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Performance improvement in detection and estimation of MC-CDMA systems over MIMO channels

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A B S T R A C T

Multiple-input Multiple-output (MIMO) multi-carrier code division multiple access (MC-CDMA) is a strong candidate for the downlink of future mobile communications to obtain high data rates. Nevertheless, during any transmission over fading channel, performance of MC-CDMA systems are highly degraded due to the presence of multiple access interference (MAI). Multi-user detection (MUD) and channel estimation play a major role in overcoming MAI and characterising the channel, respectively. In this paper, space time serial interference cancellation (STSIC) detection using random and Gold codes and turbo aided iterative channel estimation (ICE) techniques are extended for MC-CDMA system MIMO channels to overcome MAI. Simulation results show STSIC outperforms optimal MUD and linear MUD techniques in mitigating MAI and turbo aided ICE surpasses ICE in characterising the channel with reduced error rates.

1. Introduction

The increasing need to transmit at high data rates and to increase the capacity over wireless channels have motivated the development of multi-carrier code division multiple access (MC-CDMA) based multiple-input multiple-output (MIMO) systems for next generation mobile communication. MC-CDMA has emerged as a promising technique for future wireless systems. This owes to the fact that it combines orthogonal frequency division multiplexing (OFDM) and CDMA [1]. MC-CDMA systems additionally employs multiple-input multiple-output (MIMO) techniques to increase the capacity of wireless link significantly by combining the advantages of spatial diversity which enable different users to share the available spectrum [2]. However, capacity of the system is limited by multiple access interference (MAI) from other users. By providing near-far resistance at the receiver and by utilising known user spreading codes, multi-user detection (MUD) techniques emerged to overcome the inherent shortcomings of MAI [3].

Optimal MUD has exponential computational complexity and is therefore impractical [4]. Several low complexity MUD such as decorrelator, minimum mean square error (MMSE) successive interference cancellation (SIC) and parallel interference cancellation (PIC) [5,6] have been proposed. The decorrelator detector eliminates the correlation between different users by restoring their orthogonality and by doing so they might amplify noise [5]. Noise amplification was constrained in MMSE MUD by utilising Wiener filter criterion [7]. SIC is more popular [8] as it has strong error-correcting codes and can achieve impressive spectral efficiency under ideal conditions. SIC based MMSE detection technique for MC-CDMA with frequency domain equalisation proposed in Ref. [9] reduces interference among users by restoring orthogonality among spreading sequences. Binary genetic algorithm based MUD for MC-CDMA system was proposed [10] with less computational

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complexity. Particle swarm optimisation MUD for MC-CDMA system was put forward in [11] outperforms genetic algorithm based MUD with same computational complexity.

Adopting the advantages of SIC space time serial interference cancellation (STSIC) based MUD for MIMO MC-CDMA system is proposed to reduce MAI. STSIC receiver exploits receiver diversity by combining the received signals from each antenna using maximum ratio combining (MRC) technique and SIC. Moreover, analysis is also performed over spreading codes, with the usage of random codes and Gold codes of different lengths.

For the estimation case, the system requires channel state information (CSI) at the receiver. Hence, pilot symbols are often periodically inserted into the transmitted signal to support channel estimation (CE). Initially, CE is performed using least-squares algorithm on pilots only; and is interpolated with localised estimates (LE) on time frequency grid, exploiting the correlations of time and frequency selective radio channel. In case of pilot aided channel estimation (PACE), interpolation is achieved by cascading two one-dimensional finite-impulse response filters whose coefficients are based on MMSE criterion [12]. To improve PACE further, previously decided data symbols are used as reference in iterative channel estimation (ICE) [13]. PACE using overlap frequency domain equalisation [14] is proposed without insertion of guard interval. *Maximum aposteriori* CE based on expectation maximisation method was introduced in Ref. [15] to improve its performance. ICE algorithm for OFDM is designed to feedback the information from output of the channel decoder to estimation stage to reduce decision feedback errors. Since CE gets additional information from the estimated data symbols, ICE achieves a further reduction of bit error rate (BER). ICE is utilised in MIMO MC-CDMA system [16] to obtain better performance. They employ orthogonal STBCs built with the aid of Walsh–Hadamard (W–H) spreading codes at the transmitter [17].

Turbo coding seeks widespread applications over wireless communication for its impressive coding gain and has the capability to work in harmony with MC-CDMA system. A low complexity non-linear matched filter utilising turbo processing [18] is proposed for MC-CDMA for CE. Furthermore, in this paper turbo aided ICE is proposed to improve the estimation of MC-CDMA system by reducing their error rates.

2. Detection for multi-user MIMO MC-CDMA system

2.1. MUD in MC-CDMA

MUD process in MC-CDMA systems can be classified into three as optimal MUD, linear MUD and non-linear MUD. The optimal MUD simultaneously detects all users' data to jointly minimise the effects of MAI. The optimal MUD is the maximum likelihood (ML) receiver that yields the optimal estimate of the transmitted data $\hat{b}$ and is given by

$$\hat{b}_{opt} = \arg\max\{Q(\hat{b})\} = 2\mathrm{Re}\left\{\left((\hat{b})^H(\widehat{C})^H r\right) - (\hat{b})^H(\widehat{C})^H\widehat{C}\hat{b}\right\} \tag{1}$$

where

argmax{.} is the argument maximising the expression,
$Q(\hat{b})$ is the data to be maximised,
$(.)^H$ is the Hermitian transposition,
Re {.} is the real part of a complex number,
r is the matched filter output vector,
$\widehat{C}$ is the channel adjusted spreading matrix.

First term of Eq. (1) is the received signal vector which is pre multiplied by $\widehat{C}$ and their product is the output of MRC. The MRC outputs represent sufficient statistics to perform ML detection as it provides the optimal estimation of the transmitted data symbol if a single user is considered. MRC receivers provide optimal performance for single user and are often implemented in systems with multiple users. Nevertheless, MRC receiver does not jointly minimise the affects of MAI from other users, it is suboptimal and considered as a single user receiver.

Linear MUD multiplies the received matched filter output channel adjusted spreading matrix and exhibits the same degree of near-far resistance as the ML-MUD. At low SNR, noise magnification degrades the BER performance significantly as decorrelator might amplify the noise. MMSE MUD is also a linear detector where the transmitted signal is estimated via linear transformation of the receiver observations. However, it differs from decorrelator detector as it exploits the receiver's knowledge about the SNR. The MMSE MUD is given by

$$\hat{b}_{\mathrm{MMSE}} = M^i\hat{r} \tag{2}$$

where

$M^i = (\widehat{C})^H[\widehat{C}(\widehat{C})^H + \sigma^2 I]^{-1}$ and σ^2 is the noise variance and I is the identity matrix,
$\hat{r}$ is the received signal vector denoted by $(\widehat{C}\hat{b} + \hat{n})$ and $\hat{n}$ is the noise vector.