# Analysis of Successive Interference Cancellation Scheme using OOC code in Optical CDMA Systems

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*Abstract*- **Multiuser detection is an effective method to suppress MAI. In this paper we propose one of the multiuser detection schemes which are called Successive interference cancellation (SIC), this scheme known as a low-complexity multiuser detection method for DS/CDMA systems. The proposal system has been analyzed by taking into account the error in previous cancellation, and it is shown that the performance system (i.e. BER) with ideal effective power for all the users (-20dBm) is improved at each stage of cancellation process.**

## I. INTRODUCTION

Multiuser detection (MUD) direct-sequence code-division multiple access (DS-CDMA) approach offers several advantages including interference cancellation. Several studies have analyzed the performance of multiuser DSCDMA systems. It is shown that multiple access interference (MAI) limits DS-CDMA system capacity [1]. Any technique which can suppress/cancel MAI will increase the system capacity.

In recent years multi-user detection has become an attractive alternative to conventional spread spectrum detectors. It is well known that optimum multi-user detection has a much better theoretical performance than conventional detection [2-3]. We propose the interference cancellation (IC) detectors which is probably the least complex of these sub-optimum detectors. These IC schemes, while distinctly sub-optimum, still retain a performance which is considerably better than the conventional detector. The IC scheme can be implemented as a successive IC detector and a parallel IC detector.

## II. SYSTEM DESIGN

### *A. Successive Interference Cancellation*

Inspired of radio frequency (RF) MUD techniques, we propose to use a similar scheme of MUD in optical fiber communication. We call this scheme successive interference cancellation (SIC) [3]. It is employed in code division multiple access (CDMA) communication systems to improve the capacity and overall throughput of the system.

### *B. SIC Algorithm*

The concept of this scheme is focusing on the strongest user. At the receiver side the received signal will fed up to bank of conventional receiver to detect and demodulate the entire users signal. Among those users the strongest user will be selected. 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 excluding the strongest user from the new received signal (Which composed of one user signal less) is detected, demodulated, regenerated, and subtracted [3-4]. At the end, we can say that the strongest received signals are subtracted from the original signal one by one till all users have been detected, and demodulated. Fig. 1 shows the block diagram of SIC receiver In general algorithm the successive cancellations are carried as follows:

1) Recognize the strongest signal (the one with maximum correlation value).
2) Decode the strongest signal.
3) Regenerate the strongest signal using its chip sequence.
4) Cancel the strongest user.
5) Repeat until all users are decoded or a permissible number of cancellations are achieved.

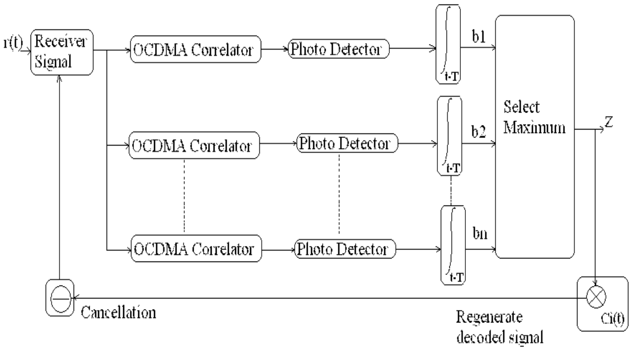


Fig.1. SIC Receiver block diagram.

### *C. General Equations*

We consider an incoherent, DS-OCDMA system consisting N users, labeled by n where $n = 1, 2 \ldots N$. On-off keying (OOK) modulation is used to transmit binary data via optical channel for each user with a specific sequence code for each. In particular, OOC will be used as the signature codes [5] in this paper. Where it's a family of (0,1) sequences of length F and weight W which satisfy that $\lambda_a$, $\lambda_c$ are equal to 1, with good auto- and cross-correlation enables the effective detection of the desired signal.

The intensity of the *n*th user signal is $S_n(t) = P_n b_n(t) c_n(t)$ where $P_n$ is the signal strength of the $n^{th}$ user, $c_{k,n} \in \{0,1\}$ refer to sequence code, and $b_{i,n} \in \{0,1\}$ is the $i^{th}$ datum bit of the $n^{th}$ user. Hence, the received signal can be expressed as:

$$r(t) = \sum_{n=1}^{N} P_n b_n(t-\tau_n) \sum_{i=1}^{F} c_n^i(t-\tau_n) + n(t) \tag{1}$$

The main function of this system based in maximum cross correlation between the users, then the effect of $n^{th}$ user's signal on the first receiver is denoted by $I_n^{(1)}$. This can be expressed as:

$$I_{n,i}(\tau_{n,i}) = \frac{1}{T}[\int_0^T c_n(t-\tau_{n,i}).c_i(t)dt] \tag{2}$$

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

The output at the received side for the first can be written as:

$$Z_1 = \frac{1}{T}\int_0^T r(t).c_1(t-\tau_1).dt \tag{3}$$

$$= \frac{1}{T}\int_0^T \ [\sum_{n=1}^{N} P_n b_n(t-\tau_n) \sum_{i=1}^{F} c_n^i(t-\tau_n) + n(t)] \ . \sum_{i=1}^{F} c_1^i(t-\tau_n).dt \tag{4}$$

$$Z_1 = \frac{P_1 b_{(1)} W}{F} + l_1 \tag{5}$$

The first term refers to the desired signal term of the first user, and the second term can be defined as:

$$l_1 = \frac{1}{F}\sum_{n=2}^{N} P_n b_n I_{n,1}(\tau_{n,1}) + n_1(t) \tag{6}$$

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:

$$r_1(t) = r(t) - Z_1.c_1(t-\tau_1) \tag{7}$$

$$= \sum_{n=2}^{N} P_n b_n(t-\tau_n).c_n(t-\tau_n) + n_1(t) - l_1.c_1(t-\tau_1) \tag{8}$$

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, after decoding and integration we got:

$$Z_2 = \frac{P_2 b_{(2)} W}{F} + l_2 \tag{9}$$

$l_2$ is defined as:

$$l_2 = \frac{1}{F}[\sum_{n=3}^{N} P_n b_n I_{n,2}(\tau_{n,2}) - l_1 I_{1,2}(\tau_{1,2})] + n_2(t) \tag{10}$$

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

$$r_j(t) = r_{j-1}(t) - Z_j.c_j(t-\tau_j) \tag{11}$$

Here $Z_j$ refers to the correlation after $j^{st}$ cancellation, then the decision variable for the $(j+1)^{st}$ user is given by:

$$Z_{j+1} = \frac{P_{j+1} b_{(j+1)} W}{F} + l_{j+1} \tag{12}$$

And $l_{j+1}$ are given by:

$$l_{j+1} = \frac{1}{F}[\sum_{n=j+2}^{N} P_n b_n I_{n,j+1}(\tau_{n,j+1}) - \sum_{i=1}^{j} l_i I_{i,i+1}(\tau_{i,i+1})] + n_{j+1}(t) \tag{13}$$

The first term is MAI of the uncancelled users; second term is cumulative noise from imperfect cancellation.

## III. INTERFERENCE ANALYSIS

In this section, we consider the effect of both MAI and thermal noise. Other sources of noise are neglected.

Related to MAI, we can define the variance of $l_{j+1}$ conditioned on $P_n$ as follows:

$$\sigma^2{}_{j+1}\big|\_MAI = \frac{1}{F}[\sum_{n=j+2}^{N} P_n{}^2 b_n^2 . \mathrm{var}[I_{n,j+1}(\tau_{n,j+1})] + \sum_{i=1}^{j} \sigma^2{}_i . \mathrm{var}[I_{i,i+1}(\tau_{i,i+1})]] \tag{14}$$

The term $I_{n,j+1}$ is a random variable that depends on the random signature sequences. Central to the analysis is the variance of this term (for the case of $n \neq j+1$). For the synchronous case, where $\tau_n$ is zero for all n, the variance of cross correlation of (2) is given by [6-7]:

$$\mathrm{var}(I_{n,j+1}) \approx \frac{1}{F} \tag{15}$$

Substituting (15) into (14) we get the variance of the noise in the decision variable:

$$\sigma^2{}_{j+1}\big|\_MAI = \frac{1}{F^2}[\sum_{n=j+2}^{N} P_n^2 + \sum_{i=1}^{j} \sigma^2{}_i] \tag{16}$$

Further we consider the effect of thermal noise:

$$4K_b T_n B/R_L \tag{17}$$

Where

$B$ noise-equivalent electrical bandwidth of the receiver; $K_b$ Boltzmann's constant; $T_n$ absolute receiver noise temperature; $R_l$ receiver load resistor.

The responsivity of the PDs and $\mathrm{R} = \eta e/h v_c$ . Here, $\eta$ 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 signal to noise ratio function of $P_n$ is:

$$SNR_{j+1} = \frac{R^2 P_{j+1}^2 W^2 / F^2}{\frac{R^2}{F^2}[\sum_{n=j+2}^{N} P_n^2 + \sum_{i=1}^{j} \sigma^2{}_i] + 4K_b T_n B/R_L} \tag{18}$$

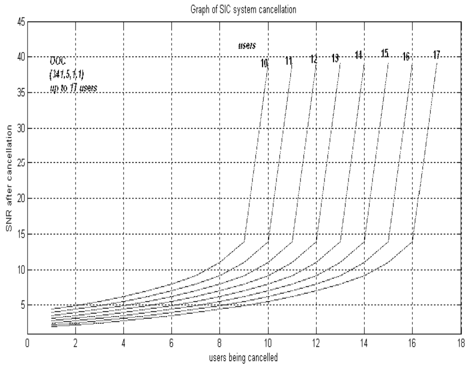
$$BER_{j+1} = Q\left( \frac{P_{j+1} . b_{j+1} w / F}{\sqrt{\frac{R^2}{F^2}[\sum_{n=j+2}^{N} P_n^2 + \sum_{i=1}^{j} \sigma^2{}_i] + 4K_b T_n B/R_L}} \right) \tag{19}$$

$$BER_{j+1} = Q\left(\sqrt{SNR_{j+1}}\right) \tag{20}$$

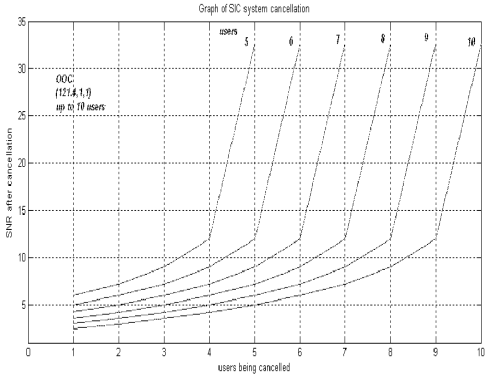
## IV. RESULTS & DISCUSSION

### *A. Performance of The SIC Scheme Under Ideal Power*

The typical parameters used in the calculations are, 193.1 THz operating frequency, 0.6 photodiode quantum efficiency, 80MHz electrical equivalent bandwidth, 300k receiver noise temperature, and 1030Ω receiver load resistor. Fig. 2 shows the relationship between signal to noise ratio and number of active users, using OOC, in different weight and different length [8]. As we can see in the figure below, the SNR of the users increases at each stage of cancellation process.



a. OOC code (341, 5, 1, 1)



b. OOC code (121, 4, 1, 1)

Fig. 2. SNR after cancellation under equal power.

As we can see from the figures above, large length give the large signal to noise ratio. Fig. 3 shows, probability of error versus number of users being cancelled under ideal power. As we see in the figure bit error rate going down at each stage of cancellation process. Fig. 4 shows relation ship between BER and number of active users

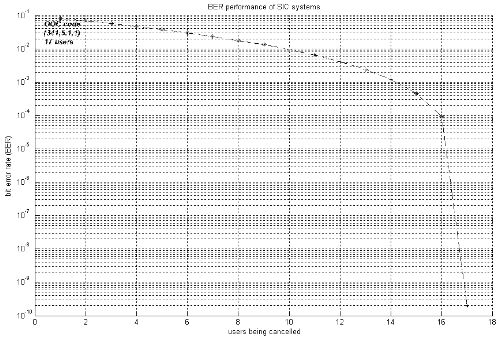


Fig. 3. bit error rate versus number of users being cancelled.

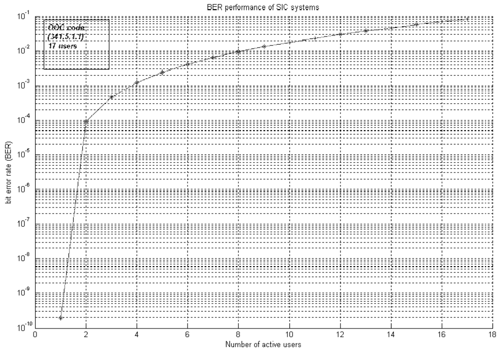


Fig.4. bit error rate versus number of active users.

## V. CONCLUSION

Throughout this paper we have presented a new proposal for interference cancellation of MUD, which called successive interference cancellation (SIC). The interference cancellation is not a perfect solution, 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 this work we have obviously analyze the performance of SIC and it is shown that the system performance improves at each stage of cancellation process.

## ACKNOWLEDGMENT

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