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Performance Impact of 2-D Codes along with Optical Hard limiter as an MAI Cancellation Techniques on O-CDMA system

Sandeep Sarowa and Shailesh Tondwal

Abstract—Several channel interference cancelation techniques have been proposed in different journals aiming at lowering to asymptotic bit error floors in optical OCDMA systems. These interference cancellation techniques are classified into two groups. One is based on the use of properties of sequence codes and another is based on the use of non linear elements in OCDMA systems. Optical hard-limiter is such a non-linear optical device which is used to reduce the MAI to some extent in OCDMA systems. Purpose of this paper is to investigate the impact of channel interference cancellation techniques when used individually or together on Incoherent Optical CDMA systems.

Keywords—Channel interference (CI), Multiple Access Interference (MAI), Optical Code Division Multiple Access (O-CDMA), Optical Orthogonal Codes (OOC), Two-Dimensional (2-D), Optical Hard limiter (OHL).

I. Introduction

Optical CDMA (O-CDMA) is a scheme which is used for multiplexing the optical communication channels that is based on the method of direct sequence spread spectrum technique. It allows the multiple users to access the network asynchronously, ability to support variable bit rate and bursty traffic, provide higher privacy and security in transmission, and allow scalability of network. Optical Code Division Multiple Access combines the large bandwidth of the fiber medium with the flexibility of the CDMA technique to achieve high-speed connectivity. In O-CDMA systems, every channel is identified by a unique pseudonoise key (signature sequence codes), whose bandwidth is much larger than that of the input data.

Optical CDMA can operate asynchronously without centralized control and does not suffers from packet collisions [4]. But the major problem associated with O-CDMA systems network is increase in the number of simultaneous active users and consequently increase in the channel interference. So in order to increase the number of simultaneous active users in O-CDMA networks, there need to analyze the channel interference cancellation techniques.

II. Incoherent O-CDMA System

In Incoherent O-CDMA systems, unipolar (0,+1) codes are used for encoding/decoding the information bits. Each receiver correlates its own signature sequence $s_i(t)$ with the combined received signal of all the users. The correlation function c(t) is obtained as the output of a filter matched to the user's own signature sequence $s_0(t)$. The output is sampled at the end of the bit interval T_b and compared to the threshold value of logical "0" and "1".

The principal noise source in O-CDMA systems is co-channel interference from other users, also known as Multiple Access Interference (MAI). The MAI is usually the dominant source of bit errors in an O-CDMA system; an intelligent design of the codeword sequences is important to reduce the contribution of MAI to the total received signal. As the number of users increases in an optical CDMA systems network the bit error rate increases, then to avoid Multiple Access Interference (MAI) from other users signature sequences should be as orthogonal as possible. Hence codes suitable for OCDMA systems should have the following properties:

1. A code should be distinguishable from a shifted version of itself.
2. A code should be distinguishable from a possibly shifted version of all other codes in the set.

However because the chip values are always non-negative, so orthogonality can be achieved only when the chip has the value "1" at some chip position the chips values of other signature sequences at the same chip position must be "0". To get a good discrimination of the "0"- and "1"-levels at the receiver side the zero power level is used for the signature sequence of the bit "0". When the received bit is "1" the interference from other users does not disturb the level detection but when the received bit is "0" the interference may cause a wrong decision.
Salehi analyzed the OCDMA systems performance taking into account channel interference and have suggested the use of an optical hard-limiter (placed before the optical correlator) to suppress some interference patterns that are capable of producing errors and have shown the improvement in system performance due to multi-user interference (MAI) [2]

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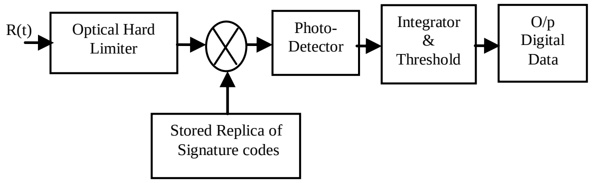

Figure 1. Receiver of Optical CDMA System with Optical Hardlimiter

Figure 2. Optical Hard-limiter

Where

$$p_{out} = \begin{cases} 0 & if \quad p_{in} < p_x \\ p_x & if \quad p_{in} \geq \quad p_x \end{cases} \tag{1}$$

A block diagram of the Noncoherent direct-detection Optical CDMA receiver using optical hard limiter before the optical correlator is shown in the Fig. 1.

Optical Hardlimiter is based upon the optical limiting process. Optical limiting is a nonlinear optical process in which the transmittance of a material decreases with increased incident light intensity. Optical limiters are one of the most important types of devices used to control the amplitude of high intensity optical pulses. These devices work due to intrinsic properties of the materials used for their fabrication. An ideal optical limiter has a linear transmittance at low input intensities, but above the threshold intensity its transmittance becomes constant. The operation of Hardlimiter is shown in Fig. 2.

III. Analysis & Results Of O-CDMA System

In OCDMA systems the encoded signature code of each user should be distinguished from a shifted version of itself and from the shifted versions of the codes of other users. When x_n and y_n are signature codes of two users the code design problem reduces to constructing codes that satisfy the following two conditions of correlation.

$$\left|\sum_{n=0}^{L_T-1} x_n x_{n+L}\right| = \begin{cases} W & for \qquad L=0 \\ \lambda_a & for \quad 1 \leq L \geq L_T - 1 \end{cases} \tag{2}$$

$$\left|\sum_{n=0}^{L_T-1} x_n x_{n+L}\right| = \{\lambda_c \quad for \quad 1 \leq L \geq L_T - 1 \tag{3}$$

The in-phase autocorrelation W is the number “1”s in x_n. It is called the weight of the code. L is the amount of shifting between the code sequences and L_T is the length of code sequence. The out-of-phase auto-correlation λ_a and the cross-correlation between the codes λ_c should minimum. However, a small out-of-phase autocorrelation is important for acquiring and maintaining the code synchronization [4], [6]. Because in Noncoherent CDMA systems x_n , y_n are unipolar (0,1) and all the terms in the correlation sums are non-negative and the codes designed to be used in radio CDMA systems in which both positive and negative values are available do not give λ_a and λ_c values small enough. Optical Orthogonal Code (C) is a family of (0, l) sequence of length L_T and weight W which satisfy the following two properties:

1. The Auto-Correlation property:

$$\sum_{n=0}^{N-1} x_n y_{n+\tau} \leq \lambda_a \tag{4}$$

for any $x = y \in C$ and any integer τ, $0 < \tau < L_T$

2. The Cross-Correlation property:

$$\sum_{n=0}^{N-1} x_n y_{n+\tau} \leq \lambda_c \tag{5}$$

for any $x \neq y \in C$ and any integer τ, $0 < \tau < L_T$

For e.g.: C = {1101000} is a (7, 3, 1, 1) OOC code.
For e.g.: C = {1100100000000, 1010000100000} is a (13, 3, 1, 1) OOC code with two codewords.

These sequence codes can further extended on the basis of number of variable used to define the characteristics of code i.e. on the basis of dimensions of codes. In 2-D optical codes, optical pulses are spread in either space and time domains or wavelength and time domains. The limitation of 1-D codes is less number of codes so there is less number of users can accommodates with these codes. In the last the intermediate approach to achieve permissible bit error rate and maximum number of users for a certain link length of real time networks to use the both optical hardlimiter and 2-D codes. Instead of viewing each wavelength as a separate channel that can support a set of optical codes, the time chips and wavelength channels can be viewed as the axes as Two-Dimensional (2-D) codeword. Fig. 3 demonstrates how the multiple- wavelength optical CDMA scheme combines to conventional WDMA and TDMA approaches.

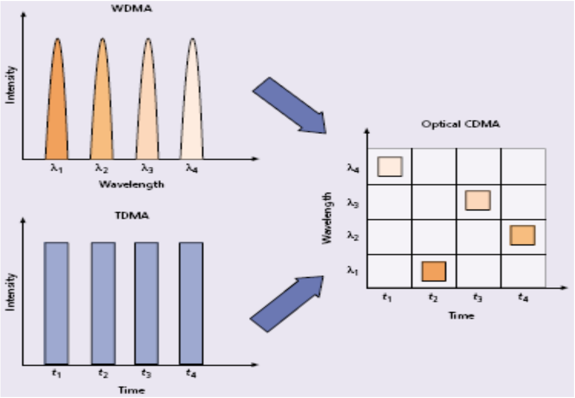

Figure 3. Multiple-Wavelength Two-Dimensional Code

In Multi-Wavelength Optical Orthogonal Codes (MWOOC's) there is spreading of the optical orthogonal codes in both the time and wavelength domains simultaneously. MWOOC's can support a much larger number of users with lower probability of error. In MWOOC's there need a tunable single wavelength laser or a bank of fixed-wavelength lasers or a broadband source spectrally sliced to provide all the required wavelengths and equal weight for all codeword. In these MWOOC's codes use $M \times N$ matrices, where M is the number of rows related to the number of available wavelengths and N is the number of columns related to number of time slots. The advantages of the MWOOC's are that the cross-correlation functions are still at most one and the number of wavelengths and code length are two independent parameters. The performance analysis begins with the formulation of the average probability to line up (or hit) with one of the pulses in a multiwavelength codeword with a pulse in another multiwavelength codeword. The error probability of the MWOOC's without hard-limiting OCDMA system given by.

$$\mathrm{Pe} \approx \frac{1}{2}\sum_{i=\mathrm{Th}}^{N-1}(-1)^{i}\left(\frac{W!}{i!\ \ (W-i)!}\right)\left(1-\frac{(q\times i)}{W}\right)^{N-1} \tag{6}$$

Where Th denotes the decision threshold of the receiver usually set equal to code weight for the optimal operation and N is the total number of simultaneous users in OCDMA network.

The probability of error the MWOOC's with hard-limiting is given by [5]

$$Pe \approx (\frac{1}{2})\sum_{i=Th}^{N-1}\left(\frac{(N-1)!}{i!\ \ (N-1-i)!}\right)q^{i}(1-q)^{N-1-i} \tag{7}$$

where q^0 and q^i denote the probability of getting one hit between the desired multiwave-length codeword originated from group 0 and group i (for i ={1,2,3….P-1}), respectively, and any interfering multiwavelength codeword in the code set. Here it was assume that the number of available wavelengths is P, the weight of the OOC is W, the length of the OOC is L_T, the cardinality of the OOC is ψ_{OOC} and the number of valid prime sequences (or groups) ψ_{group}=P. The threshold (Th) usually set equal to the code weight (W) for optimal operation and q is given by:

$$q = \frac{1}{P}q^{0} + \frac{P-1}{P}q^{i}$$

$$q^{0} = \frac{W^{2}(\varphi\times P-1)}{2L_{T}\left(\varphi\times P^{2}-1\right)}$$

$$q^{i} = \frac{W^{2}(\varphi\times P-1)+(W-1)^{2}}{2L_{T}\left(\varphi\times P^{2}-1\right)} \tag{8}$$

Results of 2-D MWOOC's codes on Incoherent OCDMA fiber-optic network for the minimum probability of error (Pe≤10^{-6}), with weight of code (W=15), taking account of different temporal length of code, with/without OHL are shown in Fig. 4 and Fig. 5.

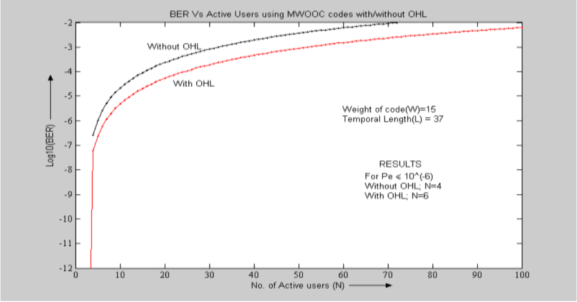

Figure 4. BER versus N using MWOOC's with/without OHL for W=15 & L_T =37

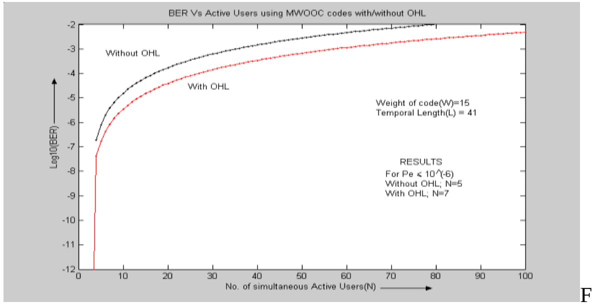

Figure 5. BER versus N using MWOOC's with/without OHL for W=15 & L_T =41

Several 2-D MWOOC's codes suitable for asynchronous OCDMA network have been reported in [9]. Among them MWOOC's codes under prime permutations (means time-spreading using OOC's codes and wavelength-spreading using prime codes) have the lowest λ_a, and λ_c values both are equal to 1. These MWOOC's 2-D codes are suitable for asynchronous OCDMA network with small numbers of users only. Another disadvantage of these MWOOC's codes is that, if the number of users has to be increased, there need either the wavelengths or the length of the sequence codes have to increase rapidly. As a result of this, for a given chip width the bit rate reduces which is not desirable and to increase the wavelengths more than the available wavelengths are practically difficult to generate. So this type of codes are not suitable for a network having large number of users and thus to departed this disadvantages need to analyze other Two-Dimensional (2-D) codes.

In Single Pulse per Row (SPR) codes pulses of different wavelength assign according to prime codes. The prime codes have been shown to support all network users simultaneously with a bit-error rate (BER) of less than 10^{-9} while employing significantly shorter codes than optical orthogonal codes [9]. Prime codes low-shifted autocorrelation (λ_a=1) ensures synchronizability. A low cross-correlation (λ_c=0) suppresses multiple-access interference (MAI) and thereby permits simultaneous access to the channel by many users. In case of SPR code, a code set is constructed using N_W wavelengths and L_T time chips in one bit period per wavelength.

A T/S AML (Temporal/Spatial Addition Modulo L_T) 2-D code family of SPR code characterized by N(L_T, R, p, W, λ_a,

λ_c), where N is the number of codes, L_T is the temporal length of code($L_T=T_b/T_c$; T_b is bit duration and T_c is chip time) , R is the number of rows which is equal to number of spatial channels (wavelengths), p is the number of pulses, W is the weight of code (W=Rxp), λ_a is the out-of-phase autocorrelation value and λ_c is the cross-correlation value [6]. The number of T/S AML codes that can be obtained for $L_T=W$, $\lambda_a=0$, $\lambda_c=1$ depends upon the type of integer L_T.

The probability of error (P_e) in case of T/S AML codes is given by:

$$Pe \approx \left(\frac{1}{2}\right)\sum_{i=Th}^{N-1}\left(\frac{(N-1)!}{i!\ (N-1-i)!}\right)\left(\frac{R}{2L_T}\right)^{i}\left(1-\frac{R}{2L_T}\right)^{N-1-i} \qquad (9)$$

The ½ factor is due the reason of sending the sequence code only when data “1” bit is transmitted and when data bit is “0” then nothing is send during this duration. Since the weight of code W = R x p, for SPR code pulses per row p=1 then $W=R=N_W$, then probability of error without optical Hardlimiter (OHL) written as:

$$Pe \approx \left(\frac{1}{2}\right)\sum_{i=Th}^{N-1}\left(\frac{(N-1)!}{i!\ (N-1-i)!}\right)\left(\frac{W}{2L_T}\right)^{i}\left(1-\frac{W}{2L_T}\right)^{N-1-i} \qquad (10)$$

The results of 2-D SPR codes on Incoherent OCDMA systems with & without OHL are evaluated. The simulated results are shown in figures Fig. 6 and Fig. 7.

As comparing the results for a permissible probability of bit error rate $Pe \le 10^{-9}$ as shown in Fig. 9 & Fig. 10, results shows that the use of OHL improves the performance of system.

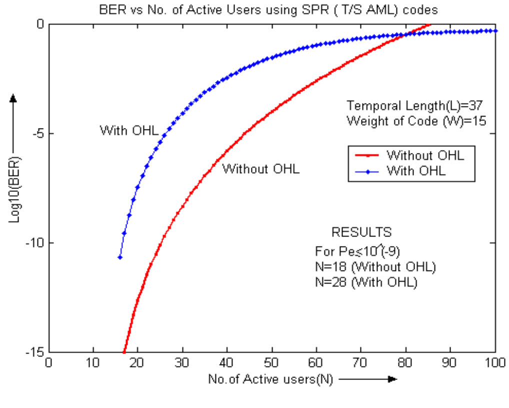

Figure 6. BER versus N using SPR codes with/without OHL with W=15, L_T =37

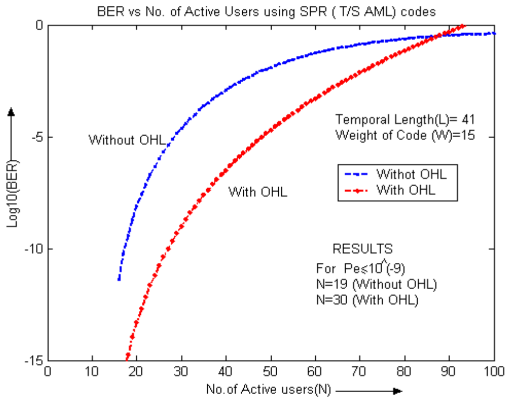

Figure 7. BER versus N using SPR codes with/without OHL with W=15, L_T=41

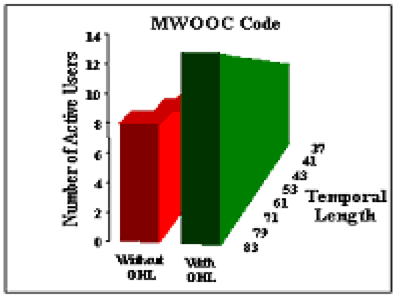

Figure 8. Impact of Optical Hardlimiter in case of Incoherent O-CDMA system using 2-D MWOOC codes.

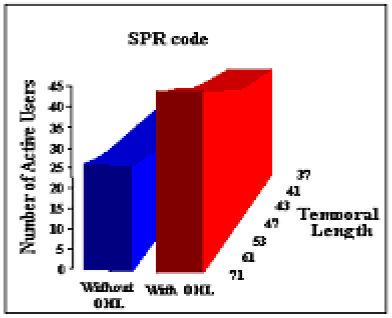

Figure 9. Impact of Optical Hardlimiter in case of Incoherent O-CDMA system using 2-D SPR codes

These codes are simulated for the different temporal lengths and then the results can be compared as shown in different figures from Fig. 8 and Fig. 9 as shown above.

IV. Conclusion

Impact of channel interference cancellation techniques used together; on Incoherent Optical CDMA systems network shows that the overall performance of system can be improved by using the both OHL & properties of codes.

One-dimensional codes with low cross correlation and autocorrelation designed for FO-CDMA networks have the disadvantage that the length of the code increases rapidly as the number of users or the weight is increased. To overcome this problem, 2-D codes were used and analyzed that using 2-D SPR codes with OHL more number of simultaneous active users can be accommodated. So by using the channel interference cancellation techniques together the performance of O-CDMA network can be improved.

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