Performance analysis of successive interference cancellation scheme for optical CDMA systems using modified prime sequence codes

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ABSTRACT

In this paper, we propose a new technique in direct sequence code division multiple access system using on-off key and modified prime sequence code, the scheme of this technique dubbed successive interference cancellation (SIC). The basic principle of SIC scheme is to subtract the strongest received signals from the original signal one by one till all users have been detected, and demodulated. In this analysis we take in account the possibilities of errors in previous cancellation. It has been shown that the proposal IC scheme with (-20dBm) effective power can suppress multiple-access interference (MAI), and improve the system performance significantly.

Keywords: Optical code-division multiple access (OCDMA), multiple-access interference (MAI), modified prime sequence codes, successive interference cancellation (SIC).

1. INTRODUCTION

Optical code division multiple access (OCDMA) systems allow multiple users to transmit information over the same physical channel. However, the performance and capacity of CDMA systems are limited by multiple access interference (MAI). Many researchers have been working in interference cancellation, where a number of different techniques are available to mitigate the cross correlation problem; Salehi and Brackett [1] have used an optical hardlimiter. Double optical hardlimiters placed before and after the optical correlator have been proposed in [2]. Lin and Wu in [3] have proposed a synchronous OCDMA system with an adaptive optical hardlimiter placed after the correlator receiver, they show the performance can be improved, compared with system with double hardlimiter. In [4] and [5] Shalaby have proposed some cancellation techniques for both ON–OFF keying (OOK) and pulse-position modulation (PPM) CDMA systems. These techniques depend on estimating the interference from knowledge of some other users' code sequences, and in [6] he has developed a receiver model which performs refined observations at chip levels rather than at frame levels. He shows that using chip-level receivers the error floors can be lowered to that of the optimum receivers.

Recently, other studies on interference cancellation techniques are inspired by radio frequency communication, such as multi-user detection (MUD) technique which typically employed in optical CDMA [7] to improve the capacity and overall throughout of the system. It is known that optimum multi-user detection (MUD) has a much better theoretical performance than conventional detection [8]. Inspired of MUD we have been introducing the successive interference cancellation (SIC) [9].

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2. DS-OCDMA SYSTEM

2.1 Performance of modified prime sequence code

We consider an incoherent DS-OCDMA system, which require (1, 0) valued code sequence with small cross correlation to mitigate multiple user interference. On-off keying (OOK) modulation is used in this paper, and prime sequence code is employed. The construction of the prime code begins with finite field (Galois field) [10]; the rules for a finite field with a prime number (p) of elements can be satisfied by carrying out the arithmetic modulo-p. The prime sequence code are the set of coded sequences of code length $F = p^2$ derived from prime sequences of length p, where p is a prime number. Starting with the Galois field $GF(p) = \{0,1,...,j,...,p-1\}$, each element $s_{x,j}$ of a prime sequence $S_x = (s_{x,0}, s_{x,1}, ..., s_{x,j}, ..., s_{x,(p-1)})$ is constructed by multiplying every element j from *GF(p)* by x, modulo *p*. the prime sequence are then mapped into a binary code sequence $C_x = (c_{x,0}, c_{x,1}, ..., c_{x,j}, ..., c_{x,(p^2-1)})$ according to:

$$C_{x,i} = \begin{cases} 1 & for\ i = s_{xj} + jp, \quad j = 0,1,...,p-1 \\ 0 & otherwise. \end{cases} \tag{1}$$

If we take any two elements in the range 0 to p — 1, and either add or multiply them, we should take the result modulo-p. [10-12] let a prime number p be given, a modified prime sequence code can be constructed, $N = P^2$ code sequences can be generated, each of weight P and length P^2, derived from prime number, according to [11], it has P distinct codeword's of which the highest peak of periodic cross-correlation (i.e., the cross-correlation constraint λ_c) is equal to one [13]. Under synchronized condition, the cross correlation function I_{xy} between any pair of code sequences x and y is given by [13]:

$$I_{x,y} = \begin{cases} p; & x = y \\ 0; & x\ and\ \ y\ are\,in\,the\,same\,group \\ 1; & x\,and\ y\ are\,in\,different\,group \end{cases} \tag{2}$$

2.2 Successive interference cancellation algorithm

The SIC works as follows; first attempting to detect and demodulate the strongest user signal currently present in the overall receiver signal, after the signal of the user has been detected and demodulated, it is presented again by regenerated and subtracted from the overall received signal, producing a new receiver signal. Then the algorithm repeats with the strongest user signal in the new received signal, the one created after the first cancellation. A block diagram showing successive interference cancellation (SIC) is given in Fig. 1, and the general algorithm of the SIC system is carried as follows [9]:

I. Recognize the strongest signal (the one with maximum correlation value).
II. Decode the strongest signal.
III. Regenerate the strongest signal using its chip sequence.
IV. Cancel the strongest user signal by subtraction.
V. Repeat until all users are decoded or a permissible number of cancellations are achieved.

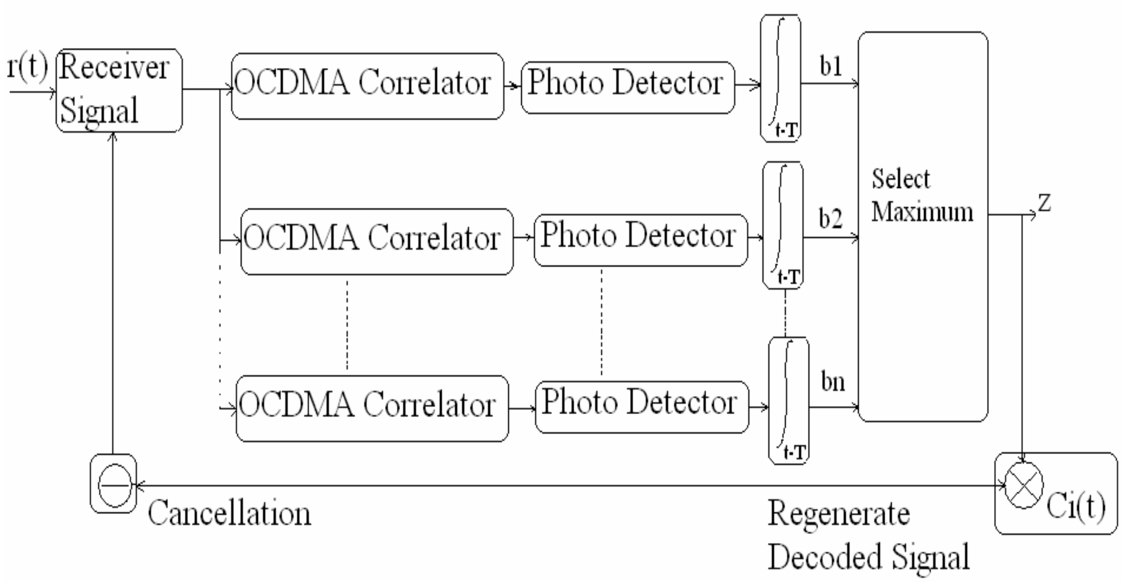

Fig. 1. SIC Receiver block diagram.

2.3 DS OCMA performance analysis

We consider here a simple system to suppress MAI, attractive technique to improve the system capacity and significantly improve BER performance system. Assuming that each user is assigned a unique prime sequence code of length p^2 and weight p and considering the total number of users $N=p^2$. The receiver signal $r(t)$ at the front end of the receiver is modeled as follows:

$$r(t) = \sum_{n=1}^{N=P^2} A_n b_n (t-\tau_n) \sum_{i=0}^{P^2-1} c_n^i (t-\tau_n) + n(t) \tag{3}$$

Where;

N total number of users
A_n signal strength of the n^{th} user
$b_n(t)$ bit sequence of n^{th} user
$c_n(t)$ spreading chip sequence of the n^{th} user
$n(t)$ noise signal (thermal noise)
P^2 code length
τ_n Time delay of the n^{th} user.

The receiver signal is fed into the bank receivers, one for each user. The sign of the output of the receiver is the corresponding user decision. Detailed analysis of the SIC scheme for incoherent DSOCDMA system can be found in [9]. After j^{th} cancellation, the decision variable for the $(j+1)^{th}$ user taking in account the code properties indicated in equation (1), is given by:

$$Z_{j+1} = \zeta_{j+1} + l_{j+1} \tag{4}$$

Where

$$\zeta_{j+1} = \frac{A_{j+1} b_{(j+1)}}{P} \tag{5}$$

$$l_{j+1} = \frac{1}{P^2}\left[\sum_{n=j+2}^{N=P^2} A_n b_n I_{n,j+1}(\tau_{n,j+1}) - \sum_{i=1}^{j} l_i I_{i,i+1}(\tau_{i,i+1})\right] + n_{j+1}(t) \tag{6}$$

In the above expression, the first term is combine the MAI of the uncancelled users; and cumulative noise from imperfect cancellation. The original prime code is analyzed by using a Gaussian approximation. The negative effects of shot noise, effect of the receiver's dark current, and other sources of noise are neglected in order to focus only on the interference (i.e., MAI), created by other simultaneous users, further more for the thermal noise, we can define the variance of l_{j+1} conditioned on A_n as follows according to [15-16]:

$$\Gamma^2{}_{j+1}\Big|\_MAI = \frac{1}{P^2}\left[\sum_{n=j+2}^{N=P^2} A_n{}^2 b_n^2 . \mathrm{var}[I_{n,j+1}(\tau_{n,j+1})] + \sum_{i=1}^{j} \Gamma^2{}_i . \mathrm{var}[I_{i,i+1}(\tau_{i,i+1})]\right] \tag{7}$$

We considering an ideal synchronous case, i.e., τ_n =0, for all n, it has been shown in [14] that the synchronous case is the worst case. Then the variance of cross correlation in equation (2) is given by [15]-[16]:

$$\mathrm{var}(I_{n,j+1}) \approx \frac{1}{P^2} \tag{8}$$

Substituting (8) into (7) we get the variance of the noise in the decision variable:

$$\Gamma^2{}_{j+1}\Big|\_MAI = \frac{1}{P^4}\left[\sum_{n=j+2}^{N=P^2} A_n^2 + \sum_{i=1}^{j} \Gamma^2{}_i\right] \tag{9}$$

Furthermore the thermal noise which has a Gaussian distribution effect has been considered:

$$\sigma_{th} = 4 K_b T_n B / R_L \tag{10}$$

Where B noise-equivalent electrical bandwidth of the receiver in hertz; K_b is Boltzmann's constant in joules per Kelvin = 1.38x10^{-23} J-K^{-1}; T_n absolute receiver noise temperature in Kelvin; and R_l is the receiver load resistor in ohm.

The responsively of the PDs is given by $\Re = \eta e / h v_c$. Here, η is the quantum efficiency, e is the electron's charge, h is the Plank's constant, and v_c is the central frequency of the original broadband optical pulse. Then from equation (4), equation (9) and equation (10), we can get the signal to noise ratio function of A_n as follows:

$$SNR_{j+1} = \frac{\Re^2 A_{j+1}^2 / P^2}{\frac{\Re^2}{P^4}[\sum_{n=j+2}^{N} A_n^2 + \sum_{i=1}^{j} \Gamma^2{}_i] + 4K_b T_n B / R_L} \tag{11}$$

To calculate the bit error rate, we shall assume the noise l_{j+1} is Gaussian with zero mean and variance $\Gamma^2{}_{j+1}$. Then the probability of error, conditioned on the A_n, is given below as follows:

$$BER_{j+1} = Q\left(\frac{|\zeta_{j+1}|}{\Gamma_{j+1}} \right) \tag{12}$$

$$= Q\left(\frac{\Re . A_{j+1} . b_{j+1} / P}{\sqrt{\frac{\Re^2}{P^4}[\sum_{n=j+2}^{N} A_n^2 + \sum_{i=1}^{j} \Gamma^2{}_i] + 4K_b T_n B / R_L}} \right) \tag{13}$$

$$BER_{j+1} = Q\left(\sqrt{SNR_{j+1}} \right) \tag{14}$$

3. SYSTEM PERFORMANCE RESULTS

In this section, we present analytical results of our mathematical model. Figure 2 shows the relation between the number of active users and signal to noise ratio, using modified prime codes (MPR) for some values of *p*, where the parameters are set as follows: *p* =7, *p*=11, *p*=13, respectively. Table 1 gives the typical parameters used in our calculations. It can be seen that, using effective power for each user assumed ideal at -20dBm, we notice that each curve ends at the point where the number of active users is equal to the code size. The SNR is significantly increased when modified prime code *p* increasing.

Remark: Noticing that for similar number of active users (40), SNR performance is increased by increasing *p*.

Table .1. Typical parameters in the system.

Parameter	Value
Operation Wavelength	193.1 THz
PD quantum efficiency	0.6
Receiver noise temperature	300k
Receiver load resistor	1030Ω
Electrical equivalent bandwidth	80MHz

Figure 3, shows variations of the BER with the number of active users, for some values of *p*, with parameters set as follows: *p* =7, *p*=11, *p*=13, respectively. Under ideal power for all users (-20dBm). It is obvious that large prime code *p*, improves bit error rate.

Figure 4, shows the relation between the number of active users and signal to noise ratio for our proposal SIC system, using modified prime codes (MPR) at *p*=13. It is seen as expected that, the performance of the system is better with higher input effective power. We show that BER is more affected by noise at lower input power as expected.

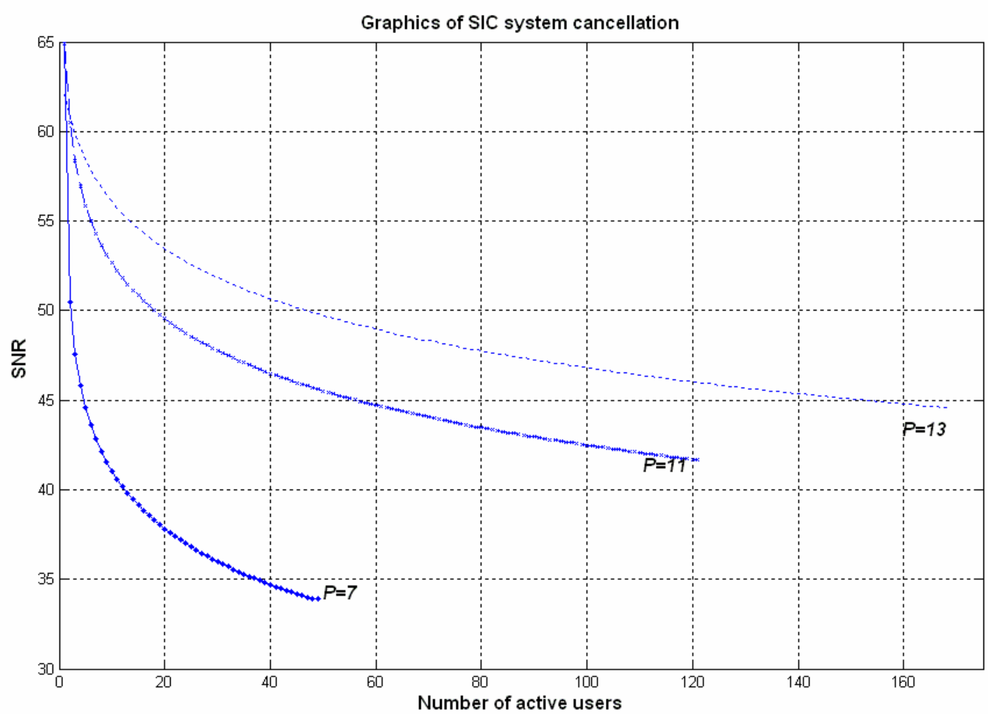

Fig.2. SNR versus number of active users with receive power (-20dBm)

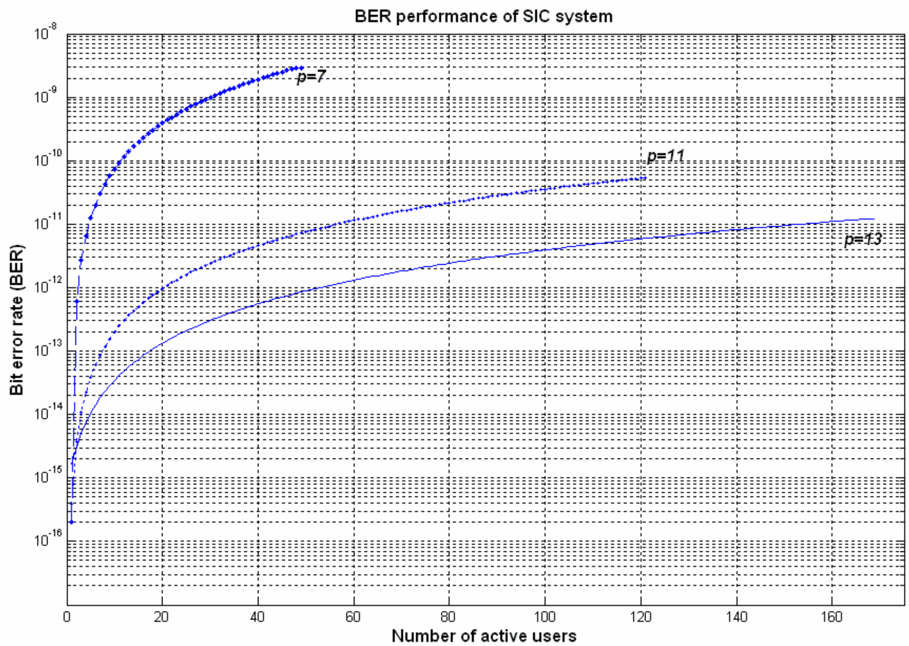

Fig.3. BER versus number of active users under ideal power (-20dBm)

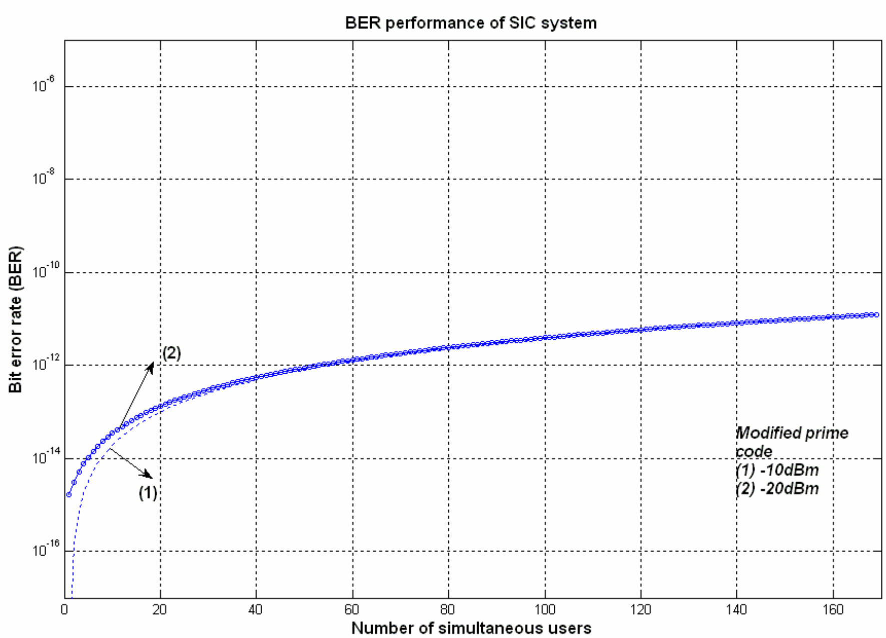

Fig .4. BER versus number of active users under different power

4. CONCLUSION

In this paper, it has been shown that the SIC is a low complexity suboptimal multiuser detector for CDMA system. The successive interference cancellation scheme performed to mitigate multiple access interference. The major problem in SIC system is the accumulated cancellation noise. An analysis of the performance of this system was presented under modified prime code. It is shown that the bit error rate performance analysis significantly improved, and it is found that bit error rate performance improves as the modified prime code p increases as well.

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