An efficient and robust multi-user detection in IDMA system

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Abstract. Multi-user detection (MUD) is a popular method in wireless communication systems to enhance efficiency by together processing the signals received from all users. The complexity of MUD has been a great problem in practical scenario. Wiener (optimum) filter yields best estimate of the input signal from noisy observations. In this paper, using Wiener filtering, a less complex and robust MUD strategy is introduced in a new multiple access scheme called interleave-division multiple-access (IDMA) which supports MUD in a simple way. The proposed IDMA system helps in achieving lower bit error rate and manages multiple number of users easily when compared to other multiple access schemes.

Keywords: Multi-user detection, iterative receiver, Wiener filter, Code Division Multiple Access (CDMA), IDMA.

1. Introduction

CDMA is widely used in recent generations of mobile cellular standards. CDMA has many novel features. In CDMA, channel is shared dynamically. Cross-cell interference is reduced. It offers asynchronous transmission and simple planning of cells. It fights fading to a greater extent. The received signals from different users are overlapped in a CDMA system, since there is a single transmission media for all users. This leads to multiple access interference. In receiver side, it is mandatory to separate the mixed signals. Multi-user detection (MUD) [1] is a suitable healing technique for multiple access interference problem prevailing in CDMA systems. Interleave-division multiple-access (IDMA) [1] [2] incorporates a very simple MUD principle. Interleavers are used as the only means of user separation. IDMA resembles CDMA by having indexed interleaving sequences as multiple access codes. For signal detection, a special filter called Wiener filter [3] is used which retrieves original information vector from an observed vector and thereby the mean square error is minimized. By manipulating the Wiener-Hopf equation, the end of solution is obtained. It gives the best estimate of the original signal. In a multiple access channel (MAC) [1], many users transmit data at the same time and overlapped signals arrive at the destination along with noise. Search done by optimum A Posteriori Probability (APP) detection in MACs is tedious among all the possible transmitted sequences resulting in complexity. This complexity is exponential to the number of users. Detection in receivers is permitted in most of the MAC schemes with affordable complexity. In such schemes, users are separated by performing orthogonal division over a common resource. Implementation of correct channel coding avoids the division of resource. IDMA emerged from CDMA with Forward Error Correction (FEC). A CDMA scheme with FEC system has a concatenated FEC code, a spreading technique(unique for every user) and an interleaver(common to all users).
in IDMA systems different interleaver is used for each user but same spreading technique is applied to all users. In this paper, using Wiener filter, low cost, simple, robust MUD strategy is proposed in an IDMA scheme.

2. Motivation

Multiple access interference and intersymbol interference decreases the efficiency of CDMA systems. The effectiveness of turbo codes in additive white Gaussian noise channels leads to the study of turbo-type multi-user detection which reduces such interference and wonderful progress is obtained.

Coding and spreading techniques are separate in conventional random waveform CDMA system. According to the analysis based on theory, optimum capacity of multiple access channels is possible only when the whole bandwidth enlargement is meant for coding. This gives the idea of merging the coding and spreading techniques using low-rate codes in order to increase the coding gain. This difficulty can be solved by applying unique interleaver for every user. Earlier this principle has been considered and its potential advantages have been explained [1] [2]. The transmission and detection principles using interleavers are discussed in this paper. The scheme (IDMA) is a special form of CDMA where bandwidth enlargement is done only by means of low-rate codes. It can also be treated as a special form of CDMA by having indexed interleaver sequences as multiple access codes.

3. Methodology

The Figure 1 gives the overall methodology employed in the proposed IDMA system. Individual user data is encoded and interleaved. Data of all users are combined and processed in MAC. Individual user data is detected using proper MUD strategy. Finally data are deinterleaved and decoded separately.

![Architecture Diagram](image)

**Figure 1.** Architecture Diagram

4. IDMA Transmitter and Receiver Principles

The structure of transmitter and receiver [1] [2] of an IDMA scheme with K users is shown in figure2. This is called interleave-division multiple-access since the users are separated by the process of interleaving and the chip-level interleavers are unique for all users.
**Transmitter structure:**

The transmitter model of an IDMA scheme is shown in the upper part of Figure 2. By using a low-rate code $C[1]$, the input data of every user is encoded. Then interleaving is done on the coded signal by an interleaver $I[1][2]$. Unique interleavers are used for every user which underlines the key principle of IDMA with an assumption that the interleavers are formed independently and randomly.

**Receiver structure:**

The receiver model of an IDMA scheme is shown in the lower part of Figure 2. A simple estimation method is done on every chip by chip-level interleavers. Elementary Signal Estimator (ESE) $[1][2]$ uses received observation $\{r(j)\}$ and extrinsic data given by decoder. The extrinsic data $\{e_{ESE}(x_k(j))\}$ about $(x_k(j))$ is the output of ESE. The de-interleaved extrinsic data is used as the priori information in the decoder(DEC). The output of decoder is the refined extrinsic data $\{e_{DEC}(x_k(j))\}$ and it is based on constraints of code $C$. The entire process is repeated for certain number of times defined earlier. The decoders yield hard decisions $\{d_k\}$ on information bits $\{d_k\}$ in final iteration. A simple detection algorithm is discussed in $[1][2]$ incorporating MUD concept.

5. **Wiener Filter**

The best estimate of a signal is produced by Wiener filter from a noisy environment $[3]$. The idea of Wiener filtering problem, is to implement a filter which can extract a signal $x(n)$ from noisy environment.

$$ r(n) = x(n) + e(n) $$

Where $e(n)$ is the noise signal. Both $x(n)$ and $e(n)$ are imagined as wide-sense stationary random processes and thus Wiener considered the issue of implementing a filter which will yield the least mean square estimate of $x(n)$. Thus, the problem is to explore the filter that reduces mean square error $\epsilon$.

$$ \epsilon = E\{|e(n)|^2\} = e(n) = x(n) - x^\wedge(n). $$

The implementation of finite impulse response Wiener filter is considered and the event of deriving Wiener-Hopf equations, which tells the coefficients of the best filter, will be the main solution $[3]$. Wiener-Hopf equations are solved for filtering operations.

**Figure 2.** Transmitter and receiver of an IDMA scheme.
Matrix Wiener Filter:
A linear Matrix Wiener Filter (MWF) [4][5] is employed to the observation signal \( r(n) \) and the resulting IDMA scheme[6][7][8] is shown in Figure 3. The MWF computes the estimates of desired signal of K users, by reducing the mean square error. The operations for MUD using Matrix Wiener Filter is listed in the below algorithm.

**Algorithm**
Step 1: Start
Step 2: Following are the input given: Derive Wiener-Hopf equations
\[ R_x W = R_{x,r} \]
Step 3: Compute Wiener Filter coefficient matrix
\[ W = R_x^{-1} R_{x,r} \]
Step 4: Compute minimum mean square error
\[ \epsilon_{\text{min}} = R_s(0) - R_s^{H} W \]
Step 5: Following are the output: Compute estimates of desired signal for K users using \( \epsilon_{\text{min}} \).
Step 6: End

Wiener filtering results in good performance and also reduces computational complexity [9][10][11]. These attributes underline the useful application of the new method in future wireless systems.

Block Conjugate Algorithm (BCG)[12][13][14] is considered as a strong and low rank implementation of MWF. So MUD strategy is also employed with BCG based Wiener filtering. In order to further increase the performance, adaptive filtering is also employed [15][16][17].

6. Results and Discussion

In this paper, a robust IDMA scheme using effective multi-user detection is explained and implemented successfully. The obtained results are elaborately explained here. Table 1 shows the various values obtained for BER versus various values of SNR. Table 2 shows the various values of
BER for various number of users in different MUD strategies. Figure 4 and Figure 5 shows the performance improvement obtained by BCG based Wiener filtering when compared to Wiener and adaptive filtering. The bit error rate obtained by this method is less than 0.001. Figure 6 shows the performance improvement obtained by IDMA employing BCG based Wiener filtering when compared to CDMA. Here the bit error rate is decreased by 0.1. Figure 7 – 9 shows the performance improvement obtained by Wiener and adaptive filtering using convolution and turbo coding schemes employed in IDMA. Here bit error rate is decreased by 0.01. Figure 10 shows the performance improvement obtained by IDMA employing adaptive filtering without iteration when compared to elementary signal estimation. Here bit error rate is decreased by 0.01. Figure 11 shows the efficiency of the IDMA system employing turbo codes over convolution codes. A considerable reduction in performance loss, in computational complexity and also in the overall complexity of receiver structure is obtained by adopting the MUD strategy using BCG based Wiener filtering.

Table 1. SNR v/s BER values of IDMA

| SNR (in dB) | BER  |
|-------------|------|
| 0           | 0.031|
| 2           | 0.0196|
| 4           | 0.0183|
| 6           | 0.0016|
| 8           | 0.0004|
| 10          | 0.0002|

Table 2. Comparison of MUD Schemes

| Type of filtering | Number of users | BER (SNR=2) |
|-------------------|-----------------|-------------|
| Wiener            | 10              | 0.01        |
| Adaptive          | 15              | 0.003       |
| BCG based Wiener  | 20              | 0.001       |

Figure 4. MUD schemes over Rayleigh Fading Channel. Figure 5. MUD schemes over AWGN channel.
Figure 6. CDMA vs IDMA.

Figure 7. Turbo coded MUD schemes.

Figure 8. Convolutionally coded IDMA

Figure 9. Turbo coded IDMA
Figure 10. Comparison of iterative ESE and non-iterative Adaptive Filtering

Figure 11. Comparison of Coding Schemes

7. Conclusion

This paper explains the interesting features of interleaver-based multiple access and the effectiveness of simple MUD technique using Wiener filtering for systems supporting many users. This scheme can be extended to adaptive IDMA system in which the system adapts to different data rates, channel conditions and power levels.

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