PERFORMANCE ANALYSES OF LINEAR MULTIUSER DETECTORS FOR DS/CDMA SYSTEMS OVER AWGN CHANNEL

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Abstract

Direct sequence code division multiple access (DS-CDMA) is a popular wireless technology. This system suffers from Multiple Access Interference (MAI) caused by Direct Sequence users and Near–Far effect due to different power levels received. Multi-User Detection schemes are used to detect the users' data in the presence of MAI and Near–Far problem. In this paper, presented comparative study between linear multiuser detectors and conventional single user matched filter in DS-CDMA system. Analysis and simulations are conducted in synchronous AWGN channel, and Gold sequence is used as the spreading code. Simulation results describe the performance of Conventional detector, Decorrelating detector and MMSE (Minimum Mean Square Error) detector. It shows that the performance of these detectors depends on the length of PN code used and Number of users. Linear multiuser detectors perform better than the conventional matched filter in terms of BER performance.

Index Terms:- *DS-CDMA, Matched Filter, AWGN, Multiuser Detection, Decorrelating detector, MMSE detector BER*

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1. INTRODUCTION

In DS-CDMA system, all of the users signals overlap in time and frequency cause mutual interference [1]. The general structure of these detectors consists of a bank of matched filters. The detection is done on the basis of a filter matched to the pseudo-random sequence of the user. This detector is known as the conventional matched filter detector. Since the conventional matched filter was designed for orthogonal signature waveforms, it suffers from many drawbacks due to the MAI term. Multi-user Detector (MUD) techniques exploit the character of the MAI by removal of the Multi-User Interference from each user's received signal before making data decision, and thus offer significant gains in capacity and Near-Far resistance over the conventional receiver. The synchronous DS-CDMA system transmitter model in [2], as in Fig- 1.

The DS-CDMA receivers are divided into Single-User and Multi-User detectors. The next sections contain an overview of conventional single user matched filter detector, and multiuser detectors. Finally, performance of the system (BER), as a function of Signal-to-Noise ratio (SNR) for the three detectors compared and stated that the MMSE detector has the best performance. Synchronous DS-CDMA system receiver [2], has a bank of K matched filters. The received signal is the noisy sum of all users' signals.

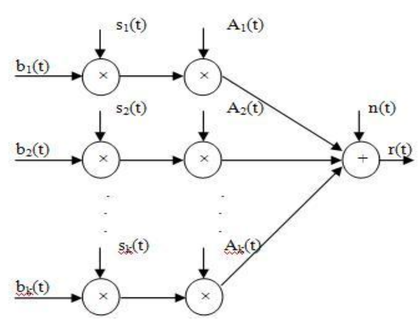

Fig-1: Synchronous DS-CDMA system transmitter model

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$$r(t) = \sum_{k=1}^{K} A_k(t) s_k(t) b_k(t) + n(t) \qquad (1)$$

Where $A_k(t)$ is channel attenuation
$s_k(t)$ is chip sequence
$b_k(t)$ is input bits & n(t) is AWGN noise

1.1 Conventional Detector

This is the simplest way to demodulate the received signal, a bank of matched filters, one matched to each user's spreading waveform, is applied to the received signal, as in Fig- 2. Thus, it demodulates all users independent of each other. This conventional matched filter detector [2] detects the data of one user at a time. This conventional detector also known as matched filter. In conventional single user digital communication system, the matched filter is used to detect the polarities of the received signal, which contain the transmitted information.

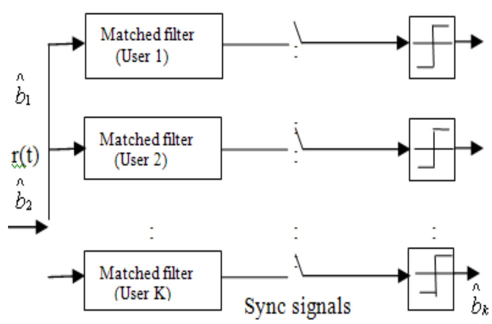

Fig-2: Conventional single-user matched filter

The output of matched filter bank is

$$y_k = \int_0^{T_b} r(t) s_k(t) dt \qquad (2)$$

$$= A_K b_K + \sum_{\substack{k=1 \\ k \neq K}}^{K-1} A_k b_k R_{kK} + n_K \qquad (3)$$

Where $R_{kK} = \int_o^T s_k(t) s_K(t) dt$ for k=1, 2, . . . K-1. (4)

From the above expression in (3), the first term is desired information which gives the sign of the information bit, second term is interference from other users and the last is due to noise. The interference from other users called multiple access interference (MAI). This method ignores MAI and treats as noise (self noise). This self-noise limit the systems capacity and can jam out all communications in the presence of a strong nearby signal (Near-Far Problem). The detector is implemented as a K separate single-input (continuous-time) single-output (discrete-time) filters with no joint processing at all. Each user is demodulated separately without taking into account to the existence of other (K-1) active users in the system. In other words, other users are considered as interference or noise. The exact knowledge of the users' signature sequences and the signal timing is needed in order to implement this detector.

The correlation between the same code waveforms (autocorrelations) is required to be larger than the correlations between different codes (cross-correlation) for successful detection. The correlation value algorithm defined in [5] can be simplified as below.

If $y < 0$ then $\hat{b} = -1$ else +1, and after that if $\hat{b} \neq b$ then error = error + 1. This detector detects the bit from the user k by correlating the received signal with the chip sequence of the user k. Thus, the conventional detector makes its decision at the output of the matched filter bank:

$$\hat{b}_k = \text{sgn}(y_k) \qquad (5)$$

2. LINEAR MULTIUSER DETECTORS

There are two categories of the most proposed detectors: linear multiuser detectors and non-linear detectors. In linear multiuser detection, a linear mapping (transformation) is applied to the soft outputs of the conventional detector to produce a new set of outputs, which hopefully provide better performance. In non-linear detection, estimates of the interference are generated and subtracted out. Multiuser detection refers to the problem of detecting transmitted signals by considering all users. In multiuser DS-CDMA systems, detection involves exploitation of the base station's knowledge of signature sequence and the correlation properties contained in MAI to extenuate interference among users and subsequently, suppress noise to better detect each user [6]. A multiuser detector called a successive interference canceller can remedy the conventional detector problem. This can be done by using linear multiuser detectors.

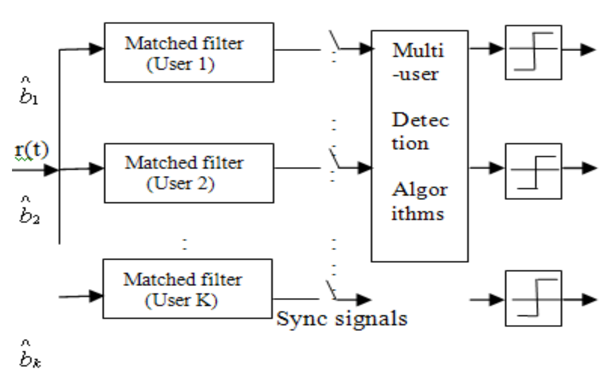

Fig-3: A typical multiuser detector for DS-CDMA

Fig- 3 shows the general structure of multiuser detection systems for detecting each *K* user's transmitted symbols from the received signal, which consists of a matched filter bank that converts the received continuous-time signal to the discrete-time statistics sampled at chip rate without masking any transmitted information relevant to demodulation. This is followed by applying multiuser detection algorithm for optimality conditions to produce the soft output statistics [2]. The soft outputs are passed to the single user decoders. With the statistic [y_1, y_2, … y_k] at the output of the matched filter, an estimate for the transmitted bits [b_1, b_2, … b_k] that minimizes the probability of error can be found.

2.1Decorrelating Detector

The Decorrelating detector as shown in Fig- 3 applies the inverse of the correlation matrix to the output of the matched filter in order to decouple the data. In the synchronous channel, Consider the output of the bank of k matched filters:

$$y = RAb + n \qquad (6)$$

Where n is a Gaussian random vector with zero mean and covariance matrix σ^2R. If we process the output vector as:

$$R^{-1}y = Ab + R^{-1}n \qquad (7)$$

Clearly the k^{th} component of vector $R^{-1}y$ is free from interference caused by any other users for any k (since A is diagonal). Note that the cross correlation matrix R [4] is invertible if signature sequences are linear independent. If the background noise is vanishing, i.e., σ= 0, then

$$\hat{b}_k = \text{sgn}(R^{-1}y)_k = \text{sgn}((Ab)_k) \qquad (8)$$

Hence, in absence of background noise, we get error free performance. In the presence of the background noise, decision is affected only by the background noise, i.e.,

$$\hat{b}_k = \text{sgn}(R^{-1}y)_k = \text{sgn}((Ab + R^{-1}n)_k) \qquad (9)$$

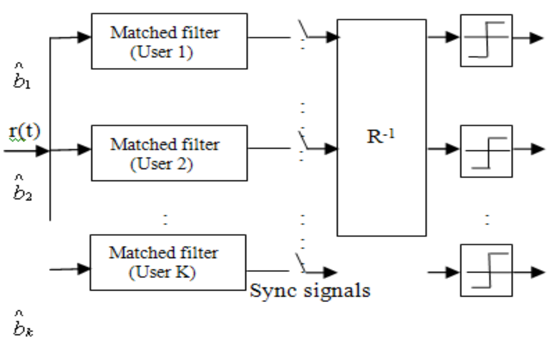

Fig-4: Decorrelating detector for DS-CDMA.

If $\hat{b}_K$ <0 then $\hat{b} = -1$ else +1 and if $\hat{b} \neq b$ then error = error + 1. Decorrelating detector can achieve any given performance level in the multiuser environment regardless of the multiuser interference, provided that the desired user is supplied enough power. Thus, it provides a substantial performance over the conventional detector under most conditions.

2.2 MMSE Detector

The MMSE implements the linear mapping which minimizes the mean-squared error between the actual data and the soft output of the conventional detector. At this stage, the MMSE detector as shown in Fig- 5, applies a modified inverse of the correlation matrix to the matched filter bank outputs, and takes into account the background noise and utilizes knowledge of the received signal powers. The amount of modification is directly proportional to the background noise, the higher the noise level, the less complete an inversion of R can be done without noise enhancement causing performance degradation. Thus, the MMSE detector balances the desire to decouple the users (and completely eliminate MAI) with the desire to not enhance the background noise [9].

The algorithm for this MMSE Detector presented in [1] is summarized as below. The MMSE detector implements a linear mapping L which minimizes the mean squared error $E[|(b_k - Ly)|]^2$. The detection algorithm is as follows:

$$\hat{b} = \text{sgn}(Ly) \qquad (10) \qquad \text{where } y = RAb + n$$

$$\text{and } \hat{b}_{MMSE} = [R + (N_0/2)A^{-2}]^{-1}y \qquad (11)$$

If $\hat{b}_{MMSE}$ <0 then $\hat{b} = -1$ else +1 and if $\hat{b} \neq b$ then error = error + 1. If the noise N_0 =0, then it converges to decorrelating detector. This detector, Performs better than the Decorrelating detector since it takes noise into account and requires an estimate of the channel at the receiver. An important disadvantage of this detector is that, unlike the Decorrelating detector, it requires estimation of the received amplitudes. Another disadvantage is that its performance depends on the powers of the interfering users [7].

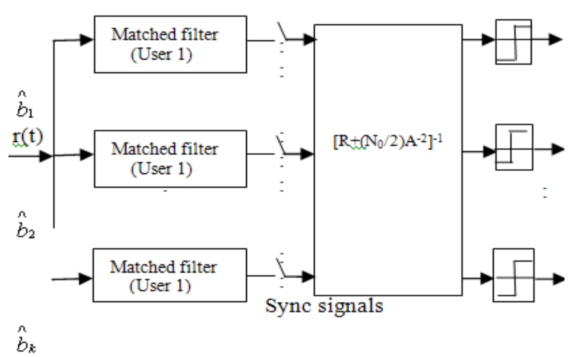

Fig-5: MMSE Detector for DS-CDMA

3. RESULTS

Detectors that are simulated include conventional single user matched filter (MF), Decorrelating detector (DD) and Minimum mean-squared error (MMSE) detector. First of all, the BER performance comparison between the conventional detector and two suboptimal linear multiuser detectors is conducted. The performance evaluation with increasing number of active users is carried out. These simulations are done with the assumption that all active users have equal power. AWGN channel is considered and there is perfect power control. Also assume that each transmitted signal arrives at the receiver over a single path.

Case 1: Two users synchronously transmitting the 5000 bits through an AWGN channel. For spreading gold sequence of length Lc=31 is used. SNR is varying from 1dB to 8dB.

Here K=Number of users and Lc= PN sequence length. The three detectors performance is almost similar. If number of users are increasing then the effect of MAI also increase that influence the detection of data. For the 2 user case the BER performance is shown in Fig- 6.

Case 2: Four users synchronously transmitting the 5000 bits through an AWGN channel. For spreading gold sequence of length Lc=31 is used. SNR is varying from1dB to 8 dB. For the 4 user case the BER performance is shown in Fig- 7

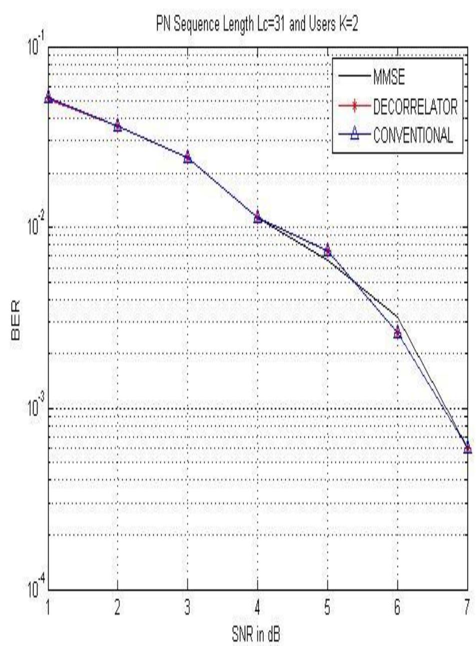

Fig-6: PN Sequence Length Lc=31 and Users K=2

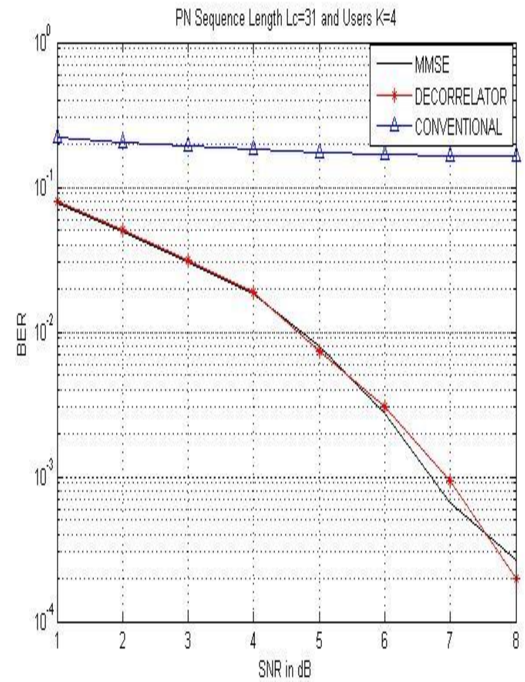

Fig- 7: Length Lc=31 and Users K=4.

The Linear multiuser detector has less BER (~10^{-3}) compare to the conventional detector (10^{-1}). Linear multiuser detectors are outperforming over the conventional detector

Case 3: Ten users synchronously transmitting the 5000 bits through an AWGN channel. For spreading gold sequence of length Lc=31 is used. SNR is varying from 1dB to 8dB. For the 10 user case the BER performance is shown in Fig- 8.

The increase in the length of the Gold codes leads to a significant rise of the signature sequences. This leads to a considerable degradation in the system performance shown in Fig- 8.

Case 4: Four users synchronously transmitting the 5000 bits through an AWGN channel. For spreading gold sequence of length Lc=63 is used. SNR is varying from 1dB to 8dB. For the 4 user case the BER performance is shown in Fig- 9. By using MMSE detector we can gain SNR compare with other detectors

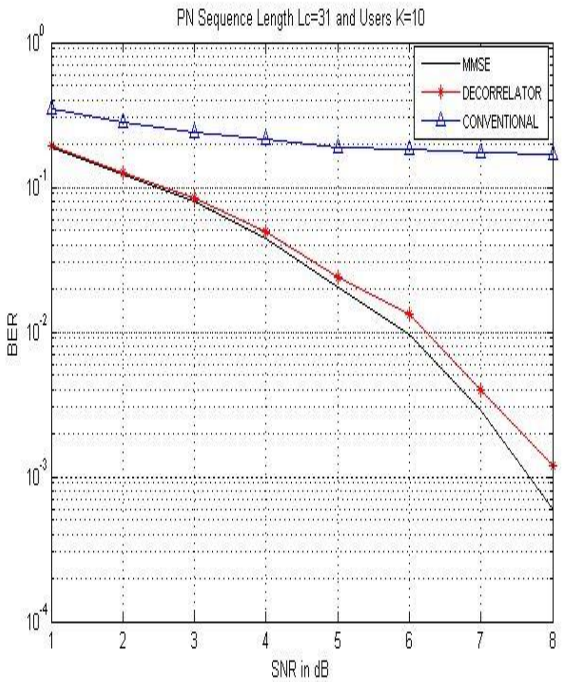

Fig- 8: Length Lc=31 and Users K=10.

Case 5: Performance comparison with near-far effect for four users and spreading gold sequence of length Lc=15 is shown in Fig- 10.

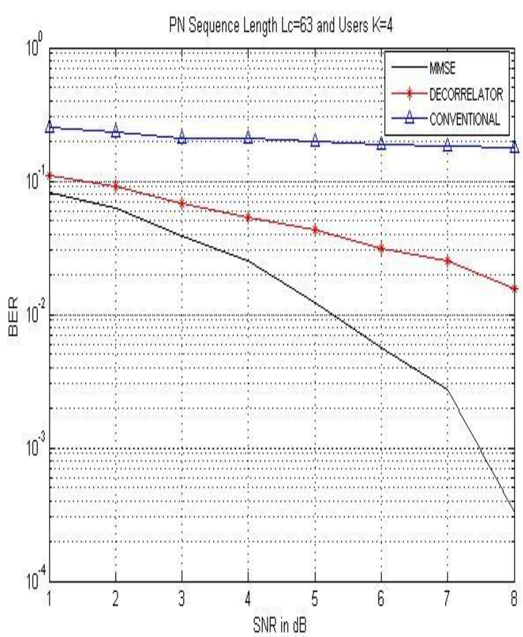

Fig- 9: Length Lc=63 and Users K=4.

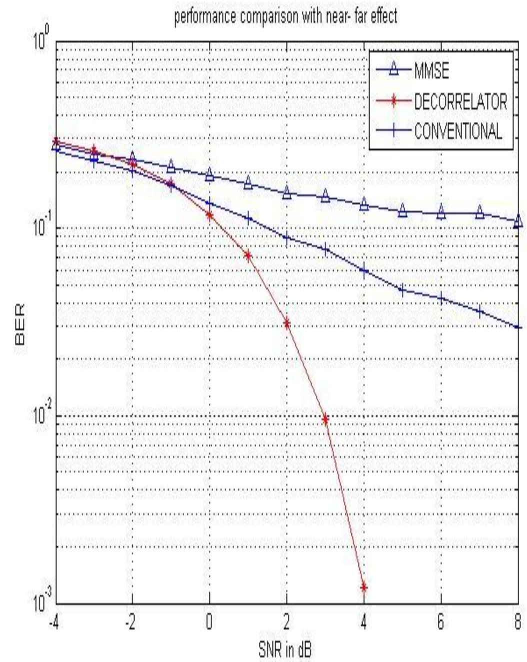

Fig- 10: Length Lc=15 and Users K=4 with near-far effect.

An important disadvantage of this detector is that, unlike the decorrelating detector, it requires estimation of the received amplitudes. Another disadvantage is that its performance depends on the powers of the interfering users [11]. Therefore, there is some loss of resistance to the near-far problem shown in above fig as compared to the Decorrelating detector.

4. CONCLUSION

MMSE detector generally performs better than the Decorrelating detector because it takes the background noise into account. With increasing in the number of users, the performance of all detectors will degrade as well. This is because as the number of interfering users increases, the amount of MAI becomes greater as well. Thus there is a trade of between the performance measures (BER vs. SNR). Depending on the situations, a suboptimum receiver satisfying the implementation constrains can be chosen. Multiuser detection holds promise for improving DS-CDMA performance and capacity. Although multiuser detection is currently in the research stage, efforts to commercialize multiuser detectors are expected in the coming years as DS-CDMA systems are more widely deployed. The success of these efforts will depend on the outcome of careful performance and cost analysis for the realistic environment.

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