LINEAR MULTIUSER MMSE DETECTOR PERFORMANCE IN SYNCHRONOUS CDMA SYSTEM

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ABSTRACT
The bit error rate performance of the conventional and linear MMSE detectors is analyzed and simulated in synchronous CDMA channel under Multiple Access Interference (MAI) and Near Far Problem circumstances. A brief overview on the multiuser detection (MUD) is given. Simulation results show the performance of the linear MMSE multiuser detector compared with the conventional multiuser detector. Conclusions are drawn from simulation results.

Keywords: Multiuser detection, MMSE detector, CDMA, Conventional detector.

1. INTRODUCTION
In CDMA systems all users share the same time intervals and frequency spectrum, unlike FDMA and TDMA systems where specific allocations are dedicated to each user. Direct Sequence CDMA (DS-CDMA) is the most popular of CDMA techniques; the DS-CDMA transmitter multiplies each user's signal by a distinct code waveform. The detector receives a signal composed of the sum of all users' signals, which overlap in time and frequency. In a conventional DS-CDMA system, a particular user's signal is detected by correlating the entire received signal with that user's code waveform [3].

As a result of DS-CDMA multiple access technique, the capacity of DS-CDMA systems is limited by the Multiple Access Interference (MAI) generated by the system itself and the Near Far Problem. MAI increases as the number of users increases, while Near Far Problem arises since the high power-undesired user avoids the successful reception of the low power-desired user. Since MAI and Near Far Problem severely degrade the performance of DS-CDMA system, a lot of researches have been carried out in multiuser detection instead of single user detection to reduce their effects. S. Verdu was the first researcher, who proposed the theory of Multiuser Detection (MUD) in 1984.

Unlike single user detection technique which treats the signals from other users as noise, multiuser detection technique jointly detects the information of multiple users (MAI) and uses this information to improve the detection of the desired signal rather than considering MAI as noise.

The optimal multiuser detector was found by Verdu in [4]. It offers high performance characteristics which come at the cost of complexity that is exponential in the number of users [3]. Low complexity detectors are required for practical implementations. Consequently, a family of suboptimal detectors is introduced in [4] and [3]. Suboptimal detectors are classified into: Linear and Nonlinear MUDs. The Linear MUDs are the conventional matched filter MUD, the decorrelator MUD and the Minimum Mean Square Error (MMSE) MUD. In this project MMSE MUD is our concern.

This report is organized as follows. In section II, the conventional DS-CDMA detector model is presented. The linear MMSE DS-CDMA detector in section III. Simulation results and performance analysis are presented in section IV. Conclusions are given in section V.

2. THE CONVENTIONAL DS-CDMA DETECTOR MODEL
Consider a synchronous DS-CDMA system shared by K synchronous users simultaneously. We consider BPSK transmission through a common AWGN channel. Each user is assigned a unique signature waveform $s_k(t)$ of duration T, where T is the symbol duration.

The simplest linear multiuser detector is the conventional matched filter detector, which doesn't consider the presence of MAI and each user is detected separately.

As shown in Figure 1, it's composed of bank of k matched filters. The received signal is correlated with signature waveform on each branch.

The outputs of matched filter for user $k$:

$$y_k = A_k b_k + \sum_{i=1,i\neq k}^{k} A_i \rho_{k_i} + n_k$$  \hspace{1cm} (1)

Where,

- $A_k$: Received amplitude of the $k$th user's signal.
- $b_k \in \{-1,+1\}$: The bit transmitted by the $k$th user. $\rho_{k_i} = \int_0^T s_k(t) s_i(t) dt$ : Crosscorrelation of the $k$th and $i$th user. $s_k$ : The normalized signature waveform of the $k$th user.
- $n_k = \int_0^T n(t) s_k(t) dt$ : Gaussian noise with zero mean and variance equal to $\sigma^2$. 


\( n(t) \): White Gaussian noise with zero mean and variance equal to \( \sigma^2 \).

Output vector of the bank of \( K \) matched filter:

\[
y = RAb + n
\]  

(2)

Where,

\[
y = [y_1, y_2, \ldots, y_K]^T, \quad R = [\rho_{kk}] : \text{Crosscorrelation matrix}
\]

\[
\rho_{kk} = \int_0^T s_k(t) s_k^*(t) dt
\]

\[
A = \text{diag} [A_1, A_2, \ldots, A_K]^T, \quad b = [b_1, b_2, \ldots, b_K]^T
\]

\( n \) is zero mean Gaussian random vector with covariance matrix equal to \( E[nn^T] = \sigma^2 R \).

The conventional detector treats the signals of all the other users as noise, and to perform well it requires that the interference from other users should be minimal. However, as the number of interfering users increases, the amount of MAI increases. Moreover, the Near Far Problem degrades the performance of the conventional detector severely. Consequently, the success of the conventional detector depends on the cross correlation property of the signature codes of the users. Therefore, we require the autocorrelation to be much larger than the crosscorrelation of different signature codes.

3. THE LINEAR MMSE DS-CDMA DETECTOR

In Minimum Mean Square Error (MMSE) detector the multiuser detection problem is converted into a linear estimation problem. The use of the MMSE criterion for CDMA receivers was first proposed in [1]. The MMSE filter minimizes the variance at the output of the filter taking into account both channel noise and interference, but ignoring the data structure [6]. The goal is to minimize the mean-square-error (MSE) between the user \( k \)'s bit and the output of the \( k \)th linear transformation.

The MMSE filter minimizes the squared error between the transmitted signals and the output of the filter [6]. It is found as

\[
\min_{M \in R^{K \times K}} E[\|b - My\|^2]
\]

Which leads into the optimal solution:

\[
M^* = (R + \sigma^2 A^2)^{-1}
\]

The optimal solution is applied on the outputs of the bank of the conventional matched filters to obtain the estimated bits.

The performance of the MMSE detector is a trade off state between the conventional detector and the decorrelating detector. It approaches the conventional detector as noise tends to infinity. As the signal-to-noise ratio goes to infinity, the MMSE detector converges to the decorrelator. Hence, it provides improved noise behavior with respect to the decorrelating detector, but it requires an estimation of the received amplitudes and noise level. The performance depends also on powers of interfering users. Unlike the conventional detector, MMSE detector has a high resistivity to the Near Far Problem [2].
4. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

Simulations are carried out by MATLAB program to compare the performance of the conventional detector and the Linear MMSE detector as a function of MAI and Near Far Problem. A synchronous CDMA channel with AWGN and 10 users (maximum) are considered. Gold sequences of length 31 (spreading factor) are used in our simulations as signature (spread) codes. The cross-correlations of Gold sequences are relatively small as compared to other spread codes.

First, we consider the case of MAI effect on the performance of the conventional detector and the Linear MMSE detector. MAI increases as the number of users increases; in our simulations we considered two, three, five, eight, and ten users to illustrate the effect of MAI. Average of bit error rate (BER) of the first user is taken as the performance measure parameter. Results are shown in Figure 3. As shown in Figure 3, the linear MMSE detector offers substantial improvement over the conventional detector as the number of users increases (MAI increases), while the performance of conventional detector degrades (Bit Error Rate increases) as the number of users increases.

![Figure 3: Simulation results of the performance of the conventional and MMSE MUDs as a function of MAI.](image)

Second, to study the effect of the Near Far Problem on the conventional and the linear MMSE detectors, we considered only two users case in our simulation. We fixed the power of the desired user and varied the power of the undesired user as follows: equal power with the desired user, doubled power, tripled power, and quadrupled power of the undesired user with respect to the desired user. Average of bit error rate (BER) of the first user is taken as the performance measure parameter. Results are shown in Figure 4.

The conventional detector performance degrades severely as the power of the interfering (undesired) user increase, while the linear MMSE detector provides a high resistance to the Near Far Problem and its performance is almost the same as the power of the undesired user increased.

![Figure 4: Simulation results of the performance of the conventional and MMSE MUDs as a function of the undesired user power (Near Far Problem, two users' case).](image)

5. CONCLUSION

A study of the conventional and the linear MMSE MUDs is carried out. Simulation results show the performance gains of the linear MMSE detector over the conventional detector. Multiuser detection shows advances against other wireless communication techniques; however, MUD practical complexity limits its implementations.

In fact, despite literally hundreds of funded research projects and proposed multiuser receiver architectures, and thousands of academic papers on the subject, industrial CDMA systems still typically employ the same basic matched filter receiver structure, or simple improvements based on it [5].
In short, significant steps have been taken recently toward the realization of practical multiuser receivers, but more research and development is needed to make multi-user receivers practical for future standards [5].

REFERENCES