Optik 123 (2012) 956–963

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Variable cross-correlation code construction for spectral amplitude coding optical CDMA networks

Hilal A. Fadhil*, Syed A. Aljunid, Hassan Y. Ahmed, Hamza M.R. AlKhafaji

School of Computer and Communication University Malaysia Perlis (UniMAP) Kuala Perlis, 02000 Perlis, Malaysia

ARTICLE INFO

Article history:
Received 15 January 2011
Accepted 27 June 2011

Keywords:
Optical code division multiple access (OCDMA)
Multiple access interference (MAI)
Cross-correlation
Phase induced intensity noise (PIIN)
Spectral amplitude coding (SAC)

ABSTRACT

We present, for the first time, several aspects of incoherent optical code-division multiple access (OCDMA) codes, focusing on the flexible variable cross-correlation code allocation and its potential for future optical networks. We briefly present a new version of the Random Diagonal (RD) codes for Spectral-Amplitude Coding (SAC) OCDMA approaches. We then concentrate on the properties specific to such schemes allowing for its increased scalability and flexibility. The main coding properties are reviewed. The RD codes provide simple matrix constructions compared to the other SAC-OCDMA codes such as Hadamard, MQC and MFH codes. This code possesses such a numerous advantages, including the efficient and easy code construction, simple encoder/decoder design, existence for every natural number *n*, and variable in-phase cross-correlation and easy to implement using Fiber Bragg Gratings (FBGs). Finally, a new detection scheme called "*NAND*" detection is developed for the variable cross-correlation RD code.

1. Introduction

Optical code division multiple access (OCDMA) is one of the competing technologies for future multiple access networks along with Wavelength Division Multiple Access and Optical Time Division Multiple Access. 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 does not transmit anything whenever a '0' is to be transmitted. The major advantage of OCDMA is asynchronous communication, which considerably reduces optical resources required for timing recovery [1]. The main objective for the design of OCDMA systems is the data extraction by a user in the presence of other users or in other words, the presence of multiple access interference (MAI). MAI is the dominant source of deterioration in an OCDMA system; therefore, good design of the code sequences and detection scheme is important to reduce the affect of MAI [1,2].

Codes for OCDMA systems employing intensity detection have to be unipolar, orthogonal (minimum cross-correlation) and constant weight to obtain low values of probability of error due to multiple access interference (MAI). Hence, a family of codes called optical orthogonal codes (OOCs) [2] have been designed. Recently, All SAC codes which have been proposed for SAC OCDMA code are focused on contact cross-correlation; the value of the cross-correlation could be zero – such as Zero cross-correlation code (ZCC) code [3], an ideal cross-correlation such as Modified Quadratic Congruence code (MQC) [4,5,9]. The three major factors that affect the performance of OCDMA are code design, detection technique and transmitter-receiver structure. Code properties are considered one of the main limitations of OCDMA. Cross-correlation function is considered one of the important factors in OCDMA code set design. Therefore, unipolar codes with new system performance need to be developed. The throughput of an OCDMA system at high offered load collapses because of interference between multiplexed codewords. Fig. 1(a) shows a case where a 0 bit is being received and Fig. 1(b) shows a case where a 1 bit is being received. In Fig. 1(a) the codewords C_1 and C_2 add up such that there is power in the 1st, 2nd, and 3rd chips, among others. Because of codewords C_1 and C_2, the receiver tuned to C_0 detects a 1 bit whether the transmitter sends a 1 bit or a 0 bit. As shown in Fig. 1(a), when a 0 bit is sent, the receiver detects a 1 bit. The packet would have an error and be lost. The overlapping between codes sequences is called cross-correlation. As the cross-correlation value becomes high the multiple access interference increased as well. Thus, the main objective of this work is to decrease the number of overlapping chips which leads to low MAI.

The main factor of performance degradation is the multiple access interference (MAI). In spectral amplitude-coding (SAC) OCDMA system MAI is solely a function of the in-phase cross-correlation values among the address (signature) sequences. If the cross-correlation among the address sequences is high, then the phase intensity induced noise (PIIN) between codes sequences increased. However, the SAC OCDMA system based on balanced

* Corresponding author.
E-mail addresses: hilaladnan@unimap.edu.my (H.A. Fadhil), syedalwee@unimap.edu.my (S.A. Aljunid).

0030-4026/$ – see front matter © 2011 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijleo.2011.07.011

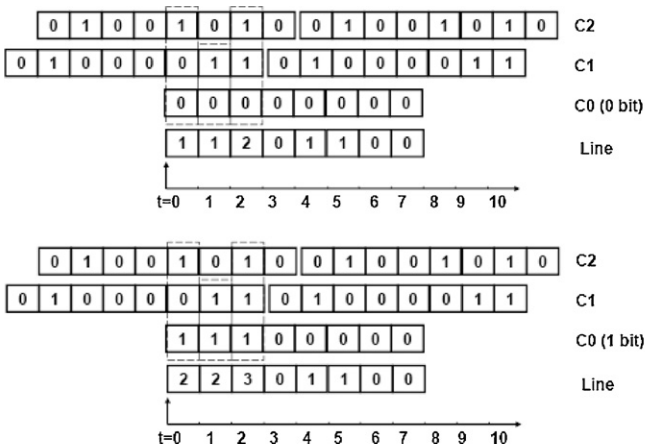

Fig. 1. (a and b) An example of multi-user interference showing three codewords C_0, C_1, and C_2. The two codewords (C_1 and C_2) interfere with another codeword (C_0).

detection becomes unable to eliminate MAI and suppress the PIIN. For the spectral-amplitude coding (SAC) OCDMA codes, such as Hadamard, Modified Quadratic Congruence (MQC), and Modified Frequency Hopping (MFH) code [3–5]. However, some of these codes have much poorer cross-correlation (e.g. Hadamard code), or the number of available codes is quite restricted (e.g. integer lattice exists for m and k where m and k need to be a co-prime; it is enough if one is an even and the other is odd), a prime number for modified quadratic congruence (MQC), a prime power for Modified Frequency Hopping (MFH) [4], and an even natural numbers for Modified Double Weight (MDW) [5]. Finally, long code length (e.g. Prime), limits the addressing flexibility of the codes, long code lengths are considered disadvantageous in their implementation, since very wide bandwidth sources are required.

In [10] it has been assumed that the cross-correlation value is always equal to zero, because of the data signal is carried on the data segment only of the RD code. In this paper, a new version of the RD code has been proposed. It has been assumed that the cross-correlation value is variable, and the data is carried out on the data segment, and code segment, respectively. It will be shown principally by extensive theoretical studies and comprehensive simulations that the transmission performance of the RD code is significantly better than that of existing SAC codes such as Modified Quadratic Congruence, (MQC), Modified Frequency Hopping (MFH) and Hadamard codes. Next generation communications networks based on variable cross-correlation will support a variety of Quality of Service (QoS)-sensitive applications like streaming multimedia and high-speed data for downlink users.

2. Random diagonal codes construction

Definition. In mathematics, a diagonal matrix is a square matrix in which the entries outside the main diagonal are all zero.

$$y_{ij} = \begin{cases} 1 & \text{when} \quad i = j \\ 0 & \text{else} \end{cases}$$

An *anti-diagonal matrix* is a matrix where all the entries are zero except those on the diagonal going from the lower left corner to the upper right corner (↗), known as the anti-diagonal

$$Y_{ij} = \text{adiag}(y_{ij}, y_{ij}, \ldots, y_{nm})\ldots$$

$$[Y] = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Step1, data segment: let the elements in this group contain only one "1" to keep cross-correlation zero at data level ($\lambda_c = 0$); this property is represented by the matrix ($K \times K$) where K will represent the number of users; these matrices have binary coefficient and a basic zero cross-code (weight = 1) is defined as [Y]. For example, three users ($K = 3$), $y(K \times K)$ can be expressed as

$$[Y] = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

where [Y] consists of ($K \times K$) matrices is given by:

$$Y_{ij} = \begin{cases} 1 & \text{for} \quad \sum_{i=1}^{K} a_{i(K-i+1)} \\ 0 & \text{otherwise} \end{cases}$$

Notice, for the above expression the cross-correlation between any two rows is always zero. The underlying cross-correlation theory could be explained as follows.

Step2, code segment: the representation of this matrix can be expressed as follows for $W = 3$

$$[Y_2] = \left[\begin{array}{ccc:cc} 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 \end{array}\right]$$

where [Y_2] consists of two parts, the weight matrix part and the basic matrix part, where the basic part [B] can be expressed as

$$[B] = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

Two conditions must be satisfied in basic part code sequences design:

(1) The total number of weights at the basic part should be equal to twice the number of weights at the diagonal part.

$$[W_B = 2 \times W_D]$$

(2) At most one cross-correlation between adjacent rows.

$$\sum_{i=1}^{K} C_k(i)C_l(i) = 1$$

The basic matrix consists of a chip-combination sequence of 2, 2, and 2 (alternating 2's) for the columns. A chip combination is defined as the summation of the spectral chips (1's and 0's) for all users (or rows) in the same column with each code sequence allowed to overlap at most, once with every other sequence in the columns of the matrix.