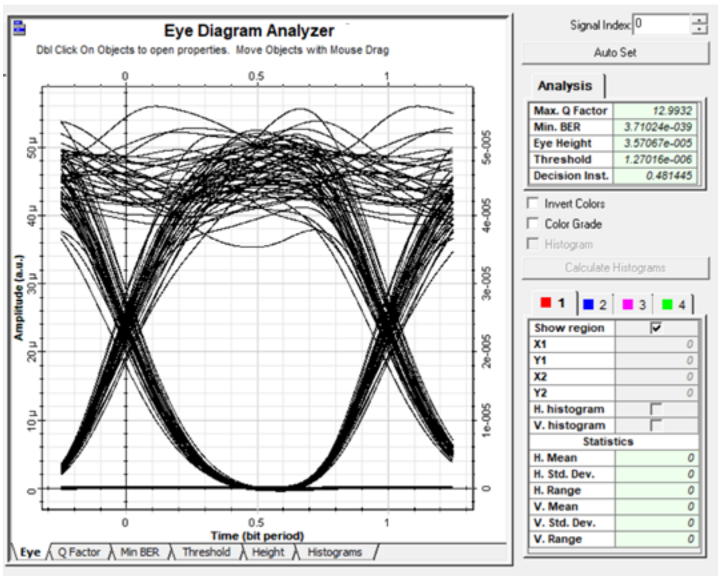

Fig. 6. Eye diagram for 9 users 2D Modified-FCC code

From the discussion, 2D Modified-FCC code was examined and applied to the optical network system and the performance shows the ability to reduce the noise. Furthermore, 2-dimensional Modified-FCC code also allow for accommodating a larger number of users or cardinality in the system with reliable SNR value.

4. Conclusions

In this paper the potential of 2-Dimensional Modified-FCC code in noise reduction for OCDMA network has been presented and discussed. Also, there is content where we show the new 2-

dimensional code development to formulate the noises equation such as PIIN, shot and thermal noise which affect the performance of the optical network. From the analysis, the code performance has been compared to the existing 2D code and show that new 2D Modified-FCC in 2D families able to reduce noise and improved system performance.

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