Performance of Parallel Interference Cancellation Scheme in VW-OCDMA Systems

Wei Liang, Jun Li, Yi Zhang, Jingling Li, and Jiayuan Wei

***Abstract*—To support multi-service and guarantee quality of service, variable-weight code is needed in OCDMA system. However, such codes suffer from high cross-correlation products which create high multiple access interference (MAI) that significantly reduces the capacity of the system. To mitigate MAI, In this paper, we study the Parallel Interference Cancellation (PIC) receiver efficiency in Variable-Weight OCDMA (VW-OCDMA). We develop the analytical expression of the error probability with variable-weight optical orthogonal code for one stage PIC receiver. Furthermore, the system has been tested for five users. Simulation results show that by using PIC receiver we obtain good performance in VW-OCDMA system, and the highest priority user can be assigned to a codeword with the largest weights to guarantee the lowest bit error rate.**

***Index Terms*—OCDMA, variable-weight optical orthogonal codes, multiple access interference, parallel interference cancellation.**

I. Introduction

Future all-optical networks require techniques to support a large number of simultaneous users demanding voice, video, and data services. Optical code division multiple access (OCDMA) systems have special features which make them suitable for this purpose [1]. Many OCDMA techniques have been proposed to provide multiple Quality of Service (QoS) by varying the weight of codewords for different services.

In Variable Weight OCDMA (VW-OCDMA) system different weights are used for multiple services which are video on demand, voice and data where higher weight is assigned to the service requiring for better QoS. Variable-weight optical orthogonal codes (VW-OOCs) are one of the alternative designs for providing differentiated QoS at the physical level in optical CDMA systems. The emphasis is on VW-OCDMA systems employing VW-OOCas signature sequence. There are many studies focused on VW-OOC [2]-[4].

However, optical orthogonal codes suffer from high cross-correlation create high multiple access interference (MAI) that significantly reduces the capacity of the system, Moreover, with increasing number of users which access to the system at the same time, the power of MAI has also increased, resulting in the Bit error probability increased and the performance of the system degradation. Therefore, the study about suppression of MAI in VW-OCDMA research is essential.

Parallel Interference Cancellation (PIC) is effective to mitigate the effect of MAI and improve the performance of the system [5]. However, the research on existing OCDMA systems almost focus on multi-user detection algorithm with constant-weight OOC. In this paper,we only take the effect of multiple access interference (MAI) into account and neglect the effect of receiver noise of active users in the system, thenwe have theoretically analyzed a Parallel Interference Cancellation optical CDMA system, using variable-weight optical orthogonal code as a signature sequence code, and simulate the performance of the system. It is shown that by using PIC receiver we obtain good performance in VW-OCDMA system, and it is has been found that the optical orthogonal code with higher weight perform better in our PIC scheme

II. System Description

A. DS-OCDMA System

In our system We consider a non-coherent, synchronous Direct Detection CDMA system, where the system consist of N users, using on-off keying (OOK) modulation to transmit binary data via optical channel for each user, and all the users are supposed to have the same transmitting energy so there is no strongest interfering signal. Fig. 1 shows the conventional OCDMA receiver. In this receiver, each optical decoder correlates its own signature code with the received optical data sequences to generate correlation function. VW-OOC will be used as the signature codes in this paper.

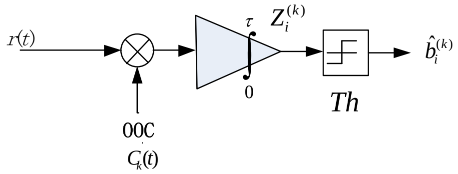

Fig. 1. Conventional OCDMA receiver.

B. Definition and the Bound on Capacity of VW-OOC

A VW-OOC C, is collection of binary (0, 1) sequences with the same code length and different code weights, generally denoted by $(F, W, \lambda_A, \lambda_c, Q)$ where *F, W*, λ_A, λ_C and *Q* are the code length, a set of code weights $W = \{w_1, w_2, \cdots, w_L\}$, a maximum value of auto- and cross-correlation, and a set of

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fraction of codewords $Q=\{q_1,q_2,\cdots,q_L\}$, respectively, where L is the number of different weights in a code set. The (0,1) sequences of a VW-OOC are called its codewords. The total number of ‘‘1s”in each codeword defines the code weight w_l, where w_l is l th code weight and $l=1,2,\cdots,L$. The capacity of a VW-OOC, denoted by $|C|$, is the number of codewords in a code set.

We consider a VW-OOC with a correlation value of $\lambda_a=\lambda_c=\lambda=1$, This is the case with the smallest correlation value in an incoherent OCDMA system. A generalization of an upper bound of capacity of an (F,W,λ,Q) VW-OOC with the case of $\lambda=1$ is [6]

$$|C|\le\frac{(F-1)}{\sum_{l=0}^{L}q_l w_l(w_l-1)} \tag{1}$$

C. Parallel Interference Cancellation Receiver

PIC receiver estimate and reduce the MAI which product by other non-desired users. Assume that the first user to be the desired one. The aim of the PIC is to reproduce the interference term due to all interfering users and to remove it from the received signal. The PIC first detects the N−1 undesired users employing the conventional correlation receiver defined with a threshold level S. The estimated interference is built by spreading the estimated data with the corresponding code sequence, and removed from the received signal r(t). The PIC involves several stages. The construction of PIC is shown in Fig. 2.

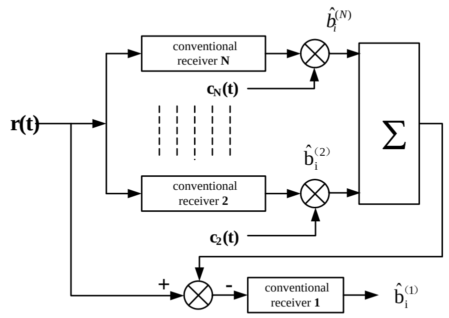

Fig. 2. The block diagram of PIC receiver.

In the case of one stage cancellation [7], PIC operates by proving the estimation $\hat{b}_i^{(k)}$ of only one non-desired user referred as user k. Then the estimated data (user k) is spread by corresponding code sequence $c_k(t)$ and remove from r(t). The signal applied to the entry of the receiver #1 can be written as follow:

$$y(t)=r(t)-\hat{b}_i^{(k)}c_k(t) \tag{2}$$

where $\hat{b}_i^{(k)}$ is the i^{th} bit of the estimated k^{th} user and $c_k(t)$ is the code sequence of user k. In the case of N-1 stages cancellation. The signal applied to the entry of the receiver #1 can be written as follow:

$$y(t)=r(t)-\sum_{j=2}^{N}\hat{b}_i^{(j)}c_j(t) \tag{3}$$

III. Theoretical Analysis

Here, we consider that MAI from other users as the only factor to degrade system performance in the theoretical analysis of the system employing VW-OOCs; the effects of shot noise, thermal noise, and other external factors, are not taken into account. Without these noise sources, an error occurs only when the cumulative effect of MAI. In an $(F,W,1,Q)$ VW-OOC, the probability that a user codeword with weight w_l overlap with another user codeword with weight $w_{l'}$, is given by [6]

$$p_{l,l'}=\frac{w_l w_{l'}}{2F} \tag{4}$$

where $l,l'\in\{1,\cdots,L\}$, $w_l,w_{l'}\in W$, Consider that g_l is the number of the interferers with codewords of weight w_l. The threshold level of the desired user 1 is given by $S_1(0<S_1\le w_1)$, The threshold level of the non-desired user k is given by $S_k(0<S_k\le w_k)$.

In the case of one stage cancellation, we obtain a equation of the signal received by receiver#1 [7]:

$$\begin{aligned} y(t)&=r(t)-\hat{b}_i^{(k)}c_k(t)\\ &=b_i^{(1)}c_1(t)+\left(b_i^{(k)}-\hat{b}_i^{(k)}\right)c_k(t)+\sum_{\substack{j=2\\ j\ne k}}^{N}b_i^{(j)}c_j(t) \end{aligned} \tag{5}$$

The decision variable of the desired user can be written [7]:

$$\begin{aligned} Z_i^{(1)}&=w_1 b_i^{(1)}+\left(b_i^{(k)}-\hat{b}_i^{(k)}\right)\int_0^T c_k(t)c_1(t)dt\\ &+\sum_{\substack{j=2\\ j\ne k}}^{N}b_i^{(j)}\int_0^T c_j(t)c_1(t)dt=w_1 b_i^{(1)}+H+I \end{aligned} \tag{6}$$

where H is the term cancellation, and I is the interference term. H have two value: $H=0, H=1$. The probability of error of the desired user 1 is

$$P_{u1}=P_0+P_1 \tag{7}$$

where, P_0 and P_1 is the probability of error when user1 send ‘0’ and ‘1’.The weight of the desired user and the weight of the non-desired user affect the probability of error, so it’s necessary to consider two cases:

1) $w_1 = w_k$

If the desired user 1 sents '0':The probability of error of user k can be written as follow:

$$P_k = \frac{1}{2}\sum_{g_1+g_2+\cdots+g_L=S_n}^{M-2}\binom{M_{w_k}-2}{g_k}(p_{k.k})^{g_k}(1-p_{k.k})^{M_{w_k}-2-g_k}\prod_{l=2}^{L}\binom{M_{w_l}}{g_l}(p_{k.l})^{g_l}(1-p_{k.l})^{M_l-g_l} \tag{8}$$

And then,

$$\begin{aligned}&prob\left(I \ge S_d+1 \middle| b_i^{(1)}=0, H=-1\right)\\&=\frac{1}{2}\sum_{g_1+g_2+\cdots+g_L=S_d+1}^{M-2}\binom{M_{w_1}-2}{g_1}(p_{1,1})^{g_1}(1-p_{1,1})^{M_{w_1}-2-g_1}\\&\prod_{l=2}^{L}\binom{M_{w_l}}{g_l}(p_{1.l})^{g_l}(1-p_{1.l})^{M_l-g_l}\end{aligned} \tag{9}$$

$$\begin{aligned}&prob\left(I \ge S_d \middle| b_i^{(1)}=0, H=0\right)\\&=\frac{1}{2}\sum_{g_1+g_2+\cdots+g_L=S_d}^{M-2}\binom{M_{w_1}-2}{g_1}(p_{1,1})^{g_1}(1-p_{1,1})^{M_{w_1}-2-g_1}\\&\prod_{l=2}^{L}\binom{M_{w_l}}{g_l}(p_{1.l})^{g_l}(1-p_{1.l})^{M_l-g_l}\end{aligned} \tag{10}$$

We define the function:

$$f(a,b,c,d)=\frac{1}{2}\sum_{g_1+g_2+\cdots+g_L=a}^{b}\binom{c}{g_d}(p_{d,d})^{g_d}(1-p_{d,d})^{c-g_d}\prod_{l=2}^{L}\binom{M_{w_l}}{g_l}(p_{d.l})^{g_l}(1-p_{d.l})^{M_l-g_l} \tag{11}$$

We can obtain:

$$prob\left(I \ge S_d+1 \middle| b_i^{(1)}=0, H=-1\right)= f\left(S_d+1, M-2, M_{w_1}-2, 1\right) \tag{12}$$

$$prob\left(I \ge S_d \middle| b_i^{(1)}=0, H=0\right)= f\left(S_d, M-2, M_{w_1}-2, 1\right) \tag{13}$$

$$P_k = f\left(S_n, M-2, M_{w_k}-2, k\right) \tag{14}$$

So,

$$\begin{aligned}&P_0 = prob\left(\hat{b}_i^{(1)}=1 \middle| b_i^{(1)}=0\right)\\&= f\left(S_n, M-2, M_{w_k}-2, k\right)\cdot f\left(S_d+1, M-2, M_{w_1}-2, 1\right)\\&+\left(1-f\left(S_n, M-2, M_{w_k}-2, k\right)\right)\cdot f\left(S_d, M-2, M_{w_1}-2, 1\right)\end{aligned} \tag{15}$$

If user 1 sents '1':

$$prob\left(I < S_d+w_1 \middle| b_i^{(1)}=1, H=0\right)=0 \tag{16}$$

$$prob\left(I < S_d-w_1+1 \middle| b_i^{(1)}=1, H=-1\right)= f\left(0, S_d-w_1, M_{w_1}-2, 1\right) \tag{17}$$

The probability of error of user k can be written as follow:

$$\begin{aligned}&P_k^{'}=\frac{1}{2}\sum_{g_1+g_2+\cdots+g_L=S_n}^{M-1}\binom{M_{w_k}-1}{g_k}(p_{k.k})^{g_k}(1-p_{k.k})^{M_{w_k}-1-g_k}\\&\prod_{l\ne k}^{L}\binom{M_{w_l}}{g_l}(p_{k.l})^{g_l}(1-p_{k.l})^{M_l-g_l}\\&= f\left(S_n, M-1, M_{w_k}-1, k\right)\end{aligned} \tag{18}$$

We can obtain:

$$\begin{aligned}&P_1 = prob\left(\hat{b}_i^{(1)}=0 \middle| b_i^{(1)}=1\right)\\&= f\left(S_n, M-1, M_{w_k}-1, k\right)\cdot f\left(0, S_d-w_1, M_{w_1}-2, 1\right)\end{aligned} \tag{19}$$

2) $w_1 \ne w_k$

We define the function:

$$f^*(a,b,c,d)=\frac{1}{2}\sum_{g_1+g_2+\cdots+g_L=a}^{b}\binom{c}{g_d}(p_{d,d})^{g_d}(1-p_{d,d})^{c-g_d}\prod_{\substack{l=2\\l\ne k}}^{L}\binom{M_{w_l}}{g_l}(p_{d.l})^{g_l}(1-p_{d.l})^{M_l-g_l} \tag{20}$$

Similarly, we obtain:

$$\begin{aligned}&P_0 = f^*\left(S_n, M-2, M_{w_k}-1, k\right)\cdot f^*\left(S_d+1, M-2, M_{w_1}-2, 1\right)\\&+\left(1-f^*\left(S_n, M-2, M_{w_k}-1, k\right)\right)\cdot f^*\left(S_d, M-2, M_{w_1}-1, 1\right)\end{aligned} \tag{21}$$

$$P_1 = f^*\left(S_n, M-1, M_{w_k}-1, k\right)\cdot f^*\left(0, S_d-w_1, M_{w_1}-2, 1\right) \tag{22}$$

IV. Simulation Result

A. Capacity of VW-OOC ($\lambda=1$)

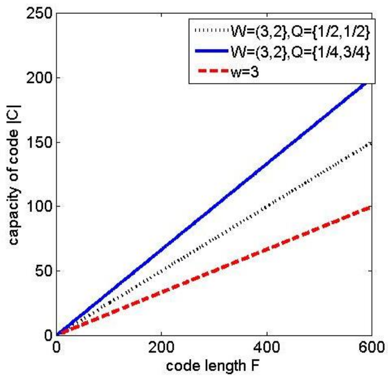

Fig. 3. upper bound on code capacity.

OCDMA system should be able to accommodate growing numbers of users. Codeword capacity affects the reliability of the OCDMA system. In order to analyze vw-ocdma system, we compared upper bound on the capacity of the variable-weight ooc and the constant-weight ooc.

To ensure the Qos of the highest priority users, these users will be assigned to codewords with the largest code weight.

Based on the above condition, we use two VW-OOC with $\lambda = 1$ and one constant-weight OOC with $\lambda = 1$. their largest code weight is 3. From Fig. 3, we can see that the capacity of the variable-weight ooc is larger than the capacity of the constant-weight ooc. VW-OOC can provided more code numbers for the system in ensuring the Qos of the highest priority users.

B. BER of One stage PIC

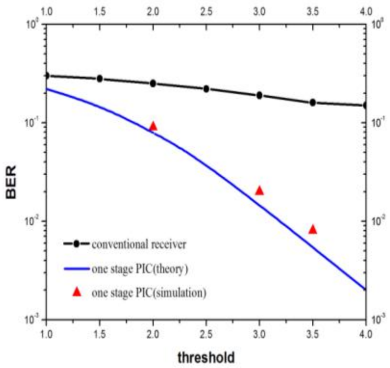

Fig. 4. the probability of error of one stage PIC receivers by employing a (101,{4,3,2},1,{5/15,5/15,5/15}) VW-OOC.

Fig. 4 shows the probability of error based on the threshold of detection of the desired user (0,21,70,99) and the non-desired user (0,7,34,64) for one stage parallel interference cancellation receiver compared to the conventional receiver. One stage PIC have good performance in VW-OCDMA system, while reducing the hardware complexity and cost. Because of the approximation made to simplify obtaining the theoretical expression, the different generate between theory and simulation.

C. BER of PIC

We briefly present here simulations results for the proposed scheme, compared the bit error rate of users with PIC schemes. We simulated in MATLAB with VW-OCDMA receiver PIC. We use triplet-weight VW-OOCs ($\lambda = 1$) for a triplet-service OCDMA system which supports differentiated QOS. To simplify the simulate, let us assume that : there are five users, ever users have the same transmitting energy, we employ the (101,{4,3,2},1,{5/15,5/15,5/15}) VW-OOCs, user1(0,21,70,99), user2(0,1,91), user3(0,24), user4(0,8), user5(0,76), we choose user1, user2 and user3 as the desired users ($w_1 = 4, w_2 = 3, w_3 = 2$).

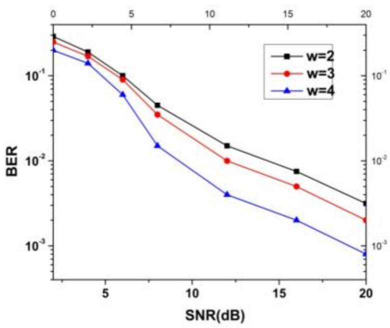

Fig. 5. Bit error rate of PIC receivers versus SNR by employing a (101,{4,3,2},1,{5/15,5/15,5/15}) VW-OOC.

From Fig. 5, we can see that by using PIC receiver we managed to obtain good performance in VW-OCDMA system. In addition, user with higher code weight always performance better than those with smaller code weight. Since the above assumes, the highest priority user can be assigned to a codeword with the largest weights to guarantee the lowest bit error rate in OCDMA with PIC receiver.

V. CONCLUSION

In this paper, we have theoretically analyzed a Parallel Interference Cancellation optical CDMA system, using variable-weight optical orthogonal code as a signature sequence code. The capacity upper bound of the variable-weight OOC ($\lambda = 1$) and the constant-weight OOC ($\lambda = 1$) has been discussed.

In addition, the system has been tested for five users. It has been shown from the simulation results that the highest priority user can be assigned to a codeword with the largest weights to guarantee the lowest bit error probability in OCDMA with PIC receiver.

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