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Soft Decision Parallel Interference Cancellation for Scrambled/Unscrambled DS-CDMA System

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***Abstract*—A soft decision linear parallel interference cancellation for the direct sequence spread spectrum CDMA systems which can accommodate more users (K = N+M >N) than the processing gain of the system is analyzed in this paper. The proposed technique accommodates N users without any mutual interference and a number of additional users at the expense of a small signal-to-noise ratio. Two sets of orthogonal Gold codes are used, one for the first N users and the other for the additional users. Both the N users and additional users are overlaid by a set-specific pseudonoise scrambling sequence. The performance of scrambled and unscrambled system for matched filter and linear parallel interference cancellation is analyzed and the scrambled system is found better than unscrambled system. The allowable load of this scheme is investigated, so that the uncoded performance with linear parallel interference cancellation detector using soft (SDIC) decision functions remains close to the single user bound for N= 64 at 33% overloading.**

***Index Terms*—Code division multiple access, Interference cancellation, Multiple access Interference, Orthogonal sequence.**

I. INTRODUCTION

In wireless systems efficient use of the available radio spectrum is a major requirement. To make a better use of radio spectrum, it is of considerable interest to assign more sequences than the spreading factor, i.e., to overload the channel. Overloaded CDMA systems are of practical interest to the mobile system operators, because they can support more number of users in a fixed bandwidth. This kind of channel overloading has been actually provisioned in third generation (3G) wireless standards [1]. Several overloading schemes have been proposed in order to cope with a number of users K = N+M > N. A trivial solution is pseudonoise, where we assign to every user a random sequence [2]. Another possibility is to assign orthogonal sequences to the first N users (set 1 users) and to assign random sequences to any additional user (set 2 user). This overloading scheme is labeled PN/O. When orthogonal sequences are assigned to the first N users and other orthogonal sequences to the additional users, we obtain the o/o overloading scheme [3, 4, 5]. Specific examples of o/o are scrambled o/o(s-o/o), overall permuted 0/0 (o-o/o), the hybrid TDMA/OCDMA scheme [3, 5] and quasi-orthogonal sequences (QOS) [6], that are part of the cdma2000 standard [7]. 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.

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 [14], the minimum mean-squared error detector [15] or linear decision directed interference cancellation [16], are devised to detect users in a nonsaturated system and are unable to cope with the high interference levels of oversaturated systems. Also Maximum Likelihood (ML) detection [17] is not an option because of its complexity that is exponential in the number of users. The optimal multiuser detector proposed by Verdu has high computational complexity. For that reason, many less complex suboptimal multiuser detectors have been proposed and studied [18]. Parallel interference cancellations (PIC) [19, 20] are among the most promising receiver for future CDMA systems. PIC simultaneously removes from each user the interference produced by remaining users accessing the channel. The standard PIC completely cancels the interference caused by all other users. LPIC's have the advantages of implementation simplicity, analytical tractability, and good performance under certain conditions. In a conventional LPIC, an estimate of the MAI for a desired user in a stage is obtained using all the other user's soft outputs from the previous stage.

The first PIC detector for code division multiple access (CDMA) communication systems was derived by Varanasi and Aazhang in [8, 9] where their PIC detector was called a multistage detector. The multistage detector was shown to have close connections to the optimum maximum-likelihood detector and also to possess several desirable properties including the potential for good performance, low computational complexity, and low decision latency. The example developed by H. Sari, F. Vanhaverbeke, and M. Moeneclaey [5] is based on a particular combination of TDMA and OCDMA. In [10], the overloading performance of Orthogonal/scrambled Orthogonal (0/s-O), which is a modification of s-O/0 scheme, is evaluated. In s-O/0 scheme the same set of Walsh Hadamard sequence is scrambled by set specific pseudo-random (PN) sequence. The BER performance of iterative multistage detection (IMSD), with hard (HDIC) and fixed soft (SDIC) decision functions for interference cancellation for overloaded O/s-O scheme are evaluated.

A tree-like correlation coefficient structure of user signatures suitable for optimal multiuser detection has been proposed in [11]. In another approach, two sets of orthogonal

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codes which are orthogonal within the sets is introduced in [4]. An iterative detection technique is adopted to cancel interference between the two sets of users. A new overloading scheme using hybrid techniques has been proposed in [10], where the spreading codes and transmission modes are different for the two sets to increase the overloading performance. The attractive property of overloading scheme was the incentive to integrate a particular type of o/o, called quasi-synchronous sequences (QOS) [6], into cdma2000 standard [12].To the best of our knowledge, the usage of orthogonal Gold codes has not been considered in any of the overloading schemes. In [13], a new method for generating different orthogonal sets of same length has been proposed. The new algorithm 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.

The new contribution of this paper is that for the s-o/o scheme two sets of orthogonal Gold codes are used and overlaid with the same set of pseudo-noise sequence. Linear parallel interference cancellation (LPIC) technique is adopted to cancel the multiuser interference (MUI) between two sets of users which use resources from different signal sets. The advantage of using parallel interference cancellation is speed compared to successive interference cancellation.

This paper is organized as follows. In the next section, PN sequence is described. In section-3 system model for S-O/O overloading scheme is explained. Interference cancellation is presented in Section-4. Section-5 explains about the Simulation. Finally, conclusion of this paper is presented.

II. PN SEQUENCES

Two general categories of spreading sequences that have been used are PN sequences and orthogonal codes. PN sequences are generated by an algorithm using some initial value called the seed. The algorithm is deterministic and therefore produces sequences of numbers that are not statistically random. However, if the algorithm is good, the resulting sequences will pass many reasonable tests of randomness. Hence, only the receiver that knows the algorithm and the seed will be able to decode the signal successfully. PN sequences find a number of uses in computers and communications, and the principles are well developed.

Gold sequences having well-defined cross correlation properties are suitable for DS/CDMA system. Gold sequences are attractive because only simple circuitry is needed to generate a large number of unique codes. They offer a large number of sequence sets with good cross-correlation properties between the single sequences. The Gold-sequences are generated by modulo-2 addition of two m-sequences clocked by the same chip-clock. The most significant key in the Gold-sequence design is that only special pairs of m-sequences deliver the desired correlation properties. Since both m-sequences have equal length L and use the same clock, the created gold-sequence is of length L given by $L= 2^n-1$. Gold sequences are generated by XOR-ing two preferred polynomials that are generated from two PN sequence generators. Gold sequences are defined for lengths of 2n-1, where n is not a multiple of 4. That means, Gold sequences are not defined for lengths of 15, 255, etc. Gold codes are well known for the lowest cross correlation values between the codes and are ideal for asynchronous, uplink communication from the mobile hand-held unit to the base station.

One can find that many cross-correlation values of Gold codes are -1. By padding one zero to the original Gold codes, it is possible to make cross-correlation values to 0 at no shift among the two sequences. In fact, 2n + 1 orthogonal code can be obtained by this simple zero padding. These codes are called orthogonal Gold codes. The length of these orthogonal Gold codes are 2n, thereby making these sequences more suitable for different applications. The correlation values of these orthogonal Gold codes are nearly equal to that of the original Gold codes.

This paper concentrates on DS/CDMA system that use orthogonal Gold codes overlaid by a common pseudo-noise scrambling sequence.

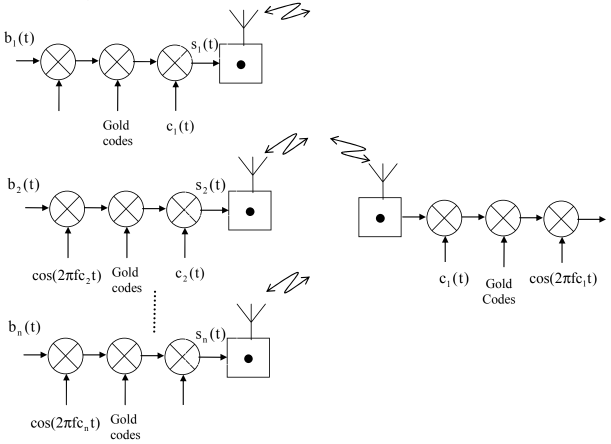

Fig.1 Basic spreading procedure

III. SYSTEM MODEL

A. *System Model without Scrambling*

Consider a DS/CDMA system with a spreading factor of N, and assume that we want to accommodate a number of users K=N+M, where M<N. It is well known that 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, we assign one set of gold sequence 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 are assigned another set of gold sequence and referred to as set-2 users.

The basic spreading procedure is shown in Fig. 1. In this the data stream to be transmitted, b_i (t), is BPSK modulated and then multiplied by orthogonal spreading codes. The resultant signal is scrambled by the spreading code for that user, $c_i(t)$. All of the signals plus noise are received at the receiver's antenna. 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-1users 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 the number of users in set-2. The signature waveform may be expressed as

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

where $s^{j}_{u,k_u} \in \{1, 1\}$, Tc is the chip duration and pc(t) is the real valued unit-energy rectangular chip pulse . All users signatures are 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, we have considered two different orthogonal Gold code sets 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

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

where the data sequences $b^{l}_{u,k_u} \in \{-1, 1\}$ 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

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

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

In 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

$$y = b_1A_1h_1S_1 + b_2A_2h_2S_2 + n \qquad (5)$$

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.

B. System Model with Scrambling

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 $S_1 = \frac{1}{\sqrt{N}}[\alpha_1\ \alpha_2 \ldots\ldots \alpha_N]$ and $S_2 = \frac{1}{\sqrt{N}}[\beta_1\ \beta_2 \ldots\ldots \beta_M]$. 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(jπ/4), exp(j3π/4), exp(j5π/4),exp(j7π/4)}.Throughout the paper, we assume that the channel is an additive white Gaussian noise (AWGN) and Rayleigh fading channel and that different users signals 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. The next section is about soft decision weighted linear parallel interference cancellation which reduces the interference due to overloading.

IV. SOFT DECISION PARALLEL INTERFERENCE CANCELLATION

We consider a multistage LPIC at the receiver. The first stage is a conventional matched filter (MF), which is a bank of K correlators, each matched to different user's spreading waveform. The received vector $y^{(1)}_{k_1}$ and $y^{(1)}_{k_2}$ 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 $y^{(1)}_{k_1}$ denotes the first stage) respectively are given by

$$y^{(1)}_{k_1} = A_{k_1}\, h_{k_1}\, b_{k_1} + \sum_{k_2=1}^{M} \rho_{k_1k_2} A_{k_2} h_{k_2} b_{k_2} + n_{k_1} \qquad (6)$$

$$y^{(1)}_{k_2} = A_{k_2}\, h_{k_2}\, b_{k_2} + \sum_{k_1=1}^{N} \rho_{k_1k_2} A_{k_1} h_{k_1} b_{k_1} + n_{k_2} \qquad (7)$$

where $\rho_{k_1k_2}$ is the cross-correlation coefficient between the set-1 users and set-2 users spreading waveforms, given by $\rho_{k_1k_2} = \int_0^T s_{k_1}(t)s_{k_2}(t)dt$, $\left|\rho_{k_1k_2}\right| \le 1$, and n_k's are complex Gaussian with zero mean and variance equal to σ^2 .The received vector $y^{(1)}_{k_1}, y^{(1)}_{k_2}$ is used for multiaccess interference(MAI) estimation and cancellation in the second parallel interference cancellation stage.

In LPIC, the MAI estimate for the set-1 users in stage m, m > 1, is obtained by multiplying $y^{(m-1)}_{k_2}$ with $\rho_{k_1k_2}$ and summing them up. i.e., $\sum_{k_2=1}^{M} \rho_{k_1k_2}\, y^{(m-1)}_{k_2}$ is the MAI estimate for the set-1 users. More specifically, an estimate of the MAI for a desired user in the current stage is obtained using all the other users soft outputs from the previous stage for cancellation in the current stage. Accordingly, the bit decision for the set-1 users after interference cancellation in the m^th stage is given by

$$b^{(m)}_{k_1} = \mathrm{sgn}\left(\mathrm{Re}\left(h^{*}_{k_1}\left(y^{(1)}_{k_1} - \sum_{k_2=1}^{M} \rho_{k_1,k_2}\, y^{(m-1)}_{k_2}\right)\right)\right) \qquad (8)$$

Similarly, the MAI estimate for the set-2 users in stage m, m > 1, is obtained by multiplying $y^{(m-1)}_{k_1}$ with $\rho_{k_1k_2}$ and summing them up. i.e., $\sum_{k_1=1}^{N} \rho_{k_1 k_2} y_{k_1}^{(m-1)}$ is the MAI estimate for the set-2 users. Accordingly, the bit decision for the set-2 users after interference cancellation in the mth stage is given by

$$b_{k2}^{(m)} = \mathrm{sgn}\left(\mathrm{Re}\left(h_{k_2}^{*}\left(y_{k_2}^{(1)} - \sum_{k_1=1}^{N} \rho_{k_1,k_2} y_{k_1}^{(m-1)}\right)\right)\right) \qquad (9)$$

V. RESULTS AND DISCUSSION

The simulation results of the proposed scheme in MATLAB to evaluate the Bit Error Rate (BER) performance in an AWGN and Rayleigh fading channel is discussed in this section. The technique for data modulation is BPSK and the spreading factor N is taken as 64. The system performance is evaluated by means of overload. The amount of overloading is defined as the ratio of maximum number of users (Kmax) 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. A three stage LPIC is adopted to efficiently increase the amount of overloading.

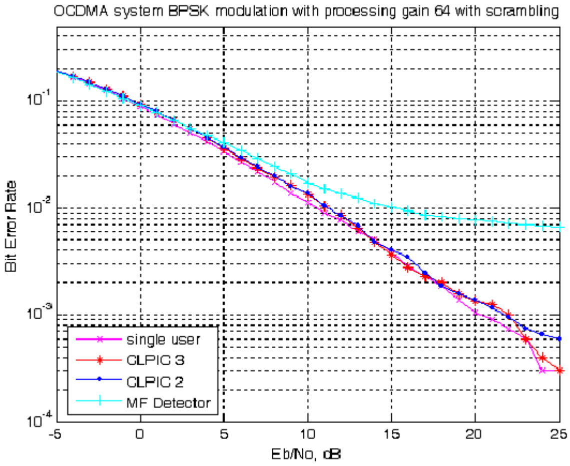

Fig.2 BER performance of S-O/O scheme with LPIC for 20% overload and N = 64

In Fig.2, the BER performance of S-O/O scheme with complex scrambling for N=64 at 20% overloading is compared for single user, matched filter, two-stage and three stage LPIC detector. Here, both the sets are scrambled by a set specific complex pseudo random sequence. It is seen that the single user detector (SUD) gives the least SIR since no interference cancellation is performed. When interference cancellation is performed the proposed three stage LPIC results in significantly better BER performance compared to two stage LPIC detector, matched filter detector and SUD. The BER performance is less than 10^{-3} for all users in two stage and three stage LPIC thus supporting an extra 4 users. The performance is better than matched filter detector whose BER is around10^{-2}.

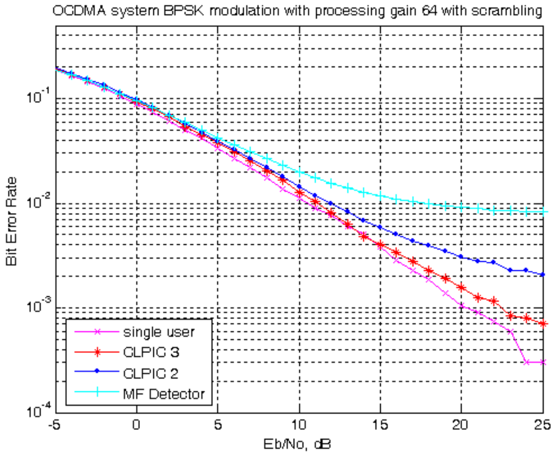

Fig.3 BER performance of S-O/O scheme with LPIC for 30% overload and N = 64

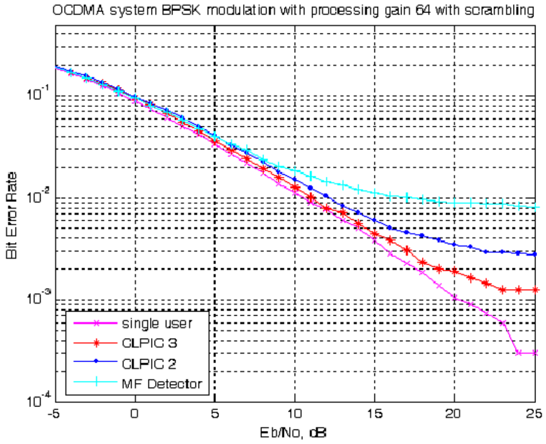

Fig.4 BER performance of S-O/O scheme with LPIC for 33% overload and N = 64

In Fig.3, and Fig.4, the BER performance of S-O/O scheme with complex scrambling at 30% and 33% overloading is shown for N=64. It is observed that extra 6 users at 30% overloading are supported at a BER of 10^{-3} in three stage LPIC as compared to single user bound. This is a significant amount of channel overloading, which can be obtained with complex scrambling. For 33% overload the BER deteriorates. Hence, complex scrambling increases the amount of overloading significantly in overloaded DS-CDMA systems. Also it is observed in all graphs that the three stage LPIC outperforms both the two stage LPIC and the matched filter detector output.

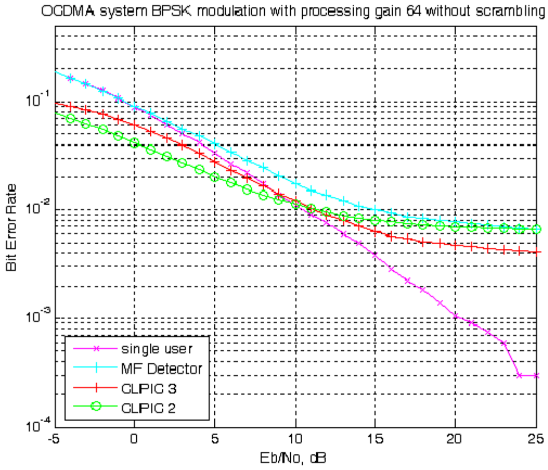

Fig.5 BER performance of O/O scheme with LPIC for 20% overload and N = 64

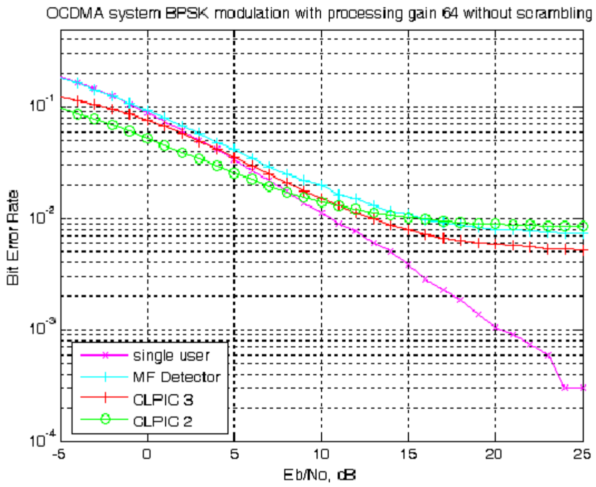

Fig.6 BER performance of O/O scheme with LPIC for 25% overload and N = 64

Fig.5, and Fig.6, gives the BER performance of O/O scheme without scrambling for N=64 at 20% and 25% respectively. The comparison is performed for single user, matched filter, two-stage and three stage LPIC detector. It is observed that BER is around 10^{-2} for all users for the second stage LPIC which is better than the matched filter output. The third stage LPIC gives good performance compared to second stage LPIC and the matched filter output. Thus the performance of the system without scrambling is less good than the system with scrambling.

VI. CONCLUSION

The performance of linear parallel interference cancellation for an overloaded direct sequence spread spectrum CDMA system was analyzed. The scrambled system proves better than unscrambled system in all the detectors. The allowable load of this scheme was investigated with linear parallel interference cancellation detector using soft (SDIC) decision functions. The LPIC remains close to the single user bound for N= 64 at 33% overloading supporting additional 6 users. Also the third stage LPIC outperforms both the two stage LPIC and the matched filter detector output for both scrambled and unscrambled system.

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