A Novel Successive Interference Cancellation Scheme in OCDMA System

[1]Tawfig Eltaif, S*tudent Member, IEEE*, [2]Hossam M. H. Shalaby, *Member, IEEE,* [1]Sahbudin Shaari, *Member, IEEE*
[1]Photonics Technology Laboratory (PTL), Institute of Micro Engineering and Nanoelectronics,
Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, MALAYSIA
[2]Elect. Eng. Dept, Fac. of Engineering, Alexandria University, Alexandria 21544, EGYPT.
E-mail: tefosat@ieee.org

***Abstract* – In DC/CDMA systems, overcoming near/far effects is imperative for satisfactory performance. One way to combat the near/far effect is to use stringent power control. Another approach is multiuser detection (MUD). In addition to mitigating the near/far effect, MUD has more fundamental potential of raising capacity by canceling MAI. In this paper we going to present MUD scheme's known as successive interference cancellation (SIC). Where DS-OCDMA receiver was studied based on the SIC technique without hard limiter. Also we mention to use this technique with hardlimiter placed before the nondesired users.**

***Index Terms* - optical code-division multiple access (OCDMA), multiple-access interference (MAI), hard limiter (HL), optical orthogonal codes (OOCs), Successive interference cancellation (SIC).**

I. INTRODUCTION

Code Division Multiple Access (CDMA) has emerged as the technology of choice for wireless and optical transmission, because it provides a number of attractive features over other multiple access schemes – time division multiple access (TDMA) and wavelength division multiple access (WDMA) to meet the high capacity, which requires each user to use different wavelength to transmit. When the number of users is large or the channel access is bursty, OCDMA offers an advantage over WDMA, due to the OCDMA characteristics of graceful degradation as the number of users increase. Other advantages of CDMA are flexibility to user allocation and security against unauthorized users. As the communication channel is not subdivided into time or frequency slots, CDMA allows random access to an indefinite number of users. As additional users subscribe to the system, they can be given unique codes and then access the channel without the need to synchronize with any other user. The capacity of CDMA systems employing the conventional matched filter detector at the receiver end is often limited by the interference due to the other users in the system, known as multiple-access interference (MAI). MAI is introduced in CDMA systems due to the inability to maintain complete orthogonally of users' signature sequences over the hostile communication channels. [1]- [5]

Due to these advantages, (CDMA) has been the focus of much research in the last twenty years, primarily in the radio frequency domain, and also in the optical domain, where the traditional method to recover the data at the receiving end of an optical CDMA system is to use an optical correlator followed by a photodetector and a decision device [1].

To enhance the performance of the correlation receiver, the simplest techniques are used, where Salehi and Brackett used an optical hard limiter before the correlator at the receiver side [3]. Although the performance of their receiver (which involved an ideal photodetector) was improved, Kwon [6] has shown that such improvement becomes insignificant or more realistic systems, e.g., with avalanche photodiodes (APDs).With the implementation of double optical hardlimiters before and after the correlator at the receiving end, Ohtsuki [7], [8] was able to significantly improve the error-rate performance. Recently, Shalaby has proposed a new receiver model, called a chip-level receiver [9]. This receiver does not require the optical hardlimiters or the correlator in its implementation; hence, it is much more practical than the correlation receiver with hardlimiters.

The other studies on interference-cancellation techniques are inspired by radio frequency (RF) communications, such as multiuser detection [1], parallel interference cancellation (PIC) [4], [10]–[14], serial interference cancellation [15], or turbo codes [16]. These techniques are more complex than the HL techniques, but they are more efficient. In [4] and [14] Shalaby *et al.* have presented several interference-cancellation techniques which significantly improve the performance for a modified prime sequence. Here in this paper we are going to design new method of interference cancellation schemes to mitigate MAI for OCDMA, based on the use of HL device and SIC.

The paper unfolds as follows; section II describes the general direct detection OCDMA system. Also the popular detection options are described in other subsections: correlation detector, optimal detector. The SIC system performance analysis is presented in section III. Finally we give our conclusion in section IV.

II. DS-OCDMA SYSTEM DESCRIPTION

A. System Structure

In our system we consider an incoherent, DS-OCDMA system, where the system consist of N users, labeled $n = 1, 2 \ldots N$, using on-off keying (OOK) modulation to transmit binary data via optical channel for each user. And specific sequence code for each user. In particular, OOC will be used as the signature codes [1] in this paper. Where it's a family of (0,1) sequences of length F and weight W which satisfy that λ_a, λ_c are equal to 1, with good auto- and cross correlation enables the effective detection of the desired signal. The *n*th user has the spreading code

$$c_n(t) = \sum_{k=-\infty}^{\infty} c_{k,n} PT_c(t - kT_c) \qquad (1)$$

Where $c_{k,n} \in \{0,1\}$, T_c refers to the chip duration, and $P_\tau(t)$ is the rectangular pulse in $[0, \tau]$ with unit amplitude. We consider an ideal synchronous case, i.e., $\tau_k = 0$. It has been shown in [3] that the synchronous case is the worst case. Let:

$$b_n(t) = \sum_{i=-\infty}^{\infty} b_{i,n} PT(t - iT) \qquad (2)$$

Refer to the binary data of the *n*th user where $b_{i,n} \in \{0,1\}$ and T is the bit duration. Then we can say that the intensity signal of the *n*th user is $S_n(t) = A_n b_n(t) c_n(t)$ where A_n is the signal strength of the *nth* user. In this case in the receiver side we can get the signal *r(t)* as sum of the user's signals. As follows:

$$r(t) = \sum_{n=1}^{N} A_n b_n(t - \tau_n) c_n(t - \tau_n) + \rho \qquad (3)$$

Where τ_n are the relative delay, and we consider an ideal synchronous case, $\tau_n = 0$. The term ρ represents the noise signal due to the dark current.

B. Conventional Correlation Receiver

It is the simplest receiver structure. Assuming the desired user is j, and as described in [3], that the receiver signal *r(t)* in case of this receiver is multiplied by the code sequence corresponding to the desired user $c_j(t)$. Then after the T period we can get the decision value $Y_i^{(j)}$.

$$Z_i^{(j)} = \int_o^T r(t).c_j(t).dt$$

$$Z_i^{(j)} = W.b_i^{(j)} + \sum_{\substack{k=1\\k\neq j}}^{N} b_i^{(j)}.\int_o^T c_k(t).c_j(t).dt \qquad (4)$$

In the above equation the second part refer to the big problem faced the researchers in OCDMA called MAI. In the next stage the value $Z_i^{(j)}$ is compared with the decision threshold level θ, to get the estimation of the transmitted bit $b_i^{(j)}$. Where in this receiver, the photon counts over all mark positions of the underlying code are collected to form one decision Variable Y:

$$Y = \sum_{i=1}^{w} Y_i \qquad (5)$$

It is clear that a threshold θ is set. And if the collected photon counts in one bit time is less than θ, "0" is declared, otherwise "1" is declared to be sent.

Also it has been shown in [3] that the error probability $p_b(\theta)$ for the ideal synchronous case is:

$$p_b(\theta) = \frac{1}{2}\sum_{i=\theta}^{N-1}\binom{N-1}{i}\left(\frac{W^2}{2F}\right)^i\left(1-\frac{W^2}{2F}\right)^{N-1-i} \qquad (6)$$

C. Conventional Correlation Receiver with hard limiter (CCR with HL)

It's an optical device [3] placing before the tapped delay line, which used to reduce the interference effect, by reducing the receiver optical power. An ideal OHL function is defined as:

$$g(x) = \begin{cases} 1, \ldots\ldots x \geq 1 \\ 0, \ldots\ldots 0 \leq x \leq 1 \end{cases} \quad (7)$$

Also in [2] has been shown that for ideal chip synchronous case the error probability is:

$$P_b(\theta) \leq \frac{1}{2}\binom{W}{\theta}\prod_{i=0}^{\theta-1}\left(1-\left(1-\frac{W^2}{2F}\right)^{N-1-i}\right) \quad (8)$$

III. SUCCESSIVE INTERFERENCE CANCELLATION

In this section we will explain a new design interference cancellation scheme which called successive IC (SIC), where the interference due to all nondesired users is estimated in order to be removed from the received signal. SIC is a multiuser detection (MUD) technique typically employed in code division multiple access (CDMA) communication systems to improve the capacity and overall throughput of the system.

A. SIC Algorithm

Operation of the system is simple, where its works by attempting to detect and demodulate the strongest user signal currently present in the overall received signal. Here the strongest user is not known beforehand, but is detected from the strength of the correlations of each of the user's chip sequence with the received signal. The correlation values can be getting from the bank of the correlator. As shown in Fig 1, the block diagram of SIC receiver without hard limiter. In the next stage after this user has been detected and demodulated; its contribution to the original signal is regenerated and subtracted from the overall received signal to get a new received signal. Then we can conclude that the algorithm repeats except the strongest user from the new received signal (that one has one less user signal) is detected, demodulated, regenerated, and subtracted.[17]-[18]. Then at the end we can say one by one the strongest received signals are subtracted from the original signal till all users have been detected, and demodulated. Fig.2 shows the flowchart of this process, and in general algorithm the successive cancellations are carried as follows:

i) Recognize the strongest signal (one with maximum correlation value).
ii) Decode the strongest user.
iii) Regenerate the strongest users' signal using its chip sequence.
iv) Cancel the strongest user.
v) Repeat (until all users are decoded or a permissible number of cancellations are achieved).

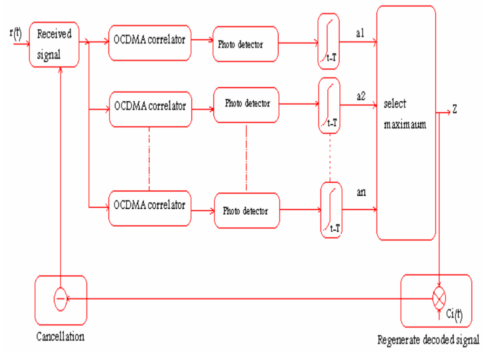

Fig. 1 SIC Receiver block diagram.

SIC with hardlimiter block diagram is shown in Fig3. In details analysis the general equations that describe SIC are presented in next section.

B. General equations

Assuming the signal coming to the receiver is *r(t)* in eq.(3). And for OOCs (F, W, 1, 1) and for synchronous case, and for *N* simultaneous users, we consider the threshold level θ_T ($0 < \theta_T \leq W$). In a general case we look for the error probability, which can be written as follows:

$$P_b = \frac{1}{2}P([E/0]+[E/1]) \quad (9)$$

As we mentioned previously the main function of this system based in maximum cross correlation between the users, then the effect n^{th} user's signal on the first receiver is denoted by $I_n^{(1)}$.

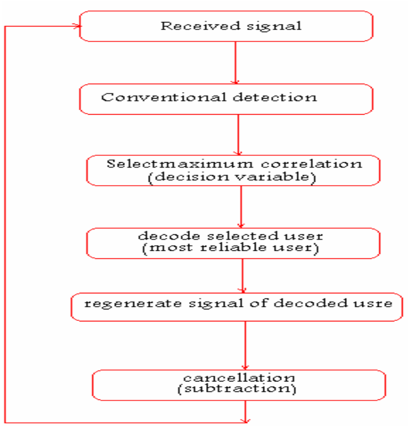

Fig. 1 Flow chart of interference cancellation schemes.

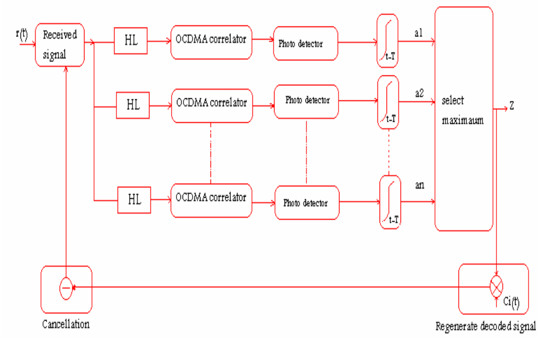

Fig. 3 SIC receiver block diagram with hardlimiter

We define the cross correlation between user i^{th} and the n^{th} user as:

$$I_{n,i}(\tau_{n,i}) = \frac{1}{T}[\int_0^T c_n(t-\tau_{n,i}).c_i(t)dt] \qquad (10)$$

Where $\tau_{n,i}$ is the time delay between the n^{th} user relative to the i^{th} user.

Hence, Z_1, the output of the first user's correlator at time T, can be written as:

$$Z_1 = \frac{1}{T_c}\int_0^T r(t).c_1(t-\tau_1).dt$$
$$= \frac{1}{T}\int_0^T [\sum_{n=1}^{N} A_n b_n(t-\tau_n)c_n(t-\tau_n) \qquad (11)$$
$$+\rho_1].c_1(t).dt$$

Then the decision on the bit is then made by using the decision variable.

$$Z_1 = b^{(1)}W + l_1 \qquad (12)$$

Where $b^{(1)}W$ refer to the desired signal term of the first user, and the second term can be defines as:

$$l_1 = \sum_{n=2}^{N} b_n I_{n,1}(\tau_{n,1}) + \rho_1 \qquad (13)$$

It is assumed that users are detected in order of decreasing signal strength such that user 1 will always correspond to the strongest user. Once this user has been detected and modulated, the result is used to regenerate the user signal. Then the regenerated signal is subtracted from the original signal. The correlation value is used for cancellation:

$$r_1(t) = r(t) - Z_1.c_1(t-\tau_1)$$
$$= \sum_{n=2}^{N} A_n b_n(t-\tau_n).c_n(t-\tau_n) \qquad (14)$$
$$+\rho_1 - l_1.c_1(t-\tau_1)$$

Now for the second strongest user, we have *(N-2)* interfering signals moreover some noise due to imperfect cancellation. In following decision statistic for user 2 after canceling user 1:

$$Z_2 = b^{(2)}W + l_2 \qquad (15)$$

And l_2 is defined as:

$$l_2 = \sum_{n=3}^{N} b_n I_{n,2}(\tau_{n,2}) + \rho_2 - c_1 I_{1,2}(\tau_{1,2}) \qquad (16)$$

In general for the j^{th} cancellations, we get:

$$r_j(t) = r_{j-1}(t) - Z_j.c_j(t-\tau_j) \qquad (17)$$

Where Z refers to the correlation after (j-1) st cancellation, then the decision variable for the (j+1) st user is given by:

$$Z_{j+1} = b_{j+1}W + l_{j+1} \qquad (18)$$

And l_{j+1} are given by:

$$l_{j+1} = \sum_{n=j+2}^{N} b_n I_{n,j+1}(\tau_{n,j+1}) +$$
$$\rho_{j+1} - \sum_{i=1}^{j} l_i I_{i,i+1}(\tau_{i,i+1}) \qquad (19)$$

In the above expression, the first term is MAI of the uncancelled users, second term is noise signal due to the dark current, and the third term is due to the cumulative noise from imperfect cancellation.

IV. Conclusion

Through this work we have presented a new proposal in interference cancellation based in OCDMA, called successive interference cancellation (SIC). The interference cancellation is never perfect, and the residual cancellation errors propagate because of the successive nature of the decoding. In fact, these residual errors are the principle capacity-limiting issue in SIC systems. In future work we need obviously to analyze the performance of SIC; also we need to analyze the practical implementation of the interference canceller.

ACKNOWLEDGEMENT

I would like to thank Dr. Salah Elfaki, University of Science & Technology, Sudan for helpful discussions.

REFERENCE

[1] M. B. Pearce and B. Aazhang, "Multiuser Detection for Optical Code Division Multiple Access Systems," *IEEE Trans. Commun*, vol. 42, no. 21314. (1994).

[2] J. A. Salehi, "Code division multiple-access techniques in optical fiber networks—Part I," *IEEE Trans. Commun.*, vol. 37, no. 8, pp. 824–842. (1989).

[3] J. A. Salehi and C. A. Brackett, "Code division multiple-access techniques in optical fiber networks—Part II: Systems performance analysis," *IEEE Trans. Commun.*, vol. 37, no. 8, pp. 834–842. (1989).

[4] H. M. H. Shalaby, "Synchronous fiber-optic CDMA systems with interference estimators," *J. Lightw. Technol.*, vol. 17, no. 11, pp. 2268–2275. (1999).

[5] C. Goursaud, A. Julien-Vergonjanne, C. Aupetit-Berthelemot, J. P. Cances, and J. M. Dumas, "DS-OCDMA Receivers Based on Parallel Interference Cancellation and Hard limiters," *IEEE Transactions Commun*, vol. 54, no. 9. (2006).

[6] H. M. Kwon, "Optical orthogonal code-division multiple-access system—Part I: APD noise and thermal noise," *IEEE Trans. Commun.*, vol. 42, pp. 2470–2479. (1994).

[7] T. Ohtsuki, "Performance analysis of direct-dectection optical asynchronous CDMA systems with double optical hard-limiters," *IEEE J. Lightwave Technol.*, vol. 15, pp. 452–457.(1997).

[8] T. Ohtsuki, "Direct-detection optical asynchronousCDMAsystems with double optical hard-limiters: APD noise and thermal noise," in *Proc. IEEE Global Telecommunications Conf. (GLOBECOM '98)*, Sydney, Australia, pp. 1616–1621. (1998).

[9] H. M. H. Shalaby, "Chip-level detection in optical code-division multiple access," *IEEE J. Lightwave Technol.*, vol. 16, pp. 1077–1087. (1998).

[10] D. Divsalar and M. K. Simon, "Improved CDMA performance using parallel interference cancellation," in *Proc. Mil. Commun. Conf.*, pp. 911–917. (1994).

[11] R. Fantacci, A. Tani, and G. Vannuccini, "Performance evaluation of an interference cancellation receiver for noncoherent optical CDMA systems," in *Proc. GLOBECOM*, vol. 3, pp. 2823–2827. (2002)

[12] C. Goursaud, N. M. Saad, Y. Zouine, A. Julien-Vergonjanne, C. Aupetit-Berthelemot, J. P. Cances, and J. M. Dumas, "Parallel multiple access interference cancellation in optical DS-CDMA systems," *Ann. Telecommun.*, vol. 9–10, pp. 1053–1068. (2004).

[13] C. Goursaud, A. Julien-Vergonjanne, Y. Zouine, C. Aupetit-Berthelemot, J. P. Cances, and J. M. Dumas, "Improvement of parallel interference cancellation technique with hard limiter," in *Proc. IEEE Globecom, Photon. Technol. Commun.*, CD-ROM. (2005)

[14] H. M. H. Shalaby and E. A. Sourour, "Co-channel interference cancellation in optical synchronous CDMA communication systems," in *Proc. IEEE 3rd Int. Symp. Spread Spectrum Tech. Appl.*, Oulu, Finland, pp. 579–583. (1994).

[15] C. Goursaud, A. Julien-Vergonjanne, Y. Zouine, M. Morelle, C. Aupetit-Berthelemot, J. P. Cances, and J. M. Dumas, "Serial interference cancellation receiver for optical CDMA systems," in *Proc. IEEE Conf. ITST*, Brest, France, pp. 403–406. (2005).

[16] C. Argon and S. W. McLaughin, "Optical OOK-CDMA and PPMCDMA systems with turbo product codes," *J. Lightw. Technol.*, vol. 20, no. 9, pp. 1653–1663. (2002).

[17] P. Pate1 and J. Holtzman, "Analysis of a Simple Successive Interference Cancellation Scheme in a DS/CDMA System," *IEEE journal on selected areas in commun*, vol. 12, no. 5. (1994).

[18] P. Patel and **I.** Holtzman, "Analysis of a simple successive interference cancellation scheme in DS/CDMA system using correlations," in *Proc. GLOBECOM* Houston, TX. (1993).