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Improvement in the Spectral Efficiency Achieved in OCDMA using 1-Dimensional OOCs

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Abstract— **An optical orthogonal code (OOC) is defined as collection of binary sequences with good auto and cross-correlation properties. Unlike bipolar code having correlation sidelobes and cross-correlation function close-to-zero, for OOC's the best correlation sidelobes and cross-correlation function is unity, which means that no distance between the positions of ones in the code are repeated.**

In this work, we study the spectral efficiency that can be achieved in OCDMA using the OOC's. the results are compared s with other codes in the same unipolar family. It is seen that, the maximum Spectral Efficiency that can be achieved with the unipolar codes remains low due to the positive nature of the optical channel. In effect, when power, rather than a bipolar quantity such as amplitude, represents the signal (as in incoherent all-optical systems), true code orthogonality, as traditionally defined is not achievable. In order to mitigate this limitation, Error Control Code (ECC) is used to increase the spectral efficiency of the unipolar OCDMA using OOCs. Results shows an improvement of the order of 30%

Keywords- Optical Code Division Multiples Access, Optical Orthogonal Code, Autocorrelation, Crosscorrelation, Multiple Access Interference, Spectral Efficiency, Forward Error Correction.

I. INTRODUCTION

Fiber-optic communication is a method of transmitting information from one place to another by sending light through an optical fiber. The main advantages of the optical fiber communications are low loss, high speed, large capacity and high reliability by the use of the broadband of the optical fiber. The huge bandwidth of optical fiber communication system can be utilized to its maximum by using multiple access techniques. This concept allows several users to transmit data simultaneously over the communication channel by simultaneously allocating the available bandwidth to each user. Several multiple access schemes have been employed in fiber optic communication to utilize the large capacity, predominantly Time Division Multiple Access (TDMA) [1] and Wave Division Multiple Access (WDMA) [2].

In the Optical TDMA technique, each user is allocated a specific time slot, where it requires short-pulsed diode lasers and provides only moderate improvements in bandwidth utilization. No partial network upgrade is possible; this makes OTDMA systems less flexible than that is desirable. While the Wave Division Multiple Access (WDMA) technique divides the available optical bandwidth into distinct wavelength channels that are used concurrently by different users. To increase the number of channels in the system, narrower bandwidth slots could be required, which would put further restrictions on the performance of the laser sources and other optical components. Furthermore, both optical TDMA and WDMA techniques require deterministic wavelength assignment and strict synchronous time-slot control, respectively.

On the other hand, OCDMA is a technique in which each user is assigned a specific code rather than a specific time slot or wavelength. This allows the same available bandwidth to be shared among the users, and the code assignments can be flexible and re-configurable. Recently, the OCDMA has received much attention as a flexible multiple access technique for computer networks due to its potential for re-configurability of multi-user codes, privacy and security in transmission, asynchronous access, simplified and decentralized network control, and the ability to support multimedia transmission with different data rates and quality-of-service (QoS) [3]. This characteristic of OCDMA makes it well-suited technology with increased capacity and large number of users of burst networks (i.e., local area network (LAN) [4] and possibly metro area network (MAN) applications [5].

Implementations of OCDMA, using a variety of coding and detection schemes, have been investigated in the last twenty years. The one proposed by Salahi and others [6,7] called the optical orthogonal code (OOC) is the most preferred for incoherent OCDMA system and is defined as a collection of binary sequences with good auto and cross-correlation properties. Unlike bipolar code having correlation side lobes and cross-correlation function close-to-zero, for OOC's the best correlation side lobes and cross-correlation function is unity, which means that no distance between the positions of ones in the code are repeated.

Optical-CDMA (O-CDMA) allows very flexible access of the large communication bandwidth available in optical fiber networks [3] with a capability to conceal the data content without relying on complex distributing nodes unlike the case of optical TDMA and WDMA [8].

II. SPECTRAL EFFICIENCY ANALYSIS

By definition, the spectral efficiency (η) of an OCDMA system is the data rate per unit channel bandwidth for a specified average power and fixed bit error rate (BER) value. Mathematically, the spectral efficiency of the system is expressed as,

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$$\eta = \frac{Total \quad Information \quad Rate}{Total \quad Bandwidth} = \frac{CR_B}{N_w \Delta f_{ch}} \qquad (1)$$

where C is the cardinality of the code which defines the number of simultaneous users transmitting on the network, R_B is the data rate per user, N_w is the number of wavelength channels employed and Δf_{ch} is the bandwidth of each wavelength channel.

Defining $n = \Delta f_{ch} / R_B$, where '*n*' is the code length, the spectral efficiency of the system is further simplified as

$$\eta = \frac{C}{n} \qquad (2)$$

for $N_w = 1$, in a single wavelength channel.

As can be seen from Eqn. (2), the spectral efficiency becomes a direct function of the number of simultaneous users transmitting on the network and length of the code. Thus, with knowledge of the cardinalities [9], the spectral efficiency achieved in the unipolar OCDMA can be analytically studied.

A. *Spectral Efficiency of OCDMA using OOC's*

For a given code length '*n*' and code weight '*w*', C denotes the cardinality of the optical orthogonal code defined as the largest possible size of any OOC. It specifies the maximum allowable users for a specified code length '***n***' and code weight '***w***'. Thus for

Thus for a (n, N_w, w, C, η) cardinality C is expressed as;

$$C = \frac{n-1}{w(w-1)} , \qquad (3)$$

the spectral efficiency η is thus

$$\eta = \frac{C}{n} = \frac{n-1}{n \times w(w-1)} \qquad (4)$$

The results achieved with Eqn. (4) are compared with those achieved with other codes [10] of the same unipolar family.

B. *Spectral Efficiency of OCDMA using Prime Codes (PC)*

For Prime Codes, the code length '*n*' and code weight '*w*' are described as $n = P^2$ and $w = P$ respectively. The maximum auto-correlation sidelobes is $\lambda_a = P-1$, and cross-correlation function is $\lambda_c = 2$. The cardinality of PC is represented by $(n, w, \lambda_a, \lambda_c)$ as $(P^2, P, P-1, 2)$ is equal to the weight C=w.

Thus for PC,

$$\eta = \frac{C}{n} = \frac{P}{P^2} = \frac{1}{P} \qquad (5)$$

C. *Spectral Efficiency of OCDMA using Extended Quadratic Congruence Code (EQCC)*

For EQCC, the code length '*n*' and code weight '*w*' are described as $n = P(2P-1)$ and $w = P$ respectively. The maximum auto-correlation sidelobes is given by $\lambda_a = 1$ and cross-correlation function is $\lambda_c = 2$. The cardinality of EQCC represented by $(n, w, \lambda_2, \lambda_c)$ as $(P(2P-1), P, 1, 2)$ is $C = P-1$.

Thus for EQCC,

$$\eta = \frac{C}{n} = \frac{P-1}{P(2P-1)} \qquad (6)$$

D. *Spectral Efficiency of OCDMA using Modified Prime Code (MPC)*

In the case of MPC, the code length '*n*' is described as $n = P^2$ for a code weight '*w*' respectively. The auto-correlation sidelobes and cross-correlation function are set to 1. The cardinality of MPC is $C < P-2$.

Thus for MPC,

$$\eta = \frac{C}{n} = \frac{P-2}{P^2} \qquad (7)$$

E. *Spectral Efficiency of OCDMA using Prime Hop Codes*

For Prime Hop codes, the code length '*n*' and code weight '*w*' are described as $n = P^2$ and $w = P$ respectively with a number of wavelength $N_w = P$ .the cardinality of the prime hop represented by (n, N_w, w, C, η), is $C = P(P-1)$.

Thus for Prime-hop,

$$\eta = \frac{C}{n} = \frac{P(P-1)}{P^3} = \frac{P-1}{P^2} \qquad (8)$$

Following the analytical results described in this section, a graph of spectral efficiency versus code weight for the various codes is plotted. The values employed for simulations are tabulated in Table I.

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Table I Optical unipolar code Parameters

Code	n	N_w	w	C
OOC	961	1	w=8	18
Prime Code	P^2=961	1	w=P=31	P=31
EQCC	P(2P-1) =1035	1	w=P=23	P-1=22
Mod PC	n=P^2=961	1	w=8	<P-2=27
Prime-hop	n=P^2=961	31	w=P=31	P(P-1) =930

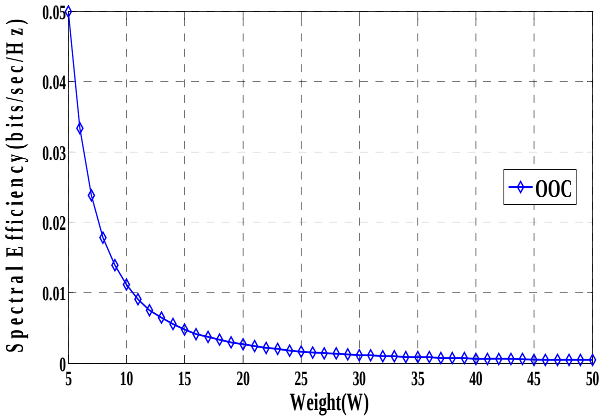

Fig.1. Spectral Efficiency of OOC of different weight

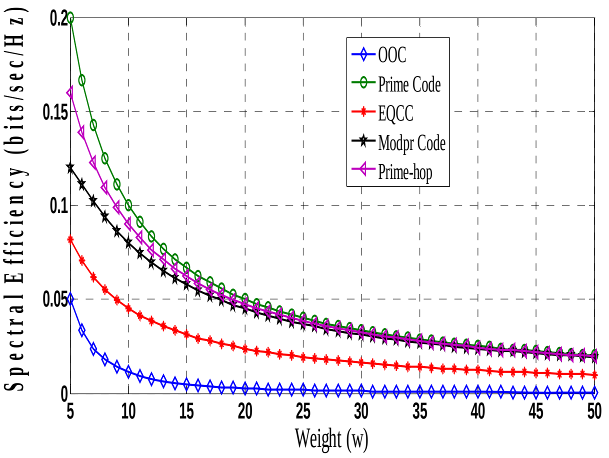

Fig.2. Comparison of spectral efficiency of various uniplar codes for the same code length

Fig. 1 shows a plot of Spectral Efficiency achieved in an OCDMA using OOC's for an increasing code weight. It can be seen, that the spectral efficiency reduces drastically with the increasing code weight. The maximum spectral efficiency of 0.05 bits/sec/Hz is observed for various low code weight of 5.

The Spectral efficiency achieved in the OCDMA using OOCs with different codes of the unipolar family for the code length n=961 is shown in Fig. 2. It can be observed that OOCs shows the least performance. This is due to the fact that for a fixed code length of n=961, of all the codes under study, OOC has the least cardinality value as tabulated in Table 1. hence the least spectral efficiency. On the other hand, hand, OOC's still promises to be the best among the unipolar family because of it excellent correlation properties and can accommodate larger number of users. We observe that prime codes achieve the highest in Spectral Efficiency for the same code length.

III. PERFORMANCE OF OOC'S USING FORWARD ERROR CORRECTION

In general, from the above simulations it is observed that the maximum Spectral Efficiency achieved with the unipolar codes remains generally poor due to the on-off keying of the optical channel. In effect, when power, rather than a bipolar quantity such as amplitude, represents the signal (as in incoherent all-optical systems), true code orthogonality, as traditionally defined is not achievable. Forward Error Correction (FEC) is used to increase the spectral efficiency of the unipolar OCDMA using OOC's.

Optimum thresholding decision [10, 11] ensures equal transition probabilities from "0 to 1" and "1 to 0". The resulting system becomes a Binary Symmetric Channel (BSC) which gives knowledge about the minimum redundancy required to achieve arbitrary error free communication.

The channel capacity is expressed as,

$$CC = 1 + P_B \log_2 P_B + (1 - P_B)\log_2(1 - P_B) \qquad (9)$$

where P_B is the transition probability from "0 to 1" and from "1 to 0" and it represent the bit error rate (BER) of the particular coding scheme. Using OOC's, the BER of the OCDMA system is showed in [6, 7].

Defining the best- case Error Control Code (ECC), the spectral efficiency η can approach $\eta_{\max}$ by ensuring minimum redundancy in the communication channel. In this idealization, the spectral efficiency of the OCDMA systems using OOC's as seen from Eqn. 4 is expressed as

$$\eta_{FEC} = \frac{C * CC}{n} = \frac{n-1}{n \times w(w-1)} * CC \qquad (10)$$

where CC is the channel capacity.

To observe the improvement in the spectral efficiency on applying the FEC, a graph (Fig.3) is plotted, using Eqn. 4 (η without FEC) and Eqn.3 (with FEC). It is observed that an improvement is achieved using FEC

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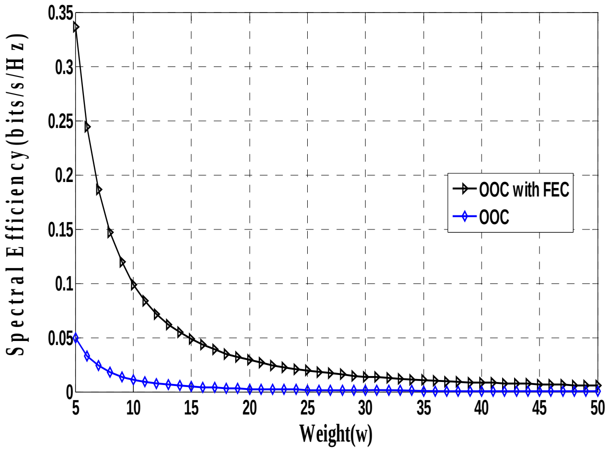

Fig.3. Improvement in Spectral Efficiency of OCDMA system using OOC with FEC

IV. CONCLUSION

In this work, the Spectral Efficiency that can be achieved in OCDMA using the OOCs has been studied. The results have been compared with other codes in the same unipolar family. Due to the positive nature of the optical channel, the true orthoganality is not achieved and the reason for poor spectral efficiency, that can be achieved with the unipolar codes.

It can be seen from the above discussions that using FEC (ECC), the Spectral Efficiency of the OCDMA systems can be improved significantly for lower code weight.

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