

# Power Control Algorithm for MMSE Receiver Based CDMA Systems

Ali F. Almutairi, Scott L. Miller, *Senior Member, IEEE*, Haniph A. Latchman, *Senior Member, IEEE*, and Tan F. Wong, *Member, IEEE*

**Abstract**—In this paper, a fully distributed power control algorithm (PCA) based on the minimum mean-squared error (MMSE) receiver is introduced. We study the convergence of the signal to interference plus noise ratio (SINR) and the total transmitted power and we compare, in terms of the capacity, the performance of a system in which the proposed PCA has been implemented and compared with a system with perfect power control. We show that capacity improvement of the order of 20% is obtained by using the proposed PCA.

## I. INTRODUCTION

THE MAIN reason for using power control in a conventional receiver based DS-CDMA system is to combat the near-far problem which occurs when an undesired user's signal overpowers the desired user's signal. The Minimum Mean Square Error (MMSE) receivers, which have been presented in [1]–[3], and others, are known to be near-far resistant but power control can still be used to reduce multiuser interference, increase the system capacity, compensate for channel loss, as well as to minimize the transmitted power and hence prolong the battery life.

As shown in [1], the MMSE receiver can achieve many of the performance levels of other multi-user receivers without the need for side information like user sequences, clock offsets, and the received powers of all the interfering signals. This receiver offers a strong potential for capacity improvement over a conventional receiver-based CDMA system.

Since the MMSE receiver is near-far resistant, one can increase the transmitted power of a user experiencing a low SINR without having a major effect on other CDMA users. Likewise, one can decrease the transmitted power of a user enjoying a high SINR to conserve battery life and to decrease adjacent cell interference for other cells.

The power control algorithm (PCA) proposed in [4] uses measurements of the mean-squared error (MSE) which require knowledge of the actual transmitted symbols. This makes it hard to implement in a fading channel since in deep fades the symbol estimates out of the decision device of the receiver are unreliable [5], [6]. Both, the power algorithms proposed in this paper and the one proposed in [7], do not use the MSE measurements. To implement the algorithm presented in [7], a sample average of the output of the MMSE receiver is required

to provide an estimate of the interference to update the power. In addition the channel gain of the desired user needs to be estimated. The PCA proposed in this paper does not require knowledge of the interference caused by other users. Indeed, only one parameter which includes the channel gain of the desired user needs to be estimated. Additionally, in contrast to the algorithms presented in [4] and [7], the proposed PCA does not require the use of pilot symbols if a constant envelope modulation is used. The PCA's presented in this paper and the ones presented in [4] and [7] converge to the same transmitted power solution.

## II. FULLY DISTRIBUTED POWER CONTROL ALGORITHM

For the  $i$ th user,  $\text{SINR}_i$  at the output of the MMSE filter is given in [3] as

$$\text{SINR}_i = \frac{p_i h_{ii} |\mathbf{a}_i^H \mathbf{c}_i|^2}{|(\mathbf{a}_i^H I)|^2 + 2\sigma^2 (\mathbf{a}_i^H \mathbf{a}_i)} \quad (1)$$

where  $p_i$  is the transmitted power;  $\mathbf{c}_i$  is the spreading of user  $i$  with a period  $N$ ;  $h_{ij}$  is the channel gain of user  $j$  to the assigned base station of user  $i$ ;  $\mathbf{a}_i$  is the filter coefficient vector that correspond to the  $i$ th user;  $I$  is the multiple access interference present in the received signal; and  $\sigma^2$  is the noise variance. For the  $i$ th user, define the desired MMSE ( $\overline{\text{MMSE}}_i$ ) as the value of the MMSE which corresponds to the desired SINR ( $\overline{\text{SINR}}_i$ ). The relation between  $\overline{\text{SINR}}_i$  and  $\overline{\text{MMSE}}_i$  is given in [3] as

$$\overline{\text{SINR}}_i = \frac{1}{\overline{\text{MMSE}}_i} - 1. \quad (2)$$

The  $\overline{\text{MMSE}}_i$  is obtained by the Wiener solution for the tap weights as described in [8], [1]–[3]. For the  $i$ th user, the  $\overline{\text{MMSE}}_i$  is given by

$$\overline{\text{MMSE}}_i = 1 - \sqrt{p_i} \sqrt{h_{ii}} \mathbf{a}_i^H \mathbf{c}_i \quad (3)$$

From (3), we can write the transmitted power in terms of  $\overline{\text{MMSE}}_i$ , the tap weights, and the spreading sequence as follows

$$p_i = \frac{(1 - \overline{\text{MMSE}}_i)^2}{h_{ii} |\mathbf{a}_i^H \mathbf{c}_i|^2} \quad (4)$$

We propose to update the transmitted power at the  $(n+1)$  iteration according to the following algorithm:

$$p_i(n+1) = \frac{(1 - \overline{\text{MMSE}}_i)^2}{h_{ii} |\mathbf{a}_i^H(n) \mathbf{c}_i|^2}. \quad (5)$$

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The authors are with the Department of Electrical and Computer Engineering, University of Florida, Gainesville, FL 32611-6130 USA (e-mail: almutair@ecl.ufl.edu).

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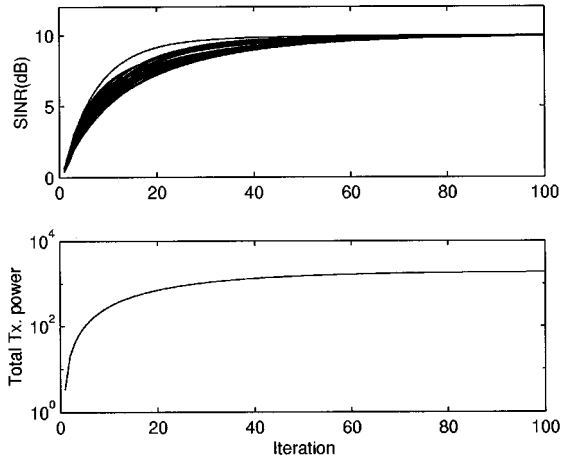


Fig. 1. The capacity improvement due to the use of the proposed power control algorithm as compared to the capacity of a system with perfect power control and theoretical bound.

It is clear that the transmitter needs to know  $(\mathbf{a}(n)_i^H \mathbf{c}_i)$  and  $h_{ii}$  to update its power. The value of these terms can be calculated by the receiver and then sent to the transmitter. The channel gain estimation can be approached as follows. The transmitter sends a pilot symbol at the beginning of each transmission period. The receiver uses the output of the MMSE receiver that corresponds to these pilot symbols to get a noisy estimate of the denominator of (5) as follows

$$z_i = d_i \sqrt{p_i} \sqrt{h_{ii}} \mathbf{a}_i^H \mathbf{c}_i + \tilde{n} \quad (6)$$

where  $\tilde{n}$  consists of the output of the filter due to the noise and the multiuser interference and  $d_i$  is the data symbol. A noisy estimate the denominator of (5) is obtained from

$$h_{ii} |(\mathbf{a}_i^H(n) \mathbf{c}_i)|^2 := \eta(n) \approx \frac{|z_i|^2}{p_i(n)}. \quad (7)$$

The value of  $|z_i/d_i|^2$  is sent from the receiver to the transmitter which divides it by the last transmitted power value to find  $\eta(n)$ . The transmitter then uses this value of  $\eta(n)$  to update its transmitted power according to (5). Furthermore, when a constant envelope modulation is used, no pilot symbols need to be sent since the value of  $|d_i|$  is constant.

### III. NUMERICAL RESULTS

In this section, we present some simulation results, shown in Figs. 1, 2, and Table I, for a single-cell synchronous MMSE receiver based DS-CDMA system using the proposed PCA. In all the results shown in this section, we use a normalized channel gain of 1, a processing gain of 31, a noise variance of 0.1, and we set the initial transmitted power of all users to 0.1. For these results, the power is updated every symbol. Although this is impractical, it reduces the simulation time and it does not have any effect on the result since we are not considering a time varying channel gain here.

To evaluate the advantage of implementing the proposed PCA, our results are compared to an MMSE receiver based system with perfect power control as well as the theoretic

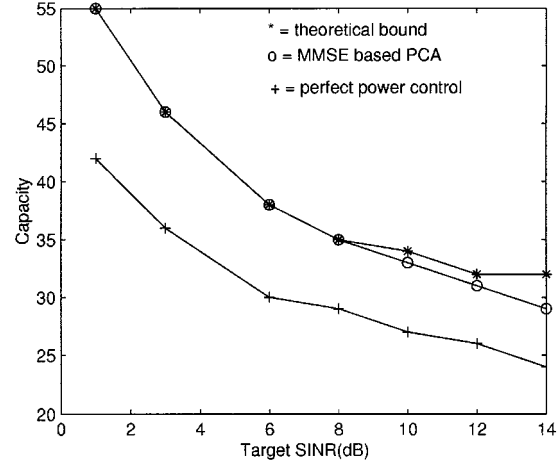


Fig. 2. A typical SINR and total transmitted power convergence of the proposed PCA algorithm with 33 users and  $\overline{\text{SINR}} = 10$  dB.

TABLE I  
SIMULATION CAPACITY AND AVERAGE TOTAL TRANSMITTED POWERS CORRESPONDING TO DIFFERENT  $\overline{\text{SINR}}$  REQUIREMENTS

$\overline{\text{SINR}}(\text{dB})$	Capacity eqn. 8	$P_t$ (simulation)	$P_t$ eqn. 10
1	55	637.4	617
3	46	850.7	796
6	38	1037.1	746
8	35	1453.3	869
10	33	2219.7	1023
12	31	1631.4	827
14	29	800.9	726

bounds using optimal spreading sequences [9] or asymptotic analysis (using large number of users and large processing gain) [10]. To facilitate comparison for the system with perfect power control, we assume that each user transmits with a constant power of  $1/K$  the average total transmitted power obtain from the proposed PCA. The proposed PCA based system was found to yield on average a capacity improvement of more than 20% over the system with perfect power control. The simulated capacity results, shown in Fig. 1, were obtained by varying the number of the CDMA system users to find the maximum number of users that can be supported by the system using a blocking probability criterion of 0.01. Blocking is defined as a scenario in which the converged value of the SINR of any user, was less than 98% of the desired  $\overline{\text{SINR}}$ ; so that the capacity of the system is given by the maximum number of users that could be present in the system while satisfying the following performance criterion

$$\Pr(\text{SINR} < 0.98\overline{\text{SINR}}) < 0.01 \quad (8)$$

The simulation results shown in Fig. 1 are found to be in agreement with the theoretical capacity upper bound given in [9] and [10] by

$$K < N \left( 1 + \frac{1}{\overline{\text{SINR}}} \right) \quad (9)$$

despite the fact that, for the results shown in this paper, short random sequences are used rather than optimal sequences as used in [9] or as asymptotic analysis using large number of users and large processing gain as in [10].

Fig. 1 shows that for a practical system as considered in the simulation study (with finite number of users and reasonable length of processing gain), it is possible to attain the same capacity as the MMSE system with optimal signature sequence [9] or that with large spreading gain [10] for a wide range of  $\overline{\text{SINR}}$  but at the expense of transmitting more power. This is further illustrated in Table I which shows the average total transmitted power,  $P_t$ , required to attain the capacities obtained by the proposed algorithm (8) for different values  $\overline{\text{SINR}}$ . It is clear that while the capacities attained by the proposed algorithm are close to the theoretical capacity bounds, the associated total transmitted powers required by the proposed algorithm are somewhat higher than that for the total power given in [10] by

$$P_t = \frac{K\overline{\text{SINR}}\sigma^2}{1 - \left(\frac{K}{N}\right) \frac{\overline{\text{SINR}}}{1 + \overline{\text{SINR}}}} \quad (10)$$

Fig. 2 shows the total transmitted power and the SINR convergence for the system using the proposed PCA with 33 users and an  $\overline{\text{SINR}}$  of 10 dB. Note that while we assume in Fig. 2 that all users have the same target SINR, the proposed PCA can support different target SINR's without any modification.

#### IV. CONCLUSION

In this letter, we have shown that despite the fact that the MMSE receiver is near-far resistant, its performance in terms of capacity can be improved by using power control. A fully

distributed power control algorithm based on a desired MMSE value was proposed and was shown to yield on average a capacity improvement of more than 20% over an MMSE based CDMA system with perfect power control where all users are received at the same power. Furthermore, the system capacity obtained by using the power control algorithm proposed in this paper is comparable to the theoretical capacity bounds of an MMSE system using optimal sequences or asymptotic assumptions.

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