Successive Blind Detection of DS/CDMA Signals

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Abstract

This paper provides an investigation into the performance of a multi-stages constant-modulus filter/ signal canceller (CMA/SC) for blind detection of direct sequence/code code division multiple-access (DS/CDMA) signals over additive white Gaussian noise (AWGN) channels. A simple stochastic gradient algorithm for implementing the scheme is presented and the convergence properties of the algorithms are analyzed. Simulation examples are given to demonstrate the robustness of the performance of the proposed scheme.

Index Terms—DS/CDMA, Multiuser, CMA, SC.

1. Introduction

The Direct sequence-code division multiple access (DS/CDMA) system implemented by direct-sequence spread spectrum (DS/SS) technique is the most promising multiplexing technology for cellular telecommunications services, such as personal communications, mobile telephony, and indoor wireless networks. The advantages of DS/SS for these services include superior operation in multi-path environments, flexibility in the allocation of channels, the ability to operate asynchronously, privacy, and increased capacity in burst or fading channels [1]. It is well known that the processing gain of a spread spectrum system will provide the system with a sufficient capability of interference rejection [2], [3]. Multiple access interference (MAI), due to many simultaneous users, constitutes the main limitation on the performance of DS/CDMA systems.

Multiuser detection techniques can efficiently suppress MAI and substantially increase the capacity of CDMA systems [4], [5]. Various multiuser detection schemes for DS/CDMA systems have been developed over the past decade. More recently, blind adaptive multiuser detection, which requires the prior knowledge of only the spreading waveform and timing of the desired user, has received considerable attention [6]. The main motivation for employing a blind scheme is to avoid the need for a training sequence, to thus offer better spectrum efficiency. The most representative methods of the blind multiuser detection include the minimum output energy (MOE) [7] and subspace approach [8]. However these methods assume a knowledge of the spreading waveform, which is not available in some applications like electronic intelligence (ELINT). The constant-modulus (CM) receiver can perform almost as well as the non-blind/trained receiver except that the CMA captures an arbitrary signal from the combined received CDMA signals, which may be of no interest. In applications like ELINT it is necessary to detect all the active users, either in a parallel or a serial manner. This paper describes a mechanism for the successive blind detection for all the active users in a DS/CDMA system. The principle of operation is based on utilizing identical successive stages for detection. Each stage, CMA detects an arbitrary signal, which is subtracted from the input of the stage by a signal canceller and the remainder is applied to the next stage to permit detection of another signal [9].

2. System and Signals Descriptions

The proposed multi-stage CMA system, for separation of co-channel DS/CDMA signals, is shown in Fig.1. The system consists of M-identical stages; each stage consists of an adaptive finite impulse response (FIR) filter followed by an adaptive signal canceller. The adaptive FIR filter is controlled by the constant modulus algorithm (CMA), which captures one of the DS/CDMA signals at the input of the stage. The signal canceller subtracts the detected signal from the combined DS/CDMA received signals at the input of the stage. This permits the next stage to capture another signal from the multiplexed CDMA input signals

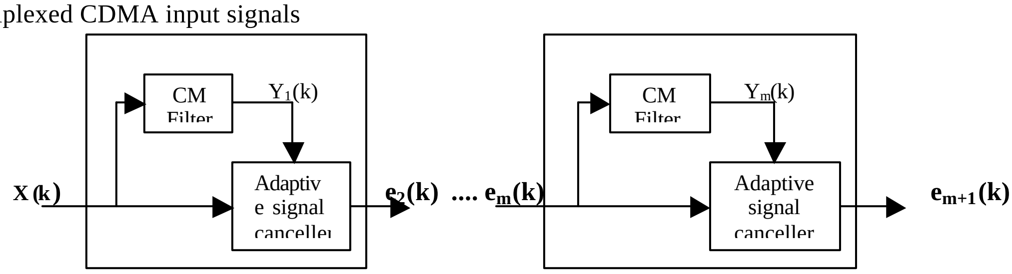

Fig. 1. Multi-stage CMA for separation of co-channel CDMA signals.

Assume that there are K active users in the observed DS/CDMA system. The received signal by the first stage is represented as

$$x(t)=\sum_{k=1}^{K} r_k(t)+n(t) \quad (1)$$

Where n(t) is additive white Gaussian noise (AWGN) with zero-mean and variance s^2. The k^{th} user signal r_k (t) in a DS/CDMA system is given by

$$r_k(t)=\sum_{j=-\infty}^{\infty} A_k b_k(j) s_k(t-jT_b-t_k)\cos(w_c t+q_k) \quad (2)$$

where, A_k, b_k, t_k and $?_k$ are the amplitude, data symbols, delay and phase of the k^{th} user signal respectively. Each user data symbols are assumed to be binary phase shift keying (BPSK) signals, that, b_k (j) = ± 1 over an interval T_b. The spreading code of the k^{th} user is given by

$$s_k(t)=\sum_{n=0}^{N-1} u_k(n) p(t-nT_c) \quad (3)$$

Where, $u_k(n)$ = ±1 is the n^{th} element of the spreading sequence for the k^{th} user and the chip waveform p(t) is a rectangular waveform of duration T_c. The chip duration T_c is assumed to be, $T_c = T_b/N$; where N is the processing gain of the spreading code.

The equivalent discrete synchronous model of the received signal at the j^{th} data symbol is given by

$$\underline{x}(j) = A_l \sum_{l=1}^{K} b_l(j) A_l U_l + \underline{n}(j) \quad (4)$$

Where U_l is the spreading sequence of the l^{th} user represented by the vector

$$U_l = [u_l(1)\ u_l(2)\ \ldots\ldots\ldots\ u_l(N)]^T \quad (5)$$

It must be noted that the spreading signal vector U_k is merely the spreading sequence of the k^{th} user only in the case of perfect synchronization. The correlation matrix of the received signal is given by [10]

$$R_{xx} = E\{\underline{x}(j)\underline{x}^*(j)\} = U\ R_{aa}\ U^* + s_n^2\ I \quad (6)$$

Where, R_{aa} is the data symbols correlation matrix and **I** is the identity matrix. The data symbols of different users are assumed to be independent binary sequences, thus, R_{aa} is a diagonal matrix whose l^{th} diagonal element is A_l^2. **U** is the N*K code matrix of the spreading sequences which is given by

$$U = [U_1\ U_2\ \ldots\ldots\ldots\ldots U_K] \quad (7)$$

s_n^2 is the variance of the noise component and T, * denotes the matrix transpose and conjugate transpose respectively. The output of the CM filter of the m^{th} stage is given by

$$y_m(n) = \underline{w}_m^T(n)\ \underline{e}_m(n) \quad (8)$$

$\underline{w}_m^T(n)$ & $\underline{e}_m(n)$ are the weight vector of the CM filter and the input of the m^{th} stage, given as

$$\underline{w}_m^T(n) = [w_{m,1}(n)\ w_{m,2}(n)\ \ldots\ldots\ldots\ w_{m,N}(n)]^T \ \ \&\ \ \underline{e}_m(n) = [e_{m,1}(n)\ e_{m,2}(n)\ \ldots\ldots\ e_{m,N}]^T$$

Note that for the first stage $\underline{e}_m(n)$ is $\underline{x}(n)$ and the output of the signal canceller of the m^{th} stage, $\underline{e}_{m+1}(n)$, represents the input of the next stage, and it can be written as

$$\underline{e}_{m+1}(n) = \underline{e}_m(n) - y_m(n)\underline{z}_m(n) = T_m(n)\underline{e}_m(n) \quad (9)$$

where we have substituted $y_m(n)$ and define the signal transfer matrix

$$T_m(n) = I - \underline{z}_m(n)\ \underline{w}_m^*(n) \quad (10)$$

The signal canceller weight vector $\underline{z}_m(n) = [z_{m,1}(n)\ z_{m,2}(n)\ \ldots\ldots\ldots z_{m,N}(n)]^T$ (11)

Using this notation, it is straightforward to write the output of the m^{th} stage in terms of the system input $\underline{e}_1(n) = \underline{x}(n)$ as follows

$$y_m(n) = \underline{w}_m^*(n) T_{m-1}(n) \ldots\ldots\ldots T_1(n)\underline{e}_1(n) = \underline{w}_m^*(n)\{\prod_{j=1}^{m-1} T_j(n)\}\underline{e}_1(n) \quad (12)$$

Associated with each stage an effective code matrix (which is analogous to U for the first stage) and an input correlation matrix (which is analogous to R_{xx}). We will denote these by U^m and R_m = E { $\underline{e}_m(n)\ \underline{e}_m^*(n)$}, respectively. Thus U^1 = U and $R_1 = R_{xx}$. For notational convenience and without loss of generality we will assume that $s_m(n)$ is captured by the m^{th} stage (for m =1,2,……..K). The construction of the effective code matrices U^m (m>1) is similar to U^1 except that, the earlier (m-1) columns are replaced by zeros, since their corresponding signals are cancelled [11].

3. Analysis of System Behavior

The constant modulus algorithm (CMA) in the $m^{\underline{th}}$ stage minimizes the mean square error between the actual amplitude of the output of the controlled FIR filter and the desired amplitude which is normalized to be unity, that, the weights of the FIR filter are updated by the CMA such that [11]

$$\underline{w}_m (n+1) = \underline{w}_m (n) + m_{cm}\, e_m^* (n)\, y_m (n)\, \underline{e}_m (n) \qquad (13)$$

where $\mu_{cm} > 0$ is the step size of the CMA and $e_m(k)$ is the scalar error at the $k^{\underline{th}}$ iteration...The corresponding update of the signal canceller weights is given by [12]

$$\underline{z}_m (n+1) = \underline{z}_m (n) + m_{sc}\, y_m^* (n)\, \underline{e}_{m+1} (n) \qquad (14)$$

where $\mu_{sc} > 0$ is the LMS step size. Because there is only one input $y_m(n)$ and N error signals, (contained in vector $\underline{e}_{m+1}(n)$), the recursion in (14) actually corresponds to N independent LMS updates.

The steady state behavior of the $m^{\underline{th}}$ stage and its optimum weight vectors $\underline{\mathbf{w}}_m$, $\underline{\mathbf{z}}_m$ are obtained by the orthogonality principle [12]. For the signal canceller weights, the orthogonality condition applied to the gradient estimate in (14), $E\{\underline{e}_{m+1}(k)\, y_m(k)\}=\underline{0}$ yields $\underline{z}_m = R_m\ \underline{w}_m\ /\ s_{Y_m}^2$ (15)

where $s_{Y_m}^2$ is the mean power of the $m^{\underline{th}}$ captured signal. To obtain the steady state weights of the CM filter of the $m^{\underline{th}}$ stage we replace the error signal e_m by $s_m(k)-y_m(k)$ [11]. Using this approximation, we obtain the optimum weights of the CM filter as $\underline{w}_m = s_{s_m}^2\ R_m^{-1}\ U_m$ (16)

where U_m is the $m^{\underline{th}}$ column of the matrix U^m and $s_{s_m}^2$ is the mean power of the $m^{\underline{th}}$ signal.

Substituting this result into (15) yields $\underline{z}_m = (s_{s_m}^2\ /\ s_{Y_m}^2)\ U_m = (\frac{1}{G_m^2})\ U_m$ (17)

where G_m is the gain of the $m^{\underline{th}}$ stage. This result could be explained as follows. The $m^{\underline{th}}$ stage captures the $m^{\underline{th}}$ user signal, the signs of the impulse response of the optimum CM filter weight vector is typical the spreading code of that user, i.e. $\mathrm{sign}(\underline{w}_1) = U_1$ [10]. The output power of this stage is amplified by the square magnitude of the CM filter, $G_m^2 = \left|\underline{w}_m\right|^2$. Evidently, implementing the signal canceller as (17) will reduce the components of the $m^{\underline{th}}$ captured user from the input of the next stage.

4. Simulation Results

In this section we provide simulation examples which is being an initial study, so the number of users was kept low, but the other parameters were realistic. Further simulations using other parameters are planned. It is assumed that 3 active users contribute to the combined, received signal at the input of the first stage. Each user transmits a binary PSK data signals modulated by a 15 chips Gold code. Each user signal is 10 dB above the background AWGN. Furthermore the data signals are perfectly synchronized and the received signal is sampled at the code chip rate. The received signal constellation and the corresponding spectrum are shown in Fig.2 (a),(b) respectively. The behavior of the multi-stage CM filter is shown in Fig.3. The convergence of the CMA in the jth stage is shown in Fig. (j-a; j=1,2,3) where the CM filter reaches the steady state and one user is captured. The spectrum of the captured signal by the jth stage CM filter is shown in Fig.(j-b; j=1,2,3) where they are compared with the jth user spectrum in Fig. (j-c; j=1,2,3). The CM filter reduces the effect of the MAI introduced by the other active users, which is clear from the agreement between the two spectra. Comparison of the convergence curves of the three stages indicates that, the smaller the number of active users, the faster the convergence of the CMA. An interesting point to be analyzed in a future work is to determine which user is detected first?. The simulations indicate that, when there is power difference between the users, the signal with the higher power is detected by the earlier stages.

5. Conclusions

We have presented a proposal for successive multi-user detection using a multi-stage CM filter and signal canceller. The CMA/SC multi-stage system shows robustness and low computational cost. Further CMA/SC does not require a knowledge of the spreading codes of the different users. In addition it offers a better steady-state performance and has a higher convergence rate. It has been shown that in a synchronous system, the CMA exhibits a lock convergence behavior when the filter, at steady state, can lock onto one user and null all other interfering users. The converged filter, at lock convergence, is equivalent to the well-known decorrelator and is orthogonal to the MAI space. The signal canceller utilizes this orthogonality to remove the detected user signal and permits another one for detection.

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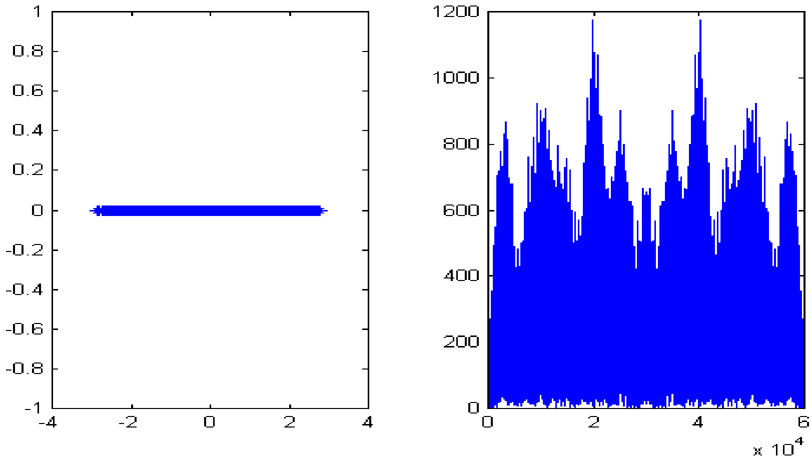

Fig.2. Received signal for 3 active users (a) Constellation (b) Spectrum

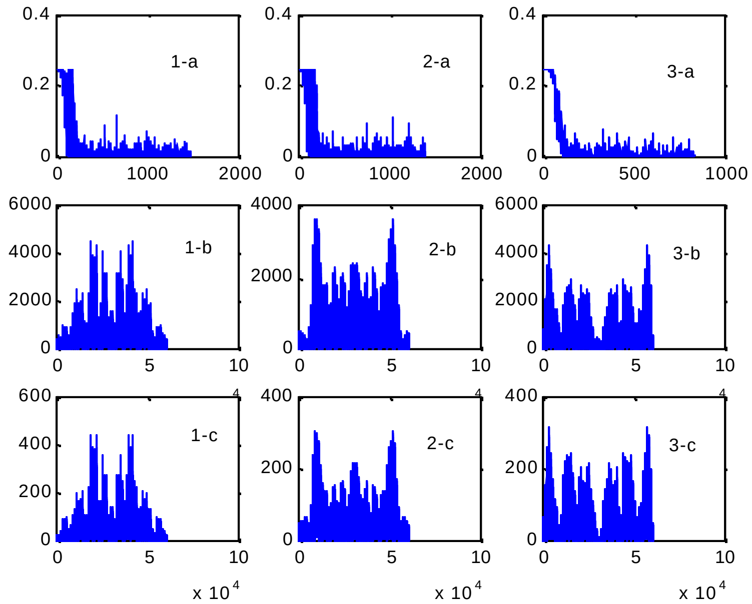

Fig.3. Behavior of the multi-stage. CMA.
(a) Convergence of CMA (b) Detected signal spectrum (c) User signal spectrum.