Precombining Adaptive LMMSE Detection for DS-CDMA Systems in Time Varying Channels: Non Blind and Blind Approaches

M.D. Kokate, T. R. Sontakke and P.W. Wani

***Abstract*—** This paper deals with an adaptive multiuser detector for direct sequence code division multiple-access (DS-CDMA) systems. A modified receiver, precombinig LMMSE is considered under time varying channel environment. Detector updating is performed with two criterions, mean square estimation (MSE) and MOE optimization technique. The adaptive implementation issues of these two schemes are quite different. MSE criterion updates the filter weights by minimizing error between data vector and adaptive vector. MOE criterion together with canonical representation of the detector results in a constrained optimization problem. Even though the canonical representation is very complicated under time varying channels, it is analyzed with assumption of average power profile of multipath replicas of user of interest. The performance of both schemes is studied for practical SNR conditions. Results show that for poor SNR, MSE precombining LMMSE is better than the blind precombining LMMSE but for greater SNR, MOE scheme outperforms with better result.

***Keywords*—** LMMSE, MOE, MUD.

I. INTRODUCTION

A major technical hurdle faced by CDMA systems designer is that the performance of CDMA demodulator is greatly affected by relative differences in desired user's and interferer's received power levels, called near-far problem and multiple access interference. The conventional approach to demodulation in CDMA systems is to neglect multiple access interference and near-far problem. This makes the system capacity-limited even under the strict power control. Furthermore, since CDMA systems operate in flat or frequency selective fading multipath channels, it is difficult to guarantee that the difference between the received signal power for the desired user and multiple access interference is kept to a minimum. One of the efficient ways to detect different users in CDMA systems is based on multiuser detection (MUD). An optimal multiuser receiver requires joint estimation of channel parameters and data symbols [1,2] with implementation complexity. The optimum MUD [3] consists of bank of matched filters and decoder whose complexity grows exponentially with the number of users. The algorithms in flat fading channel [4] or multipath environment such as in mobile base station [5, 6,7] suffer from signature mismatch and inability to optimally combine signal components from different paths. The convergence of batch processing approach [7] has not been established analytically. The linear minimum mean squared error (LMMSE) structure can be used to obtain near-far resistant receiver. The postcombining LMMSE detector has potentially lager capacity but it is not suitable to cope up with fast fading channels due to severe tracking problems. The precombining adaptive MUD proposed in this paper minimizes this drawback and achieves good performance in multipath time varying channels.

The paper is organized as follows. In Section II, the asynchronous CDMA system model is described. The principle of precombining LMMSE detectors is presented in Section III. Section IV deals with modified adaptive detectors. Numerical results are presented in Section V, followed by concluding remarks in Section VI.

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II. SYSTEM MODEL

A general DS-CDMA system with K users and L discrete mutlipath components transmitting at same time is considered. The K users are sharing the common communication channel and assumed that they are transmitted through standard multipath fading environment with independent paths. User data is antipodal modulated while the spreading is obtained by multiplying the transmitted data bit with signature waveform given by

$$s_k(t) = \sum_{n=0}^{N-1} s_k(n)\, p(t - nT_c) \qquad (1)$$

where $s_k(n) \in \{-1, +1\}$ is n^{th} chip of a binary pseudo random sequence related to user k, $N=T/T_c$ is processing gain of spreading process which is a measure of total number of chips per symbol duration T and T_c is chip period. p (t) is chip waveform.

A user of interest $k \in \{1,2,\ldots K\}$ transmits, a complex signal

$$A_{k,l}^{(m)}\, b_k^{(m)}\, s_k\left(t - \tau_{k,l}\right) \qquad (2)$$

m is symbol interval, $b_k^{(m)} \in \{-1,+1\}$ is original transmitted bit and amplitude is

$$A_{k,l} = \sqrt{E_{k,l}}\, e^{j\phi_{k,l}}$$

is transmitted complex amplitude which is assumed constant over period of transmission, $E_{k,l}$ is k^{th} symbol energy, $\phi_{k,l}$ is carrier phase, $\tau_{k,l} \in [0,T)$ is uniformly distributed transmission delay for l^{th} path and $s_k(t)$ is signature waveform of the k^{th} user. With no loss of generality, signature waveforms are assumed to be normalized and real

$$\int_0^T |s_k|^2 dt = 1 \tag{3}$$

The delay profile of τ_k is extended to the user paths in a multipath fading channel case so that $\tau_{k,l}$ are also uniformly distributed in the interval $[0,T)\forall$ k, l. This is because of the assumption that the transmitted signals pass through separated and independent channel in an asynchronous system. The channel acts like a linear filter with impulse response $h_k^m(t)$ which consists of L discrete multipath path components and given as

$$h_{k,l}^{(m)}(t) = \sum_{l=1}^{L} h_{k,l}^{(m)}\delta(t-\tau_{k,l}) \tag{4}$$

where $h^{(m)}_{k,l}$ is the complex channel gain with respect to l^{th} path of the k^{th} user at symbol interval m, $\tau_{k,l}$ is channel delay spread, assumed much smaller than symbol period T and $\delta(t)$ is the impulse function.

The complex envelope of the received signal at symbol time m can be expressed as

$$r^m(t)=\sum_{k=1}^{K}\sum_{m=-M}^{M}\sum_{l=1}^{L}h_{k,l}^{(m)}A_{k,l}^{(m)}b_k^{(m)}.s_k(t-mT-\tau_k-\tau_{k,l}^{(m)})+n(t) \tag{5}$$

where n (t) is AWGN with zero mean and variance σ^2, (2M+1) is the frame length of each user. For convenience the number of paths is assumed to be equal for all users, time invariant known delays, AWGN channel noise and signature waveform is periodic.

III. Precombining LMMSE

Precombining and postcombining interference suppression type approach may be employed for linear multiuser detection in multipath channels. Performance differences of these two schemes for known fixed channel have discussed in [8]. If user multipath product is minimum, decorrelator performs well, but if the product is large, cross-correlation matrix become ill conditioned. It may be restored for processing by partial pivoting but with high computational complexity. In such a case precombining scheme yields stable cross correlation matrix inversion and robust performance.

The precombining LMMSE receiver is

$$L = S(R+\sigma^2\textstyle\sum_h^{-1})^{-1} \in \Re^{SN\,2MXKL\,\,2M} \tag{6}$$

where

$\sum_h = \text{diag}\,[A_1^2\sum_{n1} ..{}_k^2\sum_{nK}] \in \Re^{KL2M \times KL2M}$

is the covariance matrix of h and it consists of user powers and average channel tap powers with

$\sum_{nk} = \text{diag.}\,[E[|h_{k,1}|^2]....E[|h_{k,L}|^2]] \in \Re^{L \times L}$

where $E[|h_{k,1}|^2]$ is the average power of the k^{th} user's l^{th} propagation. The output of precombining LMMSE receiver is

$$y[L] = (R+\sigma^2\textstyle\sum_h^{-1})^{-1} S^T r \in \Re^{KL} \tag{7}$$

It is evident that precombining LMMSE receiver no longer depends upon the instantaneous values of complex channel coefficients but on the average power profile.

III. Adaptive Implementation

a) MSE Criterion: The precombining LMMSE [8] is actually an adaptive RAKE receiver, where each branch is adapted independently to suppress MAI. The filter weights are calculated iteratively by using LMS algorithm. Filter is decomposed to fixed and adaptive components as

$$w^{(m)}_{k,l} = s_{k,l} + x^{(m)}_{k,l} \tag{8}$$

where $s_{k,l}$ is signature sequence of k^{th} user l^{th} path and $x^{(m)}_{k,l}$ is adaptive filter component. The coefficients may be adjusted adaptively by

$$x_{k,l}^{(m+1)} = x_{k,l}^{m} + \mu_{k,l}^{(m)}[h_{k,l}^{(m)}b_k^{(m)} - y_{ktotal}^{(m)}]*r^{(m)} \tag{9}$$

This adaptation works under normalized condition if we take

$$\mu_{k,l}^{(m)} = \frac{\mu_n^{(m)}}{\gamma + r^H(m)r(m)}$$

where μ_n is normalized step size, $0<\mu_n<2$ and γ is some fixed coefficient.

b) MOE Criterion:

The blind adaptive (BA) MUD [9] minimizes the mean output energy (MOE) subject to constraint. This receiver suppresses the sum of noise and interference, same as that by blind MMSE receiver. This is achieved by matching one of the two orthogonal filters to signature waveforms of the desired user while other is limiting MAI with adaptive structure. Adaptation rule for stochastic gradient algorithm is

$$x_1[i] = (1-\mu\lambda)\, x_1[i-1] - \mu[< y[i]-y[i]s_1> s_1] \tag{10}$$

λ is constraint on surplus energy. The BA MUD is sufficient detection scheme in stationary environments, while its performance degrades rapidly in time varying environment. In RAKE BA MUD [9,10] with time varying channel, each detector has its own independent MOE convergence process matched to a certain replica as interference to be removed. This proposal is insensitive to deep fades and larger signature mismatch, which yields in a loss of performance.

In the proposed precombining BA MUD the vector x_1 is forced to be orthogonal not only to nominal spread but also to the space spanned by all available replicas of desired user. The received continuous time signal is sampled at rate N/T and passed through multipath combiner before detection. Hence the input to the filter is

$$y_t^{(m)} = \sum_{i=1}^{L}\sum_{j=1}^{L}\sum_{k=1}^{K} a_{k,j}^{(d)}\, a'^{*(m)}_{1,j}\, w_k\, b_k^{(d)}\, s_{k,j-i}^{(d)} + n^{(m)} \tag{11}$$

for d = m-1, m, m+1; a'*(m) are estimated channel coefficients associated with each replica, $s_{k,\, j-i}$ is the part of j^{th} replica of k^{th} waveform aligned with i^{th} replica. A modified steepest descent stochastic gradient algorithm is proposed as

$$\bar{x}_1[i] = \bar{x}_1[i-1] - \mu\langle y_t[i], s_1 + \bar{x}_1[i-1]\rangle$$

$$\bullet \left[y_t - \langle y_t, s_1\rangle s1 \right] \tag{12}$$

V. Numerical Results

The main parameters used are:

BPSK transmission, carrier frequency 2GHz, symbol rate 31.49kbps, Gold code sequence of length 127, two receiving paths, channel bandwidth 4MHz, maximum delay 20µsec, processing window size M=3, Doppler spread 100Hz.

The precombining LMMSE Rake and precombining BA MUD performance is compared, in terms of probability of bit error with conventional RAKE detector with different SNR conditions as shown in Figure1. Due to imperfect adaptation, the conventional RAKE has better BER performance at low SNR's. The adaptive MOE receivers have a slower rate of convergence [9,13] but its performance is better over precombining MMSE for higher SNR levels.

IV. Conclusion

The performance of the LMMSE and blind adaptive multiuser detector for DS-CDMA systems has been studied in this paper. Numerical analysis has been used to evaluate the performance and applicability of multiuser detection in time varying multipath channels. Two receivers studied were precombining LMMSE RAKE and precombining BA MUD. Based on the results it can be concluded that precombining LMMSE receiver has no tracking constraint and performs well in fast fading.

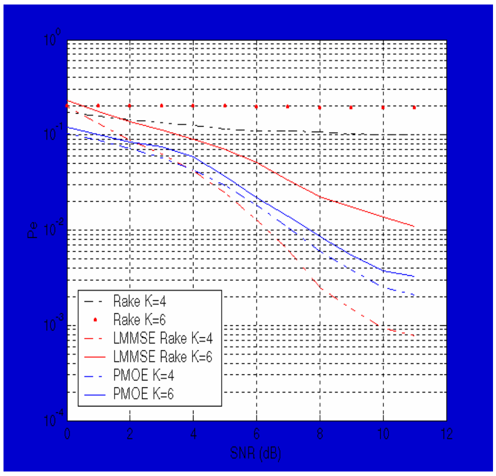

Fig. 1: BER as a function of the average SNR for the conventional RAKE, adaptive LMMSE RAKE and precombining MOE

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