Variable weight spectral amplitude coding for multiservice OCDMA networks

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Abstract

The emergence of heterogeneous data traffic such as voice over IP, video streaming and online gaming have demanded networks with capability of supporting quality of service (QoS) at the physical layer with traffic prioritisation. This paper proposes a new variable-weight code based on spectral amplitude coding for optical code-division multiple-access (OCDMA) networks to support QoS differentiation. The proposed variable-weight multi-service (VW-MS) code relies on basic matrix construction. A mathematical model is developed for performance evaluation of VW-MS OCDMA networks. It is shown that the proposed code provides an optimal code length with minimum cross-correlation value when compared to other codes. Numerical results for a VW-MS OCDMA network designed for triple-play services operating at 0.622 Gb/s, 1.25 Gb/s and 2.5 Gb/s are considered.

1. Introduction

The future Internet will consist of a wide range of applications with potentially different data bit rates and quality of service (QoS) requirements. Optical code-division multiple-access (OCDMA) has emerged as an attractive solution for optical access networks, mainly due to its ability to provide QoS differentiation at the physical layer [1]. In addition, OCDMA technology has also recently received a great deal of attention in optical sensor networks [2,3] and free-space optical networks [4]. A classical technique used to achieve QoS transmissions in OCDMA networks is based on the weight variation of the users' code sequence [5] in a way that higher code weight provides higher QoS. To this aim, one-dimensional (1-D) [5] and two-dimensional (2-D) [6] code families have been proposed to achieve QoS (or multiple services) in OCDMA networks. Another technique, based on the variation of basic matrix, has also been explored to provide QoS transmissions [7,8]. In another effort, a OCDMA system has been proposed to provide multiservices and multirates by taking the advantages of weight variation and overlapping pulse-position modulation [9]. An alternative technique, based on a multilevel power system where users transmit their signal at lower or higher power levels to achieve differentiated-QoS transmissions, has also been proposed [10,11]. Apart from physical layer, an analytical theory has been developed for assessment of the packet throughput performance of 1-D and 2-D OCDMA networks supporting multiservices and multirates [12].

Spectral amplitude coding (SAC) is a technique developed for OCDMA networks, which stands out due to the reduction of the multiple-access interference (MAI) effects [13,14], simplicity [15] and possibility of supporting QoS transmissions [16]. In variable weight SAC (VW-SAC) [16], users with high QoS requirements transmit using codes with higher weights. Although the code weight variation technique was originally developed for optical orthogonal code (OOC) [5], followed by other codes such as integer lattice OOC (IL-OOC) [17], variable weight OOC (VW-OOC) [18] and variable weight Khazani-Syed (VW-KS) [19]. VW-SAC technique has been experimentally demonstrated to be useful for QoS differentiation [16]. In this paper, a new VW-SAC code namely variable weight multi-service (VW-MS) for OCDMA networks based on basic matrix construction is proposed. Different from traditional variable weight codes which have some restrictions in weight selection (e.g. in VW-KS only even integers could be chosen for services), VW-MS supports any integer value as the code weight and maintains an optimal length in comparison to other counterparts. The proposed VW-MS allows for a weight selection not only independent of other code’s parameters, but also for arbitrary values according to the level of required QoS. Moreover, a mapping technique is used to increase the number of available codes and consequently the code cardinality.

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This paper is organised as follows. Section 2 describes and explains the code design construction of the proposed VW-MS and gives an example of a code set for 3 distinct services. A comparison of the cross-correlation properties between the VW-MS and other codes is presented in Section 3. Section 4, by its turn, presents the mathematical formalism developed for performance evaluation of the VW-SAC OCDMA network employing an AND detection scheme. Section 5 addresses the main results of the evaluation of the VW-SAC OCDMA network employing an AND detection scheme. Section 6 presents some concluding remarks.

2. Design and development of variable weight MS code

A VW-MS code is an enhanced version of the existing single weight MS [7], that allows users of different weight or priority to co-exist in a single system while maintaining the cross-correlation value of one.

2.1. Construction of MS basic matrix

MS code for SAC-OCDMA system is matrix based and characterised by (l_b, W_b, N_b, λ_a, λ_c) where W_b = 2, 3, . . . is the code weight and the number of users in basic matrix is denoted by N_b. λ_a and λ_c denote the out-of-phase autocorrelation and cross-correlation between each pair of codewords in OCDMA, respectively. Due to the structure of MS code, maximum out-of-phase autocorrelation and the ideal cross-correlation of one is maintained in order to eliminate MAI. The basic matrix for MS code is consists of N_b × l_b array depending on the value of selected weight, W_b, where elements taking the value of either 0 or 1 representing the spectral chips. The number of users in basic matrix can be varied from 1 to maximum W_b (N_b ∈ {1, 2, . . . , W_b}) based on the requirement. This matrix is the substructure of ultimate code which is expanded by mapping it. This will be thoroughly explained in Section 2.2.

The code length (l_b) of basic matrix for N_b = W_b can be calculated as

\[ l_b = \sum_{i=1}^{W_b} (i) \]  

In case the number of users in the basic matrix N_b is less than W_b, the code length of constructed matrix is as [7]:

\[ l_b = \sum_{i=1}^{W_b} i - \sum_{i=1}^{N_b} i \]  

MS code is constructed using mathematical equation and straightforward steps, hence it can be easily implemented using software programming for desired number of subscribers. The following steps explain how the basic matrix is constructed:

**Step 1:** Let P_w be the position of wth ‘1’ in the code where w = {1, 2, . . . , W}, then P_w for the first codeword, C_1 is defined as [7]:

\[ P_w = \begin{cases} 1, & w = 1 \\ P_{(w-1)} + (w - 1), & w > 1 \end{cases} \]

**Step 2:** Let C_y ∈ {0, 1} be a position in ith code, where i = {1, 2, . . . , N_b} and j = {1, 2, . . . , l_b}. Thus, C_i is defined as C_i = (C_1, C_2, C_3, . . . , C_{l_b}) and assume that {C_1, C_2, . . . , C_{l_b-1}, C_i} be previous codewords.

To construct the subsequent code, C_i, the previous generated codewords, {C_1, C_2, . . . , C_{l_b-1}}, are required. First, start from first code, C_1, find the first chip ‘1’ that has no overlapping with any of generated codewords ({C_2, C_3, . . . , C_{l_b-1}}), and place ‘1’ in this position of C_i to get the cross-correlation of one with C_i. Then repeat this for the rest codewords, {C_2, C_3, . . . , C_{l_b-1}} to maintain the correlation of one with them as well. Let the position of latest added ‘1’ in C_i be C_y. The position of C_{i(j+1)} is remained empty and subsequently, the chip values for the rest positions of \{C_{i(j+2)}, C_{i(j+3)}, . . . , C_{l_b}\} are obtained by shifting the chips of previous code, \{C_{j-1}, C_{j-2}, . . . , C_{j(l_b-j)}\} one unit to the right.

**Step 3:** Repeat step 2 for the subsequent codes until the basic code sequence C_y generated in which the number of rows is equal to the maximum number of basic users, N_b.

**Step 4:** Fill empty spaces with ‘0’.

Fig. 1(a)(a) to (d) demonstrates an example of MS code basic matrix construction for W_b = 3 for steps 1 to 4, respectively. The length of code calculated by (1) is 6 and there are N_b = 3 users which makes a 6 × 3 matrix.

2.2. Mapping technique for larger number of subscribers

In order to increase the number of users from the basic matrix, C_y, a mapping technique can be utilised. If we assume the total number of required users is N, the basic matrix repeated by M = N/N_b times, where N_b is the number of users in C_y, as the following matrix:

(1)

\[ C_B = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ & 1 & 1 & 1 & 1 & 1 \\ & & 1 & 1 & 1 & 1 \\ & & & 1 & 1 & 1 \\ & & & & 1 & 1 \\ & & & & & 1 \end{bmatrix} \]

(2)

**Fig. 1.** Construction of MS code basic matrix C_y for W = 3, with steps (a) 1 to (d) 4.
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