MULTIUSER DETECTION IN DSSS SYSTEMS

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ABSTRACT

This research paper describes Multiuser detection with minimized Multiple Access Interference (MAI). Multiuser detection seeks to enhance the performance of non-orthogonal signaling schemes for multiple access communications by combating the MAI caused by the presence of more than one user in the channel. The conventional Code Division Multiple Access (CDMA) system is interference limited system when MAI increases with increasing the number of active users, and when signals are receiving with the different power levels due to near far problem. These factors are taken into account in simulation with the exception that all active users have equal power. The main object of this research paper is to detect multiples users with minimized MAI.

Key words: Multiuser, MAI, Linear Detectors, Conventional Detector

1 INTRODUCTION

Transmitting information through a wireless channel is more challenging than through a wire line channel. The main reason is that the wireless environment has some problems. In wire line systems, like multipath and near-far interference issues. The conventional matched filter for Direct Sequence- Code Division Multiple Access is known to be optimum in a few limited scenarios. First, it was designed to be optimum for a single user in a white Gaussian noise environment. Also, in the case of multipath users, it is optimum if the transmission from all the users is synchronous and the code sequences assigned to each user are orthogonal. This sort of environment is encountered in the forward link of a cellular system where all transmissions are emanating from the base station and hence synchronized. The reverse link, however, provides a more interesting challenge, as each CDMA signal is transmitted from a different source and hence it would be very difficult to synchronize transmission.

2 CONVENTIONAL DETECTOR

The conventional DS-CDMA detector follows single user detection strategy in which each user is detected separately without regard for the other users. A better strategy is multi-user detection, where information about multiple users is used to improve detection of each individual user. This research implements a number of important multiuser detectors that have been proposed. In DS-CDMA users are multiplexed by distinct codes rather than by orthogonal frequency bands or by orthogonal time slots. A conventional DS-CDMA detector follows a single user detection strategy, in which each user is treated separately, while considering other users as interference or noise. A comprehensive look on DS-CDMA can be found in [1-4]. MAI is the interference between the active users and causes the timing offsets between signals. Conventional detectors detect each user separately and don't consider the MAI. Due to this, multiuser detection strategies have been proposed. Matlab simulation for the Conventional Detector is shown in Fig 1.

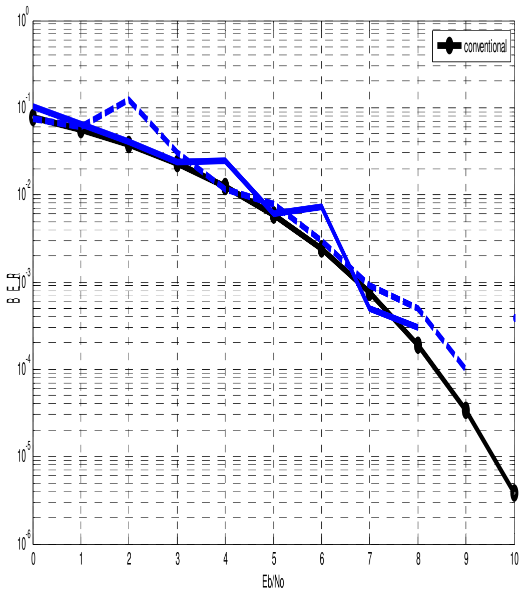

Fig 1 Conventional Detector

3 MULTIUSER DETECTIONS

There have been great interests in improving DS-CDMA detection through the use of multiuser detectors. In multiuser detection code and timing (and possibly amplitude and phase) information of multiple users are jointly used to better detect each individual user. Most of the proposed detectors have been classified in one of two categories: linear multiuser detectors and subtractive interference cancellation detectors. In linear multiuser detection, a linear mapping (transformation) is applied to the soft output of the conventional detector to produce a new set of outputs, which hopefully provide better performance. In subtractive interference cancellation detection, estimates of the interference are generated and subtracted out.

4 DETECTOR TECHNIQUES

In this research some advanced techniques for detection of multiple synchronous DS-CDMA signals. As described below

- The Decorrelating Detector.
- The Minimum Mean-Squared Error Detector.
- Multistage Interference Cancellation Detectors.

5 LINEAR DETECTORS

An important group of multiuser detectors are linear multiuser detectors. These detectors apply a linear mapping, L, to the soft output of the conventional detectors to reduce the MAI seen by each user.
In this section we briefly review two most popular of these.

5.1 Decorrelating Detector

$$D_{dec} = \mathrm{Ad} + R^{-1}\mathrm{Z}$$
$$= \mathrm{Ad} + Z_{dec}$$

This is just the decoupled data plus a noise term. Thus, we see that the Decorrelating detector completely eliminates the MAI. The Decorrelating is extensively analyzed by Lupas and Verdu in [6, 7] and is shown to have many attractive properties. Foremost among these properties are [6]:

- Provides substantial performance/capacity gains over the conventional detector under most conditions.
- Can decorrelate one bit at a time.
- Corresponds to the maximum likelihood sequence detector when the energies of all users are not known at the receiver.

Decorrelating detector has some disadvantages as well.

- A more significant disadvantage of the Decorrelating detector is that the computations needed to invert the matrix R are difficult to perform in real time.
- Another disadvantage of this detector is that it causes noise enhancement. The power associated with the noise term $R^{-1}z$ at the output of the Decorrelating detector is always greater than or equal to the power associated with the noise term [8]. Matlab simulation for the Decorrelating Detector is shown in Fig 2.

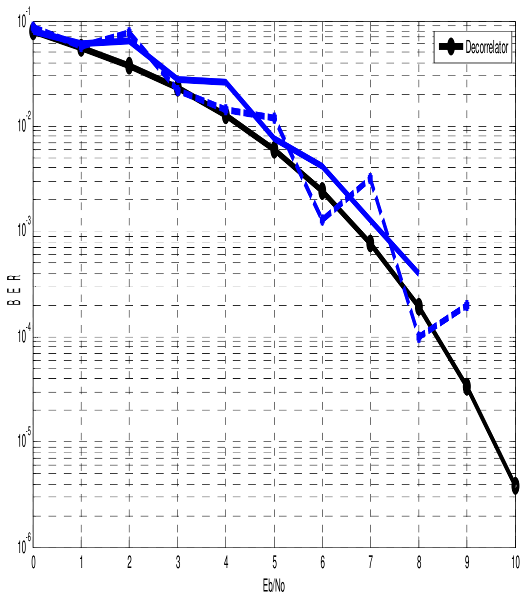

Fig 2 Decorrelating Detector

5.2 Minimum Mean-Squared Error Detector

The minimum mean squared error (MMSE) detector [9] is a linear detector which takes into account the background noise and utilizes knowledge of the received signal powers. This detector implements the linear mapping which minimizes E $[|d-L_y|^2]$, the mean squared error between the actual data and the soft output of the conventional detector. The soft estimate of the MMSE detector is simply

$$d_{MMSE} = L_{mmse} Y^{-1}$$

As it can be see that, the MMSE detector implements a partial or modified inverse of the correlation matrix. The amount of modification is directly proportional to the back-ground noise. Thus, the MMSE detector balances the desire to decouple the users (and to completely eliminates MAI) with the desire to not enhance the background noise. This multi-user detector is exactly analogous to the MMSE linear equalizer used to combat ISI [8].

The MMSE detector generally provides better probability of error performance than the Decorrelating detector as it considers the background noise The MMSE detector also has following disadvantages.

- An important disadvantage of this detector is that, unlike the Decorrelating detector, it requires estimation of the received amplitudes.
- The MMSE detector also faces the task of implementing matrix inversion.

Matlab simulations for the Minimum Mean Squared error detector are shown in Fig 3

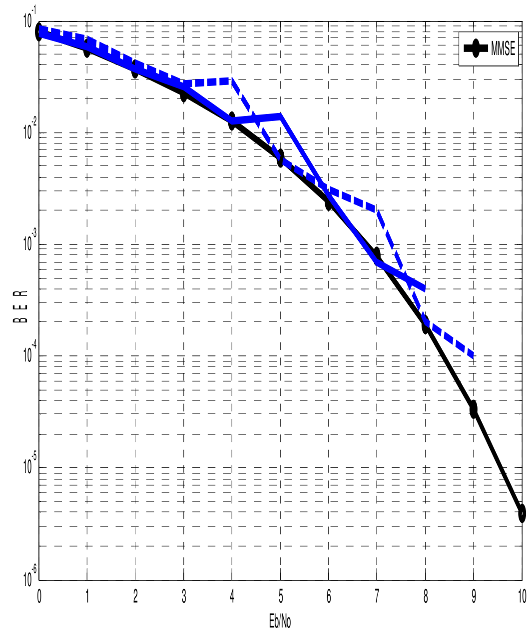

Fig 3 Minimum mean squared error detector

5.4 Subtractive Interference Cancellation (SIC)

An important group of detectors can be classified as subtractive interference cancellation detectors.

The successive interference cancellation (SIC) detector [10] takes a several approach to canceling interference. Each stage of this detector decisions, regenerates, and cancels out one additional direct-sequence user from the received signal, so that the remaining users see less MAI in the next stage. A simplified diagram of the first stage of this detector is shown in figure below.

The first stage is preceded by an operation which ranks the signals in descending order of received powers.

The first stage implements the following steps.

1. Detect with the conventional detector, the strongest signal, S_1.
2. Make a hard decision on S_1.
3. Regenerate an estimate of the received signal for one using:
   - Data decision from step 2
   - Knowledge of its PN sequence.
   - Estimates of its time and amplitude.
4. Subtract out $S_1(t)$ from the total received signal, r(t), yielding partially cleaned version of the received signal, $r_1(t)$.

Assuming that the estimates of $S_1(t)$ in step 3 above was accurate, the outputs of the first stage are:

1. A data decision on the strongest signal.
2. A modified received signal without the MAI caused by the strongest user.

This process can be repeated in a multistage structure: the k_{th} stage takes as its input the "partially cleaned" received signal output by its previous stage and outputs one additional data decision and a cleaner received signal $r_{(k)}(t)$.

The reason for canceling the signals in descending order of signal strength is straightforward [10]

- First, it is easiest to achieve acquisition and demodulation.
- Second, the removal of the strongest signal gives the most benefit for the remaining users.

The result of this algorithm is that the strongest user will not benefit from any MAI reduction. The weakest users, however, will potentially use a huge reduction in their MAI.

The SIC detector requires only a minimal amount of additional hardware and has the potential to provide a significant improvement over the conventional detector. It does, however, pose a couple of implementation difficulties. First, one additional bit delay is required per stage of cancellation. Thus, a trade-off must be made between the number of users that are cancelled out and the amount of delay that can be tolerated. Second, there is a need to reorder the signals whenever the power profile changes. Here, too a trade-off must be made between the precision of the power ordering and the acceptable processing capability.

A potential problem with the SIC detector occurs if the initial data estimates are not reliable. In this case, even if the timing, amplitude and phase estimates are perfect, if the bit estimate is wrong, the interfering effect of that bit on the signal-to-noise ratio is quadrupled in power (the amplitudes doubles, so the power quadruples). Thus, a certain minimum performance level of the conventional detector is required for the SIC detection to yield improvements; it is crucial that the data estimates of at least the strongest users that are cancelled first be reliable. Matlab simulation for the SIC Detector is shown in Fig 4.

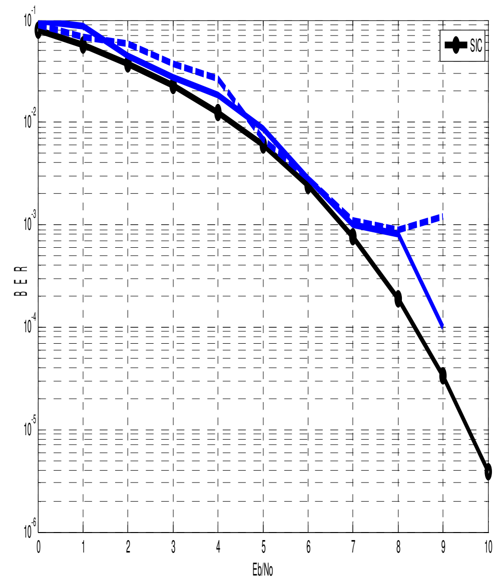

Fig 4 SIC detector

5.5 Parallel Interference Cancellation Detector

The Parallel Interference Cancellation detector (PIC) estimates and subtracts out all of the MAI for each user in parallel. The initial bit estimates $d_1(0)$, are derived from the matched filter detection. These bits are then scaled by the amplitude estimates respread by the codes, which produces delayed estimates of the received signal for each user. The partial summer sums up all but one input signal at each user which creates the complete MAI estimates for each user is passed on to a second user bank of matched filters to produce a new, hopefully, a better set of data estimates.

This process can be repeated for multiple stages. Each stage takes as its input the data estimates of the previous stage and produces a new set of estimates at its output. We can use a matrix vector formulation to compactly express the soft output of stage m +1 of the PIC detector for all N bits of all K users. As usual, for BPSK, the hard decision, d(m), are made according to the signs of the soft output, d(m). Perfect estimates coupled with our assumption of perfect amplitude and delay estimates, results in complete elimination of MAI.

The SIC detector performs better than the PIC detector in a fading environment, while the reverse is true in a well powered controlled environment. The PIC detector requires more hardware, but the SIC detector faces the problem of power reordering and large delays.

$$\text{d }(m+1)=\text{y -QAd}(m)$$
$$=\text{Ad+QA}\big(d-d(m)\big)+\text{z}$$

The term QAd(m) represents an estimate of the MAI. Various methods for improving PIC detection have been proposed. The recently proposed improved PIC detector may be the most powerful of the subtractive interference cancellation detectors.

This process can be repeated in a multistage structure: the k_{th} stage takes as its input the "partially cleaned" received signal output by its previous stage and outputs one additional data decision and a cleaner received signal $r_{(k)}(t)$.

The reason for canceling the signals in descending order of signal strength is straightforward [10].

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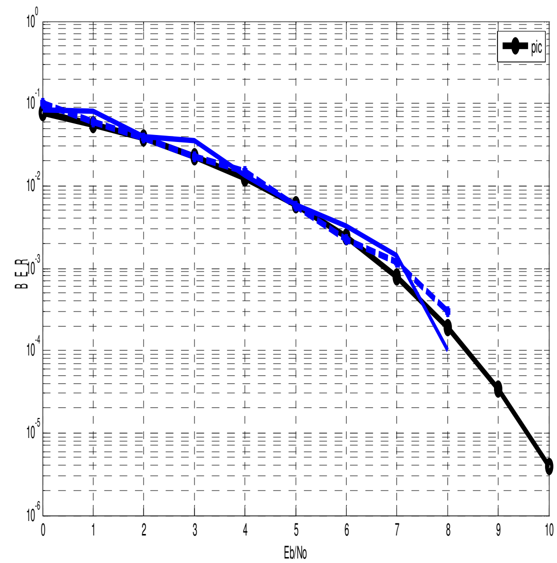

Fig 5 PIC detector

A Comparison of all Detectors discussed above, is shown in Fig 6 below.

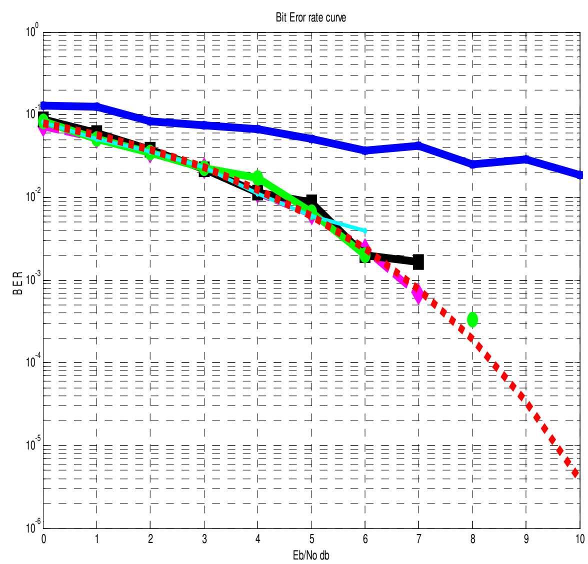

Fig 6 Comparison of all Detectors

6 CONCLUSIONS

The capacity of DS-CDMA Systems is normally limited by the allowable level of Multiple Access Interference (MAI). The MAI problem is more severe in the uplink where the transmissions are originate from the spatially distributed handsets than from the downlink where the transmissions originate from the single point---the base-station.

In the DS-CDMA downlink, the transmitted signal is the sum of all signals intended for all users. Thus for each user, the desired and interfering signals all follow the same propagation path. This research explores the advance detection techniques to mitigate the effect of uplink MAI. These techniques reduce the BER for the individual user in addition to improving the overall capacity of the system. Specifically two classes of Multiuser Detectors were studied. These classes are differentiated as:

- Linear Detectors
- Successive Interference Cancellation Detectors

Both of these have improved the performance of the system compared to the Single User Detector.

Linear MUD attempts to eliminate the local MAI. Linear MUD uses a filter at the base station. The basic principle underlying Successive Interference Cancellation Detectors is the creation at the receiver, of separate estimates of the MAI contributed by each user in order to subtract some or all of the MAI seen by each user.

7 Contributions to Knowledge

The following are the principal contributions of the research

- To implement a Simple Conventional Matched Filter.
- To implement the advanced Multi-User Detector techniques.
- To compare e the results of above mentioned Multi-User Detector techniques with each other and with that of Conventional Matched Filter.

8 Further Directions

This research can be further done in the following directions.

- In this thesis BPSK modulation technique has been used. Such results can be also attained by deploying theses techniques to QPSK, QAM modulation schemes. This is the important area which can be further explored.
- For further task in this area can be done by assuming the Relay fading channel model instead of AWGN channel model, assumed in this thesis.
- This research has been implemented by considering synchronous signals. It can be further extended to Asynchronous signals.

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