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Reduction of Multiple Access Interference in CDMA by using Improved Minimum Mean Square Error Receiver

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Abstract— Code division multiple access (CDMA) is a most promising technique for using channel efficiency. Multiple access interference (MAI) is a limiting factor for the capacity of CDMA system. Proposed design is based on the step by step practical implementation of matched filter (MF) detection and minimum mean squared error (MMSE) detection. Thus, providing flexibility of variations in all parameters of interest which are otherwise difficult to accommodate in a theoretical model. In this paper, matched filter, decorrelating filter and MMSE and other detection techniques have been proposed to alleviate the effects of the MAI.

Index Terms—Code division multiple access, Multiple access interference, multi-user detection, Minimum mean square error, Bit error rate, additive white Gaussian noise. Binary phase shift keying, Signal to noise ratio.

1 Introduction

Direct sequence code division multiple access (DSCDMA) has led to the advancement of technology in wireless communication over the past few years.

In CDMA, users are multiplexed by distinct codes rather than by orthogonal frequency band as in frequency-division multiple access (FDMA), or by orthogonal time slots as in time division multiple access (TDMA) [1]. CDMA allows all users to transmit at the same time. Also, each user is allocated the entire frequency spectrum for transmission; hence, CDMA is also known as spread spectrum communications [2]. However, due to interference of simultaneous occurrence of digital streams of information, multiple access interference (MAI) occurs in multi-access communication systems such as FDMA/TDMA/CDMA. MAI is interference due to information from other users, which if not mitigated can severely degrade the reception quality and hence the capacity of the system.. While the MAI caused by any one user is generally small, as the number of users or their power increases, MAI becomes considerable. Also the performance of system is also limited by presence of the near-far affect [3]. Therefore, analysis of the effect of MAI on the system performance as well as to find measures to reduce MAI has sought the attention of CDMA researchers. Various methods have been proposed to reduce the effects of MAI and near-far interference. In this context, matched filter, decorrelator filter and MMSE and other detection techniques have been proposed to alleviate the effects of the MAI, thereby, increasing the capacity of the CDMA system also, results in bandwidth efficient CDMA signaling. Secondly, the current solution to the near-far problem is the power control. The relative path losses and shadowing effects requires high dynamic range about 80 dB and can control power variations [10].

A potential solution to MAI is multiuser detection (MUD) which exploits the information of signals of interfering users. The joint use of code and timing (or amplitude & phase) information of multiple users for better detection of signal of individual user is known as multiuser detection (MUD). Multiuser detection can suppress MAI and improve performance and capacity effectively. The early researches on multiuser detection assumed that the codes of all users were known at the receiver and simultaneous detection of all users can be done. But it is an unrealistic to assume that a mobile station would know the codes of all the other users in a cell. Therefore multiuser detection needs to know only the code of a desired user. Conventional detectors based on the matched filter treat the MAI as additive white gaussian noise (AWGN). However, unlike AWGN, MAI has a nice correlative structure that is quantified by the cross-correlation matrix of the signature sequences. In addition, the performance of the conventional detector is seriously degraded when the near-far problem of DS-CDMA system is considered.

The rest of our paper proceeds as follows. In section II conventional DS-CDMA detector is described. Section III focuses on the structure and analysis of CDMA. Discussions of results has been done in section IV followed by Conclusions in section V.

2 Conventional DS-CDMA Detector

Now-a-days mobile communication uses a matched filter detection technique for a single user. Although it is easy to implement but when number of users increases, the performance of matched filter severely degrades. The conventional detector [5] consists of a matched filter bank (a series of transversal filters in parallel), with one filter corresponding to each user as shown in fig 1. Each matched filter corresponds to the signature waveforms of different users in the case of CDMA. Also it is worth mentioning that same information of the user's signature sequences and the signal timing is required in order to utilize this detector. Assuming there are K direct–sequence users in an asynchronous single path BPSK real channel.

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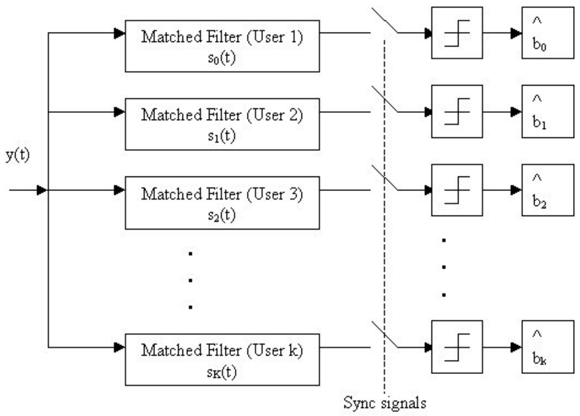

Fig. 1. A matched filter bank [8]

As shown in fig.1, the signal y(t) is the base band signal at the receiver and can be expressed as

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

where
A_k is the received amplitude of k^{th} user.
s_k is the signature waveform of k^{th} user.
b_k is the input bit of the k^{th} user.
$n(t)$ is additive white gaussian noise with two sided power spectral density of $N_0/2$ W/Hz.

Now, the decision statistic at the output of the K^{th} matched filter is given by

$$y_k = \int_0^T y(t)\, s_k(t) dt \qquad (2)$$

Fig.1 shows that each code waveform is regenerated and correlated with the received signal separately in the matched filter detector. Fig.1 also describes that the detector follows a single user strategy, and also each branch detects one user without considering the existence of other users. The matched filter output depends on the properties of the correlations between codes. Thus we require the autocorrelation of the codes to be much larger comparative to the cross-correlation of the different codes. By simplifying the eqn. (1) and (2), we get,

$$y_k = A_k b_k + \sum_{\substack{j=1 \\ j \neq k}}^{K} A_j b_j \rho_{jk} + n_k \qquad (3)$$

The 2^{nd} term in eqn. (3) is the MAI. The matched filter treats the MAI just as a white noise.

There are three approaches to eliminate the MAI from the received signal. At low signal to noise ratios, the matched filter outcome is considerable, i.e. removes interference. Another method is decorrelating detector which has poor performance at low SNRs. So in order to improve the performance by integrating some SNR information in MUD algorithms, one such approach is investigated where the mean squared error between the output and data is minimized. Thus minimum mean square error (MMSE) is a linear detector.

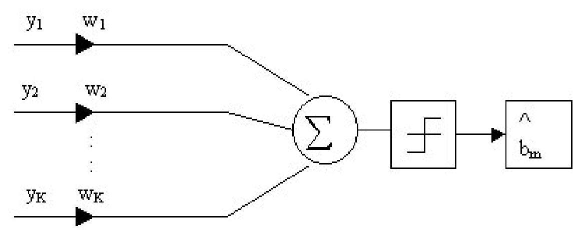

Fig. 2. MMSE linear transformation [12]

As a linear detector like the decorrelating detector, to form the decision statistic MMSE receiver also weights the received statistic y with a weight vector w. The MMSE linear detector determines a waveform c1(t) such that the minimum square error between the transmitted bit and the correlation between c1(t) and the received signal y(t) is minimized. Thus, the objective function is defined as

$$\varphi(w_1, w_2 \ldots . w_k) = E\left\{\left(b_1 - \sum_{i=1}^{K} w_i\, wy_i\right)^2\right\} \qquad (4)$$

where $(w_1, w_2 \ldots . w_k)$ are the weights operating on the received statistic $(y_1, y_2 \ldots . y_k)$. The MMSE filter W_{MMSE} can be implemented in a decentralized form with linear transformation matrix (W is the linear filter through which the output is processed) is given by [7]

$$W_{MMSE} = (R + \sigma_n^2 A^{-2})^{-1} \qquad (5)$$

The term $\sigma_n^2 A^{-2}$ represents inverse SNT for a unit amplitude vector signal, where σ_n^2 is the noise variance. Thus the linear filter for an MMSE multiuser detector is given by

$$\left(R + \frac{1}{SNR}\right)^{-1} \qquad (6)$$

MMSE linear MUD performs better than the matched filter at low and moderate SNR since it accounts for AWGN.

3 MODEL STRUCTURE AND ANALYSIS

For the matched filter, transmitter structure is shown in fig. 3.

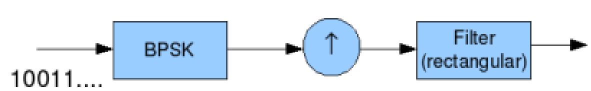

Fig. 3. Transmit block diagram

Firstly, the random binary data is given as input to the BPSK modulator circuit, then the BPSK modulator maps bits to symbols i.e. bit 0 to '-1' and bit 1 to '+1'. After the conversion of bits to their respective symbols, the up sampling block

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inserts zeros between the samples based on the oversampling factor. For example, if the oversampling factor is 4, the up-sampling block inserts 3 zeros between each sample. Now the filtration process starts, where the up sampled sequence is convolved with the filter. We have assumed rectangular i.e. to repeat the current symbol till the next symbol arrival and so on as shown in fig 4..
Mathematically, the filter can be represented as.

$$g(t) = 1, \quad 0 \leq t < T \qquad (7)$$
$$= 0 \quad \text{elsewhere}$$

The transmitted spectrum assume that the symbol duration is T=1µs and impulse response is h(t) = g(T-t). In this g(t) is a rectangular function, thus the matched filter is also rectangular. From eqn. (1), the received signal y(t) is received from the matched filter h(t). As there is noise n(t) in the received signal, the filter with the impulse response maximize the output signal to reduce noise ratio.

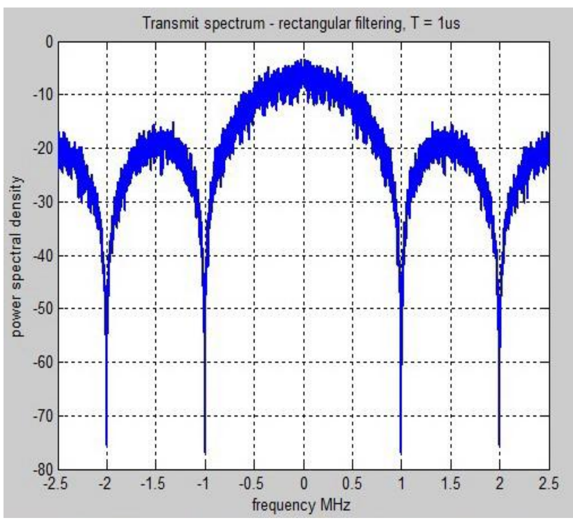

Fig. 4. BPSK signal

4 SIMULATION RESULTS

Matlab software has been used for simulation. Fig 5 represents the bit error rate performance of matched filter while Fig 6 shows the bit error rate performance for MMSE detector. Numbers of bits/symbols are randomly given to the matched filter and MMSE, and also, the value of the energy per bit to noise power spectral density ratio (E_b/N_0) is taken as 1000000 bits and 12 respectively. The comparison of results in fig 5 and 6 clearly reveals that MMSE has better BER performance as compared to matched filter, resulting in more efficient CDMA systems.

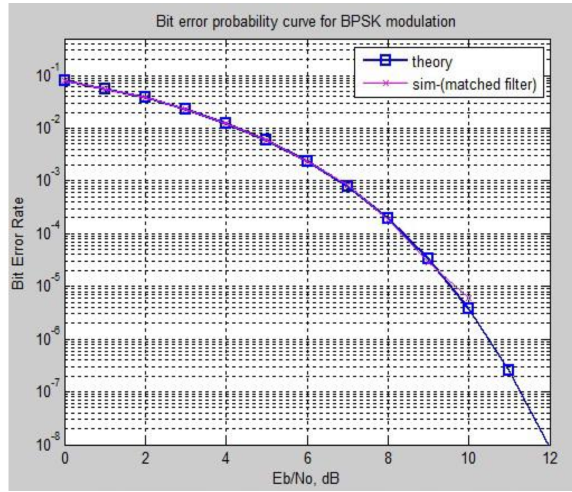

Fig. 5. Bit error rate versus E_b/N_0 of matched filter of 1000000 bits/symbols and E_b/N_0=12

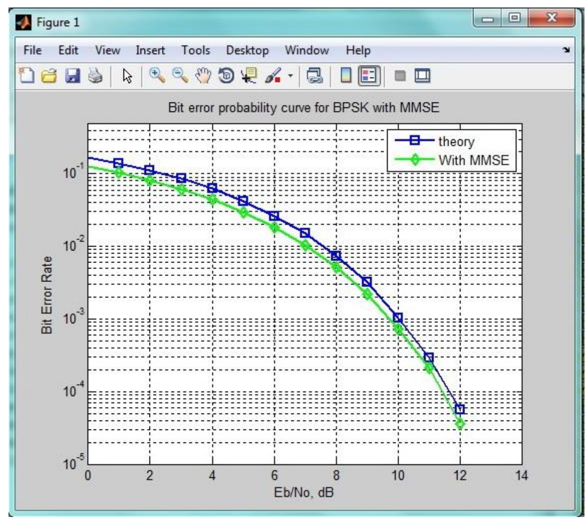

Fig. 6. Bit error rate versus E_b/N_0 of MMSE of 1000000 bits/symbols and E_b/N_0=12

5 CONCLUSION

From results conclusion has been drawn that the performance of the matched filter for less number of bits or symbols is approximately same as the theoretical values, but on increasing the number of the bits or symbols in matched filter, the performance is degraded. On the other side, MMSE detector is superior to the matched filter for any number of bits. Even on increasing the number of symbols in MMSE detector, the bit error rate is still less in comparison to matched filter output. Thus, the experimented research on Improved MMSE has the potential to maintain its BER performance while reducing the complexity.

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