Performance Analysis of Suboptimal Receiver Combining Adaptive Array Antenna and Orthogonal Decision-Feedback Detector for DS/CDMA System

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Abstract: In this paper, we propose a suboptimal receiver combining adaptive array antenna and orthogonal decision-feedback detector in DS/CDMA system. Adaptive array antenna can cancel out undesired signal using beamforming scheme. However, if there are interfering signals from undesired users with the same incident angle as that of a desired user, an adaptive array antenna cannot suppress them. The proposed receiver can cancel out remaining interference from users having nearly the same beam pattern. And we employ Orthogonal Decision-Feedback Detector (ODFD) as multiuser detection. The ODFD performs as good as the decorrelating decision -feedback detector (DDFD) with much less complexity. Simulation results show that the proposed system provides a significantly enhanced performance.

1. Introduction

Wireless communication systems are limited in performance and capacity by three major impairments [1][2].

The first of these is multipath fading, which is caused by the multiple paths that the transmitted signal can receive antenna. The signals from these paths add with different phases, resulting in a received signal amplitude and phase that vary with antenna location, direction, and polarization, as well as with time.

The second impairment is delay spread, which is the difference in propagation delays among the multiple paths. When the delay spread exceeds about 10 percent of the symbol duration, significant intersymbol interference (ISI) can occur, which limits the maximum data rate.

The third impairment is co-channel interference. Cellular systems divide the available frequency channels into channel sets, using one channel set per cell, with frequency reuse. For a given level of co-channel interference, capacity can be increased by shrinking the cell size, but at the cost of additional base stations.

There are many techniques to overcome these impairments [3].

The RAKE receiver effectively combats multipath fading by coherently combining resolvable multipath replicas of the desired signal. Multiuser detection addresses the problem of MAI by actively accounting for its presence when detecting the desired user [3][4].

More recently, there has been growing interest in using adaptive array antenna for further improving receiver performance [1][2]. The adaptive array antenna utilizes sophisticated signal- processing algorithms to continuously distinguish among desired signals, multipath, and interfering signals, as well as to calculate their directions of arrival. The adaptive approach continuously updates its beam pattern, based on changes in both the desired and interfering signal. The ability to smoothly track users with main lobes, and interfere with nulls [2] (Fig. 1(a)), insures that link budget is constantly maximized. But, if there are interfering signals and desired signal in the same beam pattern, an adaptive array antenna cannot suppress it (Fig 1(b)).

In this paper, we propose a scheme combing adaptive array antenna and orthogonal decision-feedback detector for DS/CDMA to remove this problem.

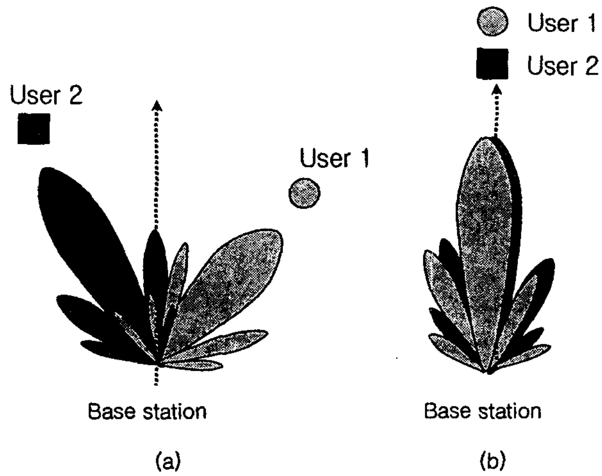

Figure 1. (a) Interfering signals and desired signal with the different incident angle
(b) Desired and interfering signals in the same incident angle

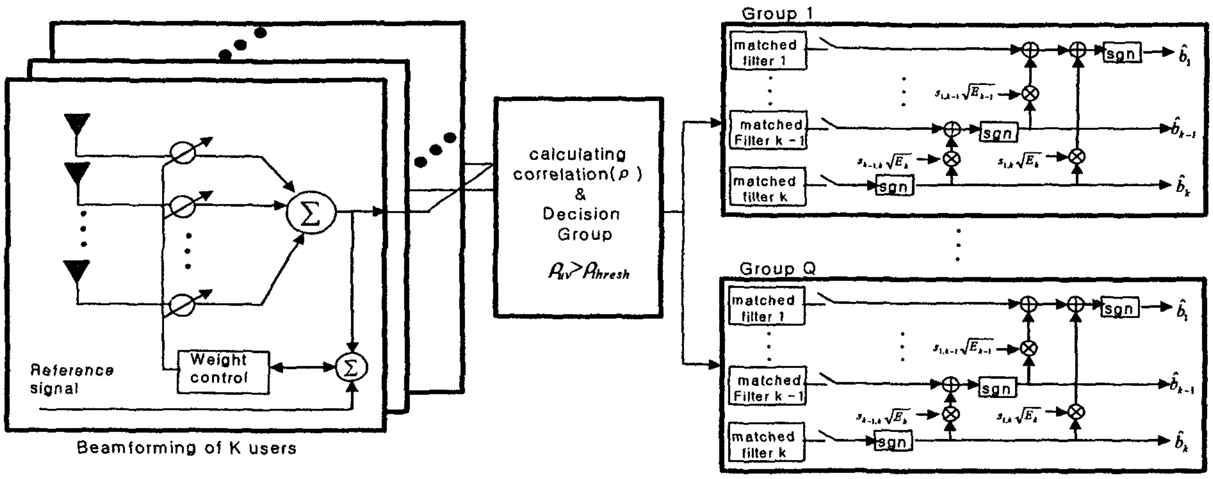

Fig 2. Block diagram of suboptimal receiver combining adaptive array antenna and orthogonal decision-feedback Detector (ODFD)

This paper is organized as follows. Section 2 presents the system model, including signal, channel and receiver model used in this paper. Section 3 shows the proposed receiver. Finally, the simulation results and conclusions are given in section 4 and 5.

2. System Model

We assume that there are K users in synchronous multiple-access channel and that kth user uses a preassigned normalized signature waveform $s_k(t)$ as its spreading code. Each waveform is restricted to a symbol interval of duration T, so that

$$\int_0^T s_k^{\,2}(t)dt = 1 \qquad (1)$$

The antipodal binary signals are considered such that binary bits 1 and 0 are represented by +1 and -1, respectively.

The kth user is assigned a finite energy signature waveform $s_k(t)$,

$$s_k(t) = \sum_{n=1}^{N} c_k(n) P_{T_c}(t - nT_c) \qquad k = 1, 2, 3, ..., K \qquad (2)$$

where $c_k(n)$ is spread sequence with ± 1. T_c is chip period. $P_{T_c}(t)$ is rectangular chip pulse shape of kth user.

The channel impulse response of kth user can be modified to take into account the Direction-Of-Arrival of multipath components [2][7].

$$h_k(t) = \sum_{l=0}^{L-1} a(\theta_{k,l})\beta_{k,l}(t)e^{j\phi_{k,l}}\delta(t - lT_c) \qquad (3)$$

where the coefficient $\beta_{k,l}(t)$ is independent complex Gaussian random variables due to Rayleigh fading of the kth user, $\phi_{k,l}$ is the phase shift caused by time variant channel and $a(\theta_{k,l})$ is the steering vector.

The steering vector is a function of the array geometry and Angle-Of-Arrival [2],

$$a(\theta_{k,l}) = [1 \;\; e^{j\phi_{k,l}} \;\; e^{j2\phi_{k,l}} \; ...... \; e^{j(M-1)\phi_{k,l}}]^T \qquad (4)$$

where $\phi_{k,l} = 2\pi \frac{d}{\lambda}\sin(\theta_{k,l})$, d is inter-element distance, λ is carrier wavelength and M is total antenna element.

The receive total signal of K users at the array antenna is given [2] by

$$u(t) = \sum_{k=1}^{K} \sqrt{w_k}\, b_k(t) s_k(t - lT_c) * h_k(t) + n(t)$$
$$= \sum_{k=1}^{K}\sum_{l=0}^{L-1} a(\theta_{k,l})\sqrt{w_k}\,\beta_{k,l}(t) s_k(t - lT_c) b_k(i) e^{j\phi_{k,l}} + n(t) \qquad (5)$$

where **n(t)** is white Gaussian noise vector and $b_k(i)$ is ith symbol of kth user.

3. Proposed Mechanism

3.1 Beamforming schemes

A block diagram proposed is shown in Figure 2. In this system, we first perform beamforming to null out the interference signal. There are a lot of beamforming algorithms used in antenna array. We use Least Mean Square(LMS) algorithm for simple structure [2][5].

We can represent kth user output signal and weighing vector as follows;

$$u_k(n) = [u_{k,0} \;\; u_{k,1} \; ...... \; u_{k,M-1}]^T \qquad (6)$$

$$w_k(n) = [w_{k,0}(n) \;\; w_{k,1} \; ..... \; w_{k,M-1}(n)]^H \qquad (7)$$

Then, weighting vector which applies to LMS algorithm is updated as follows;

$$z_n = \hat{w}_n^{\,H}\, u_n \qquad (8)$$

$$e_n = d_n - z_n \qquad (9)$$

$$\hat{w}_{n+1} = \hat{w}_n + \mu u_n e_n^{\,*} \qquad (10)$$

where initial value $\hat{w}_0$ is zero vector and μ is step size.

This beamforming scheme can cancel out undesired signal with different incident angle as that of a desired user, but interfering signals from undesired signal with the same incident angle as that of a desired user, while an adaptive array antenna cannot suppress it.

3.2 Grouping as estimation correlation coefficient between weighting vectors

Now, we calculate correlation coefficient ρ_{uv} between weighting vectors of K users to group the users who have similar weighting vector.

$$\rho_{uv} = \frac{w_u \ w_v^{\ H}}{\|w_u\| \ \|w_v\|} \tag{11}$$

where u=1, 2, …, k and v=1, 2, …, u-1.

We grouped the members which have $\rho_{uv} > \rho_{threshold}$. Total K users are arranged one of members of Q groups.

3.3 Multiuser detection in each groups

We consider Orthogonal Decision-Feedback Detector (ODFD). There are among many multiuser detection techniques [3].

It is known that Decorrelating Decision-Feedback Detector(DDFD) has good performance [6]. But this detector needs a transform matrix with a complexity growing exponentially with the number of users. Moreover, whenever the number and power level of the users in the system change, the transform matrix has to be recalculated and it consumes a lot of time [4].

Therefore, we are employing ODFD as multiuser detection [4][8].

We assume that k users belong to group q. The baseband signal in group q is [7];

$$u_{k_q}(t) = \sum_{k=1}^{K_q} \sqrt{E_k}\beta_k(t)s_k(t-T_c)w_k^{\ H}(i)a(\theta_k)b_k(i)e^{j\phi_k} + n(t)$$

$$= \sum_{k=1}^{K_q} m_k(t)a_k(t)b_k(i) + n(t) \tag{12}$$

where $m_k = s_k^T \sqrt{E_k}\phi_k\beta_k$, $a_k = w_k^{\ H}(i)a(\theta_k)$ and $\phi_k = e^{j\phi_k}$.

Using matrix expression, we can rewrite this term as follows;

$$u_{k_q}(t) = S^T E\Phi BAb + n(t) \tag{13}$$

where $S = [s_1^T \ s_2^T \ ... \ s_{k_q}^T]^T$, $E = diag(e_1 \ e_2 \ ... \ e_{k_q})$,

$\Phi = diag(\phi_1 \ \phi_2 \ ... \ \phi_{k_q})$, $B = diag(\beta_1 \ \beta_2 \ ... \ \beta_{k_q})$,

$A = diag(a_1 \ a_2 \ ... \ a_{k_q})$, and $b = [b_1 \ b_2 \ ... \ b_{k_q}]$

The input signal $u_{k_q}(t)$ is passed through a bank of matched filters.

The outputs sampled at the symbol interval T are given by

$$y = RW\Phi W\Phi B + n \tag{14}$$

where the cross-correlation matrix is $R = \int_0^T SS^T dt$ and n is Gaussian noise vector with zero mean.

Applying Gram-Schmidt Orthogonalization(GSO) procedure to columns k, k-1, …, 1 of R, we have the QU-factorization of R as [8],

$$R = QU \tag{15}$$

where Q is an orthogonal matrix and U is an upper triangular matrix.

Premultiplying the y in (14) by the symmetric conjugate of Q in (15), we have the transformed statistics as;

$$\bar{y} = Q^H y = U E \Phi B A b + Q^H \ n \tag{16}$$

where $Q^H n$ is $\tilde{n}$, a white Gaussian noise vector with zero mean, so we can rewrite output vector as follows;

$$\bar{y} = U E \Phi B A b + \tilde{n} \tag{17}$$

or kth component of $\bar{y}$ as;

$$\bar{y}_k = u_{k,k} \ w_k \ \phi_k \ \beta_k \ a_k \ b_k \tag{18}$$

which does not involve with the other users, so that its decision can be made right away.

In general, the kth user will use the previous decisions to obtain its own estimate as;

$$\hat{b}_k = \mathrm{sgn}[\bar{y}_k - \sum_{n=k+1}^{K} u_{k,n} \ w_n \ \phi_n \ \beta_n \ a_n \ \hat{b}_n] \tag{19}$$

Even though interference signal has stronger power than desired signal, this system can remove the interference effectively. So it can improve performance in bit error rate.

4. Simulation and Result

In the section, we compare the performance of omni-directional antenna (Conventional antenna), adaptive array antenna and adaptive array antenna combining multiuser detector(ODFD and DDFD).

We consider a DS/CDMA system with a processing gain, length equals to 31(Pseudo-noise sequence) in the simulation. Also, the modulation technique uses binary phase shift keying(BPSK). An 8-elements uniform linear array with half wave-length ($\lambda/2$) spacing between the elements is assumed to be located at the base station of the system to perform spatial filtering in the reverse link. We assume perfect power control in the base station, so all the signals implying on the array have the same power. Channel environment was employed single path in AWGN (Additive White Gaussian Noise) channel.

Beamforming algorithm is assumed to use Least Mean Square (LMS) and step size(μ) is 10^{-4}.

Supposed that signals incidence angle of K users are distributed irregularly in $[0, \pi/2]$.

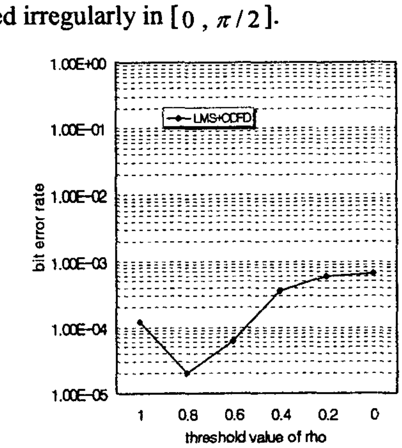

Fig 3. BER vs threshold value of correlation coefficient (Number of users=10, $E_0/N_0 = 8dB$)

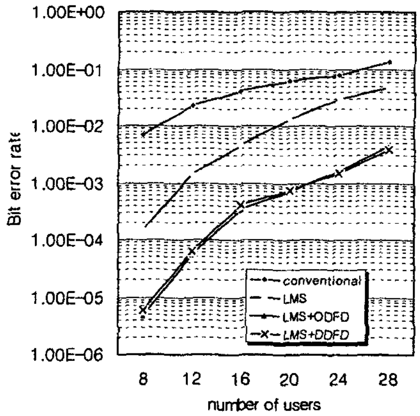

Fig 4. BER vs the number of users in AWGN channel.
($E_0 / N_0 = 8dB$, $\rho_{threshold} = 0.8$)

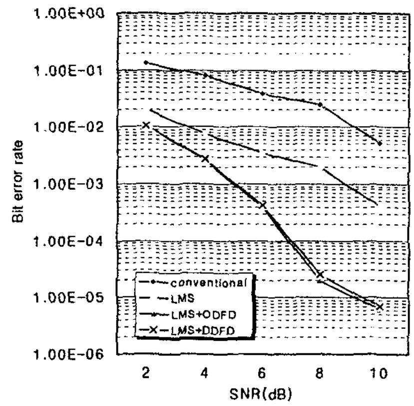

Fig 5. BER vs E_0 / N_0 (dB) in AWGN channel.
(Number of users=10, $\rho_{threshold} = 0.8$)

Fig. 3 shows the average BER as a function of $\rho_{threshold}$.
n the case of $\rho_{threshold}$ is 0, the users don't make the guoup, ınd only one ODFD is used. When $\rho_{threshold}$ is 1, one group ıas only one signal and ODFD act as single user detector.)In result, when $\rho_{threshold}$ is 0.8, the average BER is the mallest.

Fig. 4 and 5 show the average BER as a function of the ıumber of active users and of the SNR.
'he top curve is for the conventional antenna. It is clear hat the performance is inadequate due to the excess MAI. 'econd curve from the top is for the adaptive array antenna. Jsing beamforming only improves the performance as a ɜsult of suppressing the MAI form the directions other than ıat of the desired user. The third and fifth curves from the ɔp are for the combined adaptive array antenna and ıultiuser detector. The performance is greatly improved.

Fig. 6 compares the complexity of the ODFD and DDFD. 'he number of multiplications in the DDFD is about 1.5 mes more than that of the ODFD. The difference becomes gnificant if the number of users increases.

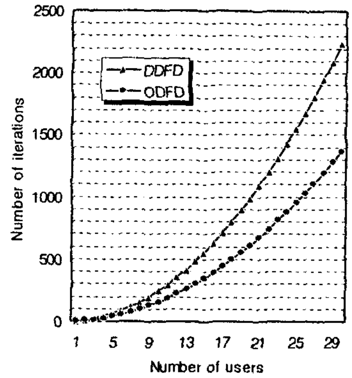

Fig 6. The amount of calculation the ODFD vs DDFD

5. Conclusion

In this paper, we proposed a suboptimal receiver combining adaptive array antenna and orthogonal decision-feedback detector to minimize the bit error rate in DS/CDMA. An adaptive array antenna cannot suppress interfering signals from undesired signal with the same incident angle as that of a desired user.

To improved this problem, we divided users who have the same incident angle, and employed multiuser detector as ODFD. Also, we calculated the threshold value of correlation coefficient to make the group optimally.

We compared with ODFD and DDFD. It is shown that they have the same performance but ODFD can reduce much complexity than DDFD.

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