Simulation of Optical CDMA using OOC Code

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Abstract- This paper examines optical CDMA (OCDMA) communication techniques with optical orthogonal codes. These optical orthogonal codes (OOC) set are constructed by using difference set methods. Simulations that show OOC reduce interference due to other users and channel noise. Probability of error can be reduce by selection of proper weight (w), length (n) & cardinality(C) of OOC.

Index Terms- OCDMA, OOC encoder, OOC decoder, Probability of error.

I. INTRODUCTION

The increasing demands for higher speed and advanced services in access networks require a bandwidth of above 50 Mbps for next-generation services to end users. The use of technologies based on optical fibers can easily achieve bandwidths higher than 100 Mbps and at the same time can reduce maintenance and repair costs.

CDMA was first applied to the optical domain in the mid-1980s by Prucnal, Salehi, and others [4]. Traditional fiber optic communication systems use either TDMA or WDMA schemes to allocate bandwidth among multiple users. Unfortunately, both present significant drawbacks in local area systems requiring large numbers of users. Optic code-division multiple-access (CDMA) system is a multiplexing system based on special codeword's which own good correlation properties. Optical orthogonal codes (OOCs) have application in OCDMA system because of their good correlation properties. Optical orthogonal codes have also found applications in mobile radio, frequency-hopping spread-spectrum communications, radar, sonar signal design, collision channel without feedback, neuromorphic networks, etc [2]. To establish the optical CDMA, we have to overcome the code orthogonality problem. Many researchers have proposed several codes such as prime code, optical orthogonal code, and so on.

Optical code-division multiple accesses (OCDMA) is one of the most important techniques supporting many simultaneous users in shared media so as to increase the transmission capacity of an optical fiber. Optical CDMA operate asynchronously, without centralized control, and it does not suffer from packet collisions. As a result, optical CDMA systems have lower latencies than TDMA or WDMA. Furthermore, since time and frequency (or wavelength) slots do not need to be allocated to each individual user, significant performance gains can be achieved through multiplexing. Also, TDMA and WDMA systems are limited by hardware because of the slot allocation requirements. In contrast, CDMA systems are only limited the tolerated bit error rate relationship to the number of users.

In section II, we introduce the optical orthogonal codes. Section III discusses optical CDMA technique. Section IV shows simulations of OCDMA with OOC set constructed by difference set methods. Section V evaluates the probability of error as a function of weight, length & no. of users.

II. OPTICAL ORTHOGONAL CODES

To reduce the crosstalk between users, an important property of the sequences (codewords) is that they produce a low correlation. OOC are a set of binary sequences with special auto- and crosscorrelation properties. The correlation being low tells us that each sequence in the code can easily be distinguished from a shifted version of itself i.e. the autocorrelation is low, and it can easily be distinguished from any combination of shifted versions of other sequences in C i.e. the crosscorrelation is low. The size of the code is the number of codewords in C and is called its cardinality and is denoted |C|.

An optical orthogonal code is a family of (0, 1) sequences with good auto- and cross-correlation properties. Thumbtack-shaped auto-correlation enables the effective detection of the desired signal and low-profiled cross-correlation makes it easy to reduce interference due to other users and channel noise. The use of optical orthogonal codes enables a large number of asynchronous users to transmit information efficiently and reliably. The lack of a network synchronization requirement enhances the flexibility of the system. In [3] Let (n, w, λa, λc) be positive integers. An (n, w, λa, λc) optical orthogonal code, or briefly a (n, w, λa, λc) - OOC, C, is a family of (0, 1) - sequences of length n and weight w satisfying the following two properties:

The Autocorrelation Property

$$\sum_{t=0}^{n-1} x_i \, x_{t+\tau} = \begin{cases} w, & \\ < \lambda \mathrm{a}, & 1 < \tau < n-1 \end{cases} \quad \ldots .(1)$$

For any x € C and any integer τ, 0 < τ < n.

The cross-correlation property:

$$\sum_{t=0}^{n-1} x_i \, y_{t+\tau} = \begin{cases} w, & \\ < \lambda \mathrm{c}, & 1 < \tau < n-1 \ldots .(2) \end{cases}$$

For x ≠ y € C and any integer τ.

Largest possible cardinality of OOC ø (n, w, λ)

$$ø(n\,,w\;\lambda) = (n-1)(n-2)\ldots\ldots.(n-\;\lambda))/(w(w-1)(w-2)\ldots\ldots$$
$$\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Often an OOC is denoted by the positions where C has ones. As an example consider the code

C = {c1, c2}= {110100000000000, 100010000100000},

Which is an (15, 3, 1) OOC with two codewords. This can be written as C = {{0, 1, 3}15, {0, 4, 9}15}.

What the correlation constraint (¸ = 1) also say is that no distances between the positions of ones in the code (C) are repeated. For example the distance between the first and the second one in c1 is 1, but as we look at two consecutivec1's (cyclic shifted) the distance 14 will also be taken into consideration. In the codes above the distances are {1, 14, 3, 12, 2, 13, 4, 11, 9, 6, 5, 10}. The distances {14, 12, 13, 11, 6, 10} are due to cyclic shifts of the codeword's (when we look at two consecutive codewords). We see here that no distance is repeated and therefore the code is an OOC with λa, = 1. If $\lambda c = 2$ it means that any distance between the positions of ones cannot be repeated more than once.

A desirable property of a code is that it should be as large as possible, i.e. contain as many codewords as possible. This to enable more users to access the channel. An OOC is said to be optimal if it has the maximum cardinality for a given (n, w, λa, λc).As mentioned in the previous section the codeword length n increases with increasing cardinality and weight.

III. OPTIMAL CDMA SYSTEM

Fiber optic code-division multiple accesses (FO-CDMA) is one technique to allow several users to transmit simultaneously over the same optical fiber. A FO-CDMA system can, for each user, is described by a data source, containing the data that will be sent, followed by an encoder and then a laser that maps the signal from electrical form to an optical pulse sequence. At the receiver end an optical correlator is used to extract the encoded data.

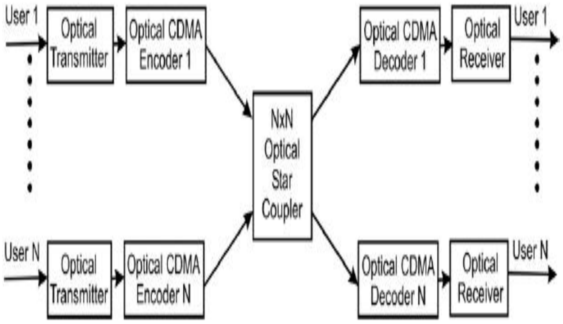

Fig.1: The Block diagram of OCDMA Network

In a FO-CDMA system it is common that each user is assigned one signature sequence called codeword. Each bit of information data is encoded by the signature sequence consisting of a number of shorter bits called chips. When this sequence is sent it represent 0.that a user with that unique signature has sent the information bit '1'. If the information bit is '0' it simply means that we send the corresponding length of zeros i.e. no light pulses during that interval. All users encoded data are then added together chip by chip and the result, which is called the superposition, are sent over the channel. If a light pulse represent the binary bit 1 (mark that this is a chip and not an information bit) and the absence of a light pulse represent the binary bit 0 the superposition mechanism has the following properties.

$0 + 1 = 1 + 0 = 1 + 1 = 1$

$0 + 0 = 0$

The individual receivers, consisting of optical correlators, continuously observe the superposition of all incoming pulse transmissions and recover the data from the corresponding transmitter. This is done by correlation between the incoming signal and stored copies of that user's unique sequence. The correlator will give a peak if the incoming stream of optical pulses contains the unique sequence and the presence of other users will be considered as noise. The decoding process is accomplished by using optical correlation.

The block diagram of CDMA system topology is shown in Fig. 1. The all user's signals are transmitted to the all users receivers by star topology of optical network. In incoherent time spread optical CDMA systems a specific binary codeword is assigned to each user. If the user is transmitting the data bit one, its transmitter sends codeword otherwise no signal is sent. Each user's optical CDMA decoder is matched to its intended signal.

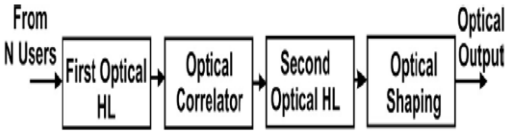

Fig.2: The block diagram of proposed optical CDMA decoder

The Fig. 2 shows the block diagram of proposed optical CDMA decoder. The proposed decoder consists of optical correlator, two optical hard-limiters (HL) and device of optical shaping. Its own correlator detects each user's signal by the means of the autocorrelation pulse, other users this signal appears as a noise. The optical HL is a non-linear device whose output optical intensities OUT depend on the input optical intensity IN. Where IN is an input optical intensity and its threshold level. Using the first and the second optical hard-limiters minimizes the multiple access interference in the system. It will be shown in the next part of this paper. The circuit of optical shaping changes optical pulse time duration. The function of optical CDMA decoder is to select the desired user's signal from received signal, which is a sum of all active users' transmitted codewords. This is achieved using Optical Orthogonal Codes (OOC), which have good correlation properties. The definition of OOC is reported in [1]. OOC allow multiple access and asynchronous transfer mode in the incoherent time spread optical CDMA system.

IV. SIMULATION OF OCDMA WITH OOC SET

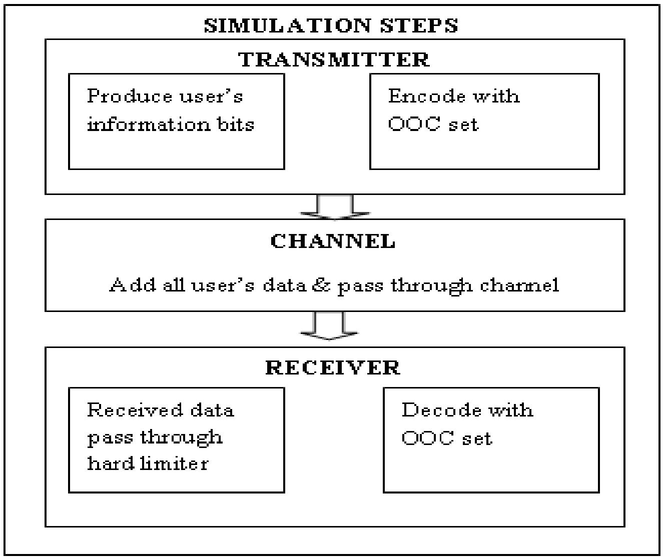

Fig. 3: Simulation steps for OCDMA with OOC set.

In FO-OCDMA, first create information bits of users & then encoded with OOC set. We used OOC set from table I, which are constructed by difference set methods [1].

Table I: OOC set using difference set methods [1]

Sr. no.	**w**	**n**	**OOC set**
1	3	13	{0,1,4} {0,2,7}
			{0,5,11} {0,9,12}
2	4	29	{0,1,3,8} {0,4,13,19}
			{0,3,22,28} {0,9,14,27}
			{0,7,26,28} {0,9,14,25}
			{0,15,23,28} {0,17,20,27}
3	5		{0,1,4,11,29} {0,2,8,17,22}
			{0,1,4,11,29} {0,5,14,20,22}
			{0,1,4,11,29} {0,9,15,17,36}
			{0,7,9,12,20} {0,16,17,31,35}
			{0,16,22,26,40} {0,21,29,32,34}

We consider an incoherent time spread optical CDMA system with *N* transmitters and receiver pairs (Fig. 1). *N* users share the same optical medium usually, but not exclusive, in a star topology. Each information bit from user *k* is encoded into a codeword.

$$C_k(t) = \sum_{i=1}^{n} C_k(i)\, P_k(t - iTc) \qquad \dots\dots(4)$$

where n is the length of the codeword, C_k [i] €{0,1} for $1 \le i \le n$, is the i -th chip value of the k -th user's codeword and Tc is the chip duration. Let C_k = {c_k [1],c_k [2],...............c_k[n]} is a vector representing the discrete form of the code. The chip signaling waveform p (t) i , for $1 \le i \le n$, is assumed to be rectangular with unit energy. Each transmitter broadcasts its encoded signal to all the receivers in the system.

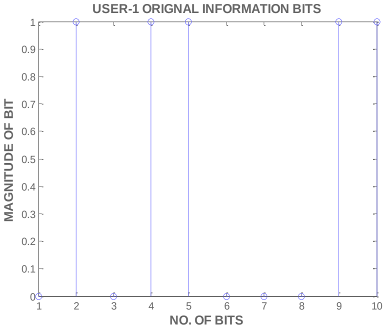

Fig.4 (a): user1 information bits

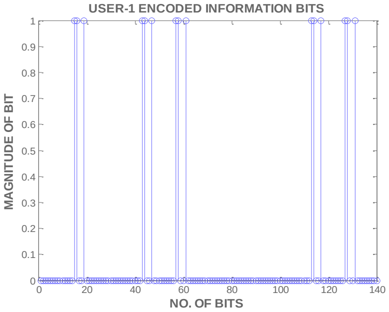

Fig.4 (b): user1 encoded data with OOC set

Fig4 (a) & (b) shows the original data & encoded data of user1,which are transmitted through the optical channel.OOC set are the signatures code are available at the transmitter as well as the receiver. The received signal is a sum of all the active *K* user's transmitted signals.

$$R(t) = \sum_{k=1}^{k} b_k\, C_k(t - \tau_k) \dots\dots(5)$$

where b_k €{0,1} is the k -th user's information bit and $0 \le \tau_k \le T$ is time delay for k = 1,.....,K . The receiver applies an optical correlator to the incoming signal to extract the desired user's information bit. We assume that the desired user's signal is denoted by k = 1.

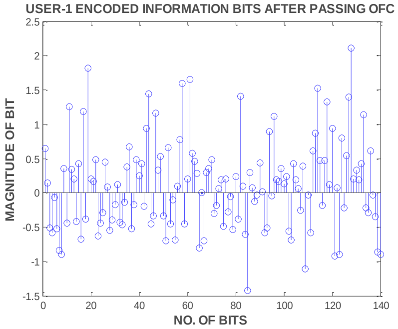

Fig.4 (c): channel output (received data)

Fig4(c) shows the received data from the channel. The signal of desired user's optical correlator output is thus,

$$y_1 = \int_0^T C_1(t)\, R_1(t)\, dt = b_1 N + MAI \qquad \dots\dots(6)$$

Where T= nTc is the time duration of one information bit. The first term in (4) corresponds to the desired users and the second one is multiple access interference (MAI). MAI is produced by simultaneously present optical codewords in the system. This model has neglected the effects of quantum noise and thermal noise in the photo detection process.

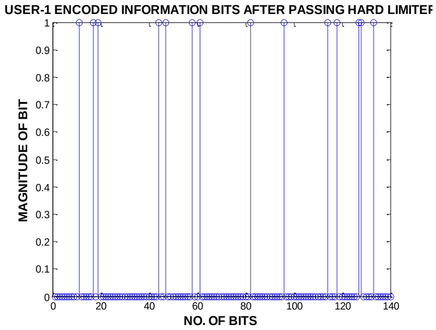

Fig.4 (d): output of hard limiter at receiver1

The received signals are passed through the hard limiter. An ideal optical hard-limiter is defined as

$$g(x) = \begin{cases} 1, & x \geq 1 \\ 0, & 0 \leq x < 1 \end{cases}$$

Therefore, if an optical light intensity (x) is bigger than or equal to one, the hard-limiter would clip the intensity back to one, and if the optical light intensity is smaller than one, the response of the optical hard-limiter would be zero. This ideal nonlinear process would enhance the system performance because it would exclude some combinations of interference patterns from causing errors as in the soft-limiter case, i.e., the patterns that caused errors by analog summation of light intensity rather than by exact reproduction of the particular pattern with no analog effect. The threshold value can be chosen under the following condition.

$0 \leq \text{threshold} \leq w$ ……………... (7)

Fig.4(d)shoes output of hard limiter of a receiver. Then this signal is get decoded with OOC decoder at the receiver side.Fig4 (e) shows the decoded output ,which is nothing but original data of a user1.As for ten bit information there is no error bit. Similarly we can calculate probability of error as a function of weight, length of OOC & no. of users.

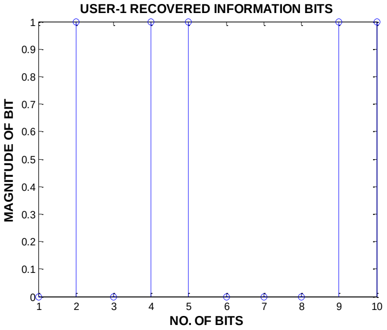

Fig.4 (e): decoder output of user1

$$PE = \frac{1}{2}\sum_{i=th}^{k-1}\binom{k-1}{i}\left(\frac{w^2}{2n}\right)^i\left(1-\frac{w^2}{2n}\right)^{k-1-i}$$ ……(8)

Where PE & k are probability of error and no. of users respectively. Fig.5shows several dependency of PE. Fig.5 (a) shows w-dependency of PE. As the sum of 1s in the code, w, goes up, PE gets lowered. Note that the highest threshold value under (4) would make the lowest PE on the same w. In the Fig. 5(b), we can find K-dependency of PE. As the number of accommodated users, K, goes up, PE gets higher. This is definitely due to the increasing interference. In Fig.5 (c), a length of code, n, is tested in different values, 100, 200, 500, 1000 and 2000. As n goes up, PE gets lowered resulting in long processing time. So we need to deal with the trade off problem on the low error rate and processing time.

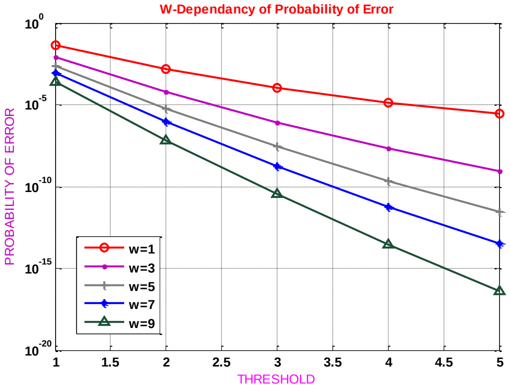

Fig.5 (a)

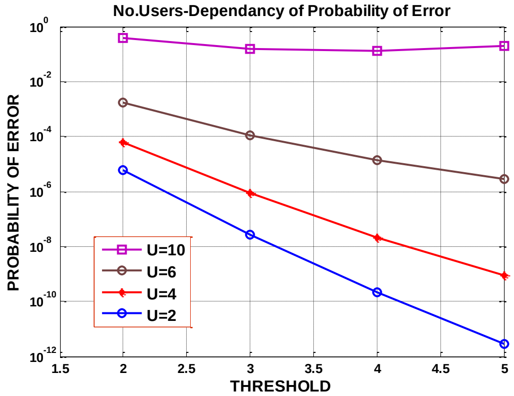

Fig.5 (b)

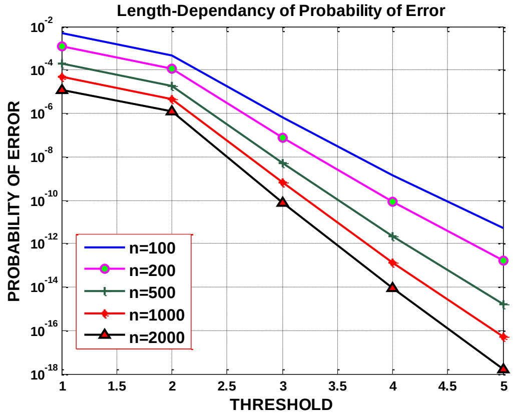

Fig.5 (c)

Fig.5. (a) *n*-dependency of probability of error (b)w- *d*ependency of probability of error (c) *K*-dependency of probability of error

V. CONCLUSION

In this report, we introduced the optical CDMA with the OOC set constructed by difference set methods. OCDMA scheme was successfully applied by using the optical orthogonal codes. OOC reduce interference due to other users and channel noise.OOC enables a large number of asynchronous users to transmit information efficiently and reliably. However, OOC revealed some drawbacks, requirement of long sequences resulting in long signal processing time and severe degradation due to fast adding of cross correlation. Optical hard-limiter showed remarkable improvement in reducing interference due to other users. We also presented that the threshold value, code length, and total numbers of users are important factors for the probability of error.

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