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Study of Multiuser Detection for CDMA Systems Using Decorrelating Detector Method

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Abstract: MIMO is a technique to increase data rate significantly with multiple antennas at both the transmitter and receiver. MIMO takes the advantage of random fading and multipath delay spread. MIMO systems will need to function reliably in interference limited environment in order to be effective. CDMA systems are designed to operate in an interference free environment and for this reason it is used in modern cellular systems. The combination of MIMO and CDMA can further improve the system transmission rate over the traditional CDMA system. Multiuser MIMO CDMA systems are considered where each user has multiple transmit antennas, different transmit antennas of the same user use the same spreading code. Decorrelating detector method is used to detect the signals with Gaussian Noise. In many wireless systems the ambient noise is known through experimental measurements to be decidedly non-Gaussian due to largely impulsive phenomena. The performance of many multiuser detectors can degrade substantially in the presence of such impulsive ambient noise. For combating Multi Access Interference and impulsive noise in CDMA communication systems, a technique based on m-estimation is used. Performance comparison shows that m-estimation has better performance under non-Gaussian noise than the other detection techniques.

I. INTRODUCTION

The developing wireless services require higher data rates from future cellular wireless communication systems. However, new radio frequency bands are very scarce if available at all. CDMA is a promising technique for beyond 3G wireless systems. The main technical and theoretical challenges in future wireless system concepts creation are:

1) Bandwidth efficiency challenge (2–10 b/s/Hz)
2) Frequency selectivity challenge due to the large bandwidth (□□100 MHz)

The bandwidth efficiency challenge requires novel solutions in both the network and physical layers. The latter could include powerful coding and modulation methods, transmission adaptation techniques, and antenna configurations. Multiple-input multiple-output (MIMO) communications based on multiple transmit and receive antennae is a very promising technique to increase bandwidth efficiency, and is seen as a potential key solution for fading channels with rich enough scattering. The frequency selectivity challenge means that the multipath delay spread of the channel is very large due to the large bandwidth, causing very severe intersymbol interference (ISI).

This paper is organized as follows: The system model is described in Section II. In Section III gives the results. The conclusion is given in Section VI.

II. RELATED WORKS

Multiple-input and multiple-output (MIMO) is a technique to increase data rate significantly with multiple antennas at both the transmitter and receiver [11]. In MIMO systems, there are many spatial coding schemes including space time codes with spatial code rate less than or equal to 1 [17] and spatial multiplexing with spatial code rate > 1 [15], [19]. By combining MIMO and CDMA, the resulting MIMO CDMA system [4], [5] can further improve the system transmission rate over the traditional CDMA system. In the MIMO CDMA systems considered in the literature, there are two different approaches to assign spreading codes. The one is multiple spreading code approach, in which different antennas are assigned to different spreading codes such as [1], [3], [10]. Since the data streams of different antennas are distinguishable by different spreading codes, the inter antenna interference (IAI) is greatly reduced. The other is single spreading code approach, in which different antennas are assigned to the same spreading code [4]. In this case, the error rate performance is dictated by IAI [9]. Deng et al. [6] propose a detection method with single spreading code approach in the V-BLAST coded DS-

CDMA system. This scheme uses a redundant bit (spatial code rate = the number of transmit antenna for one user/2) in order to identify the transmit antenna. This coding scheme results in data rate loss. The performance of non Gaussian noise is improved using differential detection and L-D (Limiter Discriminator) detection. L-D detector outperforms differential detection. The signal detectors designed for Gaussian statistics may suffer significant degradation when the actual statistics deviate from the Gaussian model [21]. Both man-made noise and low frequency atmospheric interference environments are basically impulsive noise. That is they have a highly structured form, characterized by significant probabilities of large interference level. Under such environment the performance of the receiver systems, designed to perform optimally in Gaussian noise, degrades significantly. For this a non linear decorrelating detector is used to improve the performance of the system.

III. System Definition

K-user uplink CDMA system is considered. Each user (mobile station) has N_t transmit antennas and the base station has N_r receive antennas. For simplicity, PAM modulation is used. The extension to higher-order modulation formats is straightforward but at the cost of higher complexity (larger D_2 in (3)).

A. Transmitter

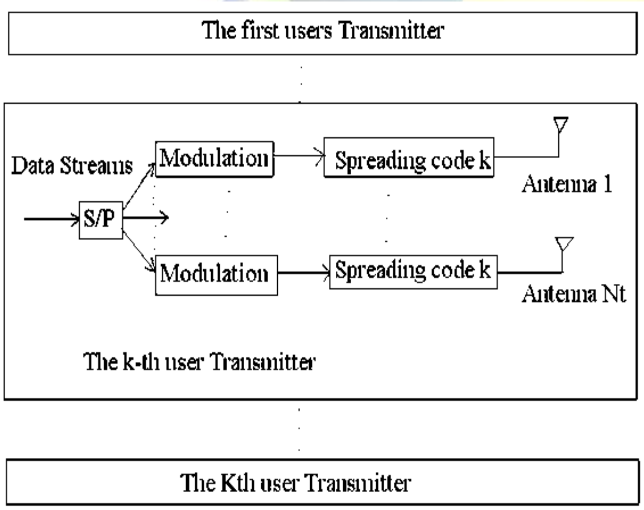

Figure 1: Structure of Transmitter

At the transmitter, data streams are passed through serialto- parallel converter, modulation, and spreading. The structure of the transmitter is depicted in Fig. 1. At the *m*-th symbol interval [$(m-1)T, mT$], the data symbol $d^{(m)}_{k,i}$ is transmitted through the *i*-th transmit antenna of the *k*-th user, $i = 1, \ldots, N_t$, $k = 1, \ldots, K$, where N_t denotes the number of the transmit antenna. T denotes the symbol interval and m denotes the symbol index, $m = 1, 2, \ldots, M$, where M is the number of symbols in one data frame. Then, the data symbol is spread by the aperiodic spreading sequence (periodic spreading sequence is its special case) shown in equation (1). (see Next Page). Result is shown for both m-sequence and orthogonal codes. N is the processing gain, $c_{(m-1)N+n,k}$, $n = 0, \ldots, N-1$, is the spreading sequence for the user k, and $\psi(t)$ is the normalized chip waveform with duration [0, T_c]. The spreading sequence $s_k(t)$ is independent of the transmit antenna index i, because we use the same spreading sequence in all transmit antennas of one user. In (1), the scalar $1/\sqrt{N}$ makes each user's transmitted power be independent of the number of the transmit antenna (N_t). The equation of signal transmission for the *k*-th user's *i*-th transmit antenna is given by

$$x_{k,i}(t) = \sum_{m=1}^{m} d_{k,i}(m) s_k(t-(m-1)T), \quad i = 1,2,\ldots.N_t \qquad (2)$$

B. Multipath fading Channel

The channel coefficients [7] can be calculated according to the formula

$$c(k) = -a_1 c(k-1) - a_2 c(k-2) + w(k)$$
$$a_1 = -2 r_d \cos(2\pi f_p T)$$
$$a_2 = r_d^2$$
$$f_p = f_d \sqrt{2}$$

Where w(k) – complex zero mean white Gaussian process, a_1, a_2 – Physical Parameter, f_p- spectral peak frequency, r_d -pole radius.

Let L denote the number of multiple paths. $\tau^{(m)}_{k,j,l}$ denotes the *l*-th multipath delay from the *k*-th user's transmit antennas to the *j*-th receive antenna at the *m*-th symbol interval. $h^{(m)}_{k,i,j,l}$ denotes the *l*-th multipath channel coefficient from the *k*-th user's *i*-th transmit antenna to the *j*-th receive antenna at the *m*-th symbol interval. These L multipaths from one transmit antenna to one receive antenna are correlated. The channel is a time-varying correlated multipath fading channel with normalized Doppler frequency fd

$$f_d = \frac{V_{\max} f_c}{c} \qquad (3)$$

where Vmax, fc, and c denote maximum velocity of the

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mobile unit, radio carrier frequency, and speed of light, respectively. The channel coefficients are

$$h_{k,i,j}^{(m)} = [h_{k,i,j,1}^{(m)} \ldots\ldots h_{k,i,j,L}^{(m)}]$$

C. Noise Function

Noise is added to the faded signal in the channel. Error rate is calculated for various SNR values. Real time noise contains manmade noise and some low frequency atmospheric interference. They follow non Gaussian distribution. Non Gaussian noise is designed using the following formula [2], [12], [21]

$$f = (1-\xi)N(0,\nu^2) + \xi N(0,k\nu^2)$$

With $\nu > 0, 0 \le \xi \le 1, k \ge 1$. The $N(0,\nu^2)$ term represents the nominal background noise, and the $N(0,k\nu^2)$ term represents an impulsive component, with ξ representing the probability that impulses occur. The total noise variance is given by

$$\sigma^2 \underline{\underline{\Delta}} (1-\xi)\nu^2 + \xi k\nu^2$$

D. Receiver

The received signal includes all of the transmitted signals multiplied by an *L*-path Rayleigh fading process from all transmit antennas and the noise in the receive antennas. Thus, the received signal at the *j*-th receive antenna has the lowpass equivalent representation given by (4). At the *m*-th symbol interval, *k*-th user matched filter output is sampled at $t = mT + \tau_{k,i,l}^{(m)}, l = 1,2,\ldots\ldots,L$ (*L* multiple paths) to form the statistics.

$$s_k(t-(m-1)T) = \sum_{n=0}^{N-1} \frac{1}{\sqrt{N_t N}} c_{(m-1)N+n,k}\, \psi(t-(m-1)T-nT_c) \quad (1)$$

$$r_j(t) = \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{i=1}^{Nt}\sum_{l=1}^{L} d_{k,j}^{(m)} s_k(t-(m-1)T-\tau_{k,j,l}^{(m)})\, h_{k,i,j,l}^{(m)} + n_j(t) \quad (4)$$

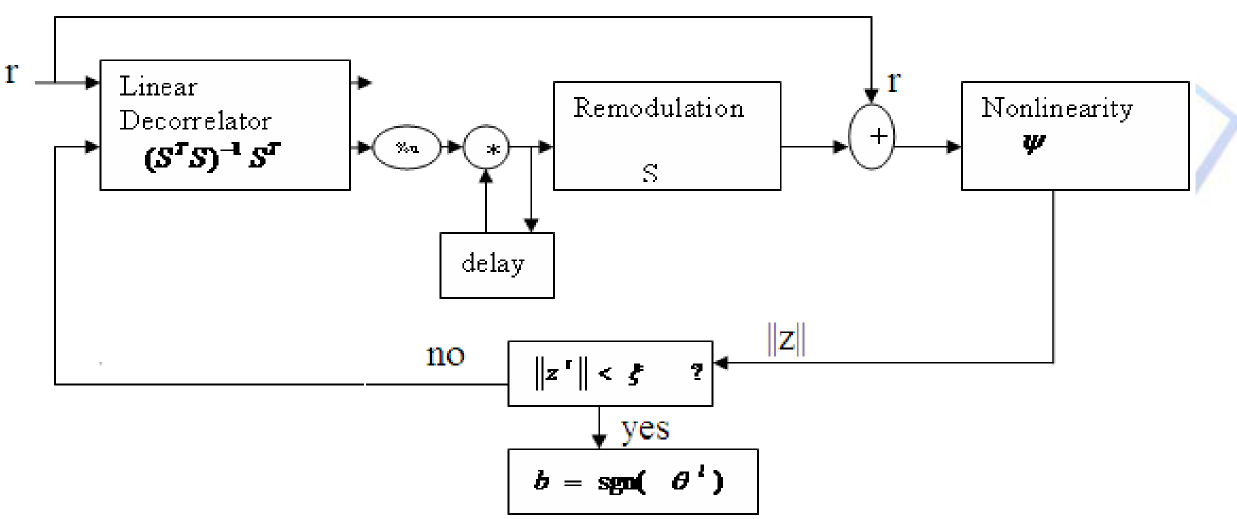

Fig.2. Block Diagram of m-estimation Method

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Decorrelating detection method is used to detect the signals.

i. Decorrelating Detector

The received signal is despread with the PN sequence, and then multiplied with the covariance matrix R^{-1}. They are given by the following equations.

$$rec = r * S;$$
$$R = S * S^T$$
$$op = rec * inv(S * S^T)$$

where S denotes the spread sequence of all the users

ii. M-Estimation Method

Performance of the system under non-Gaussian noise is poor compared to that of the Gaussian noise. M-estimation method is used to improve the performance of the system. Linear detectors do not perform well under non-Gaussian noise. Non-linear detectors (Huber Estimator) are used under such cases, even though they are complex to design. (Fig. 3.See Previous page)

$$z^l = \psi(r - S^T \theta^l)$$
$$\theta^{l+1} = \theta^l + \frac{1}{\mu}(S^T S)^{-1} S^T z^l$$
$$\psi(x) = \begin{cases} \dfrac{x}{\sigma^2}, & for\ |x| \le k\sigma^2 \\ k\,\mathrm{sgn}(x), & for\ |x| > k\sigma^2 \end{cases}$$

Where $\theta = (S^T S)^{-1} S^T r$

$$\theta = R^{-1} S^T r$$
$$k = \frac{1.5}{\sigma}$$

μ is the step parameter, $\mu = \sigma^2, \psi$ is the nonlinear function

III. Results And Discussion

Performance of the MIMO CDMA systems with Gaussian and ambient impulsive non-Gaussian noise are analyzed with orthogonal codes and non-orthogonal codes, m-sequence. The received signal is processed through decorrelating detector. Performance of the system under non-Gaussian noise is poor compared to that of Gaussian noise. M-estimation method is used to improve the performance of the system under non-Gaussian noise. Two user two antenna systems are considered. Input sequence of length 100000 is used. Outputs are shown for m-sequence spreading and orthogonal code spreading. For orthogonal codes a sequence of length 4 is used. For m-sequence the sequence length is taken to be 7. Performance of the system under non-Gaussian noise is poor compared to that of the Gaussian noise, for both the spreading sequences, Fig (4), (5), (7), (8). Output of the m-estimation for Gaussian and non-Gaussian noise is shown in Fig (6) and (9). BER of the non-Gaussian noise is reduced compared to that of the Gaussian noise. Table shows the BER for user 1 for all the SNR values between 15 and 30. The following outputs depict the performance comparison.

For Orthogonal codes

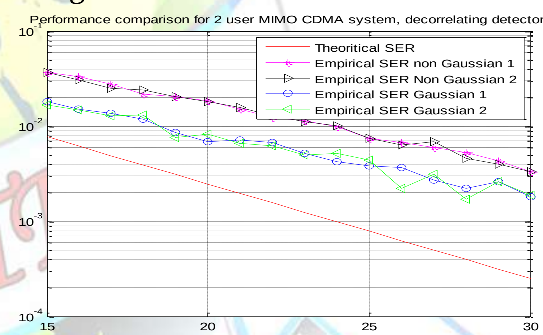

Fig.3. output for Decorrelating Detector

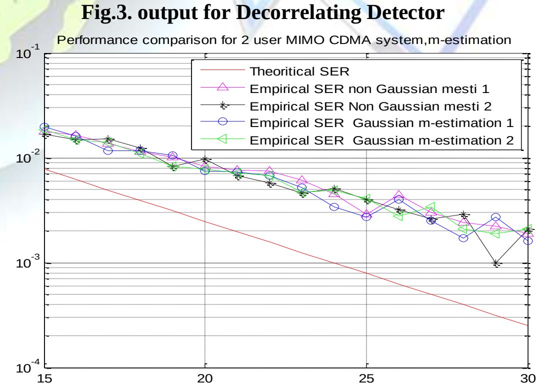

Fig.4. Output for M-estimation

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For M-sequence

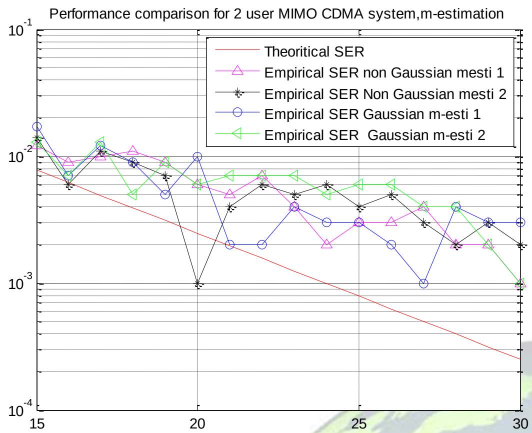

Fig.9. Output for M-estimation

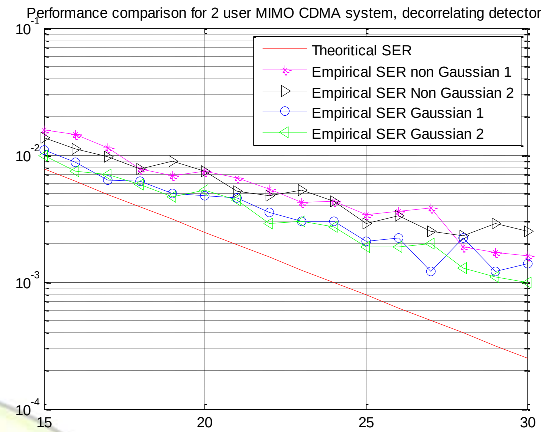

Fig.5. output for Decorrelating Detector

Table.1. M-Sequence Spreading, DD-Decorrelating Detector and M-Estimation

		DD		M-estimation	
SNR	Theoretical	Gaussian	Non Gaussian	Gaussian	Non-Gaussian
15	0.0077	0.0110	0.0158	0.0170	0.0120
16	0.0062	0.0087	0.0146	0.0070	0.0090
17	0.0049	0.0064	0.0113	0.0120	0.0100
18	0.0039	0.0062	0.0077	0.0090	0.0110
19	0.0031	0.0050	0.0069	0.0050	0.0090
20	0.0025	0.0048	0.0075	0.0100	0.0060
21	0.0020	0.0046	0.0066	0.0020	0.0050
22	0.0016	0.0035	0.0054	0.0020	0.0070
23	0.0012	0.0030	0.0042	0.0040	0.0040
24	0.0010	0.0030	0.0043	0.0030	0.0020
25	0.0008	0.0021	0.0034	0.0030	0.0030
26	0.0006	0.0022	0.0036	0.0020	0.0030
27	0.0005	0.0012	0.0038	0.0010	0.0040
28	0.0004	0.0022	0.0019	0.0040	0.0020
29	0.0003	0.0012	0.0017	0.0030	0.0020
30	0.0002	0.0014	0.0016	0.0030	0.0010

BER for Gaussian noise and Non-Gaussian noise for Decorrelating Detector and M-Estimation method is shown. It can be inferred that the performance of M-estimation method under Non-Gaussian noise is better compared to that of the Gaussian noise.

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Table.2. Orthogonal Spreading, DD-Decorrelating Detector and M-Estimation

		DD		M-estimation	
SNR	Theoretical	Gaussian	Non-Gaussian	Gaussian	Non-Gaussian
15	0.0077	0.0181	0.0371	0.0197	0.0178
16	0.0062	0.0151	0.0335	0.0160	0.0165
17	0.0049	0.0136	0.0279	0.0116	0.0137
18	0.0039	0.0118	0.0216	0.0116	0.0113
19	0.0031	0.0086	0.0203	0.0105	0.0102
20	0.0025	0.0069	0.0186	0.0074	0.0082
21	0.0020	0.0072	0.0152	0.0073	0.0076
22	0.0016	0.0068	0.0123	0.0067	0.0074
23	0.0012	0.0052	0.0113	0.0052	0.0061
24	0.0010	0.0042	0.0099	0.0034	0.0045
25	0.0008	0.0038	0.0074	0.0027	0.0029
26	0.0006	0.0037	0.0068	0.0040	0.0044
27	0.0005	0.0027	0.0060	0.0025	0.0030
28	0.0004	0.0022	0.0053	0.0017	0.0024
29	0.0003	0.0026	0.0043	0.0027	0.0022
30	0.0002	0.0018	0.0033	0.0016	0.0019

BER for Gaussian noise and Non-Gaussian noise for Decorrelating Detector and M-Estimation method is shown. It can be inferred that the performance of M-estimation method under Non-Gaussian noise is better compared to that of the Gaussian noise.

IV. CONCLUSION

In many practical wireless channels in which multiuser detection techniques may be applied , the ambient noise is likely to have an impulsive component that gives rise to larger tail probabilities than is predicted by the Gaussian model. Impulsive noise can seriously degrade the error probability of the linear multiuser detectors for the given level of noise power. M-estimation method is used to improve the performance of the system under non-Gaussian noise. Performance of the system under Gaussian and non-Gaussian noise is shown in the table for Decorrelating detector for two user two antenna systems. Theoretical value is compared with the practical value. M-estimation method gives better performance under non-Gaussian noise compared to that of the decorrelating detector.

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