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Predominance Performance of Sequential Algorithm (SeQ) Code in an Optical CDMA Networks

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Abstract: This study present a new Sequential Algorithm (SeQ) code structure for Optical Code Division Multiple Access (OCDMA) system with flexible cross-correlation has been proposed. In contrary to the existing codes, this SeQ code provides much better performance in term of Bit Error Rate (BER) and Signal Noise Ratio (SNR) for any number of active users. This newly proposed code can adapt to any variable numbers of users by using tridiagonal code matrix. The result obtained from comparison with existing code, DCS, MDW and Hadamard. Thus, at the typical error rate of optical communication system BER = 10^{-9} this study illustrate that SeQ code can accommodate 190 numbers of simultaneous users compared with DCS (W = 4), MDW (W = 4) and Hadamard (W = 4). This SeQ code capable to enhance performance BER about 46, 27, 100% in comparison with DCS (W = 4), MDW (W = 4) and Hadamard (W = 4) codes. In addition, SeQ code has revealed that this code can improve OCDMA system due SeQ code has highest SNR of 200 numbers of simultaneous users compared with DCS (W = 4) and MDW (W = 4). Thus, the results obtained in this study as an evidence that SeQ code was truly performed better than existing codes and applicable to enhance OCDMA system network for future generation usage.

Key words: Optical Division Multiple Access (OCDMA), Sequential Algorithm (SeQ) code, Bit Error Rate (BER), Signal Noise Ratio (SNR), tridiagonal code matrix, system

INTRODUCTION

In modern communication systems, fiber-optics have an advanced developments over the past three decades as the transmission media. The optical fiber communication links provided several advantages such as large transmission bandwidth, lower attenuation, lower immunity to electromagnetic interference, smaller physical size and high level of security. In OCDMA, the interested of fiber-optics has been steadily growth up and this trend accelerating due to the optical fiber penetration within first-mile and the establishment of Passive Optical Network (PON) technology as a pragmatic solution for residential access (Kumar *et al*., 2015). OCDMA network systems are multiplexing procedure which each communication channel is distinguished by a specific optical code rather than a wavelength or time-slot. Before transmission process, each data bit need to encoded transform operation optically. At the receiver to cover the original data the reverse decoding operation is required. The encoding and decoding operations alone constitute optical coding (Abd *et al*., 2012a, b). The OCDMA system is recognized as one of the most important technologies are created to support many users in shared media simultaneously and capable to increase transmission capacity (Parikh and Paliwal, 2015). The concept of assigning spreading codes to each user in a fiber optic communication network is used in OCDMA. A user transmits an assigned code whenever a '1' is to be transmitted and '0' does not transmit anything (Rashidi *et al*., 2014). In the advantages of OCDMA is can eliminating the effect of MAI when code with flexibility cross-correlation property by utilized an address sequences and balance detection at the receiver (Abd *et al*., 2012a, b). While PIIN depends on the number of interfering users and cannot be improved by increasing the transmitted power or additional amplification at the receiver side. Since, the signal amplification is always accompanied by an equal amount of noise amplification and cannot improve the ratio of signal power to noise power (Atri *et al*., 2014). In this study, a new code SeQ code has been developed. This code assumed that the in

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phase cross correlation value can flexible which ensures that each codeword can be easily distinguish from every other address sequence. This SeQ code constructed with simple tridagonal matrix property and any given number of users and weights. The system performance significantly improves with the existing code Dynamic Cyclic Shift (DCS), Modified Double Weight (MDW) and Hadamard code. This SeQ code is proposed for PIIN and MAI cancellation. The huge advantages of this proposed code are can support high cardinality, low received power and short code length.

MATERIALS AND METHODS

SeQ code coding properties: A set of codes K for the user is binary [0, 1] sequences of length N, code-weight W (the number of “1” in each code word) and the maximum cross-correlation, λ_c. The optimum code set is one having any desired cross-correlation properties to support the maximum number of users with shortest code length. The least for the short haul optical networking to ensured guaranteed quality of services with low error probabilities for giving number of users K.

Step 1: A set of K, length of code N and code-weight W for K users. This set of codes is then represented by a K×N matrix $A^w{}_K$ where the elements a_{ij} of $A^w{}_K$ is binary [0, 1] known as tridiagonal code matrix can be written as:

$$A_K^w = \left\{ a_{ij} = \text{'0' or '1' for} \quad \begin{matrix} i = 1, 2, ..., K \\ j = 1, 2, ..., N \end{matrix} \right. \tag{1}$$

K codes, represented by the K rows of the code matrix are unique and independent of each other, $A^w{}_K$ should have rank K. Moreover for $A^w{}_K$ to have rank K:

$$N > K \tag{2}$$

Step 2: The K×N optical code matrix $A^w{}_K$ as defined by Eq. 2. The code-weight of each of the K codes is assumed to be W. The tridiagonal code matrix $A^w{}_K$ is given by Eq. 3 and the rows A_1, A_2, A_K represent the K code words:

$$A_K^w = \begin{bmatrix} a_{11} & b_{12} & c_{13} & 0 & \cdots & 0 & 0 \\ 0 & d_{14} & a_{21} & b_{22} & \cdots & 0 & 0 \\ 0 & 0 & c_{23} & d_{24} & \cdots & 0 & 0 \\ \vdots & \ddots & \ddots & \ddots & \cdots & 0 & 0 \\ 0 & 0 & 0 & 0 & \cdots & c_{i-1} & a_{KN} \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_K \end{bmatrix} \tag{3}$$

Where:

$$A_1 = a_{11}, b_{12}, \cdots d_{1N}$$
$$A_2 = d_{14}, a_{21}, \cdots b_{2N}$$
$$A_3 = c_{23}, d_{24}, \cdots a_{3N}$$
$$A_K = 0, 0, \cdots c_{1-i}, a_{KN}$$

Step 3: The K codes, represented in Eq. 3 are to represent a valid set of K code word with in phase cross-correlations λ_c and code-weight W, it must satisfy the following conditions: the elements $\{a_{ij}\}$ of $A^w{}_K$ must have values “0” or “1”:

$$a_{ij} = \text{“0” or “1” for } i = 1, 2, .. K, j = 1, 2, N \tag{4}$$

The code-weight W of each code word should be equal to W where:

$$\sum_{j=1}^{N} \alpha_{ij} = W, \; i = 1, 2 ... K \tag{5}$$

There should not exceed between any of the K, code words (K rows of the matrix $A^w{}_K$) and code-weight W in phase cross-correlation, λ_c. That is:

$$A_i A_i^T = \begin{cases} \le \lambda_c \text{ for } i \ne j \\ = W \text{ fori} = j \end{cases} \tag{6}$$

From Eq. 6, it is seen that the $W = A_i A_i^T$ is the in-phase auto-correlation function of codes. $A_i A_j^T$ is the out of phase correlation between the ith and the jth codes. It follows that $A_i A_i^T$ should be greater than $A_i A_j^T$. In other words:

$$W \ge \lambda_c \tag{7}$$

All K rows of $A^w{}_K$ should be linearly independent because each codeword must be uniquely different from other words. That is to say the rank of the matrix $A^w{}_K$ should be K. One of the matrices that satisfies the four conditions above is the K×N matrix $A^w{}_K$ whose ith row is given by:

$$A_i = \overbrace{11..1}^{w}\,\overbrace{0...0}^{r\,(K-i)} \tag{8}$$

The length N of the codes which is the length of the rows of the matrix $A^w{}_K$ is given by:

$$N = WK - \lambda_c \, (K-1) \tag{9}$$

Step 4: On the basis of the above discussions, the construction of an optical code having a value of K, code-weight W, λ_c consists of the following steps:

- For a given number of users K and code-weight W, forms a set of flexible in phase cross-correlation code with a minimum length as given by Eq. 8
- The length N of code matrix has defined by Eq. 9
- The K rows of the code matrix that give the K optical CDMA codes having flexible in phase cross correlation, code-weight W and shortest code length

The SNR is defined as the average signal to noise power, SNR = $[I^2/\sigma^2]$ where σ^2 is the average power of noise which is given by:

$$\sigma^2 = \left\langle i^2_{shot} \right\rangle + \left\langle i^2_{PIIN} \right\rangle + \left\langle i^2_{thermal} \right\rangle \tag{10}$$

Equation 10 can be expressed as:

$$\sigma^2 = 2eBI + I^2 B\tau_c + \frac{4K_b T_n B}{R_L} \tag{11}$$

Where:

e = Electron charge
I = Average photocurrent
I^2 = Power spectral density for
I, B = Noise equivalent of electrical bandwidth
K_b = Boltzmann constant
T_n = Absolute receiver noise temperature
R_L = Receiver load resistor

Equation 11 it has been assumed that the optical bandwidth is much larger than the maximum electrical bandwidth. The coherence source time τ_c is given as:

$$\tau_c = \frac{\int_0^\infty G^2(v)\, dv}{\int_0^\infty G(v)\, dv} \tag{12}$$

where, G(v) denotes as the single sideband source Power of Spectral Density (PSD). Noticed, the effect of receiver's dark current has been neglected in this proposed system analysis. The broadband pulse coming thru to the FBG as an incoherent light field is mixed and incident upon a photo-detector output.

The proposed system was analyzed with transmitter and receiver. That are important for mathematical preliminaries simplicity. Since, to analyze the proposed system. The following assumptions:

- Each unpolarized source PSD and its spectrum are flat over the system bandwidth of $[V_0 \pm (v/2)]$ with amplitude P_{sr}, Δv, v_0 is the central optical frequency and Δv is the optical source bandwidth expressed in Hertz

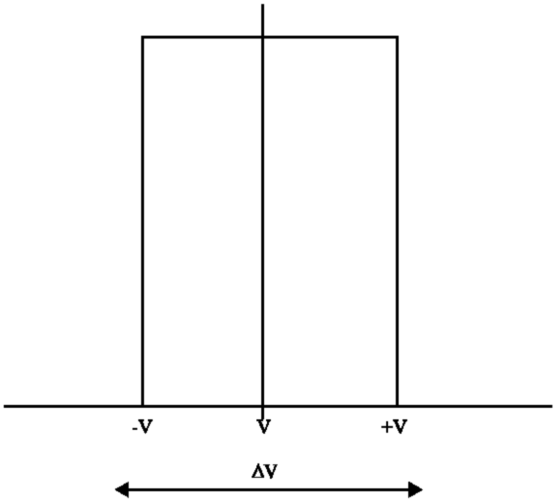

Fig. 1: Bandwidth of ΔV

- Each user has equal power at receiver
- Each nit stream for each user is synchronized
- Each power spectral component has an identical spectral width

Based on the above assumptions, the proposed system can easily analyze using the Gaussian approximation. The PSD of the received optical signals can written as:

$$G(v) = \frac{P_{sr}}{\Delta v} \sum_{K=1}^{K} d_K \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} [\Pi(i)] \tag{13}$$

Where:

P_{sr} = Received power from a single source
ΔV = Assumed as perfect rectangular unit step function

Figure 1 showed the bandwidth. Where, the {0, 1} is an element of unit step function given as follows:

$$\left.\begin{array}{l} 1, \text{ for } v \geq 0 \\ 0, \text{ for } v < 0 \end{array}\right\} \in \prod(i) \tag{14}$$

Equation 13 is the total incident power PSD at the input of PIN1 and PIN2 and can be written as:

$$\begin{gathered} \int_0^\infty G_1(v)dv = \frac{P_{sr}}{\Delta V} \sum\nolimits_{i = j,\, i \neq j} dK \sum\nolimits_{j=1}^{j} \sum\nolimits_{i=j}^{K} X_{ij}\ Y_{ij} \\ \left\{ u \left[\frac{\Delta v}{N} \right] dv = \frac{P_{sr}}{N} + \frac{P_{sr}}{N} \sum_{i = j,\, i \neq j} dK \right. \end{gathered} \tag{15}$$

$$\int_0^{\infty} G_2(v)\,dv = \frac{P_{sr}}{\Delta v}\sum_{i=j,\,i\neq j} dK \sum_{j=1}^{j}\sum_{i=1}^{K} X_{ij}\times$$
$$Y_{ij}\left\{u\left[\frac{\Delta v}{N}\right] dv = \frac{P_{sr}}{N}+\frac{P_{sr}}{N}\sum_{i=j,\,i\neq j} dK\right. \qquad (16)$$

PSD spectrum will be calculated and the photodiode current I and can be written as follows:

$$I = \Re\int_0^{\infty} G(v)\,dv \qquad (17)$$

$\Re$ represents as the responsively of the photodetectors. Consequently from Eq. 13 the photo current i can be expressed as:

$$I = \Re\left[\frac{P_{sr}[W]}{N}\right] \qquad (18)$$

The power of shot noise can be written by subtracting Eq. 15 and 16, respectively as:

$$\left\langle i^2_{shot}\right\rangle = 2eB\Re\left[\frac{P_{sr}}{N}\right][W+3] \qquad (19)$$

The PIIN noise will dominate the broadband sources. Hence, with PSD from each user is the same from that we calculate the receiver PIIN noise directly from the total PSD of each photodiode. By using an Eq. 19 the PIIN noise at the receiver output is given by:

$$\left\langle i^2_{PIIN}\right\rangle = B(I_1^2\tau_{c1}+I_1^2\tau_{c2}) = I^2\times\tau_c\times B \qquad (20)$$

Where:

I_1 and I_2 = The average photodiode currents

τ_{c1} and τ_{c2} = The coherence times of light incident on each photodiode

By using Eq. 13, 15, 16 and 20, the variance of the PIIN noise at the receiver can be expressed as:

$$\left\langle i^2_{PIIN}\right\rangle = \frac{B\Re^2 P_{sr}^2 KW}{N^2\Delta v}[3W+1] \qquad (21)$$

Since, from Eq. 3 until Eq. 7 shown the properties of SeQ code are unique and independent of each other, Eq. 21 is also independent of the active user's data, consequently, proposed coding system does not depend on the timing of transitions in the data and it applied to the asynchronous system. Thermal noise is given as:

$$\left\langle i^2_{Thermal}\right\rangle = \frac{4K_b\,T_nB}{RL} \qquad (22)$$

Table 1: Typical parameters for theoretical calculations

Parameters	Values
Electron's charge	$e = 1.60217646\times10^{-19}$ coulombs
PD quantum	$\eta = 0.75$
Electrical bandwidth	B = 80 MHz
Boltzmann constant	$K_b = 1.38\times10^{-23}$ W/K/Hz
Receiver noise	$T_n = 300$ K
Receiver load resistor	$R_L = 1030\,\Omega$
Data transmission rate	$R_b = 155$ Mbps
Broadband line width	$\Delta\lambda = 3.75$ THz

From Eq. 18, 19 and 21, the SNR for the proposed SeQ code in the OCDMA coding system is defined by:

$$SNR = \frac{\left[\frac{\Re P_{sr}W}{N}\right]^2}{\left[\frac{2eB\Re P_{sr}}{N}\right][3W+1]+B\Re \left[\frac{P^2srKW}{N^2\Delta V}\right][3W+1]+\frac{4KbT_nB}{RL}} \qquad (23)$$

Since, there is no pulses are sent for the data bit '0' an assuming that the noise distribution is Gaussian, thus, the corresponding BER can be obtained as follows:

$$BER = \frac{1}{2}\,efrc\left(\sqrt{\frac{SNR}{8}}\right) \qquad (24)$$

Finally, Eq. 23 and 24 will be used for the numerical calculation for an evaluation of the proposed SeQ code OCDMA coding system utilizing SeQ code. The performance of the SeQ code has been compared numerically with the existing OCDMA codes such as DCS, MDW and Hadamard. The numerical parameters used are shown in Table 1.

RESULTS AND DISCUSSION

Performance analysis: Figure 2 shows the relation between performances of BER to the numbers of simultaneous of users of SeQ code (W = 4), DCS (W = 4), MDW (W = 4) and Hadamard (W = 4). The performance of BER analyzed from Eq. 24. The SeQ code (W = 4), DCS (W = 4), MDW (W = 4) and Hadamard (W = 4) considered for 200 numbers of simultaneous users at 155 Mbps bit rate and effective power-10 dBm. From the plots, the performance of BER becomes increasingly degraded as the number of simultaneous users increased. At the error floor BER = 10^{-9}, SeQ code (W = 4) shows the excellent performance compared with DCS (W = 4), MDW (W = 4) and Hadamard (W = 4). Figure 2 shows the SeQ code (W = 4) can accommodate 190 numbers of simultaneous of users in comparison with DCS (W = 4), MDW (W = 4) and Hadamard (W = 4) are 130, 150 and 20 numbers of

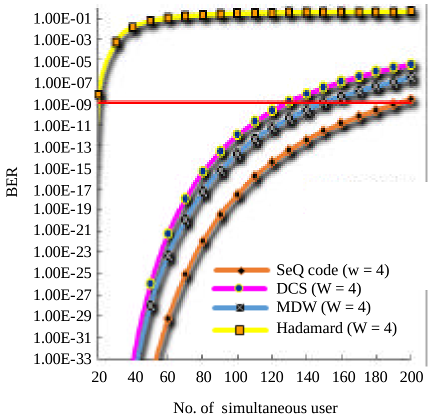

Fig. 2: Performance BER versus numbers of simultaneous users of SeQ code (W = 4), DCS (W = 4), MDW (W = 4) and Hadamard (W = 4)

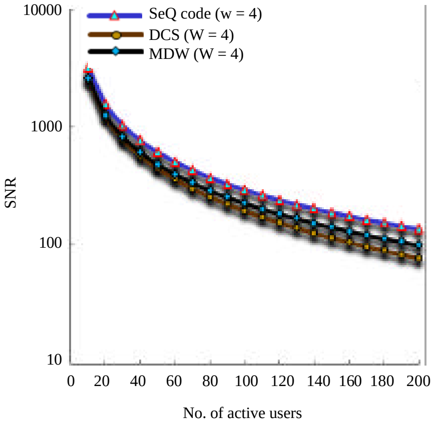

Fig. 3: Relation between performance of SNR and numbers of active users of SeQ code (W = 4), DCS (W = 4) and MDW (W = 4)

simultaneous users. Since, each code sequence is assigned to specific BER = 10^{-9} error floor, the SeQ code has cardinality improvement about 46, 27 and 100% of DCS (W = 4), MDW (W = 4) and Hadamard (W = 4) codes. Thus, SeQ code presents excellent performance due to the arrangement of the code algorithm and in phase cross-correlation cause the SeQ code curve is the nearest to the error floor which is BER = 10^{-9}. Hence, this result revealed that SeQ code can enhance the performance of the OCDMA system better than others existing codes.

SNR is an important indicator that describes the ratio of the level of a desired signal to the level of the background noise at the receiver. Figure 3 demonstrates the performance of SNR versus numbers of active users of SeQ code (W = 4), DCS (W = 4) and MDW (W = 4). This SNR was analyzed based on Eq. 11. This result, proposed the effective power P_{sr} = -10 dBm and 155 Mbps of 200 numbers of users. From the graph, the SNR curves slightly decrease each other as the numbers of active users increased. It can be seen that the SeQ code (W = 4) was the superior curve performance in comparison with DCS (W = 4) and MDW (W = 4). The SeQ code (W = 4) was the highest SNR as opposed to DCS (W = 4) and MDW (W = 4), respectively. Hence, this result revealed that the SeQ code can effectively eliminate the effect of PIIN noise and yield a good result due the flexibility of in-phase cross-correlation of SeQ code compared with DCS (W = 4) and MDW (W = 4), respectively. In addition, the higher the SNR will enhance the system capacity of the system. Hence, the SeQ code has capable to enhance the OCDMA system for future generation and various numbers of users.

CONCLUSION

The algorithm of the SeQ code develop to enhance the impact of correlation that has been presented in OCDMA system. The SeQ code had shown excellent performance indicated that SeQ OCDMA coding system can accommodate a highest numbers of simultaneous users 190 at the error floor BER = 10^{-9}. From the results, this SeQ code will give an opportunity in OCDMA system for better quality of service in optical access for future generation's usage.

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