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A novel technique to increase the capacity of code division multiple access system using scrambled spreading sequences

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Abstract

A multistage Linear Parallel Interference Cancellation (LPIC) approach is presented to mitigate the effect of multiuser interference in uplink Direct Sequence Code Division Multiple Access (DS CDMA) system. The system is overloaded to accommodate more number of users than the processing gain of the system. The performance of this overloading scheme is evaluated by assigning one set of orthogonal Gold codes to the first N users and another set of orthogonal Gold codes to extra users. Both the sets are overlaid by a common pseudo noise scrambling sequence. This paper proposes a novel technique of using Weighted Linear Parallel Interference Cancellation (WLPIC) for overloaded CDMA system resulting in bandwidth saving, better performance and increase in the speed of interference cancellation. Also this technique considerably reduces the multiple-access interference, since set-1 users suffer from interference of the set-2 users only, while the set-2 users suffer from interference of the set-1 users. This provides a way for accommodating additional users in the same available bandwidth. Considerable conservation of time is achieved by avoiding the usage of conventional successive Interference Cancellation (IC) for scrambled CDMA system. The empirical results show that this scheme provides 50% overloading with three-stage weighted linear parallel interference cancellation (WLPIC) technique for $N = 64$ at a Bit Error Rate (BER) of 10^{-3} and 75% overloading at a BER of 10^{-2}. The three-stage WLPIC scheme clearly outperforms matched filter detector, Conventional LPIC and the two-stage WLPIC on Additive White Gaussian Noise (AWGN) channel.

Keywords: Interference Cancellation (IC), Orthogonal Gold Codes, Overloading, Pseudo-noise spreading sequence, Scrambling, and Weighted Linear Parallel Interference Cancellation (WLPIC)

1. Introduction

Multiple access is a technique whereby many subscribers or local stations can share the use of a communication channel at the same time or nearly so, in spite of the fact that the individual transmissions may originate from widely different locations. Multiple access is the only means of communication among users in wireless systems such as mobile system, cellular terrestrial systems and satellite based systems.

The channel capacity of a given channel is the amount of information that can be reliably transmitted over a communications channel with arbitrarily small error probability. The product of number of samples per second and the information per sample yields the channel capacity of the system and the ideal channel capacity for DS CDMA technique is 54Mbps at 2.4GHz. The possibility of many users sharing the available communication channel offers noticeable advantages in terms of flexible and cost-efficient use of the channel in these applications.

Overloading is a bandwidth efficient scheme to accommodate more number of users than the spreading factor N in a DS CDMA system (Kumar et al., 2007). This kind of channel overloading has been actually provisioned in third generation (3G) wireless standards (Adachi et al., 1998). Several overloading schemes have been proposed in order to cope with number of users $K = N+M > N$ where N is the spreading factor and M is the additional number of users than the spreading factor.

Verdu et al. (1999) has used pseudonoise sequence in which every user were assigned a random sequence. Vanhaverbeke et al., 2000 has used an overloading scheme labeled PN/O, where the first *N* users (set-1 users) were assigned orthogonal sequences and any additional user (set-2 users) were assigned with random sequences. If orthogonal sequences are assigned to both the first *N* users and the additional users, then the overloading scheme is termed as Orthogonal/Orthogonal (O/O) (Sari et al. 2000a, 2000b). Specific examples are scrambled O/O (S-O/O), overall permuted O/O (o-O/O), the hybrid TDMA/OCDMA scheme (Sari et al. 2000a, 2000b) and quasi-orthogonal sequences (QOS) (Yang et al., 2000), that are part of the cdma2000 standard (Vanhaverbeke et al., 2003). The introduction of O/O is justified by the fact that the set-1 users suffer from interference of the set-2 users only, while the set-2 users suffer from interference of the set-1 users only resulting in residual multiple-access interference present at the filter output.

Multiuser detection (MUD) is required in order to obtain a satisfactory performance of the users in any oversaturated system (i.e. $K > N$). Linear MUD'S, such as the decorrelator (Lapar et al., 1989), the minimum mean-squared error detector (Madhow et al. 1994) and linear decision directed interference cancellation (Ramussen et al., 2000), are devised to detect users in a non-saturated system. Hence they are unable to cope with the high interference levels of oversaturated systems. Also Maximum Likelihood (ML) detection (Verdu et al., 1984) is not an alternative because of its complexity that is exponential in the number of users.

On the other hand, nonlinear decision-directed MUD (Verdu et al., 1998), and more precisely nonlinear parallel interference cancellation (PIC) and nonlinear successive interference cancellation (SIC), are considered to have a good complexity-performance trade-off as compared to other MUD'S and are the evident choice of multiuser detection in an oversaturated system. For a multistage detector, PIC has the advantage of speed over SIC, since the users can be detected in parallel at every stage for PIC. This paper concentrates on overloaded DS CDMA system that use orthogonal Gold codes overlaid by a common pseudo-noise scrambling sequence on AWGN channel.

To achieve better performance, bandwidth saving and increase in the speed of interference cancellation, WLPIC is used for overloaded CDMA system. Set-1 users of this system suffer from interference of the set-2 users only, while the set-2 users suffer from interference of the set-1 users only. This leads to significant reduction in the multiple-access interference. Thus additional users can be accommodated in the same available bandwidth. Also, considerable conservation of time is achieved by avoiding the usage of conventional successive IC for scrambled CDMA system (Vanhaverbeke et al., 2000). Moreover, multiple users of the same spectrum can share the bandwidth due to the existence of orthogonality. The probability of error for different users is given in Table 1.

Table 1: Probability of Bit Error

Set-1 users	Set-2 users	Probability of bit error
20	2	10^{-4}
20	5	10^{-4}
20	8	10^{-3}
20	10	10^{-3}
20	13	10^{-2}
20	15	10^{-2}

Three stages of WLPIC were performed and its performance was compared with Matched Filter (MF) detector and single user detector. It was found that even the second stage of WLPIC outperforms the MF detector. Also it was observed that the third stage of WLPIC approaches the single user performance.

2. Related Works

In the recent past many researches were carried out by considering the uplink and reverse link and had suggested appropriate multiuser detection (MUD) schemes at the base station receiver. For example, a method of accommodating K=N+M users in an N-dimensional signal space that does not compromise the minimum Euclidean distance of the orthogonal signaling has been presented in (Ross et al. (1992) for AWGN channel. If more users are added without decreasing the minimum Euclidean distance, then it is difficult to achieve required symbol synchronization. This is because of the power limited signals that lie in a finite dimensional vector space causing an increase in modulation complexity and reduced throughput.

A tree-like correlation coefficient structure of user signatures proposed by Learned et al. (1997) may be suitable for optimal multiuser detection, but has not reduced the computational complexity significantly. This motivates further research in the area of oversaturated communications to unblock the obstacle of computational complexity.

Another approach introduced in (Vanhaverbeke et al., 2000) analyzes the system using two sets of orthogonal Walsh–Hadamard (WH) spreading sequences that are orthogonal within the sets. An iterative interference detection and cancellation is adopted for interference cancellation. But two steps are involved in all the iterations and hence the detection process is time consuming. Kumar et al., 2007 have studied the overloading performance using the same set of Walsh-Hadamard sequence scrambled by set specific pseudo-random (PN) sequence. The major pitfall is the occurrence of an error floor due to SIC on increasing the overloading to 30% and above.

Tikiya et al., 2006 has proposed weighted LPIC for CDMA system encoded using PN sequence. The major drawback of this approach is not accommodating additional number of users for the available bandwidth. The example developed by Sari et al., 2000 is based on a particular combination of TDMA and OCDMA. The problem is that it involves two different types of multiple access techniques which imply two types of transmitters and receivers.

An overloading scheme using hybrid techniques proposed in (Kumar et al., 2007), where the spreading codes and transmission modes are different for the two sets to increase the overloading performance. The basic motive of this overloading scheme was to integrate quasi-synchronous sequences (QOS) (Yang et al., 2000), into cdma2000 standard (Release B 2001).

Kumar et al., 2008 have uniquely used the orthogonal Gold codes scrambled with pseudo noise sequence to study the overloading performance. The authors adopted the successive IC that consumes much time due to stage by stage IC. Donelen et al., 1999 have proposed a method for generating different orthogonal sets of same length that generates (N-1) distinct orthogonal sets of N sequences of length N. Such sequence sets would offer low intracell interference, when used in overloaded environment. However in this method time shift between the sequences are not considered during the peak cross-correlation calculation.

This paper is organized as follows. The system model for the S-O/O overloading scheme is presented in the next section and the interference cancellation is explained in section 4. Section-5 and Section-6 deal with SIR analysis and Optimum weights, respectively. Simulation results are presented and discussed in Section-7 followed by conclusion of this paper in section-8.

3. System Model

Consider a DS CDMA system with a spreading factor of N, and $K=N+M$ (where $M<N$) users are to be accommodated. The number of orthogonal sequences of length N is exactly N, and therefore orthogonal sequences of this length can be assigned to N users only. Accordingly, one set of gold sequence was assigned to the first N users referred to as set-1 users, and overlay them by a set-specific PN sequence for scrambling. The additional M users were assigned another set of gold sequence referred to as set-2 users and scrambled by a set-specific PN sequence. This concept of orthogonality avoids Inter Symbol Interference (ISI) among set-1 users, as-well-as among set-2 users. However, set-1 users suffer from interference of the set-2 users only, while the set-2 users suffer from interference of the set-1 users only.

The signal $s_{u,k_u}(t)$ is the signature waveform of the k^{th} user in set-u, where $u \in \{1,2\}$, $k_1 \in \{1,2\ldots..N\}$ for set-1 users and $k_2 \in \{1,2\ldots..M\}$ for set-2 users ($M \leq N$). Here N is the number of users in set-1 and M is the number of users in set-2. The signature waveform is expressed as (Kumar et al., 2008)

$$s_{u,k_u}(t) = \sum_{j=1}^{N} s_{u,k_u}^{j} p_c(t - jT_c) \tag{1}$$

where $s_{u,k_u}^{j} \in \{1, 1\}$, Tc is the chip duration and $p_c(t)$ is the real valued unit-energy rectangular chip pulse. All users signatures were normalized such that $\left\| s_{u,k_u}(t) \right\|^2 =1$. We assume that all set-1 users are operational and hence N denotes the maximum number of users in set-1. Let us denote S_1 and S_2 as the signature matrices of the set-1 and set-2 users respectively. In this paper, two different orthogonal Gold code sets are considered for set-1 and set-2 users.

Let us denote b_1 and b_2 as the data matrices of the set-1 and set-2 users respectively. The data signal $b_{u,k_u}(t)$ of the k^{th} users in set-u, may be expressed as

$$b_{u,k_u}(t) = \sum_{l=-\infty}^{\infty} b_{u,k_u}^{l} p_{T_b}(t - lT_b) \tag{2}$$

where the data sequences $b_{u,k_u}^{l} \in \{-1,1\}$ are independent and identically distributed (i.i.d.) random variables taking values of +1 and -1 with equal probability. In eqn. (2) T_b is the bit duration, N is the spreading factor and $p_{T_b}(t)$ is the rectangular pulse of the information data bits. Matrices A_1 and A_2 are diagonal matrices of received signal amplitudes for two sets of users and can be expressed as

$$A_1 = diag[A_{1,1}cos(\phi_{1,1}), \ldots, A_{1,N}cos(\phi_{1,N})] \tag{3}$$

$$A_2 = diag[A_{2,1}cos(\phi_{2,1}), \ldots, A_{2,M}cos(\phi_{2,M})] \tag{4}$$

In above eqn. (3, 4), A_{u,k_u} is the complex channel attenuation for the k^{th} user of the set-u. For AWGN channel, A_{u,k_u} =1. The phase term is ϕ_{u,k_u} for the k^{th} user in set-u. The discrete-time matrix model of the received BPSK modulated CDMA signal after demodulating and chip matched filtering is given as

$$y = b_1 A_1 h_1 S_1 + b_2 A_2 h_2 S_2 + N \tag{5}$$

The vector N is AWGN noise with zero mean, and variance equal to σ^2. The complex channel fade coefficient h_1 and h_2 correspond to the set-1 and set-2 users. The fade coefficients are assumed to be i.i.d complex Gaussian random variable (i.e., fade amplitudes are Rayleigh distributed) with zero mean and expectation of one. The channel fade is assumed to remain constant over one bit interval.

The orthogonal Gold codes of both the sets are overlaid by a set-specific pseudo-noise (PN) sequence which is the same for all users within the set. In other words, we have $S_1 = \frac{1}{\sqrt{N}} [\alpha_1 \ \alpha_2 \ \ldots.. \alpha_N]$ and $S_2 = \frac{1}{\sqrt{N}} [\beta_1 \ \beta_2 \ \ldots. \beta_M]$. Let $P_1 = (p_{11}, p_{21}, \ldots. p_{N1})^T$ and $P_2 = (p_{12}, p_{22}, \ldots. p_{N2})^T$ designate the PN sequences overlaying the orthogonal Gold sequences in the two sets of users. In order to split the interference power evenly over the in-phase and quadrature components of the useful signal (irrespective of the carrier phase), we consider complex valued PN sequences: the chips p_{nu} randomly takes their values from the set $\{exp\ (j\pi/4),\ exp\ (j3\pi/4),\ exp\ (j5\pi/4),\ exp\ (j7\pi/4)\}$. Throughout the paper, it is assumed that the channel is an additive white Gaussian noise (AWGN) channel and that the signals of different users are in perfect time synchronism. Then, there is obviously no mutual interference between the N users and the only interference for them is that of the M additional users.

4. Interference Cancellation

A multistage LPIC is used at the receiver. The first stage is a conventional Matched Filter, which is a bank of K correlators, each matched to a different users spreading waveform. The received vector $y_{k_1}^{(1)}$ and $y_{k_2}^{(1)}$ at the output of the first stage of the matched filter detector for the set-1 users and set-2 users (the superscript (1) in $y_{k_1}^{(1)}$ denotes the first stage) respectively are given in eqn. (6,7)

$$y_{k_1}^{(1)} = A_{k_1} \ h_{k_1} \ b_{k_1} + \sum_{k_2=1}^{M} \rho_{k_1 k_2} A_{k_2} h_{k_2} b_{k_2} + n_{k_1} \tag{6}$$

$$y_{k_2}^{(1)} = A_{k_2} \ h_{k_2} \ b_{k_2} + \sum_{k_1=1}^{N} \rho_{k_1 k_2} A_{k_1} h_{k_1} b_{k_1} + n_{k_2} \tag{7}$$

where $\rho_{k_1 k_2}$ is the cross-correlation coefficient between the set-1 users and set-2 users spreading waveforms, given by $\rho_{k_1 k_2} = \int_0^T s_{k_1}(t) s_{k_2}(t) dt$, $\left|\rho_{k_1 k_2}\right| \le 1$, and n_k's are complex Gaussian with zero mean and variance equal to σ^2. The received vector $y_{k_1}^{(1)}, y_{k_2}^{(1)}$ is used for multiaccess interference (MAI) estimation and cancellation in the second stage of weighted LPIC.

4.1 Weighted LPIC: In a weighted LPIC, the MAI estimate for the set-1 users and set-2 users in stage M, $M > 1$, is weighted by a factor $p_{k_1}^{(m)}$ and $p_{k_2}^{(m)}$ respectively before cancellation. In other words, $p_{k_1}^{(m)} \sum_{k_2=1}^{M} \rho_{k_1,k_2} \ y_{k_2}^{(m-1)}$ and $p_{k_2}^{(m)} \sum_{k_1=1}^{N} \rho_{k_1,k_2} \ y_{k_1}^{(m-1)}$ are the weighted MAI estimate for the set-1 users and set-2 users respectively. That is, the m^{th} stage output of the set-1 users and set-2 users respectively are given by eqn. (8,9)

$$y_{k_1}^{(m)} = y_{k_1}^{(1)} - p_{k_1}^{(m)} \sum_{k_2=1}^{M} \rho_{k_1,k_2} \ y_{k_2}^{(m-1)} \tag{8}$$

$$y_{k_2}^{(m)} = y_{k_2}^{(1)} - p_{k_2}^{(m)} \sum_{k_1=1}^{N} \rho_{k_1,k_2} \ y_{k_1}^{(m-1)} \tag{9}$$

The bit decision for the set-1 users and set-2 users after weighted interference cancellation in stage M are respectively given by eqn. (10,11)

$$b_{k_1}^{(m)} = sgn\left(Re\left(h_{k_1}^{*} \ y_{k_1}^{m}\right)\right) \tag{10}$$

$$b_{k_2}^{(m)} = sgn\left(Re\left(h_{k_2}^{*} \ y_{k_2}^{m}\right)\right) \tag{11}$$

In the following, we obtain exact expressions for the average SIR's at the output of the weighted LPIC, which are then used to obtain closed-form expressions for the optimum weights.

5. SIR Analysis

Signal-to-interference ratio (SIR) is a measure used to quantify how much a signal has been corrupted by noise and multiuser interference. It is defined as the ratio of signal power to the noise power (including multiuser interference) corrupting the signal. SIR is useful in the analysis, design, understanding and assessment of the quality of various multiuser detectors. The evaluation of the derived closed-form analytical expression of the SIR results in good estimation of the SIR. Also, the higher SIR leads to lower BER. An analytical expression for the SIR using a weighted three-stage PIC receiver is presented in this section.

5.1 Average SIR at 2nd Stage Output of set-1 users: The weighted interference cancelled output of the 2nd stage for the set-1 users is given by eqn. (12)

$$y_{k_1}^{(2)} = y_{k_1}^{(1)} - p_{k_1}^{(1)} \sum_{k_2=1}^{M} \rho_{k_1,k_2}\, y_{k_2}^{(1)} = A_{k_1}\, h_{k_1}\, b_{k_1} \left(1 - p_{k_1}^{(2)} \sum_{k_2=1}^{M} \rho_{k_1,k_2}^2\right) + I_{k_1}^{(2)} + N_{k_1}^{(2)} \tag{12}$$

The terms $I_{k_1}^{(2)}$ and $N_{k_1}^{(2)}$ in (12) represent the interference and noise terms introduced due to imperfect cancellation in using the soft output values from the matched filter stage. Since h_k's are complex Gaussian, both $I_{k_1}^{(2)}$ and $N_{k_1}^{(2)}$ are linear combinations of Gaussian random variable with zero mean and variance equal to $\sigma^2_{I_{k_1}^{(2)}}$ and $\sigma^2_{N_{k_1}^{(2)}}$ respectively.

The average SIR of the set-1 users at the output of the second stage, $SIR_{k_1}^{(2)}$ is then given by eqn. (13)

$$SIR_{k_1}^{(2)} = \frac{2A_{k_1}^2 \left(1 - p_{k_1}^{(2)} \sum_{k_2=1}^{M} \rho_{k_1,k_2}^2\right)^2}{\sigma^2_{I_{k_1}^{(2)}} + \sigma^2_{N_{k_1}^{(2)}}} \tag{13}$$

The optimum weight for the second stage, $p_{k_1,opt}^{(2)}$, is chosen to be the value of $p_{k_1}^{(2)}$ that maximizes the average SIR in (13).

5.2 Average SIR at 2nd Stage Output of set-2 users: The weighted interference cancelled output of the 2nd stage for the set-2 users is given by eqn. (14)

$$y_{k_2}^{(2)} = y_{k_2}^{(1)} - p_{k_2}^{(1)} \sum_{k_1=1}^{N} \rho_{k_1,k_2}\, y_{k_1}^{(1)} = A_{k_2}\, h_{k_2}\, b_{k_2} \left(1 - p_{k_2}^{(2)} \sum_{k_1=1}^{N} \rho_{k_1,k_2}^2\right) + I_{k_2}^{(2)} + N_{k_2}^{(2)} \tag{14}$$

The terms $I_{k_2}^{(2)}$ and $N_{k_2}^{(2)}$ in (14) represent the interference and noise terms introduced due to imperfect cancellation in using the soft output values from the matched filter stage. Since h_k's are complex Gaussian, both $I_{k_2}^{(2)}$ and $N_{k_2}^{(2)}$ are linear combinations of Gaussian random variable with zero mean and variance equal to $\sigma^2_{I_{k_2}^{(2)}}$ and $\sigma^2_{N_{k_2}^{(2)}}$ respectively.

The average SIR of the set-2 users at the output of the second stage, $SIR_{k_2}^{(2)}$ is then given by eqn. (15)

$$SIR_{k_2}^{(2)} = \frac{2A_{k_2}^2 \left(1 - p_{k_2}^{(2)} \sum_{k_1=1}^{N} \rho_{k_1,k_2}^2\right)^2}{\sigma^2_{I_{k_2}^{(2)}} + \sigma^2_{N_{k_2}^{(2)}}} \tag{15}$$

The optimum weight for the second stage, $p_{k_2,opt}^{(2)}$, is chosen to be the value of $p_{k_2}^{(2)}$ that maximizes the average SIR in (15).

5.3 Average SIR at 3rd Stage Output of set-1 users: The soft values of the interference cancelled outputs of all the other users from the second stage are used to reconstruct (estimate) the MAI for the set-1 user in the third stage. The MAI estimate is then weighted by the factor $p_{k_1}^{(3)}$ and cancelled. The third stage output of the set-1 user, $y_{k_1}^{(3)}$ is then given by eqn. (16)

$$y_{k_1}^{(3)} = y_{k_1}^{(1)} - p_{k_1}^{(3)} \sum_{k_2=1}^{M} \rho_{k_1,k_2}\, y_{k_2}^{(2)} = A_{k_1}\, h_{k_1}\, b_{k_1} X + I_{k_1}^{(3)} + N_{k_1}^{(3)} \tag{16}$$

where

$$X = 1 - p_{k_1}^{(3)} \sum_{k_2=1}^{M} \rho_{k_1 k_2}^2 (1 - p_{k_2}^{(2)}) + p_{k_1}^{(3)} \sum_{k_2=1}^{M} \rho_{k_1,k_2}\, p_{k_2}^{(2)} \sum_{j_1=1}^{K} \rho_{j_1,k_2} \tag{17}$$

The terms $I_{k_1}^{(3)}$ and $N_{k_1}^{(3)}$ in (16) represent the interference and noise terms introduced due to imperfect cancellation in using the soft output values from the second filter stage. The average SIR of the set-1 user at the output of the second stage, $SIR_{k_1}^{(2)}$ is then given by eqn. (18)

$$SIR_{k_1}^{(2)} = \frac{2A_{k_1}^2 X^2}{\sigma_{I_{k_1}^{(3)}}^2 + \sigma_{N_{k_1}^{(3)}}^2} \tag{18}$$

The optimum weight for the third stage, $p_{k_1,opt}^{(3)}$, is chosen to be the value of $p_{k_1}^{(3)}$ that maximizes the average SIR in (18).

*5.4 Average SIR at 3rd Stage Output of s*et-*2 users:* The soft values of the interference cancelled outputs of all the other users from the second stage are used to reconstruct (estimate) the MAI for the set-2 user in the third stage. The MAI estimate is then weighted by the factor $p_{k_2}^{(3)}$ and cancelled. The third stage output of the set-2 user, $y_{k_2}^{(3)}$ is then given by eqn. (19)

$$y_{k_2}^{(3)} = y_{k_2}^{(1)} - p_{k_2}^{(3)} \sum_{k_1=1}^{N} \rho_{k_1,k_2}\, y_{k_1}^{(2)} = A_{k_2}\, h_{k_2}\, b_{k_2} X + I_{k_2}^{(3)} + N_{k_2}^{(3)} \tag{19}$$

where

$$X = 1 - p_{k_2}^{(3)} \sum_{k_1=1}^{N} \rho_{k_1 k_2}^2 (1 - p_{k_1}^{(2)}) + p_{k_2}^{(3)} \sum_{k_1=1}^{N} \rho_{k_1,k_2}\, p_{k_1}^{(2)} \sum_{j_2=1}^{K} \rho_{j_2,k_1} \tag{20}$$

The terms $I_{k_2}^{(3)}$ and $N_{k_2}^{(3)}$ in (19) represent the interference and noise terms introduced due to imperfect cancellation in using the soft output values from the second filter stage. The average SIR of the set-2 user at the output of the third stage, $SIR_{k_2}^{(3)}$ is then given by eqn. (21)

$$SIR_{k_2}^{(3)} = \frac{2A_{k_2}^2 X^2}{\sigma_{I_{k_2}^{(3)}}^2 + \sigma_{N_{k_2}^{(3)}}^2} \tag{21}$$

The optimum weight for the third stage, $p_{k_2,opt}^{(3)}$, is chosen to be the value of $p_{k_2}^{(3)}$ that maximizes the average SIR in (21). A closed-form expression for $p_{k_1,opt}^{(2)}$ & $p_{k_2,opt}^{(2)}$ is presented in the next section.

6. Optimum Weights in Closed Form

The MAI estimates are to be properly weighted before cancellation for improving the performance of Conventional Linear Parallel Conventional (CLPIC). The value of the weight is kept low at the early stages and large at the later stages (Divsalar et al., 1998). In the more formal approach adopted by Tikiya.V et al., 2006, the derived average SIR expressions are used to obtain the closed-form expressions for the optimum weights and achieved better performance than that of the CLPIC by using optimum weights.

The expressions for the optimum weights $p_{k_1,opt}^{(2)}$ and $p_{k_2,opt}^{(2)}$ for second stage is obtained by differentiating (13) and (15) with respect to $p_{k_1}^{(2)}$ and $p_{k_2}^{(2)}$, respectively, and equating to zero. Accordingly, the expression for $p_{k_1,opt}^{(2)}$, in closed-form is

$$p_{k_1,opt}^{(2)} = \frac{c_1(1-a_1)+e_1}{-a_1(c_1+e_1)+c_1+d_1+2e_1-\sigma^2(a_1^2-f_1)} \tag{22}$$

where

$a_1 = \sum_{k_2=1}^{M} \rho_{k_1,k_2}^2$, $c_1 = \sum_{k_2=1}^{M} A_{k_2}^2 \rho_{k_1,k_2}^2$, $d_1 = \sum_{k_2=1}^{M} A_{k_2}^2 \left(\sum_{j=1}^{k} \rho_{k_1,k_2} \rho_{j_1,k_2} \right)^2$, $e_1 = \sum_{k_2=1}^{M} A_{k_1}^2 \rho_{k_1,k_2} \sum_{j_1=1}^{K} \rho_{j_1,k_2}$ and $f_1 = \sum_{k_2=1}^{M} \rho_{k_1,k_2} \sum_{j_1=1}^{K} \rho_{j_1,k_2}$

Likewise, the closed-form expression for $p_{k_2,opt}^{(2)}$ can be obtained as

$$p_{k_2,opt}^{(2)} = \frac{c_2(1-a_2)+e_2}{-a_2(c_2+e_2)+c_2+d_2+2e_2-\sigma^2(a_2^2-f_2)} \tag{23}$$

Where $a_2 = \sum_{k_1=1}^{N} \rho_{k_1,k_2}^2$, $c_2 = \sum_{k_1=1}^{N} A_{k_1}^2 \rho_{k_1,k_2}^2$, $d_2 = \sum_{k_1=1}^{N} A_{k_1}^2 \left(\sum_{j=1}^{k} \rho_{k_1,k_2} \rho_{j_1,k_1} \right)^2$,

$e_2 = \sum_{k_1=1}^{N} A_{k_2}^2 \rho_{k_1,k_2} \sum_{j_2=1}^{K} \rho_{j_2,k_1}$ and $f_2 = \sum_{k_1=1}^{N} \rho_{k_1,k_2} \sum_{j_2=1}^{K} \rho_{j_2,k_1}$

Similarly the expressions for the optimum weights $p_{k_1,opt}^{(3)}$ and $p_{k_2,opt}^{(3)}$ for the third stage is obtained by differentiating (18) and (21) with respect to $p_{k_1}^{(3)}$ and $p_{k_2}^{(3)}$, respectively, and equating to zero.

7. Results and Discussion

The simulation results of the proposed scheme implemented in MATLAB - 7.0 to evaluate the BER performance of an AWGN and Rayleigh fading channel is discussed in this section. BPSK was used for data modulation with the spreading factor N = 64.

The length of the orthogonal Gold code used in the system is 63. The number of users selected for study and analysis depends upon the length of the orthogonal Gold codes and the Pseudo noise sequence. Hence the number of set-1 users may be any number between 1 and 63. The number of set-1 users considered for this study is 20. The system performance was evaluated by means of overload. The amount of overloading is defined as the ratio of maximum number of users (K_{max}) and the spreading factor N, such that for all users desired BER is achieved with small SNR degradation as compared to the single user bound. To increase the amount of overloading, an efficient three-stage weighted LPIC was used. Its performance was compared with matched filter and single user detector. It was found that the weighted LPIC at the third stage approaches the single user bound. However due to overloading the system performance was degraded slightly as compared to the single user performance.

In Figure 1, BER performance of S-O/O scheme with complex scrambling is shown for N=64 at 11% overloading for single user, matched filter and weighted LPIC detector. It is observed that the second and third stage output of WLPIC approaches the single user detector at a BER of 10^{-4}. The Figure 2 shows that the BER performance deteriorates at 25% overloading when compared to the single user detector. However, the third stage WLPIC outperforms both the second stage WLPIC and the matched filter detector output.

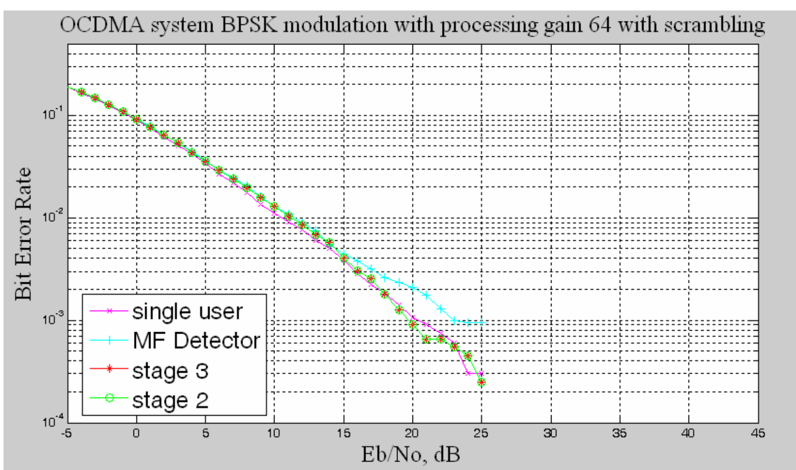

Figure 1: BER performance of S-O/O scheme with WLPIC for 11% overload and N = 64

In Figure 3 the BER performance of S-O/O scheme with complex scrambling for N=64 at 41% overloading is shown for single user, matched filter and weighted LPIC detector. It is evident that the three-stage WLPIC remains close to single user detector supporting eight additional users at 41% overloading. The BER performance of S-O/O scheme with complex scrambling for N=64 at 50% overloading of single user, matched filter and weighted LPIC detector is shown in Figure 4. The 50% overloading supports additional 10 users at the BER of 10^{-3}. Hence, significant quantum of channel overloading can be obtained with complex scrambling.

Figure 5 and Figure 6 shows the BER performance of S-O/O scheme with complex scrambling for N=64 at 63% and 75% overloading respectively. Both the graphs were plotted for single user, matched filter and weighted LPIC detector. The BER in both the cases approaches 10^{-2}. Thus 15 additional users at 75% overloading was supported at the expense of increased BER. The empirical results show that the third stage of WLPIC outperforms over the second stage WLPIC and the matched filter detector in all the above discussed cases. Hence, the complex scrambling increases substantial amount of overloading in overloaded DS CDMA systems.

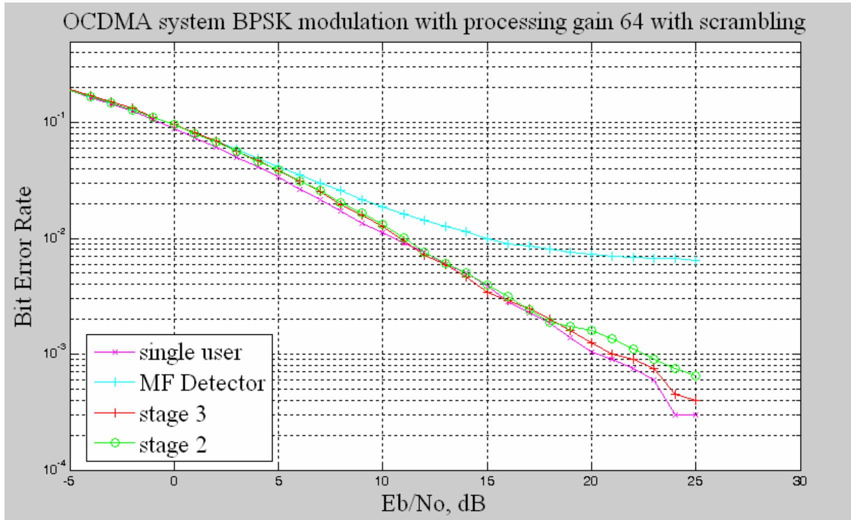

Figure 2: BER performance of S-O/O scheme with WLPIC for 25% overload and $N = 64$

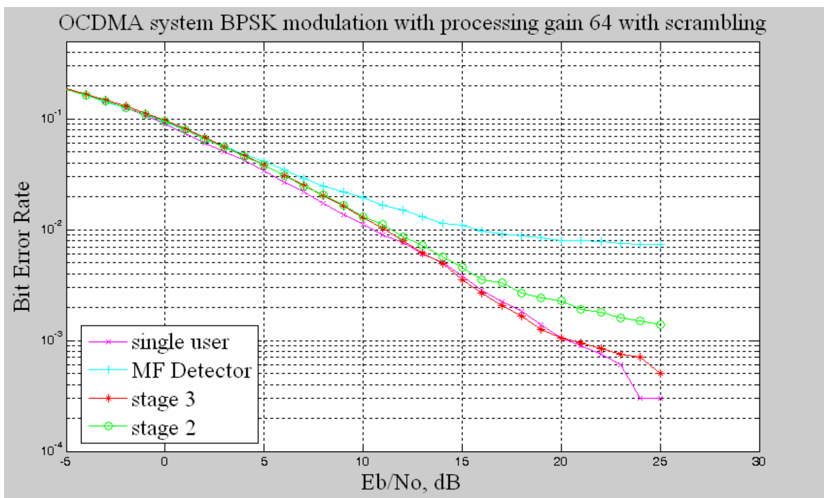

Figure 3: BER performance of S-O/O scheme with WLPIC for 41% overload and $N = 64$

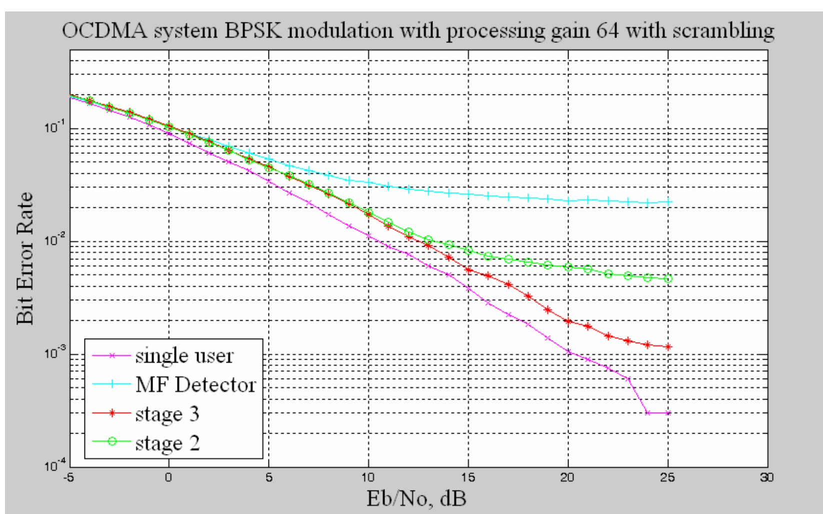

Figure 4: BER performance of S-O/O scheme with WLPIC for 50% overload and $N = 64$

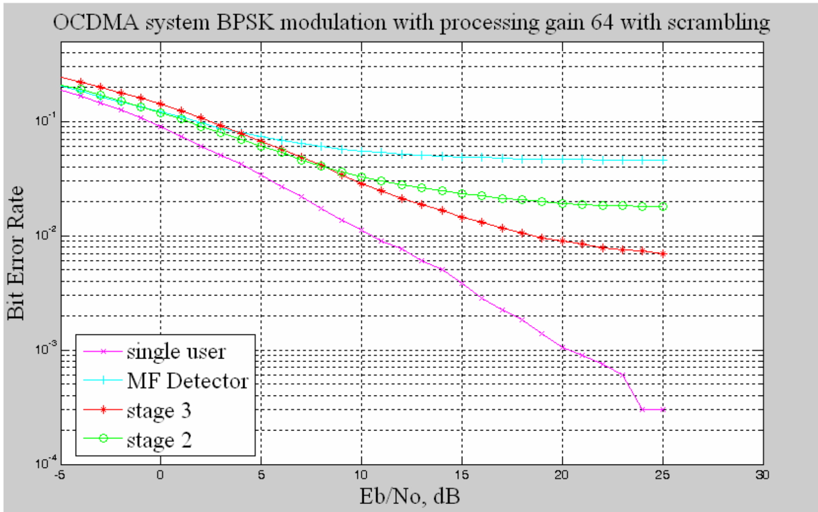

Figure 5: BER performance of S-O/O scheme with WLPIC for 63% overload and N = 64

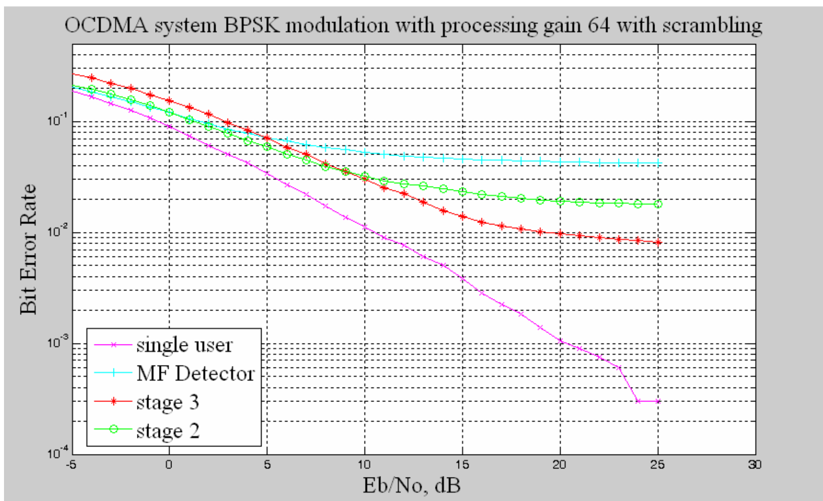

Figure 6: BER performance of S-O/O scheme with WLPIC for 75% overload and N = 64

8. Conclusion

A three-stage weighted linear parallel interference cancellation approach was presented to mitigate the effect of multiuser interference. The BER performance of matched filter detector, two-stage WLPIC and three-stage WLPIC receiver has been evaluated through MATLAB simulation. It is thus shown that this scheme provides 50% overloading with three-stage weighted LPIC receiver for N= 64 at a BER of 10^{-3} and 75% overloading at a BER of 10^{-2}. Hence, the system is accommodating more users than the processing gain of the system. It is also proved that the performance of scrambled system with three-stage weighted LPIC is better than two-stage weighted LPIC and the matched filter detector. The signal to interference ratio was evaluated and the average SIR is maximized to obtain the optimum weights. As capacity of the channel is the maximum of the mutual information communicated between the input and output of the channel, future study has to be conducted in obtaining the channel capacity of the system.

Nomenclature

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CLPIC	Conventional Linear Parallel Interference Cancellation
DS CDMA	Direct Sequence Code Division Multiple Access
IC	Interference Cancellation
LPIC	Linear Parallel Interference Cancellation
MAI	Multi-access Interference

MF	Matched Filter
ML	Maximum Likelihood
MUD	Multiuser detection
O/O	Orthogonal / Orthogonal
PIC	Parallel Interference Cancellation
PN	Pseudo Noise sequence
SIC	Successive Interference Cancellation
SIR	Signal to Interference Ratio
WLPIC	Weighted Linear Parallel Interference Cancellation

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