Performance Evaluation of Adaptive MRC-MMSE Multiuser Detector for DS-CDMA System in Rayleigh and Nakagami Channels

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***Abstract*- Among all the available multiple access techniques, CDMA has the unique feature that it allows sharing of the same channel by all active users. CDMA performance is degraded up to some extent by two phenomenon i.e. Multiple-access interference (MAI) and multipath distortion. In the multiuser adaptive receiver for direct sequence code division multiple access (DS_CDMA) system the performance of least mean square (LMS) adaptive algorithm in three channels viz. flat, multipath Rayleigh and flat Nakagami channels is studied in this paper. For improving the performance of CDMA system by reducing interference among users, maximum ratio combining (MRC); a diversity scheme is used as a preprocessor to the adaptive MMSE detector of DS-CDMA system. Simulation result shows the bit error rate (BER) performance in above different channels.**

Keywords - DS-CDMA, MUD, Adaptive MMSE Detector, Maximum Ratio Combining (MRC), Rayleigh and Nakagami Channels.

I. INTRODUCTION

A number of mobile communication systems use the code division multiple access (CDMA) technique. In CDMA, the user uses the different code sequences that are transmitted simultaneously and share the same amount of bandwidth. The CDMA system offers narrow-bandwidth, soft capacity, and soft handoff; it also have anti-multipath and anti-jamming capabilities. Bandwidth of DS-CDMA is used more efficiently because the whole frequency band can be used all the time. Despite of so many advantages, the performance of DS-CDMA system is reduced by two phenomenon i.e. multiple-access interference (MAI) and multipath channel distortion. This problem cannot be eliminated by conventional matched filter detector. To improve the performance of DS-CDMA systems, a number of advanced signal processing techniques have been proposed. These techniques having two major categories: Multi-user detection [1-4] and Space-time processing or diversity combing [5].

Multi-user detectors are used to reject MAI, while detecting any given user, the information of the other users are taken into consideration. To reduce the MAI adaptive multiuser detection [4] technique is used. The adaptive MMSE receiver [4], [8] has much better performance and simple implementation than conventional matched filter receiver. This adaptive algorithm is divided into two major categories one is least mean square (LMS) and other is recursive least square (RLS) [8].

The most suitable way in which decoding in multipath channel can be done using information from different paths is Maximum Ratio Combining (MRC). The performance of adaptive MMSE receivers may be improved using MRC technique in flat, multipath Rayleigh and flat Nakagami channels. In this paper the modified Adaptive MRC-MMSE algorithm has been applied to the downlink (base station to mobile) of DS-CDMA system.

The system description is introduced in section II with establishing the required notations and definitions needed for rest of this paper. Section III briefly discusses the adaptive algorithm for MMSE detector. A modified adaptive MMSE-MRC scheme is described in section IV. Simulation results are shown in Section V, and main conclusions are summarized in Section VI.

II. SYSTEM DESCRIPTION

In this analysis, DS-CDMA system is modeled, used in downlink as shown in Figure1 [10] and binary phase shift keying (BPSK) modulation is considered with perfect power control environment. The channel is assumed to be fully synchronized antipodal DS-CDMA system .Here each user's symbol is modulated by unique spreading code. An additive white Gaussian noise (AWGN) channel is used to transmit combined data of all user's. Here K active users and N transmitted symbols in L multipath environment are assumed during the observation interval, the received signal is given by Equation (1) [10],

$$r(t) = \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{l=0}^{L-1} A_k b_k^{(n)} h_{k,l}(t) s_k(t) + n(t) \qquad (1)$$

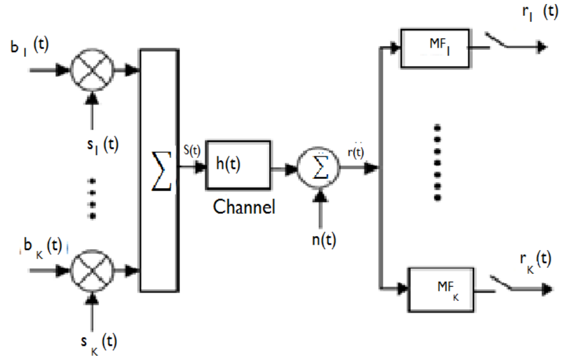

Fig. 1: A K-user downlink DS-CDMA system.

Where A_k is the amplitude given by $\sqrt{E_k/T}$, E_k is the energy/symbol, $b_k{}^{(n)}$ is the n^th^ information symbol transmitted in symbol time T_b, $h_{k,l}$ (t) is the channel response of fading channel and s_k (t) is the spreading sequence of k^th^ user with chip duration of T_c. The transmitted data and spreading sequence consist of rectangular pulses of duration T_b and T_c respectively, with values {+1,-1}.The length of spreading sequence G is given by $T_b = GT_c$. The noise n(t) is a complex AWGN with zero mean and two-sided power spectral density of No/2 W/Hz

To develop detail description of the system model, the Rayleigh fading channel and the Nakagami–m fading channel are described below:

A. Channel Model

1) Rayleigh Fading Model

In Rayleigh fading the radio signal is reach at the receiver after scattering by objects in the environment. Here it is assumed that the Doppler spread is smaller than the signal bandwidth i.e. transmitted signal of each user is received over a frequency selective slow fading channel and channel is wide sense stationary uncorrelated scattering model.

The impulse response of K^{th} user given by [7],[11]

$$h_k(\tau, t) = \sum_{l=1}^{L} f_{kl}(t)\delta\big(\tau - \tau_{kl}(t)\big) \qquad (2)$$

Where, L is the number of received paths, $\tau_{kl}(t)$ is propagation delay and $f_{kl}(t)$ represent the complex- valued time-varying channel coefficients of the l^{th} path for the k^{th} user, $f_{kl}(t) = \alpha_{kl}(t)exp(j\phi_{kl}(t))$, where $\alpha_{kl}(t)$ is the Rayleigh distributed channel gain, and $\phi_{kl}(t)$ is the channel phase uniformly distributed over interval [0,2π].

2) Nakagami-m Fading channel

In this model, the impulse response is a complex valued Gaussian time varying random process where, the required user has a complex Gaussian time varying channel gain whose Nakagami random variable represents amplitude and uniform random variable over 2π interval represents phase.

The probability distribution function of flat Nakagami-m channel is a related to the gamma distribution and is given by [9], [12],

$$f(x; m, \Omega) = \frac{2m^m}{\Gamma(m)\Omega^m} x^{2m-1} \exp\left(-\frac{m}{\Omega}x^2\right) \qquad (3)$$

Where, m is the fading severity parameter whose value is ≥1/2 and is derived as

$$m = \frac{E^2[X^2]}{Var[X^2]} \qquad (4)$$

And Ω is the controlling spread parameter, is given by

$$\Omega = E[X^2] \qquad (5)$$

The channel response is stored in a matrix H. Now, equation (1) can be expressed as,

$$r=SHAB+n \qquad (6)$$

Here, r is a matrix of all possible received signals. These received signals are send into the bank of matched filters. To recover the information transmitted by each user, these signals are passed through a group of correlators at the receiving end. Hence the k^th^ correlator output under synchronous condition would be,

$$\hat{b}_{k(MF)} = sign(S_k^H r) \qquad (7)$$

Where S_k^H=[0….s_k….0].s_k Being the k^th^ user's signature code.

Above equation (7) can be expressed as

$$\hat{b}_{k(MF)} = sign(b_{MF}) \qquad (8)$$

Where $b_{MF} = RHAB + N$ (9)

In equation (9), R is the normalized cross-correlation matrix of the spreading sequences and N is noise component of MF output. Hence these demodulated results are then used as an input to multi-user detectors [2],[8],[6] to improve the bit-error performance because this b_{MF} having error due to multipath destroys orthogonality present in spreading sequences .

III. ADAPTIVE MMSE DETECTOR

Most of the adaptive DS-CDMA detectors are based on linear receivers, especially on MMSE receivers. The goal of this detector is to minimize the Mean Square Error in the output of the linear filter. Using an adaptive algorithm, the implementation of this detector can be done by a simple tapped delay line filter. Figure.2 shows the block diagram of the adaptive multiuser detector.

Least Mean Square adaption:

The Least Mean Square (LMS) algorithm approximates the steepest descent method. From Figure.2 [8], coefficient update is as follows:

$$w_1(n+1) = w_1 + \mu b(n) e^*(n) \qquad (10)$$

Where, μ is the step size, the time is indicated by n and

$$w_1(n) = [w_{11} \quad w_{12} \dots\dots\dots \quad w_{1k}]^T \qquad (11)$$

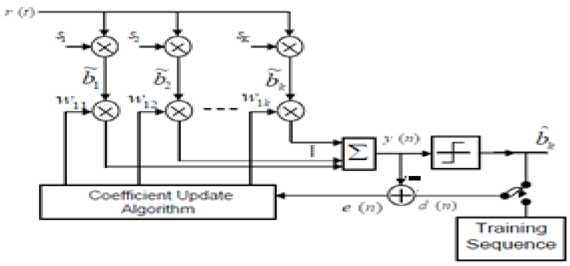

Fig. 2: A k user Multiuser Adaptive MMSE detector

$$b(n) = \left[\widetilde{b_1}, \widetilde{b_2}, \ldots\ldots.. \widetilde{b_k}\right]^T \qquad (12)$$
$$e(n) = d(n) - y(n) \qquad (13)$$
$$y(n) = w_1^H(n).b(n) \qquad (14)$$

d (n) is the desired signal. Initially this signal is set the training sequences and then it will be switched to the output of the adaptive filter. Step size is bounded for the stable operation and acceptable convergence speed. The convergence speed is lower for lower value of µ. Robustness and simplicity to noise are main advantage of LMS.

IV. MODIFIED ADAPTIVE MMSE-MRC DETECTOR

In a multipath fading channel, multiple transmitted signals are received by propagation delay. When delayed in time by more than chip duration, these multipath components appear like correlated noise at DS-CDMA receiver A separate correlation receiver is provided to combine the time shifted version of original signal .To avoid this, Maximum Ratio Combining (MRC) which identifies few strong multipath signals and then combines them after doing adjustment for delays can be used which is a better technology. In this detector, the channel coefficients and spreading code of the desired user are used for the detection process.

Let $r_{k,l}^{(n)}$ be the input sample vector to the lth receiver branch during the n^{th} symbol. The received signal vectors are fed to linear filters with impulse response of $w_{k,l}^{(n)}$. The output of the receiver branch is given by [10]:

$$y_{k,l}^{(n)} = w_{k,l}^{(n)} r_{k,l}^{(n)} \qquad (15)$$

The error function $e_{k,l}^{(n)}$ is the difference between the filter outputs and the reference signals which is used to update the filter weights,

$$e_{k,l}^{(n)} = d_{k,l}^{(n)} - y_{k,l}^{(n)} \qquad (16)$$

The product of data symbols and channel coefficients is the reference signal in the adaptive MMSE-MRC detector given by,

$$d_{k,l}^{(n)} = h_{k,l}^{(n)} \widehat{b_k^{(n)}} \qquad (17)$$

The data decisions or a training sequence can be used as $\widehat{b_k}^{(n)}$. Data decisions are generated initially by a conventional MF-MRC receiver for adapting the receiver. The absolute value of the estimated channel coefficients can also be used. Hence, this adaptive receiver does not necessarily require separate training sequence. Using the MSE criterion$\left(E\left[\left|e_{k,l}^{(n)}\right|^2\right]\right)$, the optimal filter coefficients are derived. Now it is convenient to decompose the filter vector to fixed and adaptive components [10]:

$$w_{k,l}^{(n)} = S_k^H + x_{k,l}^{(n)} \qquad (18)$$

Where, $S_k^H = [0 \ldots\ldots S_k \ldots 0\,]$ is the fixed spreading sequence of the k^{th} user and $x^{(n)}$ is the adaptive component. If standard LMS algorithm is used for adapting the filter, the updates for the adaptive component can be written as [10],

$$x_{k,l}^{(n)} = x_{k,l}^{(n-1)} + \mu_{k,l}^{(n)} e_{k,l}^{(n)} r_{k,l}^{*(n)} \qquad (19)$$

Where $\mu_{k,l}^{(n)}$controls the rate of convergence of the algorithm, known as the time variant step size parameter.

V. SIMULATION RESULTS

Results of simulation are presented in Figure (3.5), for synchronous downlink DS-CDMA system in Rayleigh flat, 8frequency selective and Nakagami flat channels. BPSK modulation is assumed with bits ±1 being equiprobable and gold sequences of length 31 are used to spread each data bit. User symbols of all kinds are transmitted with same power. Simulation results are obtained using Monte-Carlo simulation. In each trial 2000 data bits are generated for each user with the first 100 bits to allow the tap weights to settle and the last 1900 bits counting towards finding BER with the iteration of 500 times. In multipath Rayleigh fading channel, four paths are taken and in Nakagami-m fading value of m= 2, Ω=0.9 is taken. User one is always desired user while other users are viewed as interferers. All plots use a logarithmic scale for ease of comparison.

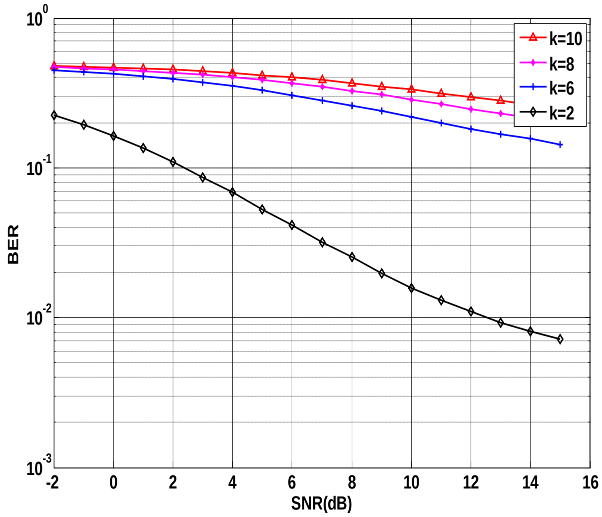

Fig.3 BER curve with different number of users in flat Nakagami fading channel.

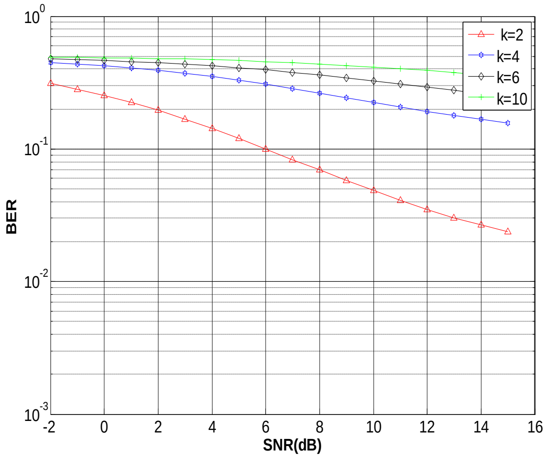

Fig. 4 BER curve with different number of users in flat Rayleigh Fading channel.

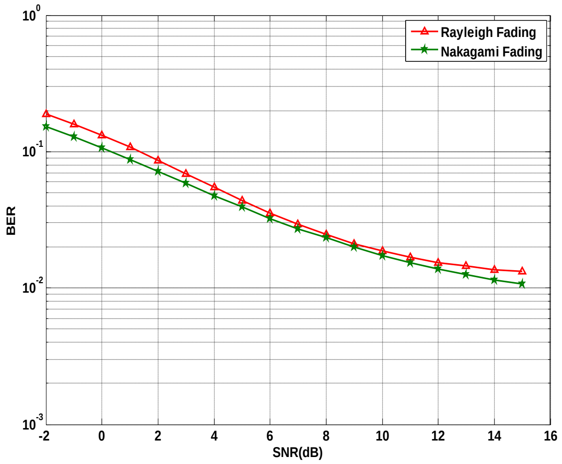

Fig.5 Performance of adaptive MMSE –MRC detector in various channles

VI. CONCLUSION

A modified adaptive MMSE-MRC detector is studied in this paper. The behavior of this detector in flat, multipath Rayleigh and in Nakagami-m channels is simulated. The performance has been evaluated in terms of the bit error rate. These results shows the equivalence between Rayleigh Fading channel with multipath and Nakagami fading channel, for signals combined by a maximal ratio scheme.

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