An Efficient Method to Reduce an MAI's Effects in Spectral Amplitude Coding OCDMA Network

Kamal E. Amaseb, Hassan Y. Ahmed, and Medien Zeghid

Abstract—Multiple Access Interference (MAI) in Spectral-Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA) scheme hardly limits the system performance. This problem increases proportionally with the amount of concurrent users. In addition, phase induce intensity noise (PIIN) coming from spontaneous emission process of light source is extra impairment leads to system drop needs to be tackled too. Towards conquer the specified problems, Vectors Combinatorial (VC) codes which based on grouping of certain vectors is proposed. Any positive integer number can be used in both weights and user's parameters in code building procedure, these technique nominees our code to be a potential reliable applicant for future optical communication schemes. Such flexibility is an exceptional property for VC compared to SAC-OCDMA counterparts' codes. Compared with the systems employing Hadamard, Modified Frequency Hopping (MFH), Modified Quadratic-Congruence (MQC), and Modified Double Weight (MDW), numerical results show that, VC is effective to reduce the power of MAI and PIIN. It has been exposed that, performance can be superior significantly when VC is used

Index Terms—Vectors Combinatorial (VC); Multiple Access Interference (MAI); Spectral-Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA); Bit Error Rate (BER); PIIN; SNR.

I. INTRODUCTION

Multiple access modes are a prerequisite for optical systems and wireless network, which permit several of users to access the network together by sharing a transmission medium and using bandwidth aggressively. CDMA is used widely in wireless networks [1]. The excellent done of CDMA in wireless networks, motivate the telecommunication community to examine the conceivable of CDMA implementation in the optical field. Optical CDMA inherited the CDMA benefits, (which include security and spectral efficiency) and Provide asynchronous data transfer for simple network monitoring and management. OCDMA designed for the future optical fibre networks and permits managers to the data routing without concerning complicated multiplexers and de-multiplexers [1]. OCDMA has attracted considerable research attention for the future access network because of its protocol sensitiveness, high network scalability, no packet crash [2]. (SAC-OCDMA) is easy, asynchronous, economically, powerfully and flexible encoding method that can quell

multiple access interference (MAI) that can be completely removed by spectral coding existent in traditional systems [1]. (MAI) is considered as a dominating system-degradation factor for the OCDMA networks. In (SAC-OCDMA) scheme, the impact of MAI can be diminutive by utilizing codes through fixed in-phase cross-correlations [3]. Let us define $\lambda = \sum_{i=1}^L x_i y_i$. As the in-phase cross correlation of two diverse code sequence $X=(x_1, x_2, \dots, x_L)$ and $Y=(y_1, y_2, \dots, y_L)$. However, codes with perfect cross correlation have been considered extensively in [6] -[11], conversely, several of these codes have extremely poor cross correlation (e.g. Hadamard code), or limited obtainable codes number (e.g. Prime number, prime power, even and odd natural number for (MQC, MFH, MDW, EDW, EMD and DDW codes respectively). Furthermore, the potential noise created by multi users aimed to share the medium concurrently will be limited' the OCDMA performance, stated of the MAI. VC code is one of the famous methods that are used to prevent the MAI. Recount studied showed that, the cross correlation properties are not the main issues in building codes, the code length very important for addressing well. When the Long of code length is a disadvantage the code requisite either very wide or narrow filters of bandwidths. When the code is short, it has a limited range of choice. Thus, equalization between the number of code words and code lengths should be completed. VC code exists for applying code length that is neither very long code nor very short.

II. LAYOUT

The new submitted code in this paper is a family of $[0, 1]$ which is characterized by (L, N, W, λ_c) when L is the length, N is the number of users, W is the weight (number of ones) and λ_c is the cross correlation. There many benefits of the proposed VC code family, we can show as follows:

- 1) Can be used any positive integer number of weights.
- 2) More flexible for number of users.
- 3) Simple code construction.

The rest of the paper is organized as follows. In Section III described the family of newly built codes. In Section IV, display the analytical results of system performance. The code properties debated from view of contrast in section V. We have the conclusion in Section VI.

III. VC CODE DEVELOPMENT

A. Definition

Euclidean vector is a geometric object that has both a magnitude (and length) and direction; the size of the vector is the distance between the two points where an initial point A connecting with a terminal point B . Each vector has only two points (A and B) where two "1s" will be placed in A and

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B positions respectively. In Math's, normal basis of the w -dimensional Euclidean space R^W is the basis acquired by taking the W basis vectors: $\{V_i: 1 \leq i \leq W\}$ [13]

Where vector V_i with is equal 1 in the i^{th} form and 0 In another place. E.g., the standard basis for R^3 (i.e., $W=3$) is given by the vectors as [13]:

$$\vec{V}_1 = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

$$\vec{V}_2 = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \quad (2)$$

$$\vec{V}_3 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \quad (3)$$

$$VC = \begin{bmatrix} \text{user\#1} & 1 & 1 & \dots & 1 & 0 & 0 & \dots & 0 & \dots & 0 \\ \text{user\#2} & 1 & 0 & \dots & 0 & 1 & 1 & \dots & 1 & \dots & 0 \\ . & 0 & 1 & \dots & 0 & 1 & 0 & \dots & 0 & \dots & 0 \\ . & 0 & 0 & \dots & . & 0 & 1 & \dots & . & \dots & . \\ . & 0 & 0 & \dots & . & 0 & 0 & \dots & . & \dots & . \\ . & 0 & 0 & \dots & . & 0 & 0 & \dots & . & \dots & 1 \\ \text{usre\#n} & 0 & 0 & \dots & 1 & 0 & 0 & \dots & 1 & \dots & 1 \end{bmatrix}$$

Fig. 1. A general matrix of VC when $N=W+1$

The new (VC) code can be designed by isolating the code classification into three stages which are stage one builds vector, stage tow put the vector in the group and the last one is mapping technique [14].

$$\vec{V}_{(i, i+1)} = \begin{bmatrix} 1 \\ 0 \\ . \\ . \\ 1 \end{bmatrix} \quad (4)$$

B. Stage 1: Building the Vector

In this Stage, first we built a pillar vector which has two "1s" when the cross correlation equivalent 1. Second, we let pillar vector $V_{(i, i+1)}$ whose i^{th} element is "1" and in the last one we put others zero and length equals N [14].

C. Stage 2: Putting the Vector in Group

When the weight (W) value in the row (which is called user) arranged make the *in-phase* cross correlation (CC) precisely equals 1 for every column, all vector in Fig. 1 is guided as $V_{(i, i+1)}$ for i fixed to user arrangement and $i+1$ shifts to the down by one up to N to make the CC with $N-1$ is accurately equals to 1 (i.e., for $N=4, i=1$; $V_{(i, i+1)} = V_{12}, V_{13}, V_{14}$; for $N=4, i=2, V_{(i, i+1)} = V_{23}, V_{34}$; for $N=4, i=3, V_{(i, i+1)} = V_{34}$) which means i denotes number of row (user). After combining all column vectors in Fig. 1, we have to create (0, 1) sequence. To be more perfect we can perceive that each column vector holds two "1s"; the number of "1s" per row is represented by W ; in case the number of users is

represented by N , the sequence $(V_{12} V_{13} \dots V_{1N})(V_{23} V_{24} \dots V_{2N}) \dots (V_{(N-1)N})$ gives a code perfect in-phase CC ($\lambda=1$) called Ideal Case (IC).

D. Stage 2: Mapping technique

when $N-1=W$ in this case it content limited users, the Ideal Case (IC) can be built simply using a column vector. To overcome this problem, we applied a mapping technique (see Fig. 2). The mapping technique mechanism used in order to add more number of users behind the basic number of users given by the basic matrix for an exact weight [7]. Subsequently, N can be written.

$$N = P(W + 1) + R \quad (5)$$

Clarify number of $(W+1)$ recurrent in diagonal method where P, R is positive integer numbers, and the outstanding users after unit separation for N correspondingly, and R can be expressed as: [13]

$$R = N \bmod P(W + 1) \quad (6)$$

Fig. 2. The major steps and points for VC code family construction

1. Start.
2. Declare variables.
3. Initialize total value = 0.
4. Get a number from the user.
5. If the number is not equal to -1, go to step 6, otherwise go to step 7.
6. Calculate sum.
7. Display sum of numbers.
8. End.

First, go over weight W , number of users N , and remaining users R . If $N > W+1$ satisfied, VC code without mapping technique will be constructed. The parameters (W, R) have to be added if the state $N > W+1$ && $R < W+1$ is mollified (see Fig. 3). To clarify (5) and (6) where mod appears modulo division, let us think through the example $N=6, W=2$, substitute the values in (5), (6), gives $6=2 \times (2+1) + 0$, which means $P=2$ and $R=0$. For $N=6, W=3$, gives

$6=1 \times (3+1) + 2$ which means $P=1$ and $R=2$.

A mapping technique have apply to added more number of users in VC code family, (see Fig. 3) Which are works by diagonally repeating the IC for the $(W+1)$ users P -times and filling the void with zeros. The length of that section is $P \cdot \frac{W(W+1)}{2}$. Consequently, an IC with the parameters (W, R) have to add if $R < W+1$ is satisfied (i.e., $R = N \bmod P (W+1) \neq 0$) (see Fig. 3). The length of that second section of the code is $\frac{R \times (2W - R + 1)}{2}$. Finally, the whole length L is given by:

$$L = \frac{WN + R(w + 1 - R)}{2} \quad (7)$$

$N =$

P

$\begin{bmatrix} W+1 & 0 & 0 & 0 & 0 \\ 0 & W+1 & 0 & 0 & 0 \\ 0 & 0 & W+1 & 0 & 0 \\ 0 & 0 & 0 & W+1 & 0 \end{bmatrix}$

R

$\begin{bmatrix} 0 & 0 & 0 & 0 & p \end{bmatrix}$

Fig. 3. Graphic representation of mapping techniques for $N = P(W+1) + R$

In Table I, $N=10$ & $W = 4$ by using (5), (6) gives $10=2 \times (4+1) + 2$, resulting $P=2$ and $R=2$ that means we should repeated (9) tow time.[13]

($P=2$) in diagonal fashion, resulting to 8 users and add two other users ($R=1$) after user#8 in diagonal fashion also. By using (12) $L = 10 \times 4 + 2(4-1+2)/2$, the code length will be 17. In Table I, there are three clusters of codes, the first one (first six columns) is the VC code with the parameter value (3,4) which means $W=4$ and $N=4$ having CC equal to 1; the second (from columns 7 to 12) is a duplication from the first one with the parameters (3, 4); the third cluster (from columns 13 to 17) is the VC with the parameters (3,2) which means $W=4$ and $N=2$ (i.e., $R=N$) since the condition $R < W+1$ ($2 < 4$) is contented having CC matches to resistor [13].

TABLE I: VC CODE FOR $N > W+1$ & $R < W+1$

1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
0	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0
0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0
0	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1

IV. SYSTEM PERFORMANCE

We can compute the Signal to Noise Ratio (SNR) by using the similar in [10]-[11] when we used the different codes. The phase induced intensity noise, the photodiode shot noise and the thermal noise are taken into account. Signal to noise ratio (SNR) of the VC code family is given by:

$$SNR = \frac{\frac{R^2 P_{sr}^2 W^2}{L^2}}{\frac{P_{sr} e B R}{L} [(N-1) + W] + \frac{P_{sr}^2 B R^2 N}{2 \Delta V L^2} [(N-1) + W + (N-1)/P + R] + \frac{4 K_B T_B B}{R_L}} \quad (8)$$

where $\mathfrak{R}$ is the photodiode reacting, P_{sr} is the efficacious power of a broadband source at the receiver, e is the electronic charge, B is an tantamount noise bandwidth of the receiver, K_B is the Boltzmann's constant, T_n is the Absolute receiver noise temperature, R_L is the receiver load resistor, ΔV is the optical source bandwidth, W, N, L, P and R are the code weight, the number of users, the number of mappings, the code length and the remaining of users after modulo operation respectively as being the parameters of VC itself. The Bit Error Rate (BER) is computed from the SNR using the Gaussian approximation as [11]-[12].

$$BER = 0.5 \operatorname{erfc} \sqrt{SNR/8} \quad (9)$$

TABLE II: THE SUBSEQUENT PARAMETER OF (VC) [7]-[10]

Subsequent parameters	ΔV	B	T_n	R_L	η	Λ
	3.75 THz	1.625 GHz	300 K	1030 Ω	0.6	1550 nm

V. COMPARISON AND EVALUATION

We use the ideal in phase CC to complete a series of code family, for comparison, some properties of the code like for example VC code, MQC, MDW, MFH, EMD, DDW and Hadamard, which are registered in Table III. It is shown that VC codes exist for all even, odd and prime positive integer, while MDW codes are existing for even n weights, Hadamard codes are existing only when the weight is $2m-1$ where $m \geq 2$, MQC and MFH are existing for a prime number p and a prime power q given by $q = p^n$ where n is a positive integer correspondingly. The table also displays that, the VC codes have the best cross correlation, while Hadamard codes when the number of users increased have increasing value of cross correlation.

Fig. 4 demonstrations the relative among the number of active users and the SNR for VCC when the parameters used in the VCC codes building are $W=4, P=2, R=1$. The SNR for MQC, Hadamard and MFH are also displayed as a reference with the parameters $p=13, q=16$ and code length $N=256$ for MQC, Hadamard codes and MFH respectively.

TABLE II: SAC-OCDMA CODES COMPARISONS

Code family	Existence	Weight	Size	Λ	Code length	SNR
MQC	Primes $p > 2$	$p+1$	p^2	1	p^2+p	[7-8] $\frac{\Delta v(p+1)}{BK[(K-1)/p + p + K]}$
EMD	All GF		w	1	$K + [K(W-2) + 1]$	[1] $\frac{[R P_{st} W/N] 2}{eBRP_{st} W/N + 4Kk_b T_n B/R_i}$
MDW	Even integer n	Any number even greater than 2	N_B	1	K_B	[4-5] $\frac{2(\frac{W}{\lambda} - 1)\Delta v}{BK[(\frac{K}{2} + \frac{W}{\lambda} - 2)]}$
DDW	Even integer	2	$w/2+1$	1	$K+1$	[3] $\frac{R^2 P_{st}^2 W^2}{N^2} (W-1)^2$ $\frac{2eBRP_{st} W}{N} (W-1) + \frac{R^2 BP_{st}^2 KW^2}{2N^2 \Delta v} (W-1) + \frac{4K_b T_n B}{R_L}$
Hadamard d	$m \geq 2$	2^{m-1}	$2^m - 1$	$\frac{2^m - 1}{2}$	2^m	[9] $\frac{\Delta v}{BK(K+1)}$
VC	$N > W+1$	Positive integer	Any number of users	1	$(WN + R(W+1-R))/2$	Refer to Eq (8)

In Fig. 4, the power user is -10dBm which is concentration taking into account the impacts of power noise, shot noise and thermal noise. It is shown that the VCC code allows SNRs much greater than MFH, Hadamard and MQC, with the great values of P and R higher SNR can be achieved with high number of active users for small weight.

Fig. 4. SNR versus the number of simultaneous users

In Fig. 5, shows the BER is in contrast to the number of working users when $P_{sr} = -10\text{dBm}$, we can keep an eye the lower BER of VC code than MQC, MFH and Hadamard codes even for lower value of $W=4$ compared to $W=14$, $W=17$. This is due to good arrangement of VC code building using mapping techniques which reduces the MAI and PIIN. It has obviously shown that the system using VC code is extremely low BER than that using MQC, MFH and Hadamard consequent to perfect properties of VC code design which decreases the MAI and PIIN.

Fig. 5. BER versus the number of active users

Fig. 6 shows the BER variations with effective power P_{sr} when $W=14$, $P=2$ and the number of active users is 30. Also shown the performance of the former system using MQC ($W=14$) and MFH ($W=17$) for comparison. In this figure, we have concentration taking into account the impacts of the intensity noise, thermal noise and shot noise at 2.5Gb/s. It has shown that, the VC code gives a much better performance when the effective power P_{sr} is large (when $P_{sr} > -18\text{dBm}$). This due to elimination of the MAI effects through cross correlation controls by using mapping techniques [6]. At the lower values of P_{sr} (when $P_{sr} < -18\text{dBm}$), the performance of the system for all codes is nearly the same.

Fig. 6. BER versus effective source power P_{sr} with 30 active users at 2.5 GB/s

Fig. 7 displays the PIIN plotted against the received power for the VC, MQC and MFH uses the parameters: $W=4, 12$ and 10 for VC, MQC and MFH respectively at data rate 2.5 GB/s. We can see that when the received power increases from the figure, the PIIN noise for all the codes increases linearly. The PIIN noise of VC code family is less compared to that of MQC and MFH codes. Also the PIIN noise can be successfully suppressed by using VC code family. This is because by using mapping techniques, the interference power from other users is reduced by the increase of the code length, and finally eliminates the MAI effects.

Fig. 7. PIIN Noise versus Number of Active Users for VC, MQC and MFH codes at data rate 2.5Gb/s for different values of W .

The received power and corresponding eye pattern diagram for VC codes are shown in Fig. 8. The eye graph illustrated in Fig. 8 (b) clearly explains that the VC code gives enhanced performance, having a bigger eye opening. The vertical space between the highest of the eye opening and maximum signal level gives the degree of disfigurement. The more the eye closes the tougher it is to discriminate among 1 s and 0 s in the signal. The height of the eye opening at the specified sampling time shows the noise margin or immunity to noise.

(a)

(b)

Fig. 8. Eye diagram for VC code at 10Gbit/s for 50 km (a) NRZ format (b) RZ format

VI. CONCLUSION

This paper, a presents a new code using ideal in-phase cross correlation (CC) is done. In the vector combination (VC) codes which based on grouping of certain vectors any positive integer number can be used in both weights and user parameters in code building procedure. This code is discussed and described with related equations. The outcome of system operation compared with reported codes. The benefit of the VC code can shortly as follows:

- 1) Large tractability in choosing the number of users than MQC, MFH, MDW, DDW, EMD and Hadamard codes (free cardinality);
- 2) Good property in cross-correlation control;
- 3) Short length;
- 4) It has shown that performance can be improved significantly when VC code used instead of MQC, MFH, MDW, DDW, EMD and Hadamard codes.

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