MODIFIED ADAPTIVE MULTIUSER DETECTOR FOR DS-CDMA MULTIPATH FADING

*Amit K. Dutta and Sayfe Kiaei**

Electrical and Computer Engineering
Oregon State University, Corvallis, OR-97331, USA
*Motorola, Portable Radio Group
Austin, Texas, USA.

ABSTRACT

Fading is a critical issue for the next generation of Digital Cellular System using DS-CDMA. The problem of reducing bit error rate (BER) in presence of multipath fading is addressed. A new method is proposed based on adaptive Near-Far resistant demodulation techniques. It can be modified to eliminate the detrimental effect of fading in presence of power control. In addition this method will drastically reduce hardware complexity and increase cell capacity for Digital Cellular System.

1.0 INTRODUCTION

Direct Sequence Code Division Multiple Access (DS-CDMA) is the multiplex method used for the next generation of Wireless digital standards (IS-95 Cellular, PCS and DECT). CDMA offers various advantages such as soft capacity limit, higher cell capacity and soft handoff [1, 2]. However, in DS-CDMA, the greatest challenge is the Near-Far problem. This is prominent only in DS-CDMA uplink, during transmission from subscriber to the base-station. Near-Far problem occurs when a transmitter near the base-station produces a very strong interference with other weak signals at the base station [3]. Ideally, the spreading codes for DS-CDMA should be orthogonal. However, in practice, the codes are non-orthogonal, which creates interference in conventional matched filter demodulation. In the presence of fast fading, power level of the received signal falls considerably from its average power level. During this condition, near-far resistant demodulator or adaptive power control solutions alone will not suffice. The objective of this work is to introduce a new near far adaptive demodulator which is capable of low BER in presence of power control under multipath fading. There are several Near-Far resistant demodulation techniques which can be applied with varying computational complexity in hardware. These are:

- Decorrelating detector for synchronous transmission [4].
- One-shot decorrelating detector for asynchronous transmission [5].
- Blind adaptation for synchronous and asynchronous transmission [6].
- Partially adaptive multiuser detection [7].

Decorrelating detector for synchronous [4] and asynchronous [5] DS-CDMA system is quite complex and requires knowledge of the starting time for each subscriber in the cell along with their codes. Blind adaptive method [6] has an advantage as it works for both synchronous and asynchronous system with knowledge of the code sequence of only one user.

It has been observed on different approaches that even with Near-Far resistant demodulator, performance of weak transmitter depends on the signal to noise ratio (SNR) at the receiving antenna. Hence, if we want to keep bit error rate (BER) constant for all users in a cell, we have to maintain constant received energy at the receiver. In this case, we need power control, even then, the received energy fluctuates considerably due to the multipath fading.

2.0 CHANNEL MODEL

Consider the following baseband received signal model for the asynchronous AWGN channel with multipath Rayleigh fading [7],

$$y(t) = \sum_{n=-N}^{N} \sum_{k=1}^{K} a_k b_k[n] s_k(t - nT - \tau_k) + \sigma u(t)$$

where, y(t) is the received signal, a_k is the kth user amplitude (for multipath Rayleigh fading, this will be varying with time), $b_k[n]$ is the nth bit of the kth user and $s_k(t)$ is the kth user's spreading chip waveform offset by $k \varepsilon [0,T]$. T is the bit duration, τ_k is integer number of one chip duration T_c, u(t) is normalized AWGN and σ^2 is the white noise power. The spreading waveform is defined as:

$$s_k(t) = \sum_{l=0}^{L-1} g_k[l] p(t - lT_c)$$

where, $g_k[l]$ ε {-1,+1} for all k, l is the spreading sequence for the kth user, p(t) is the chip waveform defined on $[0,T_c]$, L is the number of chips per bit. Here, it is assumed $T = LT_c$. This paper mainly deals with asynchronous system, where it is assumed that kth user is shifted by one chip duration T_c successively from the previous users. Also, it is assumed that the length of complete chip sequence is L.

The conventional receiver estimates the kth user's transmitted bit sequence $b_k[n]$, by taking the inner product of sampled received signal y[n] with desired user's code of length L.

$$\hat{b}_k[n] = \text{sgn}(g_k^t y[n])$$

where, g^t_k is the transpose of g_k. The performance of the receiver degrades with increase in overall user numbers.

Adaptive receiver, as mentioned in [5] and [7] works directly over the received signal y[n] (sampled version of y(t)). Hence, the optimization process is subjected to AWGN present in y[n] and also it will be affected during fading as the amplitude a_k changes with time for individual user. Both of the above mentioned methods adaptively generates a sequence (one may call it w_k for kth user), such that the inner product of w_k and y[n] (for the kth user) helps to estimate the transmitted bit of the desired user,

$$\hat{b}_k[n] = \text{sgn}(w_k^t y[n])$$

The adaptation sequence w_k is corrupted by the presence of noise and the amplitude is fading which leads to erroneous estimation of transmitted bits. The model for transmit and receiver structure is shown in Figure-1.

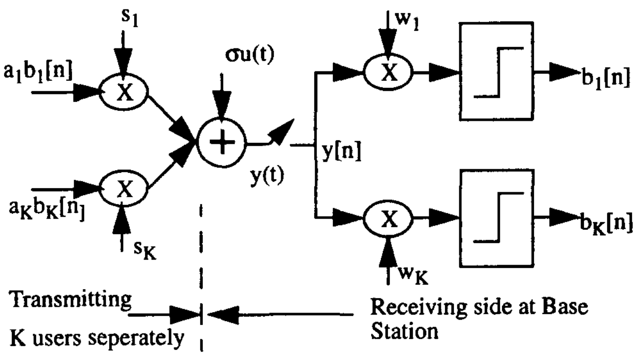

FIGURE 1. Model of transmit and receive structure for DS-CDMA

In the proposed method, the signal y'[n] is generated for the adaptation using the knowledge of s_k and K, the number of users. For the adaptation b_k is generated randomly, keeping the amplitude a_k at constant. This approach is explained in detail in the following section.

3.0 ADAPTIVE EQUALIZATION APPROACH

The method described in this paper, a variation of adaptive equalization, is not affected by the AWGN and multipath Rayleigh fading in the channel. Adaptation process takes place for all users, whenever a new user arrives. While forming y'[n], it is assumed that s_k and τ_k are known for all K users. Here, it is also assumed that s_{k+1} and τ_{k+1} are known for K+1 users using synchronization procedure mentioned in section 5. The block diagram in Figure-2 explains the basic mechanism of this method.

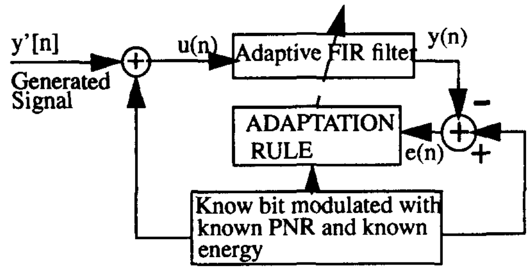

FIGURE 2. Usage of Near-Far resistant adaptive rule to improve BER in multipath fading.

The adaptive rule used here is simple least mean square (LMS) algorithm [10]:

$$y(n) = w(n)u(n)$$

$$e(n) = d(n) - y(n)$$

and

$$w(n+1) = w(n) + \mu u(n)e(n)$$

Figure-4 shows the convergence of error e for 30 users, the 30th user is a new comer. From this figure, it becomes clear that the adaptation process is slow for large number of users. Hence, another method (decision feedback cancellation) is proposed to nullify this slow convergence as explained in Figure-3.

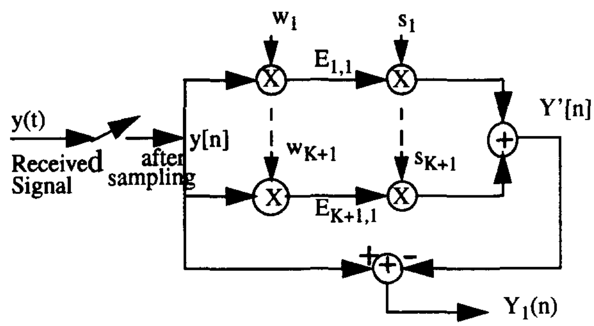

FIGURE 3. Decision Feedback for better Multiuser Interference Rejection.

This figure explains how demodulation is performed on real received signal. Here, w_1 to w_{K+1} stands for intermediate values of converged parameters. The first approximate amplitudes $E_{k,1}$ for kth user is formed from the inner product between w_k and y[n] as shown below, for all users.

$$E_{k,1}[n] = (w_k^t y[n])$$

Then we try to form $y_1[n]$, as shown in the following equation,

$$y_1[n] = y[n] - \sum_{k=1}^{K+1} E_{k,1} s_k$$

where, K is the number of existing users. For simplicity in understanding, the delay τ_k is omitted.

This process can be repeated for several times and in absence of noise, can achieve perfect multiuser interference cancellation. In presence of noise in the receiving end, the noise term in y1[n] can be given as,

$$\sigma_1^2 = (1 + x_1{}^2 + \ldots + x_{K+1}{}^2)\sigma^2$$

where,

$$x_k^2 = w_k^t w_k$$

Hence, in presence of noise, decision feedback cancellation will be limited to two or three loops. Finally, the estimation of the transmitted bit is done by adding all amplitudes found for the nth bit of kth users as shown below, where three feedback cancellation loops has been considered.

$$E_k[n] = E_{k,1}[n] + \ldots + E_{k,3}[n]$$

When one user stops transmitting, the interference for other users goes down. If one user leaves permanently, then, off-line adaptation has to be carried out to arrive at new set of w_k for other transmitting users.

4.0 OVERSAMPLING

The simplest way of reducing the noise variance in decision feedback cancellation path is by introduction of oversampling of the input signal. If the oversampling ratio is R, then theoretically one can achieve $\sigma_1{}^2=1+30/(L*R)$. Oversampling requires greater number of multiplier not only in active receiver structure, but also in off-line LMS adaptation structure. But, the most important benefit of oversampling is that if starting point for users bits are in fraction of chip duration then convergence in off-line LMS adaptation is much faster and better. In this paper, over sampling ratio of 4 is used.

5.0 SYNCHRONIZATION

Till now, the knowledge of the starting point for the new user has been assumed. To find that, one can use blind adaptation for the existing users with previously adapted value as the starting point [6]. Convergence in synchronization without AWGN for 29 users is shown in Figure-7. Synchronization is on-line process as it works on real y[n]. Then, it is possible to use multiple decision feedback cancellation to get the 30th user data along with noise. Now one can use the chip sequence of 30th user to slide along to get the maximum correlation and to decide the starting epoch of the user.

6.0 SIMULATION

Figure-3 shows the convergence of error in off-line adaptive LMS method in absence of noise. Here, the asynchronous users are shifted by one full chip duration and the pseudo-random sequences are generated using maximal length shift register (MLSR) configuration as mentioned in [9]. But it should be considered that this performance of convergence and bit error rate is not valid for all difference shifts (here, it is 1 for each user). Moreover, as it is not possible to simulate all the combinations, a kind of Monte-Carlo simulation has to be used to get the worst performance in convergence. Figure-5 and 6 show the SNR versus BER (bit error rate) in presence of gaussian noise with single stage of decision feedback cancellation (Figure-2) without and with Rayleigh Fading. Figure 8 and 9 shows the BER without and with Rayleigh fading using the demodulator whose parameters (w_k) have been found using R. Lupas's one shot approach [5, 8].

Here, convergence for 30 users has been achieved using MLSR of length 6 (hence, the chip length for one user is 63 in one transmitted bit). If the modulation uses $\pi/4$- QPSK method, one can afford 1/2 convolution encoding in modulator and Viterbi detector in demodulator, totally using 1.26 MHz, assuming 10 kbits is primary user data rate. The encoding will reduce the bit error rate during Rayleigh Fading. For generating the Rayleigh Faded envelope in simulation, 13 paths of reflections have been used without any direct component, with speed of the vehicle at 60 m.p.h. and radio frequency of 900 MHz. [11] has been followed extensively for simulation of Rayleigh fading.

REFERENCES

[1] P. Jung, P. W. Baier, A. Steil "Advantages of CDMA and Spread Spectrum Techniques over FDMA and TDMA in Cellular Mobile Radio Applications," IEEE Trans. on Vehicular Technology, vol. 42, No. 3, August 1993.

[2] K. S. Gilhousen, I. M. Jacobs, R. Padovani, A. J. Viterbi, L. A. Weaver Jr., C. E. Wheatley "On the Capacity of a Cellular CDMA System," IEEE Trans. Vehicular Technology, vol. 40, No. 2, May 1991.

[3] W. C. Y. Lee, "Mobile Cellular Telecommunications Systems," McGraw-Hill, 1989.

[4] R. Lupas., S. Verdu, "Linear multiuser detectors for synchronous code-division-multiple-access channels," IEEE Trans. Inform. Theory, pp. 123-136, January 1989.

[5] R. Lupas, "Near-Far resistant linear multi-user detection," Ph.D. dissertation, Princeton University, January 1989.

[6] M. Honig, U. Madhow, S. Verdu, "Blind adaptive multiuser detection," IEEE Trans. Inform. Theory, pp. 944-960, July 1995.

[7] J. B. Schodorf., D. B. Williams, "Partially adaptive multiuser detection," IEEE VTS Proceedings of 46th Vehicular Technology Conference, pp. 367-371, 1996.

[8] T. F. Myers, "Proposed Implementation of a Near-Far Resistant Multiuser Detector without Matrix Inversion using Delta-Sigma Modulation," M.S. dissertation, Oregon State University, April 1992.

[9] A. J. Viterbi, "CDMA, Principles of Spread Spectrum," Addison-Wesley, Reading MA, 1995, ISBN 0-201-63374-4

[10] S. Haykins, "Adaptive Filter Theory," 3rd ed., Prentice Hall, Upper Saddle River, N.J., 1996, ISBN 0-13-322760-X

[11] W. C. Jakes, Jr. "Microwave Mobile Communication," John-Wiley & Sons, 1974, ISBN 0-471-43720-4

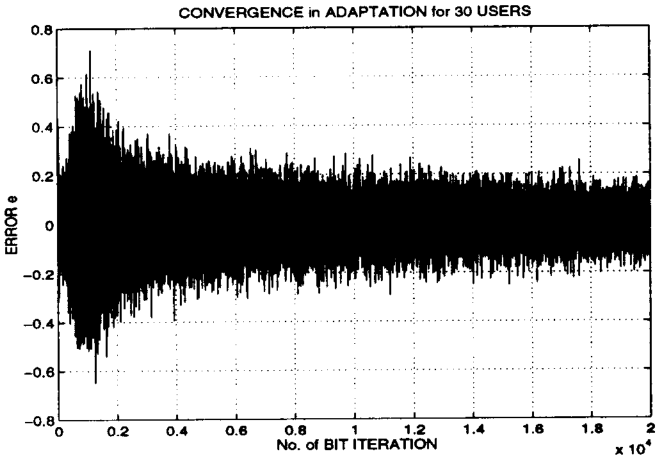

FIGURE 4. Convergence of Error for LMS adaptation with 30 Users.

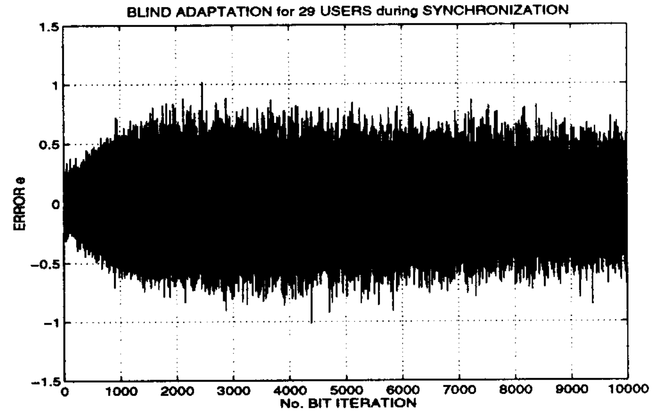

FIGURE 7. Convergence of Blind Adaptation with 29 Users, so that Synchrnization is possible.

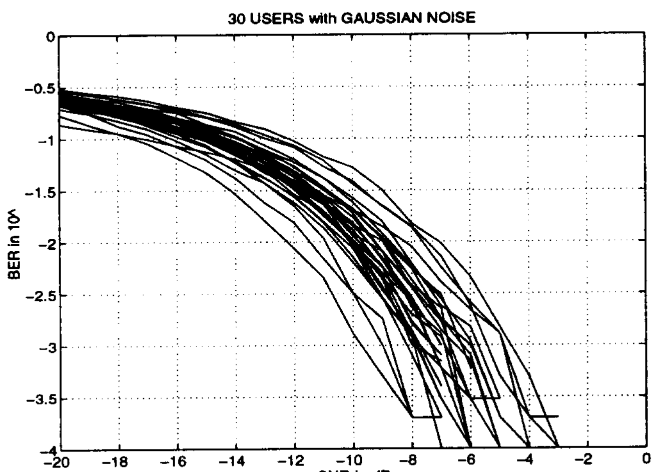

FIGURE 5. Bit error rae for 30 Users in presence of Gaussian noise.

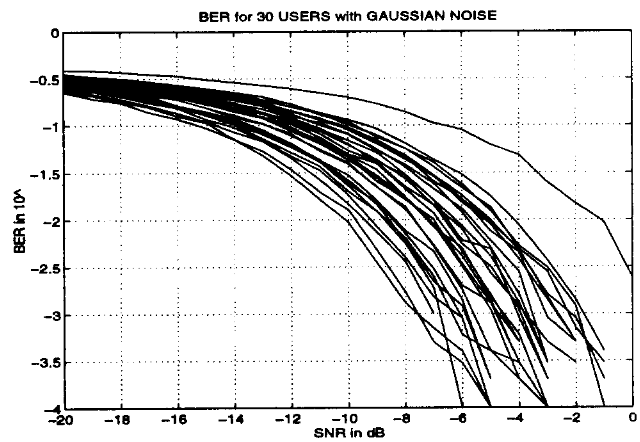

FIGURE 8. Bit error rate for 30 users in presence of Gaussian noise using demodulator whose coefficients are from R. Lupas's one shot approach.

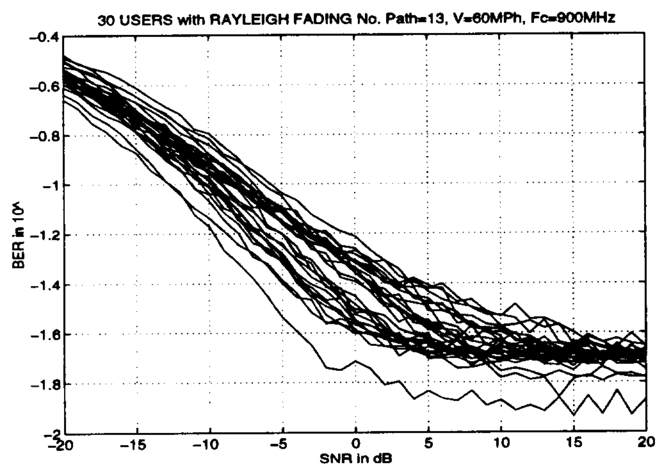

FIGURE 6. Bit error rate for 30 Users in presence of Rayleigh Fading and Gaussian Noise.

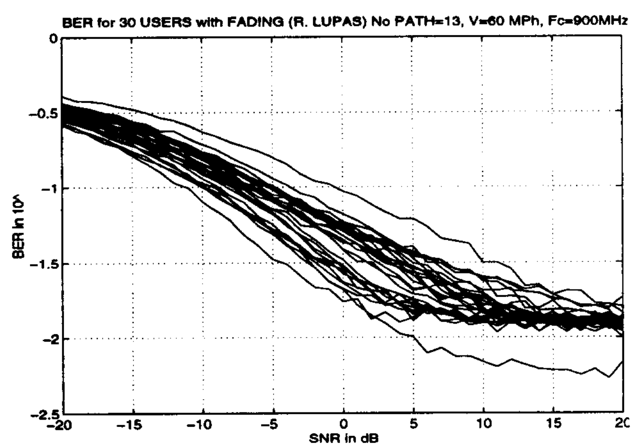

FIGURE 9. Bit error rate for 30 users in presence of Gaussian noise and Rayleigh Fading using demodulator whose coefficients are from R. Lupas's one shot approach.