# Multiuser Detector with Transmit Diversity in the Convolutionally Coded DS/CDMA Systems

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**Abstract** - Transmit diversity can significantly improve system performance by providing diversity gain against Rayleigh fading channels for downlink CDMA systems. In this paper, a delay transmit diversity scheme combined with multiuser detection is proposed for the convolutionally coded CDMA systems. The performance of the proposed detector is evaluated and compared with the uncoded system and the conventional coded system without multiuser detection. The simulation results show that the significant improvement can be achieved in the system performance.[1]

## I. Introduction

The performance of the code division multiple access (CDMA) system with one antenna for transmitting and receiving is rather poor in flat fading channels. By deploying multiple transmit and receive antennas, the antenna diversity can be utilized to improve the system performance, especially for the application of the rapid data flow. Because of the strict complexity requirements of terminals and the characteristics of the downlink channel, multiple receive antennas is not a desired solution to improve the downlink capacity. Alternative solutions have been proposed that the transmit diversity (TD) at the base station with multiple transmit antennas will increase downlink capacity with only minor increase in the terminal implementations. In fact, it can be shown that multiple transmit antennas can provide more diversity gains than same number of receive antennas. A number of TD schemes have been published in [1]-[5].

A method of using convolutional codes with a multi-antenna transmission scheme for CDMA systems is proposed in [6]. The better system performance can be achieved comparing to the uncoded delay diversity approach [2] when the fading is not very slow and the interleaving depth is large. But the multiple access interference (MAI) degrade the system performance both in uplink and downlink. In this paper, transmit diversity with multiuser detection (MUD) is proposed to combat against MAI. The encoded bits are distributed to the multiple transmit antennas. The multiuser detection will be utilized to matigate the MAI effects.

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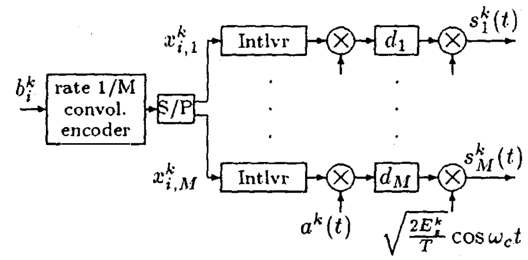


Fig. 1. The transmitter with multi-antenna for the $k$th user

The rest of the paper is organized as follows: Section II presents the system model of transmit and receive antennas and the cyclostationary minimized output energy (CMOE) MUD approach. The performance analysis of the proposed detector is expressed in Section III. The system performance of the proposed concept is evaluated and compared to competing proposals in Secion III. Finally, the conclusions are given in Section IV.

## II. System Model

Without loss of generality, we consider downlink performance of a DS/CDMA system consisting of $K$ users transmitting synchronously over frequency nonselective Rayleigh fading channels. The binary data $b_i^k$ of duration $T$ enters a rate $1/M$ convolutional encoder at the $i$th data bit interval, and produces $M$ coded bits $\{x_{i,1}^k, \cdots, x_{i,M}^k\}$ in the transmitter of the $k$th user. The receiver demodulates a received signal coherently (with or without MUD) and decodes by Viterbi-Algorithm with perfect channel state information (CSI).

### A. Transmitter Model

The transmitter of the $k$th user is shown in Fig.1. Each transmitter is assumed to have $M$ antennas. Each of the $M$ coded bits at some data bit interval is assigned to different antenna respectively. Define the $k$th user's coded information signal at the $m$th antenna as

$$x_m^k(t) = \sum_{i=-\infty}^{\infty} x_{i,m}^k P_T(t - iT), \qquad (1)$$

where $P_T$ is a rectangular pulse of duration $T$. The spreading signature of the $k$th user is defined as

$$a^k(t) = \sum_{j=-\infty}^{\infty} a_j^k \psi(t - jT_c), \qquad (2)$$

where $a_j^k$ is the $j$th chip ($\pm 1$) of the $k$th user's spreading code and $\psi(\cdot)$ is the chip waveform. In this paper, we assume that $\psi(\cdot)$ is a rectangular pulse of duration $T_c$, and that each spreading sequence has a period of $N = T/T_c$ which just spans one coded bit. After the spreading procedure, time delay $d_m$ is intentionally introduced at the $m$th antenna for all users before transmission. We assume that $d_m/T_c$ is an integer and , without loss of generality, define $d_1 = 0$, and $d_1 < d_2 < \cdots < d_M < T$. The resulting transmitted signal of $k$th user from $m$th antenna is given by

$$s_m^k(t) = \sqrt{\frac{2E_S^k}{T}} x_m^k(t - d_m) a^k(t - d_m) cos\omega_c t, \quad (3)$$

where $\omega_c$ is the carrier frequency and $E_s^k$ is the energy of a coded bit defined as

$$E_s^k = \int_0^T [s_m^k(t)]^2 dt. \qquad (4)$$

Then, the energy of a data bit is given by $E_b^k = ME_s^k$. The transmitted signal of the $m$th antenna is

$$s_m(t) = \sum_{k=1}^{K} s_m^k(t) \qquad (5)$$

### B. Channel Model

In this paper, we assume a frequency-nonselective Rayleigh fading channel. The lowpass equivalent impulse response of the channel for the link between the $m$th antenna of the base station to the antenna of the $k$th user's receiver can be modeled as

$$h_m^k(t) = \beta_m^k(t)\delta(t)e^{j\theta_m^k} \qquad (6)$$

where $\delta(\cdot)$ is the Kronecker delta, $\theta_m^k$ is a phase-shift, and $\beta_m^k(t)$ is a path gain due to Rayleigh fading. For simplicity, a path gain is normalized to satisfy $E[|\beta_m^k(t)|^2] = 1, \forall m$. $\theta_m^k$ is an independent random variable uniformly distributed over the interval $[0, 2\pi)$. In addition to fading, the signal is corrupted by additive white Gaussian noise (AWGN) with two sided power spectral density of $N_0/2$.

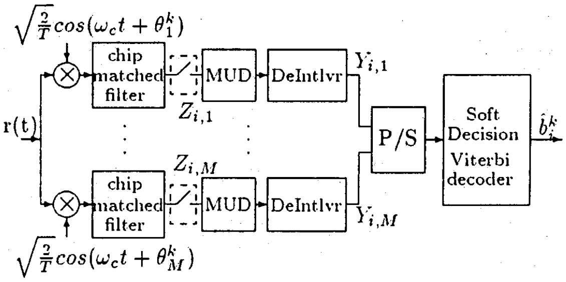


Fig. 2. The receiver for the $k$th user

### C. Receiver Model

Fig.2 shows the structure of the receiver. The main difference between the proposed receiver and the structure as refered in [6] is that a MUD is utilized to combat MAI. In the assumed downlink system, the signals for all users arrive at each terminal synchronously in single-path. The continuous-time received signal of the $n$th user is given by

$$\begin{aligned} r_n(t) = \sum_{k=1}^{K} \sqrt{\frac{2E_s^k}{T}} \sum_{m=1}^{M} \beta_m^n(t) x_m^k(t - d_m) \\ a^k(t - d_m) cos(\omega_c t + \theta_m^n) + n(t), \end{aligned} \qquad (7)$$

where $n(t)$ is the Gaussian noise component.
It is assumed that user 1 is the desired user and the signal $s_m^1$ will be demodulated. Without loss of generality, a perfect synchronization is assumed. Then the outputs of the chip matched filter sampling at chip rate can be given by

$$Z_{i,m} = \sqrt{E_s^1}\{\beta_{i,m}^1 x_{i,m}^1 A_1 + S_{i,m} + I_{i,m}\} + N_{i,m}, \quad (8)$$

where $Z_{i,m}, A_1, S_{i,m}, I_{i,m}, N_{i,m}$ are all $N \times 1$ vectors. $Z_{i,m}$ is samples of chip matched filter output, $A_1$ is the user's normalized spreading code, i.e. $|A_1|^2 = 1$, $S_{i,m}$ is the user's self interference from other transmit antennas, $I_{i,m}$ is other users' interference, $N_{i,m}$ is the additive noise.
The conventional receiver which correlates $Z_{i,m}$ with $A_1$ has not utilized the cyclostationary property of the spread sequence. In this paper, the MUD algorithm constrained minimum output energy (CMOE) [7] which can exploite this property is used. This MUD algorithm chooses $W_{1,m}$ to minimize the output energy (MOE) $\min E\{|W_{1,m}^H Z_{i,m}|^2\}$ while satisfying $W_{1,m}^H A_1 = 1$.

The solution of $W_{1,m}$ is

$$W_{1,m} = \frac{R_{Z_m}^{-1} A_1}{A_1^H R_{Z_m}^{-1} A_1} \tag{9}$$

$R_{Z_m}$ is the correlation matrix of $Z_{i,m}$. Simulations show that a block processing based on direct matrix inversion (DMI) is preferred; the block length should be chosen to tradeoff between BER performance, time delay, and the changing rate of the number of active users. In simulations, we assumed that we averaged the correlation matrix $R_{Z_m}$ from sufficient data samples. At the same time, $R_{Z_m}^{-1}$ can also be calculated on-line with matrix inversion lemma. Other processing techniques are the same as in [6].

### D. Performance Analysis

Because MUD algorithm can amplify the variance of noise and suppress interference, different $W_{k,m}$ will be created in CMOE MUD due to the different delays introduced at each transmit antenna. Then, the sum of noise and MAI will be affected variedly. As the CSI is known, the variance can be estimated by statistics of detected data. In the system without too many interfering users (i.e., if the whole spanned space of the correlation matrix can be divided into two subspaces as signal subspace and noise subspace), the noise variance is $|W_{1,m}|^2 N_0/2$. Otherwise, enough data samples are needed to estimate the noise and interference variance. Fortunately, Viterbi algorithm is robust enough to endure some degree of mismatch in channel estimation; in our simulations, we did not estimate the noise variance of each signal stream from different transmitting antennas. For convenience of analysis, the values of the variance of interference and noise are assumed to be the same for the signal stream from each antenna.

With the same derivation steps refered in [6], the approximate bit error rate (BER) performance is

$$P_b \cong \sum_{\tilde{x} \neq x} w(x, \tilde{x}) P(x \rightarrow \tilde{x}), \tag{10}$$

where $x$ is the transmitted sequence, $\tilde{x}$ is a possible coded bit sequence other than $x$, $w(x, \tilde{x})$ is the number of bit errors associated with each error event as $\tilde{x}$ is the decoder result, the summation is taken over the set of dominant(or most probable) error events. $P(x \rightarrow \tilde{x})$ is a pairwise error probability. In very slow fading channel,

$$P(x \rightarrow \tilde{x}) = \frac{1}{2} \sum_{m=1}^{M} \pi_m \left[ 1 - \sqrt{\frac{H_m \gamma_s}{1 + H_m \gamma_s}} \right], \tag{11}$$

where $H_m$ represents the Hamming Distance in the $m$th antenna,

$$\gamma_s = \left( \frac{E_m\{|W_{1,m}|^2\} N_0}{E_s} + 2\sigma_Z^2 \right)^{-1} \tag{12}$$

where $\sigma_Z^2$ is the remanent variance of MAI which can be reduced significantly by MUD algorithm,

$$\pi_m = \prod_{\substack{i=1 \\ i \neq m}}^{M} \frac{H_m}{H_m - H_i}. \tag{13}$$

In memoryless fading channel(fully interleaved channel),

$$P(x \rightarrow \tilde{x}) = \left[ \frac{1}{2} \left( 1 - \sqrt{\frac{\gamma_s}{1 + \gamma_s}} \right) \right]^H \sum_{k=0}^{H-1} \binom{H-1-k}{k} \left[ \frac{1}{2} \left( 1 + \sqrt{\frac{\gamma_s}{1 + \gamma_s}} \right) \right]^k, \tag{14}$$

where $H$ represents the Hamming Distance between $x$ and $\tilde{x}$. In case of good code which can achieve the diversity advantage of $M$ as the number of transmit antenna, $H_m$ can be decided by the transfer function $T(D_1, \cdots, D_M, N)$.

## III. Numerical Results

In this section, the BER performance of the proposed method is evaluated and compared with the competing proposals. The downlink CDMA system with doppler frequency as 100Hz and symbol rate as 9600 b/s is assumed. In the transmit antennas, same block interleaver depth [10x10] is used for all the users. 63-bit Gold sequences are used as spreading codes for each user. The convolutional code with 8-state maximum free distance [8] is used in simulations. The code frame size is set as 200 data bits (including tailing bits). It was assumed that M=2 widely spaced diversity antennas are located at the base station. This number has been chosen since dual diversity provides a large proportion of the gain available from diversity techniques. Using two antennas also minimizes the complexity increase required and matches the space diversity configuration typically used on the uplink. When serious MAI exists, the increase of the number of transmit antennas will not always result in corresponding improvements of BER performance. In simulations, two transmit antennas are used at the base station and one receive antenna at the terminal.

In the simulations, the convolutional coded DS/CDMA method is also compared with the uncoded delay diversity scheme [2]. In the simulations for the uncoded delay diversity method, the same MUD algorithm is used for signals from different transmit antennas. The differential time delay in simulation is set as 1 chip duration.

The simulated BER performances are shown in Fig.3-5 for the system with 5, 35 and 45 co-channel users.

From the simulation results, it can be noticed that the performance of the proposed detector is much better than the coded delay diversity without MUD. The performance improvement of the coded delay diversity method without MUD over the uncoded delay diversity method gradually decreases to zero (or even less). Then the coded delay diversity method with MUD degrades slower than coded delay diversity method without MUD. MUD combined with delay diversity methods can improve the performance significantly.

## IV. Conclusion

In this paper, multiuser detection is jointly utilized with the convolutional coded delay transmit diversity in downlink systems. By using multiuser detection, the multiple access interference can be effecitively mitigated. The significante improvement of system performance can be achieved, especially for heavily-loaded systems. The proposed algorithm can be straightforward applied to the other TD approaches such as the space time transmit diversity (STTD)[1], etc.

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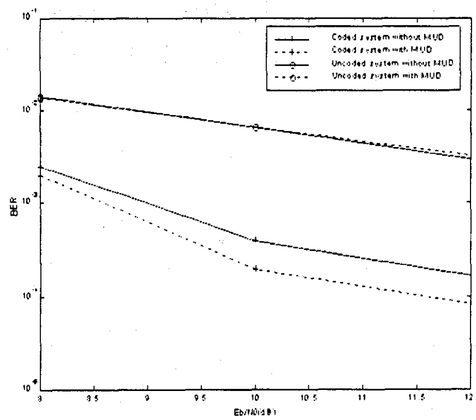


Fig. 3. BER performance of 5 users

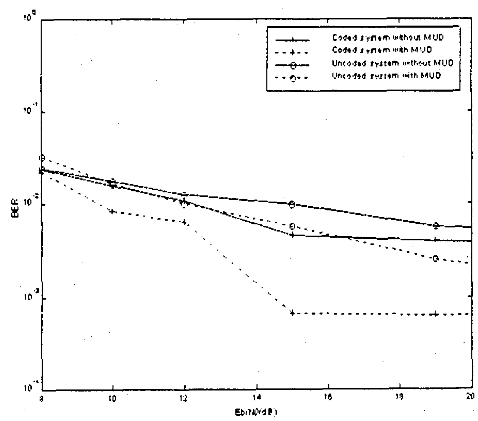


Fig. 4. BER performance of 35 users

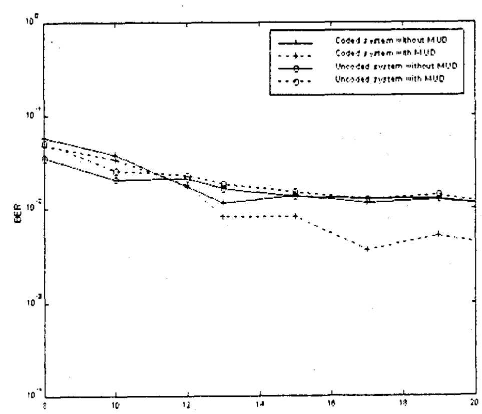


Fig. 5. BER performance of 45 users