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Performance Evaluation of a Novel Optimization Sequential Algorithm (SeQ) Code for FTTH Network

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Abstract. The SeQ codes has advantages, such as variable cross-correlation property at any given number of users and weights, as well as effectively suppressed the impacts of phase induced intensity noise (PIIN) and multiple access interference (MAI) cancellation property. The result revealed, at system performance analysis of BER = 10^{-09}, the SeQ code capable to achieved 1 Gbps up to 60 km.

1 Introduction

Multiple Access are used to allow a large number of mobile users to share the allocated spectrum in the most efficient manner. The types of multiple access are TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access) [1]. In CDMA, the same bandwidth is occupied by all the users. However, they are all assigned separate codes, which differentiates them from each other's [2]. Optical CDMA system provide users both simultaneous and asynchronous access to networks with high security. CDMA is a strong candidate for creating effective multiple methods for the multiple methods for the optical subcarrier access network because of its asynchronous access and code multiplexing [3]. Optical network provide higher capacity and reduced costs for new applications such as internet, video, multimedia and advanced digital services. The OCDMA network system allow to each subscriber a specific code word. The code word permits to the transmitter to modulate its data sequences. In order to satisfy faster and more reliable optical communication system requirements and optimize the huge optical bandwidth sharing [4]. The main advantages of OCDMA compared with others techniques are the high capacity for higher connectivity, have more flexible bandwidth usage, higher granularity and scalability within optical networks, capable improved crosstalk performance, asynchronous access, and have potential for improved system security as number of users on the network has specific address code [5]. In OCDMA system, a bit of "1" is to be transmitted as an assigned code and a bit of "0" does not transmitted anything [5]. In OCDMA, most important consideration are code design. Multiple Access Interference (MAI) is the interference from other users transmitting at the same time, which will limit the effective error probability with the presence of noise in the overall system [6].

In OCDMA, PIIN will increase between codes sequences because of inappropriate cross users and cannot be improved by increasing the transmitted power [7]. There have several codes have proposed for OCDMA system, such as Flexible Cross-Correlation (FCC), Modified Double Weight (MDW), Dynamic Cyclic Shift (DCS), Modified Frequency Hopping (MFH) and Hadamard code. This paper present, algorithm called Sequential Algorithm (SeQ) code has been developed. This proposed code was developed based on superior performance of Flexible Cross Correlation proposed by [7] where, SeQ code utilizing even and odd properties in order to enhance the limitations occurs in the existing codes.

2 Sequential Algorithm (SeQ) Code Design Approach

The SeQ code design is concerned about mathematical preliminaries to design codes for any given number of users and weights to have minimum code length. Since, optical codes may be represented as vectors; linear algebra has been used for the design of these codes. The codes are treated as rows of a matrix of finite dimension; hence, the methods of design and analysis of matrix algebra is best suited in these cases. For the codes be unique, the code matrix is required to have a finite value of its rank for a given set of users. The in phase auto-correlation functions and the cross-correlation functions of the codes can easily be defined in term of the dot and cross product of the rows of the matrix. The auto-correlation of each codeword $a_i = (a, a_2, a_3 .. a_N)$ and the cross-correlation between any two distinct codeword $A_i = (a_1, a, a .. a_N)$and $B_j = (b_1, b_2, b_3 .. b_N)$,respectively. Optical code are family of *K* (for *K* users) binary [0, 1] sequences of length *N*, code weight *W* (the number of "1" in each codeword) and the maximum cross-correlation, λ_a. The auto and cross-correlation functions of these sequences are defined by [7];

$$\lambda_a(\tau) = \sum_{i=1}^{N} a_i a_{i+\tau} = W \ for \ \tau = 0 \quad (1)$$

$$\lambda_{ab}(\tau) = \sum_{i=1}^{N} a_i b_{i+\tau} \leq 1 \ for \ \tau = 0 \quad (2)$$

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Hence, major bottleneck in the successful implementation of all optical networks is basically when all the users try to transmit their data simultaneously. It is noteworthy when designing coding sequences such that, it must cause least overlapping between data chips. Now, let $A = \{a_n\}$ and $B = \{b_n\}$ be the sequences of length N such that the vector form can be written as [8];

$$\left.\begin{aligned} \{a_n\} &= '0' \; or \; '1', i = 0, \ldots N-1 \\ \{b_n\} &= '0' \; or \; '1', i = 0, \ldots N-1 \end{aligned}\right\} \quad (3)$$

Since a_n is a {0, 1} binary sequence, the maximum value of λ_a (τ) in Eq (1) is for τ = 0 and is equal to W, the code weight of the sequence can be expressed as;

$$\lambda_a(0) = W \quad (4)$$

The codes described by Eq (3) can also be represented in vector form as;

$$\left.\begin{aligned} A &= \{a_i\} = for \; i = 0, 1, \ldots N-1 \\ B &= \{b_i\} = for \; i = 0, 1 \ldots N-1 \end{aligned}\right\} \quad (5)$$

where, X and Y are vectors of length N with elements as defined by Eq (5). In terms of the vectors X and Y, Eqs (1) and (2) can be written as [9];

$$\left.\begin{aligned} \lambda_a(0) &= AA^T = W \\ \lambda_{ab}(0) &= AB^T \end{aligned}\right\} \quad (6)$$

where, A^T and B^T denote the transpose of vectors A and B, respectively.

Table 1: Codeword of SeQ code for W=3, K=4 and $\lambda_a \leq 1$

Basic	Parity
(1 2 4)	1 1 0 1 0 0 0
(2 3 5)	0 1 1 0 1 0 0
(3 4 6)	0 0 1 1 0 1 0
(4 5 7)	0 0 0 1 1 0 1

Notice that the code weight of each row more than two, and the relation between N and K for SeQ code can be express as:

$$N = K + 2W - 3 \quad (7)$$

2.1 Signal to Noise Ratio Performance Analysis

The Signal Noise Ratio (SNR) is defined as the average signal to noise power, $SNR = \left[\frac{I^2}{\sigma^2}\right]$, where σ^2 is the average power of noise which is given by [9],

$$\sigma^2 = \langle i^2_{shot} \rangle + \langle i^2_{PIIN} \rangle + \langle i^2_{thermal} \rangle \quad (8)$$

$\mathcal{R}$ represents as the responsively of the photo-detectors. Hence the photo current I can be expressed as;

$$I = \Re\left[\frac{P_{sr}[W]}{N}\right] \quad (9)$$

The power of *Shot* noise can be written as [7];

$$\langle i^2_{shot} \rangle = 2eB\mathcal{R}\left[\frac{P_{sr}}{N}\right][3W + 1] \quad (10)$$

The Phase Induced Intensity Noise (PIIN) noise will dominate the broadband sources. The PIIN noise at the receiver output is given by;

$$\langle i^2_{PIIN} \rangle = B(I_1^2 \tau_{c1} + I_1^2 \tau_{c2}) = I^2 * \tau_c * B \quad (11)$$

Furthermore, the variance of the PIIN noise at the receiver can be expressed as;

$$\langle i^2_{PIIN} \rangle = \frac{B\mathcal{R}^2 P_{sr}^2 KW}{N^2 \Delta_V}[3W + 1] \quad (12)$$

Thermal noise is given as [8];

$$\langle i^2_{Thermal} \rangle = \frac{4K_b T_n B}{R_L} \quad (13)$$

From Eqs. (9), (10), and (12), the SNR for the proposed SeQ code in the ODCMA coding system is derived as [6];

$$SNR = \frac{\left[\frac{\Re P_{sr} W}{N}\right]^2}{\left[\frac{2eB\Re P_{sr}}{N}\right][3W+1] + B\Re\left[\frac{P_{sr}^2 KW}{N^2 \Delta V}\right][3W+1] + \frac{4K_b T_n B}{R_L}} \quad (14)$$

Since, the corresponding BER can be obtained as follows [6];

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

Finally, Eqs. (14) and (15) will be used for the theoretical calculation for an evaluation of the proposed OCDMA coding system utilizing SeQ code. The performance of the SeQ code will be compared with the existing OCDMA codes, respectively. The theoretical parameters are shown in Table 2.

Table 2: Typical parameters for theoretical calculations.

Parameter	**Value**
Electron's charge	$e = 1.60217646 \times 10^{-19}$ coulombs
PD quantum	η = 0.75
Electrical bandwidth	B = 80 MHz
Boltzmann constant	$K_b = 1.38 \times 10^{-23}$ W/K/Hz
Receiver noise	$T_n = 300$K
Receiver load resistor	$R_L = 1030$ Ω
Data transmission rate	$R_b = 155$ Mbps
Broadband line width	Δλ = 3.75 THz

3 Result and Discussion

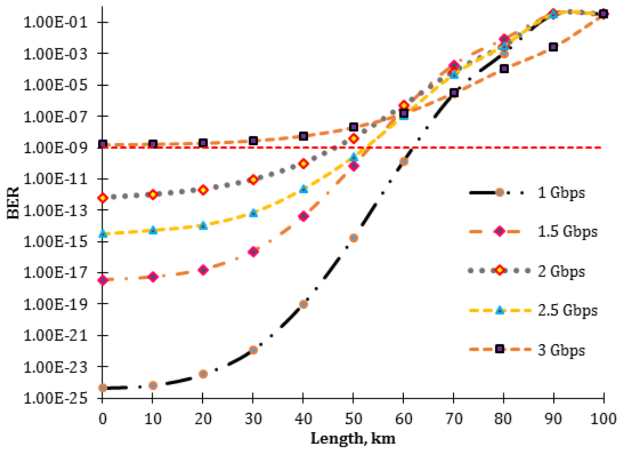

Fig. 1. Performance BER versus Fiber Length (km) for SeQ code (W=4) at Different Bit Rates.

Fig. 1 shows the performance of BER versus fiber length (km) for SeQ code (W=4) at variance bit rate of 1 Gbps, 1.5 Gbps, 2 Gbps, 2.5 Gbps, and 3 Gbps, respectively. From the graph, 1 Gbps bit rate shows the excellent performance of BER compared with 1.5 Gbps, 2 Gbps, 2.5 Gbps, and 3 Gbps. Even the 3 Gbps the worst performance yet still at BER = 10^{-09}. However, at permissible BER = $10^{-09,}$ 1 Gbps bit rate capable to support the performance of BER up to 60 km. Contrast with 1. 5 Gbps, 2 Gbps, 2.5 Gbps and 3 Gbps bit rate only can perform at 55 km, 50 km, 45 km and 30 km, respectively. From these observation, SeQ (W=4) at 1 Gbps can successfully eliminate and suppressed the effects of PIIN and MAI for the OCDMA coding system.

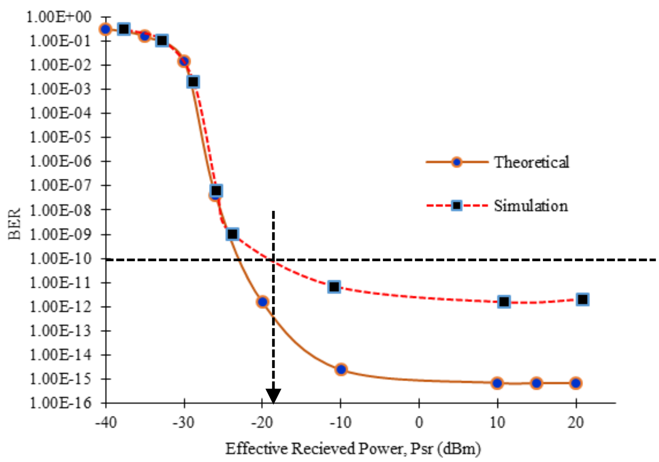

Fig. 2. Relationship Performance of BER versus effective power theoretical and simulation of SeQ code (W=4).

Fig. 2 illustrates the comparison between theoretical and simulation for BER performance versus various effective received power, P_{sr} for SeQ code. From the graph plots, the theoretical results on BER performance with effective receive power P_{sr} are close to the simulation results when the effective received power, P_{sr} are increased. At error floor BER= 10^{-09}, the effective received power, P_{sr} for theoretical and simulation are -24 dBm. Nevertheless, the performance of BER increasingly degrade after the effective received power, P_{sr} are increased. However, the theoretical result supposed to be excellent compared with the simulation result. It can be observed that, when the effective received power, P_{sr} are increased the performance BER are constant. For theoretical analysis result the BER performance is 10^{-15} whereas, for simulation analysis the BER performance is 10^{-11}, respectively. This performance are not parallel due to very tough to achieve a fix BER in simulation rather that theoretical result. In addition, there are addition losses in the components used in simulation which are not included in the theoretical formula Eqs. (14) and (15).

Conclusion

The new SeQ code address code capable to enhance the impact of noises influences has been presented. The SeQ code had shown superior performance where at BER = 10^{-09} can achieve bit rate of 1 Gbps up to 60 km as compared to 15 Gbps, 2 Gbps, 2.5 Gbps and 3 Gbps, respectively. The system successfully degrade the BER, due to PIIN and MAI can be suppressed by using SeQ code. From the result, 1 Gbps shows the excellent performance compared with existing bit rate. For OCDMA system, 1 Gbps was the suitable enough speed for FTTH and LAN network. Besides that, as an evidence that SeQ have enhanced the system compared with existing code, the simulation result compared with theoretical result for validation that SeQ code capable to enhanced the system. From the result obtain, theoretical result can achieve good performance compared with theoretical result, quite difficult to achieve exactly effective receive power due to come component can't be included in theoretical result.

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