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Linear multiuser detection for a DS-CDMA system

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ABSTRACT

DS-Code division multiple access is considered as the third generation of cellular mobile used in interim standard 95(IS-95) [1] and it is currently being standardized for universal mobile telecommunication systems (UMTS). CDMA offers attractive features, such as frequency reuse, soft handoff, increased capacity, and multipath combating. In a CDMA system, several users simultaneously transmit information over a common channel using pre-assigned codes. The conventional single user detector consists of a bank of filters matched to the spreading codes. This detector suffers from two problems. First, multiple access interference (MAI) produced by the other co-channel users is a significant limitation to the capacity of this detector. The second problem is the near-far effect which occurs when the relative received power of interfering signals becomes larger. A potential solution is multi-user detection which exploits the information of signals of interfering users. In the present study performance of various linear detectors like matched filter detector, MMSE detector, and adaptive LMS detector are studied. These are the linear detectors that operate linearly on the received signal statistics and are suboptimal detectors. The matched filter bank is the conventional detector and offers the simplest way of demodulating CDMA signals .The detector resulting from the MMSE (minimum mean square error) criterion shows better performance over the conventional one for low SNR value. Adaptive LMS is employed to enhance the BER performance in MUD application. Several factors motivated the research to apply neural network as multi-user detector.

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ABSTRACT

DS-Code division multiple access is considered as the third generation of cellular mobile used in interim standard 95(IS-95) [1] and it is currently being standardized for universal mobile telecommunication systems (UMTS). CDMA offers attractive features, such as frequency reuse, soft handoff, increased capacity, and multipath combating. In a CDMA system, several users simultaneously transmit information over a common channel using pre-assigned codes. The conventional single user detector consists of a bank of filters matched to the spreading codes. This detector suffers from two problems. First, multiple access interference (MAI) produced by the other co-channel users is a significant limitation to the capacity of this detector. The second problem is the near-far effect which occurs when the relative received power of interfering signals becomes larger. A potential solution is multi-user detection which exploits the information of signals of interfering users. In the present study performance of various linear detectors like matched filter detector, MMSE detector, and adaptive LMS detector are studied. These are the linear detectors that operate linearly on the received signal statistics and are suboptimal detectors. The matched filter bank is the conventional detector and offers the simplest way of demodulating CDMA signals .The detector resulting from the MMSE (minimum mean square error) criterion shows better performance over the conventional one for low SNR value. Adaptive LMS is employed to enhance the BER performance in MUD application. Several factors motivated the research to apply neural network as multi-user detector.

1. INTRODUCTION

Multiuser Detection

This chapter contains a brief explanation of multiuser detection for a DS-CDMA system. Treated are both the asynchronous and synchronous cases. The detector presented in the report is mainly based on the linear Minimum Mean Square Error (MMSE) detector. Multiuser detection concerns the detection of information sent simultaneously by several transmitters sharing a multiple-access channel. A more challenging channel sharing strategy is the CDMA approach, where all users share the same time and frequency band. To distinguish between the different users, a unique waveform (code) is assigned to each user. Therefore, the received signal from all users is a superposition of the individually transmitted signals. As a result, the task of the multiuser detector is to reliably demodulate the information from a specific user. The conventional detector used in single-user systems is the matched filter receiver.

It is well known that this receiver is optimal in the minimum of probability of error sense in demodulation of a single existing user in AWGN environment. In demodulation of a user in CDMA system, the noise components from the different matched filters are not uncorrelated due to the cross-correlation between users. Hence, the colored noise should be taken into consideration in demodulation.

The performance of the conventional detector can be acceptable, when the received signals have the similar energies and the waveforms have low cross-correlation. Basically, the user with high power makes detection of users with low power impossible. This is known as the near-far effect problem. To combat this problem it is required to use accurate power control and design waveforms with as low cross-correlation as possible. However, it is typically not possible to design codes that are orthogonal in the receiver, either because the transmissions from different users are uncoordinated (asynchronous) or that the channel is a multipath channel. As a consequence, in asynchronous and multipath CDMA systems, the conventional receiver will always suffer from the near-far effect, and the performance will be limited by the interference from other users. Multiuser detection is then a good method to cope with the problem of near-far effects and the interference limited performance.

Linear Detector

In general, there exist many optimum detectors for a DS-CDMA system, but they usually require a high computational complexity. For example, the complexity of the maximum likelihood (ML) detector grows exponentially with the number of users. One class of detectors with substantially lower complexity is the linear filter detectors. For these detectors, the complexity increases linearly with the number of users. There are two well known linear detectors, i.e., the decorrelator detector and the MMSE detector. The former will decorrelate the channel making the information of interest orthogonal to the interference. Nevertheless, its major drawback is the noise enhancement due to the inverse filtering. The latter does not completely remove the interference, which for low signal-to-noise ratios results in better performance since the noise is not enhanced in the same way as the decorrelator does. It has been shown that, for very low signal-to-noise ratios the MMSE detector converges to the conventional receiver, and for the high signal-to-noise ratios it converges to the decorrelator. We shall then focus on the MMSE linear multiuser detector

2. **MUD CONCEPTS AND TECHNIQUES:**

A baseband model of a CDMA uplink is shown below. The signal received at the BS is the superposition of signals from all users, multipath components for each user's signal, and Additive White Gaussian Noise (AWGN). The figure also includes channel encoders for each transmitter. There are Nu users in the system and the data signals from these users are designated as d_1 (t), d2 (t),...,d_{Nu}(t). The data symbols within the data signals are spread by multiplying with respective spreading sequences K_1 (t), K_2 (t),... ,K_{Nu}(t). The channel introduces delays $\tau_1,\tau_2,\ldots,\tau_{Nu}$ to signals from different users, and $A_1(t),A_2(t),\ldots,A_{Nu}(t)$ are the fading coefficients for the single resolvable path of each user. Spreading sequences K_1(t), K_2(t),... ,K_{Nu}(t) is given by Where $c_{im}$is the m^{th} chip of the spreading sequence K_i(t).N is the length of spreading sequence. p (t) is the chip pulse shape that is assumed to be rectangular Another BPSK model can be shown below-Baseband signal for the k^{th} user is:

$$u_k(t) = \sum_{i=0}^{\infty} x_k(i)\cdot c_k(i)\cdot s_k(t - iT - \tau_k)$$

$x_k(i)$ is the i^{th} input symbol of the k^{th} user.
$c_k(i)$ is the real, positive channel gain.
$s_k(t)$ is the signature waveform containing the PN sequence.
τ_k is the transmission delay; for synchronous CDMA, τ_k=0 for all users.
Received signal at baseband is given by-

$$y(t) = \sum^{K} u_k(t) + z(t)$$

$k = 1$

Where K number of users $z(t)$ is the complex AWGN Sampled output of the matched filter for the k^th^ user.

$$y_k = \int_0^T y(t) s_k(t) dt$$

$$= c_k x_k + \sum_{j \neq k}^{K} x_j c_j \int_0^T s_k(t) s_j(t) dt + \int_0^T s_k(t) z(t) dt$$

1). 1st term - desired information
2). 2nd term - MAI
3). 3rd term - noise

Let's assume two-user case (K=2), and

$$r = \int_0^T s_1(t) s_2(t) dt$$

Outputs of the matched filters are:

$$y_1 = c_1 x_1 + r c_2 x_2 + z_1$$

$$y_2 = c_2 x_2 + r c_1 x_1 + z_2$$

Detected symbol for user k: $\hat{x}_k = \text{sgn}(y_k)$

If user 1 is much stronger than user 2 (the near/far problem), the MAI term rc_1x_1 present in the signal of user 2 is very large.

MUD Algorithms:

A flowchart depicting the algorithm used for MUD is given below- Our emphasis is on finding a suboptimal method to find a combination having proper complexity and performance. In this work, we mainly deal with Successive Interference Cancellation which is a nonlinear suboptimal method of MUD.

Optimum Multiuser Detection:

The matched filter detector, described above, was believed to be the optimum detector until proved otherwise by Verdu in the early 1980's. His optimum solution jointly maximizes the likelihood functions for K users by choosing the bits {b1, b2, …, bK} that minimizes the mean square error (MSE) between the estimated received signal and the actual composite received signal, which is the sum of the received signals for all K users plus noise. It has been shown that the complexity of the optimum detector is O (2K), which increases exponentially with the number of users. In addition to complexity, the optimum detector requires a priori knowledge of the amplitudes of all K users, which is typically not available to the receiver. Although, the optimum detector has been shown to dramatically increase the capacity of the system, its complexity deems it infeasible to implement in the real world. The work by Verdu gave hope that the capacity can ultimately increase using suboptimal multiuser detectors that balance between the two extreme cases of using the optimal detector or the matched filter detector. Hence, some linear multiuser detectors were proposed to accomplish that goal.

Linear Multiuser Detection:

Linear multiuser detectors attempt to attain as much of the capacity increase as the optimum detector while reducing the complexity of the system such that it can be implemented. They are simply linear filters that attempt to suppress MAI. In these detectors, a linear mapping (transformation) is applied to the soft outputs of the conventional detector to produce a better set of outputs to provide better performance. The two popular linear multiuser detectors are the decorrelating detector [4-6] and the Minimum Mean Square Error (MMSE) detector [7, 8]. They are highly analogous to the zero-forcing and MMSE equalizers used to combat inter-symbol interference (ISI) in a single- user channel [1]. The decorrelating detector attempts to completely eliminate all MAI while the MMSE detector tries to minimize the square of the residual noise plus interference. Therefore, the decorrelating detector is a special case of the MMSE detector, where the noise is zero. The decorrelating detector has the same noise enhancement problem as the zero-forcing equalizer. It is also the decorrelating detector attempts to completely eliminate all MAI while the MMSE undefined when there are more users simultaneously using the channel than spreading chip per information bit, since it is impossible to drive the interference noise to zero in this situation [3].

The MMSE, on the other hand, requires accurate channel and user information, as does the optimum detector. Along with the channel and user knowledge, the MMSE requires a KxK matrix inversion which becomes extremely complex to evaluate as K increases. Figures 1 and 2 below show the performance comparison of the optimum detector and linear MUD to the conventional matched filter. The show the Shanon capacities as a function of the number of users K divided by the spreading factor N and the energy per bit E divided by the noise spectral density N0, respectively. Other multiuser detection techniques include non-linear MUD, such as the Decision-Feedback (DF) multiuser detector and the turbo multiuser detector, and Interference Cancellation (IC) MUD. The next two sections will analyze the two different IC schemes, SIC and PIC, respectively in more detail. Following that will be a performance comparison of the two schemes.

Successive Interference Cancellation:
Sampled output of the matched filter for the k^{th} user:

$$y_k = \int_0^T y(t) s_k(t)\,dt$$

$$= c_k x_k + \sum_{j \neq k}^{K} x_j c_j \int_0^T s_k(t) s_j(t)\,dt + \int_0^T s_k(t)\, z(t)\,dt$$

In this equation to cancel the Multiple Access Interference (MAI), the factors $x_j c_j$ are needed, in addition to the cross-correlations. One of the methods could be estimating xj and cj separately. The other approach would be to estimate the product $x_j c_j$ directly by using the correlator output. The strongest signal has to be cancelled before the detection of other signals because it is most negative. The best estimate of signal strength is from the strongest signal because the best bit decision is made on that signal the strongest signal has the minimum MAI, since the strongest signal is excluded from its own MAI. An alternative called the *Parallel Interference Cancellers* simultaneously subtract off all of the users' signals from all of the others. It works better than SIC when all of the users are received with equal strength (e.g. under power control).

Decision is made for the stronger user
1: $\hat{x}_1 = \text{sgn}(y_1)$.
Subtract the estimate of MAI from the signal of the weaker user:

$$\hat{x}_2 = \text{sign}(y_2 - r c_1 \hat{x}_1) = \text{sign}(c_2 x_2 + r c_1 (x_1 - \hat{x}_1) + z_2)$$

All MAI can be subtracted from user 2 signal provided estimate is correct. MAI is reduced and near/far problem is alleviated.

3. MUD CONCEPTS AND TECHNIQUES:

A baseband model of a CDMA uplink is shown below. The signal received at the BS is the superposition of signals from all users, multipath components for each user's signal, and Additive White Gaussian Noise (AWGN). The figure also includes channel encoders for each transmitter.

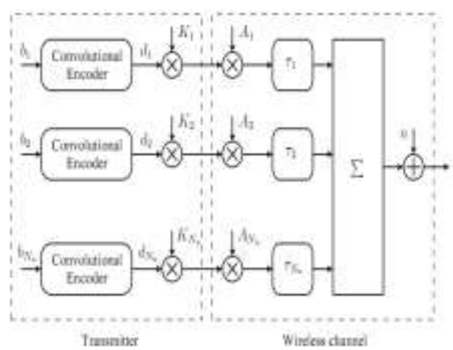

Fig 1.3 CDMA Channel Model (ref. [4])

There are Nu users in the system and the data signals from these users are designated as d1 (t),d2(t),...,dNu(t). The data symbols within the data signals are spread by multiplying with respective spreading sequences K1 (t) K2 (t),... ,KNu(t). The channel introduces delays τ1,τ2,...,τNu to signals from different users, and A1(t),A2(t),...,ANu(t) are the fading coefficients for the single resolvable path of each user. Spreading sequences K1(t), K2(t),... ,KNu(t) is given by

$$K_i(t) = \sum_{m=1}^{N} c_{im} p(t-(m-1)T_c)$$

Where,
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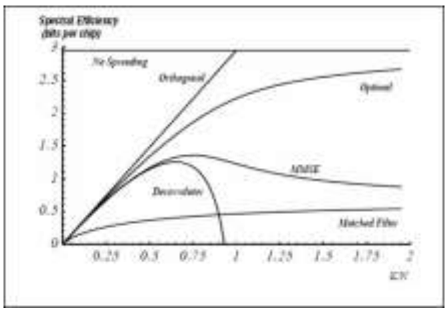

Fig 1 is spectral efficiency vs system loading at

Eb/no=10db [3]

4. CONCLUSION

The inclusion of SIC in a CDMA receiver can significantly improve its performance relative to that of conventional CDMA receiver where no interference cancellation is attempted. SIC appears to be more resistant to fading than PIC, and achieves better result with regards to BER and capacity performance, it suffers mightily from a high processing delay.

FUTURE WORK

While doing practical implementation, problem occurred due to processing delay, sensitivity and robustness. Capacity improvements only on the uplink would only be partly used anyway in determining overall capacity. Cost of doing multiuser detection must be as low as possible so that there is a performance/cost trade off advantage. By using better channel estimation technique the performance of the SIC can be improved further. For delay, one of the way is to limit the number of cancellation also Group wise SIC (GSIC) has proposed to deal with delay it

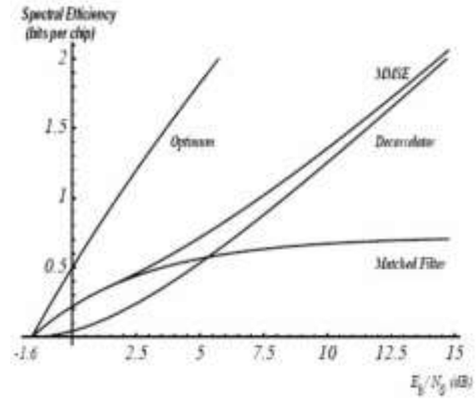

Fig 2. Is large K spectral efficiency with optimum K/N [3]

may degrade the performance. Investigation of GSIC and comparison it to PIC and SIC could be left.

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