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An Approach to Minimize the Impact of Residual MAI in MMSE Multiuser Detector

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Abstract: Capacity of CDMA system is interference limited. Multiuser detection is one of the methods used to enhance the capacity of CDMA system. In this paper, an improved MMSE based multiuser detector is proposed. The conventional detector is optimized to combat the Additive White Guassian Noise (AWGN), while MMSE detector has the lowest Bit Error Rate (BER) among suboptimum linear detectors. The proposed detector uses the conventional detector output in arriving at its decision; therefore a substantial improvement could be expected. For a synchronous CDMA system, our simulation results show a significant improvement in BER over MMSE detector.

Key words: MAI, Multiuser detection, MMSE, interference, Bit Error Rate, AWGN

INTRODUCTION

Code Division Multiple Access (CDMA) scheme has been accepted for current and future wireless systems because of its advantages such as decentralized access of the users to the channel without any need for a prior scheduling of the channel, graceful degradation of the performance of individual users as the number of users increase, and immunity to intentional jamming and multipath. However, a significant disadvantage of CDMA is the near-far effect which occurs as a result of the non-orthogonality of the codes with which users modulate their information bits. In near-far situations strong users can degrade the performance of the weak users significantly. In order to overcome the near-far problem, one commonly used method is Multiuser Detection (MUD).

Multiuser Detection for interference suppression is an active research topic in CDMA communication systems. Multiuser detection techniques offer the removal of Multiple Access Interference (MAI). The promising feature of near far resistance offered by multiuser detectors also eliminates the need of stringent power control (Moshavi, 1996). In the past two decades, a number of multiuser detectors have been proposed (Verdu, 1998). The optimum multiuser detection offers very attractive performance characteristics (in the sense of maximizing likelihood) which come at the expense of complexity that is exponential in the number of users (Moshavi, 1996 and Duel Hallen *et al.,* 1995). Due to the computational complexity requirements of optimal multiuser detector, there has been considerable interest in suboptimal multiuser detectors. Among various suboptimum detectors proposed linear multiuser detection has been widely studied because of their low-complexity integrated mathematical analysis.

The simplest linear multiuser detector is conventional Matched Filter (MF) receiver, which neglects the presence of MAI. The MF receiver is optimal in the special case of synchronous orthogonal CDMA, but exhibits unacceptable performance degradation in a non-orthogonal multiuser environment (Verdu, 1998). Among various suboptimum detectors proposed, the linear decorrelating detector has received the most attention and is well cited due to its computational simplicity (linear in the number of users) and near far resistant property. A major drawback associated with this detector is the effect of noise enhancement (analogous to that of zero forcing equalizer), which limits its performance in situations where noise level is dominant over MAI (Lupas *et al.*). The Minimum Mean Square Error (MMSE) based detector overcomes this limitation and at the same time maintains computational simplicity and near far resistance. The MMSE detector is of most practical importance among all linear estimates based multiuser detectors as it offers best tradeoff between MAI residue and noise variance (Xie *et al.*, 1990 and Madhow *et al.* 1994). The MMSE detector can also be implemented adaptively and it has robust performance in changing environment.

In this paper, an improved linear multiuser detector based on decisions of MMSE detector has been proposed. In the proposed detector, we attempt to improve the performance of MMSE detector by combining the outputs of conventional detector and MMSE detector. The main objective is to take the output of the MMSE detector as a primary decision and use it to estimate the amount of residual MAI caused by each user and then remove it from the output of conventional CDMA detector. The MMSE detector takes into account both the interference from users and the background noise and the conventional detector has no augmented noise term. Thus, using both

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outputs has a potential for a considerable performance enhancement.

MATERIALS AND METHODS

System model: For sake of simplicity, a BPSK transmission through an Additive White Guassian Noise (AWGN) channel shared by K simultaneous users employing a synchrounous DS-CDMA system with no multipath has been considered. The received signal can be written as

$$r(t) = \sum_{k=1}^{K} A_k b_k s_k + n(t), \quad t \in [0.T] \qquad (1)$$

where A_k, is the amplitude, $b_k \in \{+1, -1\}$ are the k^{th} users transmitted bits, s_k is the normalized signature code waveform of the k^{th} user and n(t) is AWGN noise with two sided power spectral density of $N_o/2$ W/Hz (Xie *et al.*, 1990).

In the case of conventional detection, the receiver consists of a bank of matched-filter each matched to the corresponding user's signature waveforms. The output of the k^{th} correlator is given by:

$$y_k = \int_0^T s_K(t) r(t) dt \qquad (2)$$

$$= A_k b_k + \sum_{\substack{i=1 \\ i \neq k}}^{K} A_i b_i \rho_{ki} + n_k \qquad (3)$$

which in matrix vector system can be represented as

$$y = RAB + n \qquad (4)$$

where,

$y = (y_1, y_2, ..., y_k)$
$B = [b_1, b_2, ..., b_k]^T$
$A = \text{diag}\ \{A_1, A_2, ..., A_k\}$

$R = (\rho_{ij})_{K \times K}$ is the cross-correlation matrix which is symmetric, and nonnegative.

linear multiuser detectors: Linear multiuser detector: applies linear transformation to the outputs of the conventional detector (Moshavi, 1996). The two successful linear multiuser detectors are the decorrelating detector and the Minimum Mean Square Error (MMSE) detector. The decorrelating detector outputs the signs of the matched filter outputs in (4) multiplied by the inverse cross correlation matrix R^{-1},

$$y_{dec} = R^{-1}(RAB + n)$$
$$= AB + R^{-1}n \qquad (5)$$

It is clear from (5) that the decorrelating detector eliminates MAI completely, thus providing unbiased estimates. However, because of the $R^{-1}n$ term in (5), the decorrelating detector considerably enhances the noise in the system (Lupas e*t al.*, 1989). This drawback limits the use of decorrelating detector in real environment. The other linear multiuser detector is MMSE detector. Linear transformation applied to (4) in MMSE is

$$y_{MMSE} = (R + \sigma^2 A^{-2})^{-1} (RAB + n) \qquad (6)$$

The linear MMSE detector takes into consideration the background noise and interference from other users. Thus the linear MMSE has the features of the decorrelating detector, except that it requires knowledge of the received amplitudes (Lupas e*t al.*, 1989). If either the background noise level or the k^{th} user received energy dominates, then the MMSE detector approaches the conventional matched filter: on the other hand as the background noise level vanishes $\sigma \to 0$, the MMSE detector approaches the decorrelating detector. Therefore, the multiuser efficiency and the near-far resistance of the MMSE detector are the same as those of the decorrelating detector. In particular, it also achieves optimal near-far resistance. The decorrelating detector and MF are thus the limiting cases of the MMSE detector. Due to these features, MMSE detector is more practicable.

Improved MMSE detector: The proposed algorithm is based on the output from the MMSE detector due to its less BER among allAugust 28, 2009 linear suboptimum multiuser detectors. Furthermore, linear MMSE detector can be implemented adaptively with training sequences.

Fig. (1) shows the block diagram of the proposed improved MMSE detector. The input to the estimator is the primary decision taken from the output of the linear MMSE detector. Since, MMSE detector has the knowledge of the amplitude and signature code waveform of all the users; these are used with the primary decision of the MMSE to estimate the residual MAI.

Under perfect power control, received signal level from every user is the same. As the second term in (3) gives the interference signal due to all users, the Bit Error Rate can be improved by removing this interference from the received signal. The signature waveforms and amplitudes of all the users on the receiving end are known while b_i is unknown. It is then necessary to use an estimate of b_i defined as d and is taken from the decision of the MMSE detector.

$$\hat{d} = \text{sgn}(y_{MMSE}) \qquad (7)$$

These decisions are used to estimate residual MAI using their signature code waveforms and amplitudes and can be written as

$$MAI_{est} = \sum_{\substack{i=1 \\ i \neq k}}^{K} A_i \hat{d}_i \rho_{ki}, \quad \rho_{ii} = 0 \qquad (8)$$

This estimated MAI is then subtracted from the received signal.

$$r(t) - MAI_{est} =$$
$$A_k b_k + \sum_{\substack{i=1 \\ i \neq k}}^{K} A_i b_i \rho_{ki} + n_k - \sum_{\substack{i=1 \\ i \neq k}}^{K} A_i \hat{d}_i \rho_{ki}$$

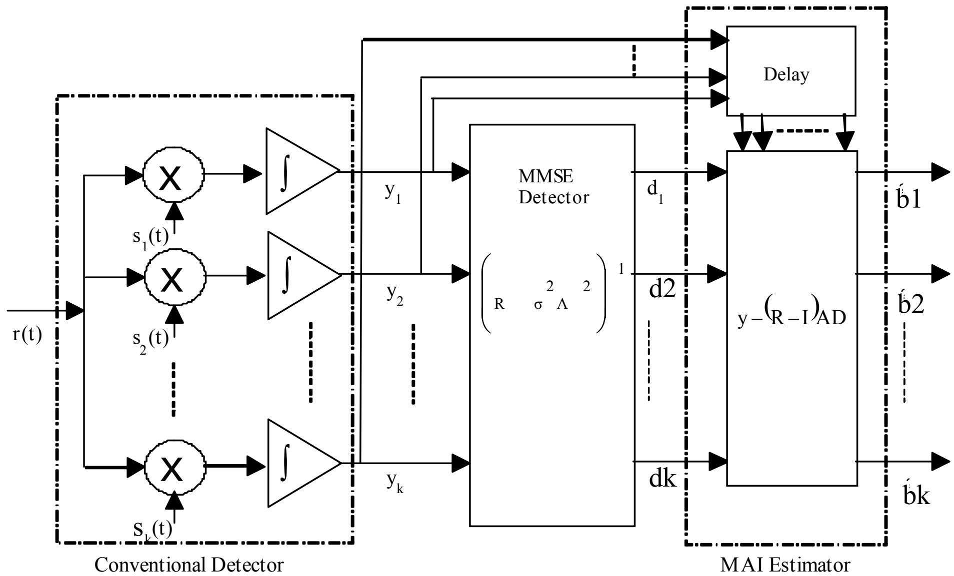

Fig. 1: Block diagram of Proposed Detector

$$= A_k b_k + \sum_{\substack{i=1 \\ i \neq k}}^{K} A_i \rho_{ki} \left(b_i - \hat{d}_i \right) + n_k \quad (9)$$

In matrix vector notation, MAI_{est} can be written as

$$MAI_{est} = (R-1)AD \quad (10)$$

where, **D** is the bit decision matrix taken from the output of MMSE detector. Thus, the output of the improved MMSE detector is given as

$$\hat{b} = \mathrm{sgn}\left(y - MAI_{est} \right) \quad (11)$$

Therefore, the proposed detector has less MAI than MMSE detector due to the reduction of residual MAI. This reduction in MAI will show a significant improvement in the capacity of CDMA system over MMSE detector.

RESULTS AND DISCUSSIONS

Simulation results: In all simulations, a simulated DS-CDMA data with AWGN channel is considered. All

CDMA signals are generated with BPSK data modulation and gold codes of length 31 are used as the spreading codes. It is assumed that there are equal power users. It is also assumed that receiver has knowledge of the amplitudes of the users and their signature code waveforms i.e. the correlation matrix is known. The proposed detector has been examined in various situations. The results are presented to compare the proposed multiuser detector with conventional and MMSE detectors. The following simulations are done to show the performance of the multi-user detectors with varying signal-to-noise ratio (SNR) levels and in multi-user interference (MAI) environment i.e. varying number of users in the system.

Fig. 2 presents the variation in Bit Error Rate (BER) with SNR for 10 users. It is clear from the result that the proposed detector shows lowest BER as compared to conventional detector and MMSE detector with variation in SNR on the channel. In Fig. 3, BER is plotted with variation in number of users on the channel with E_b / N_0 = 9dB. As the number of users increases, BER will also increase due to the presence of MAI in the conventional detector. However, MMSE multiuser detector shows significant improvement in BER output due to its multiuser detection capability. The proposed detector shows further improvement in the output of MMSE detector without increase in complexity.

Finally, simulations are carried out to analyze the performance of the proposed detector in terms of degradation factor (Fig. 4, 5). Degradation factor is defined as the ratio (in dB) of the E_b / N_0 required to achieve a given Bit Error Rate in the presence of users, to that which would be required to achieve the same level of performance if only a single user was communicating (Honig *et al.*, 1995). The simulations are done for two scenarios i) BER = 10^{-1}, 25 users and ii) BER = 10^{-2}, 20 users. In the first case, simulation is shown in Fig. (5), in which degradation factor of conventional detector saturates with only a small number of users while the proposed detector outperforms the MMSE detector. The proposed detector shows up to 8dB gain over MMSE detector which is an advantage. In the second case, thegain up to 6 dB is achievable.

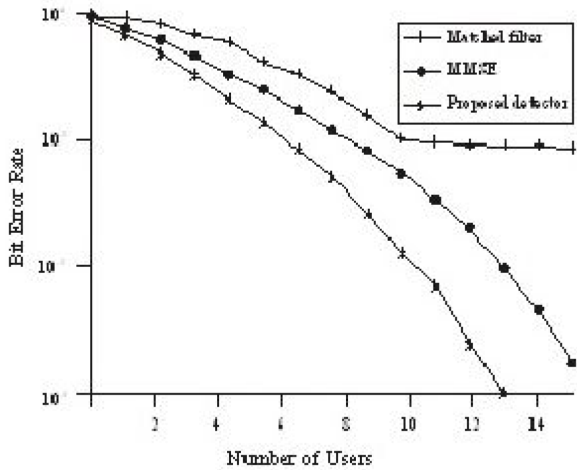

Fig. 2: Bit Error Rate vs. SNR (dB) for K = 10 users

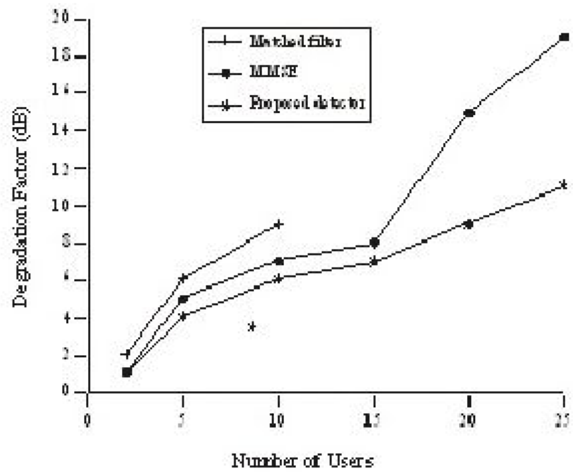

Fig. 4: Degradation Factor vs. Number of users for BER = 10^{-1}

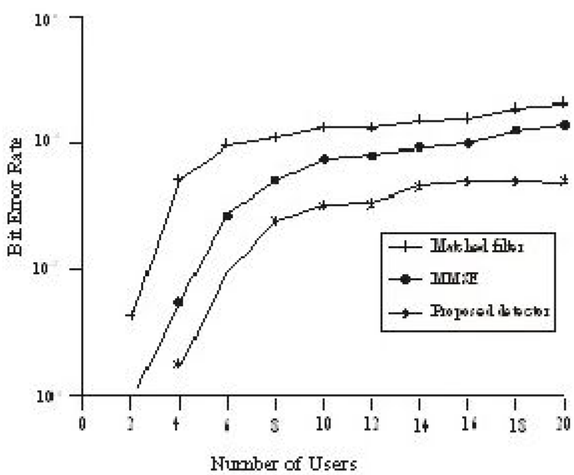

Fig. 3: Bit Error Rate vs. Number of users for SNR = 9 dB

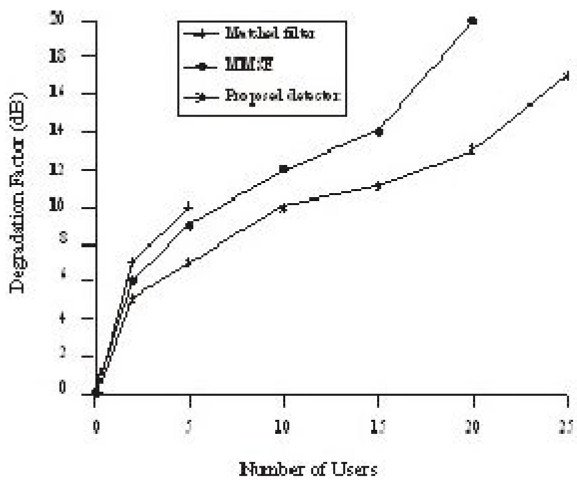

Fig. 5: Degradation Factor vs. Number of users for BER = 10^{-2}

CONCLUSION

An improved MMSE detector has been proposed and its performance is studied under AWGN channel. In the proposed detector, the estimation of MAI is done from the outputs of MMSE detector, which also has residual MAI in the decisions. When this estimated MAI is subtracted from the conventional detector output, the effect of residual MAI also gets reduced. This ensures further reduction in BER as compared to MMSE detector without any increase in the complexity of the system.

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