Adaptive Beamforming Method Based on Closed-Loop Power Control for DS-CDMA Receiver in Multipath Fading Channels

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Abstract—In this paper, we propose smart step closed-loop power control (SSPC) algorithm in a direct sequence-code division multiple access (DS-CDMA) receiver in the presence of frequency-selective Rayleigh fading. This receiver consists of three stages. In the first stage, with conjugate gradient (CG) adaptive beamforming algorithm, the desired users’ signal in an arbitrary path is passed and the inter-path interference is canceled in other paths in each RAKE finger. Also in this stage, the multiple access interference (MAI) from other users is reduced. Thus, the matched filter (MF) can be used for the MAI reduction in each RAKE finger in the second stage. Also in the third stage, the output signals from the matched filters are combined according to the conventional maximal ratio combining (MRC) principle and then are fed into the decision circuit of the desired user. The simulation results indicate that the convergence speed of the SSPC algorithm is faster than other algorithms. Also, we observe that significant saving in total transmit power (TTP) are possible with our proposed algorithm.

Keywords—adaptive beamforming; closed-loop power control; DS-CDMA; total transmit power

I. INTRODUCTION

Code-division multiple access (CDMA) for cellular communication networks requires the implementation of some form of adaptive power control. In the uplink of CDMA systems, the maximum number of supportable users per cell is limited by multipath fading, shadowing, and near-far effects that cause fluctuations of the received power at the base station (BS). Two types of power control are often considered: closed-loop power control and open-loop power control [1], [2]. In a closed-loop power control, according to the received signal power at a base station, the base station sends a command to a mobile set to adjust the transmit power of the mobile. Also, closed-loop power control is employed to combat fast channel fluctuations due to fading. Closed-loop algorithms can effectively compensate fading variations when the power control updating time is smaller than the correlation time of the channel. However, in an open-loop power control, a mobile user adjusts its transmit power according to its received power in the downlink [1]-[4]. In this paper, an adaptive closed-loop power control algorithm is proposed to compensate for near-far effects.

Diversity and power control are two effective techniques for enhancing the signal-to-interference-plus-noise ratio (SINR) for wireless networks. Diversity exploits the random nature of radio propagation by finding independent (or, at least, highly uncorrelated) signal paths for communication. If one radio path undergoes a deep fade, another independent path may have a strong signal. By having more than one path to select from, the SINR at the receiver can be improved. The diversity scheme can be divided into three methods: 1) the space diversity; 2) the time diversity; 3) the frequency diversity. In these schemes, the same information is first received (or transmitted) at different locations (or time slots/frequency bands). After that, these signals are combined to increase the received SINR. The antenna array is an example of the space diversity, which uses a beamformer to increase the SINR for a particular direction [5], [6].

The goal of this paper is to extend the works in [7] and [8] by considering multiple-cell system and closed-loop power control. In these papers, a RAKE receiver in single-cell system was proposed in the presence of frequency-selective Rayleigh fading channel, and perfect power control (PPC) was considered.

In this work, the performance analysis of direct-sequence (DS)-CDMA system in frequency-selective Rayleigh fading channel has been studied. If the delay spread in a multipath channel is larger than a fraction of a symbol, the delayed components will cause inter-symbol interference (ISI). Adaptive receiver beamforming schemes have been widely used to reduce both co-channel interference (CCI) and ISI and to decrease the bit error rate (BER) by adjusting the beam pattern such that the effective SINR at the output of the beamformer is optimally increased [9]. Also, in this paper a RAKE receiver in DS-CDMA system is analyzed in three stages according to Fig. 1 [7]. In the first stage, this receiver uses conjugate gradient (CG) adaptive beamforming to find optimum antenna weights.
assuming perfect estimation of the channel parameters (direction, delay, and power) for the desired user. The desired user resolvable paths’ directions are fed to the CG beamformer to cancel out the CCI from other directions. Also, the RAKE receiver uses conventional demodulation in the second stage and conventional maximal ratio combining (MRC) in the third stage to reduce multiple-access interference (MAI). Reducing the MAI and the CCI will further decrease the system BER.

In this paper, we propose smart step closed-loop power control (SSPC) algorithm for minimizing the total transmit power (TTP). The rest of this paper is organized as follows. The system model is presented in Section II. The RAKE receiver structure is described in Section III. In Section IV, we propose the SSPC algorithm. Section V presents switched-beam (SB) technique and equal sectoring (ES) method. Finally, simulation results and conclusions are given in Section VI and Section VII, respectively.

II. SYSTEM MODEL

In this paper, we focus on the uplink communication paths in a DS-CDMA cellular system. L replicas of the signal, due to both some form of diversity reception (for instance antenna diversity) and channel frequency selectivity, are assumed Rayleigh distributed and optimally combined through a RAKE receiver according to Fig.1. Also assume that there are M active base stations in the network, with K_{m} users connected to mth base station, where 1 ≤ m ≤ M. Also assume that each base station uses an antenna array of S sensors and N weights, where S = 2N – 1, to receive signals from all users. Note that in CG adaptation algorithm, unlike other adaptation algorithms, the number of weights is less than the number of sensors. Also, for simplicity we assume a synchronous DS-CDMA scheme and BPSK modulation in order to simplify the analysis of proposed algorithm. Additionally, in this paper we assume a slow fading channel. Hence, the received signal in the base station q and sensor s from all users can be written as [7], [10], [11]

\[
r_{q,s}(t) = \sum_{k} p_{k,m}(t) \Gamma_{k}(x,y) \sum_{l=1}^{L} \alpha_{k,m,l} b_{k,m}(t - \tau_{k,m,l}) c_{k,m}(t) + n(t)
\]

where \(c_{k,m}(t)\) is the pseudo noise (PN) chips of user \(k\) in cell \(m\) (user \(k,m\)) with a chip period of \(T_{c}\); \(b_{k,m}(t)\) is the information bit sequence of user \(k,m\) with a bit period of \(T_{b} = GT_{c}\), where \(G\) is processing gain; \(\tau_{k,m,l}\) is the lth path time delay for user \(k,m\); \(\theta_{k,m,l}\) is the direction of arrival (DoA) in the lth path for user \(k,m\); \(\alpha_{k,m,l}\) is the complex Gaussian fading channel coefficient from the lth path of user \(k,m\); \(\lambda\) is signal wavelength; \(d\) is the distance between the antenna elements that for avoid the spatial aliasing should be defined as \(d = 0.5\lambda\); \(n(t)\) is an additive white Gaussian noise (AWGN) process with a two-sided power spectral density (PSD) of \(N_{0}/2\)

\[
\Gamma_{k}(x,y) = \begin{cases} 1 & : k \in S_{BSq} \\ \min_{m \in \Theta_{k}} \left\{ d_{k,m}(x,y) / 10^{5/10} \right\} & : k \in S_{o} \\ d_{k,q}(x,y) / 10^{5/10} & : k \in S_{BSq} \end{cases}
\]

where \(L_{\text{ar}}\) is path-loss exponent; \(d_{k,m}(x,y)\) and \(d_{k,q}(x,y)\) are the distance between user \(k\) and BS \(m\) and BS \(q\), respectively. Also the variable \(\Theta_{k}\) defined the set of the nearest BSs to user \(k\); \(\xi_{k,m}\) is a random variable modeling the shadowing between user \(k\) and BS \(m\); \(S_{BSq}\) is the set of users that connected to BS \(q\) and \(S_{o}\) is the set of users that not connected to BS \(q\) [2]. Also in (1)

\[
p'_{k.m} = d_{k,m}^{-L_{\text{ar}}}(x,y) 10^{-5/10} \times p_{k,m}
\]

is the received power in the BS \(m\) of user \(k,m\) in the presence of closed-loop power control where \(p_{k,m}\) is the transmitted power of user \(k,m\) that in the case of the PPC, \(p'_{k,m}\) is fixed for all users within cell \(m\) ( \(p'_{k,m} = E_{b}/T_{b}\) where \(E_{b}\) is the energy per bit for all users) [2], [7].

The received signal in the base station \(q\) in sensor \(s\) for user \(i,q\) is given by [7]
\[ r_{i,q,s}(t) = \sum_{l=1}^{L} \sqrt{p_{i,q}^2} b_{i,q}(t - \tau_{i,q,l}) c_{i,q}(t - \tau_{i,q,l}) \times \alpha_{i,q,l} \exp(-j2\pi s d \sin \theta_{i,q,l} / \lambda) + I_{i,q,s}(t) + n(t) \]  

(4)

where \( I_{i,q,s}(t) \) is the interference for user \( i,q \) in sensor \( s \) and can be shown to be

\[
I_{i,q,s}(t) = \sum_{m=1}^{M} \sum_{k=1}^{K_m} \sum_{l=1}^{L} \sqrt{p_{k,m}^2} \Gamma_k(x,y) g_{k,m}(t - \tau_{k,m,l}) \times c_{k,m}(t - \tau_{k,m,l}) \exp(-j2\pi s d \sin \theta_{k,m,l} / \lambda)
\]

(5)

where \( K_m \) is the number of users in cell \( m \) and \( M \) is the number of base stations/cells.

III. RAKE RECEIVER PERFORMANCE ANALYSIS

The RAKE receiver structure in the DS-CDMA system is shown in Fig. 1. The received signal is spatially processed by a CG beamforming circuit, one for each resolvable path (L beamformers). The resultant signal is then passed on to a set of parallel matched filters, on a finger-by-finger basis. Also, the output signals from the \( L \) matched filters are combined according to the conventional MRC principle and then are fed into the decision circuit of the desired user [7].

A. Conjugate Gradient Adaptive Beamforming Stage

It is well known that an array of \( N \) weights has \( N-1 \) degree of freedom for adaptive beamforming [7], [11]. This means that with an array of \( N \) weights, one can generate \( N-1 \) pattern nulls and a beam maximum in desired directions. From (5), it is clear that the number of users is \( K_u = \sum_{m=1}^{M} K_m \) and the number of interferes is \( L K_u - 1 \). To null all of these interferes; one would have to have \( L K_u \) weights, which is not practical. So, we focus only on the \( L \) paths of the desired user (inter-path interference). Thus, the minimum number of the antenna array weights is \( L \) where, typically, \( L \) varies from 2 to 6 [7].

In this paper, we use the CG adaptive beamforming (CGBF) algorithm that is used of orthogonal principle. On this basis, a set of vectors \( w_j \) is to select such that they are \[ A \times \text{orthogonal, i.e.,} \quad \langle Aw_i, Aw_j \rangle = 0 \quad \text{for} \quad i \neq j \]. The optimum weights at time \( n \) are obtained by minimizing [7]

\[
\| x^{(j)}_{i,q}(n) \|^2 = x^H_{i,q}(n)x^{(j)}_{i,q}(n)
\]

(6)

\[
x^{(j)}_{i,q}(n) = A^H_q n w^{(j)}_{i,q}(n) - y^{(j)}_{i,q}
\]

(7)

where \( A_q \) is the \( N \times N \) signal matrix in the base station \( q \). Also,

\[
y^{(j)}_{i,q}(n) = \begin{bmatrix} e^{-j(N-1)\theta_{i,q,j}/2} & \ldots & e^{j(N-1)\theta_{i,q,j}/2} \end{bmatrix}^T
\]

(9)

and

\[
w^{(j)}_{i,q}(n) = \begin{bmatrix} w^{(j)}_{i,q,0}(n) & w^{(j)}_{i,q,1}(n) & \ldots & w^{(j)}_{i,q,N-1}(n) \end{bmatrix}^T
\]

(10)

are the excitation and weight vectors (\( N \times 1 \) for user \( i,q \) in the \( j \)th path, respectively.

It should be mentioned that CG algorithm has two main characteristics [7]:

1- This algorithm can produce a solution of the matrix equation very efficiently and converge in a finite number of iterations (the number of beamformer weights).

2- In CG algorithm, the convergence is guaranteed for any possible condition of the signal matrix, according to (8).

According to the method of CG, the updated value of the weight vector for user \( i,q \) in the \( j \)th path at time \( n+1 \) is computed by using the simple recursive relation [7], [9]:

\[
w^{(j)}_{i,q}(n+1) = w^{(j)}_{i,q}(n) + \kappa^{(j)}_{i,q}(n)b^{(j)}_{i,q}(n)
\]

(11)

where

\[
\kappa^{(j)}_{i,q}(n) = \frac{\| A^H_q n w^{(j)}_{i,q}(n) \|^2}{\| A^H_q b^{(j)}_{i,q}(n) \|^2}
\]

(12)

\[
x^{(j)}_{i,q}(n+1) = x^{(j)}_{i,q}(n) + \kappa^{(j)}_{i,q}(n)b^{(j)}_{i,q}(n)
\]

\[
b^{(j)}_{i,q}(0) = -A^H_q n w^{(j)}_{i,q}(0)
\]

\[
b^{(j)}_{i,q}(n+1) = A^H_q x^{(j)}_{i,q}(n+1) + n^{(j)}_{i,q}(n)b^{(j)}_{i,q}(n)
\]

\[
n^{(j)}_{i,q}(n) = \frac{\| A^H_q x^{(j)}_{i,q}(n) \|^2}{\| A^H_q b^{(j)}_{i,q}(n) \|^2}
\]

The output signal from the \( j \)th CG beamformer (\( j = 1, \ldots, L \)) can be written as [7]

\[
y^{(j)}_{i,q}(t) = \sqrt{p_{i,q}^2} b_{i,q}(t - \tau_{i,q,j}) c_{i,q}(t - \tau_{i,q,j}) + n^{(j)}_{i,q}(t) + I^{(j)}_{i,q}(t)
\]

(13)

where \( n^{(j)}(t) \) is a zero mean Gaussian noise of variance \( \sigma^2 \) and \( I^{(j)}_{i,q}(t) \), the MAI, is defined as

\[
I^{(j)}_{i,q}(t) = \sum_{m=1}^{M} \sum_{k=1}^{K_m} \sum_{l=1}^{L} \sqrt{p_{k,m}^2} \Gamma_k(x,y) g^{(j)}_{i,q}(\theta_{k,m,l})
\]

\[
\times c_{k,m,l}(t - \tau_{k,m,l}) c_{k,m}(t - \tau_{k,m,l})
\]

(14)
where

\[ g_{i,q}^{(j)}(\theta) = \left[e^{-j(N-1)\theta/2} \ldots e^{-jN\theta/2}\right] \times w_{i,q}^{(j)} \] (15)

is the magnitude response of the jth beamformer for user i,q toward the direction of arrival \( \theta \) and \( w_{i,q}^{(j)} \) is the jth beamformer’s weight vector for user \( i,q \) [7].

B. Matched Filter Stage

Using beamforming will only cancel out the inter-path interference for the desired user and will reduce the MAI from the users whose signals arrive at different angles from the desired user signal (out-beam interference). Now, in the second stage of the RAKE receiver, the output signal from the jth beamformer is directly passes on to a filter matched to the desired user’s signature sequence. The jth matched filter output corresponding to the nth bit is [7]:

\[ z_{i,q}^{(j)}(n) = \sqrt{p_{i,q} b_{i,q}(n)} \alpha_{i,q} + I_{i,q}^{(j)}(n) + n^{(j)}(n) \] (16)

where

\[ I_{i,q}^{(j)}(n) = \frac{1}{T_b} \frac{nT_b + \tau_{i,q,j}}{nT_b + \tau_{i,q,j}} \int I_{i,q}^{(j)}(t) c_{i,q}(t - \tau_{i,q,j}) dt \] (17)

\[ n^{(j)}(n) = \frac{1}{T_b} \frac{nT_b + \tau_{i,q,j}}{nT_b + \tau_{i,q,j}} \int n^{(j)}(t) c_{i,q}(t - \tau_{i,q,j}) dt \] (18)

If we assume that the paths’ delays from all users are less than the symbol duration \( \tau_{k,m,l} < T_b \) for all users’ signals on all paths, the nth bit MAI at the output of the jth beamformer can be expressed as [7]

\[ I_{i,q}^{(j)}(n) = \sum_{m=1}^{M} \sum_{k=1}^{L_{k,m}} \sum_{l=1}^{K_m} \frac{p_{k,m,l}(x,y)}{E[|y_{i,q}^{(j)}(\theta_{k,m,l})|^2]} \times \alpha_{k,m,l} b_{k,m,l}(n) R_{k,l}^{(j)}(\tau_{i,q,j} - \tau_{k,m,l}) \] (19)

where the autocorrelation function \( R_{k,l}^{(j)}(\tau) \) is [7,12]:

\[ R_{i,k}(\tau) = \frac{1}{T_b} \int c_{i,q}(t) c_{k,m}(t + \tau) dt \] (20)

If all users’ delays are multiples of the chip period, then

\[ R_{i,k}(\tau) = \frac{1}{G} \sum_{l_1=0}^{G-1} \sum_{l_2=0}^{G-1} c_{i,q}(l_1) c_{k,m}(l_2) R_{c}^{(j)}(\tau - (l_1 - l_2)T_c) \] (21)

where the autocorrelation function \( R_{c}^{(j)}(\tau) \) is:

\[ R_{c}^{(j)}(\tau) = \frac{1}{T_b} \int c(t)c(t + \tau) dt . \] (22)

In the case of a maximal-length sequence (m-sequence) and for \( 0 \leq \tau \leq T_b \), we have [12]:

\[ R_{c}(\tau) = \begin{cases} 1 - \frac{|\tau|}{T_b} (1 + 1/G) & : |\tau| \leq T_c \\ -1/G & : |\tau| > T_c \end{cases} \] (23)

C. Maximal Ratio Combining Stage

Diversity combining has been considered as an efficient way to combat multipath fading because the combined SINR is increased compared with the SINR of each diversity branch. The optimum combiner is the MRC whose SINR is the sum of the SINR’s of each individual diversity branch [12,13].

After the finger-matched filter, the fingers’ signals are combined according to the MRC principle in the third stage of the RAKE receiver. In this paper, we use the conventional MRC that the signal of user \( i,q \) in the \( j \)th path is combined using multiplying by the complex conjugate of \( \alpha_{i,q,j} \).

The SINR in output of the RAKE receiver for user \( i,q \) is [7,13]:

\[ \text{SINR}_{i,q}(\alpha) = \sum_{j=1}^{L} \text{SINR}_{i,q}^{(j)}(\alpha) \] (24)

where

\[ \text{SINR}_{i,q}^{(j)}(\alpha) = \frac{p_{i,q}^{(j)} |\alpha_{i,q,j}|^2}{E[|y_{i,q}^{(j)}(\theta)|^2] + E[|\nu^{(j)}|^2]} \] (25)

is the SINR in output of the RAKE receiver in path \( j \) for user \( i,q \).

Also, we can be rewritten the SINR in (25) by (26), that shown at the bottom of the page [7,14], where

\[ \Gamma_k(x,y) = E[\Gamma_k(x,y)] \] and \( \alpha_{k,m,j}^2 = E[|\alpha_{k,m,j}|^2] \).

IV. SMART STEP POWER CONTROL ALGORITHM

Power control is an intelligent way of adjusting the transmitted powers in cellular systems so that the TTP is minimized, but at the same time, the user SINRs satisfies the system quality of service (QoS) requirements [4].

Depending on the location where the decision on how to
adjust the transmitted powers is made, the power control algorithm can be divided into two groups: centralized and distributed techniques [1]-[4], [10]. In centralized power control, a network center can simultaneously compute the optimal power levels for all users. However, it requires measurement of all the link gains and the communication overhead between a network center and base stations. Thus, it is difficult to realize in a large system [10]. Distributed power control, on the other hand, uses only local information to determine transmitter power levels. It is much more scalable than centralized power control. However, transmitter power levels may not be optimal, resulting in performance degradation [4].

The distributed closed-loop power control problem has been investigated by many researchers from many perspectives during recent years [1]-[4]. For instance, the conventional fast closed-loop power control strategy used in practice in CDMA systems is a fixed-step controller based on SINR measurements. The fixed-step power control (FSPC) algorithm is defined by [4]

\[ p_{i,q}^{n+1} = p_{i,q}^n + \delta \text{sign}(\gamma_{i,q}^* - \gamma_{i,q}^n) \quad (27) \]

where \( p_{i,q}^n \), \( \gamma_{i,q}^n \), and \( \gamma_{i,q}^* \) are the transmitter power, SINR target and measured SINR of user \( i,q \) at time \( n' \), respectively, and \( \delta \) is the fixed step size. Also \( p_{i,q}^{n+1} \) is transmitter power control (TPC) command in the feedback link of the base station to user \( i,q \) at time \( n'+1 \) (all signals are in decibels).

Also in [15], variable step closed-loop power control (VSPC) algorithm has been proposed. In this algorithm, variable step size is discrete with mode \( q_v \). It is shown that the performance of VSPC algorithm with mode \( q_v = 4 \) is found to be worse than that of a fixed step algorithm (\( q_v = 1 \)) under practical situations with loop delay of two power control intervals, but the convergence speed of VSPC algorithm is higher than FSPC algorithm. Also in this algorithm, the variance of the SINR mis-adjustment is reduced in compared to FSPC algorithm.

A typical loop delay situation encountered in WCDMA systems is presented in [4]. The slot at time \( n't \) is transmitted using power \( p^{n'} \). The receiver measures SINR \( \gamma^{n'} \) over a number of pilots and/or symbols and derives a TPC command. The command is transmitted to the transmitter in the feedback link and the transmitter adjusts its power at \( (n'+1)\tau \) according to the command. It should be mentioned that since the power control signaling is standardized, the loop delays are known exactly [4].

In this paper we present the smart step closed-loop power control algorithm. The SSPC algorithm defines as follows.

\[ p_{i,q}^{n+1} = p_{i,q}^n + \delta |\gamma_{i,q}^* - \gamma_{i,q}^n| \text{sign}(\gamma_{i,q}^* - \gamma_{i,q}^n) \quad (28) \]

This algorithm is implemented as follows.

1) Select the initial transmitted power vector \( (n' = 0) \) for all users within cell \( m \) as

\[ p_m^{0} = \left[ p_{1,m}^{0} \ p_{2,m}^{0} \ldots \ p_{K,m}^{0} \right] , \quad 1 \leq m \leq M \ . \]

2) Estimate the weight vector for all users with the CG algorithm using (11).

3) Calculate the SINR for all users using (24).

4) If \( |\gamma_{k,m}^* - \gamma_{k,m}^{n'}| > \varepsilon_0 \) for each user then set \( n' = n' + 1 \) and calculate the TPC for all users at time \( n'+1 \) using (28) and go back to 2), where \( \varepsilon_0 \) is threshold value.

5) Finally, if \( |\gamma_{k,m}^* - \gamma_{k,m}^{n'}| < \varepsilon_0 \) for all users then algorithm ends.

VI. SWITCHED-BEAM TECHNIQUE AND EQUAL SECTORING METHOD

One simple alternative to the fully adaptive antenna is the switched-beam architecture in which the best beam is chosen from a number of fixed steered beams. Switched-beam systems are technologically the simplest and can be implemented by using a number of fixed, independent, or directional antennas [16]. We list the conditions of the SB technique for this paper as follows.

1) Coverage angle for all beams is 30° and overlap between consecutive beams is 20°. Thus each base station has 36 beams.

2) Each user can use one beam for its each path to communicate with a base station at any time.

Also, one simple method to sectorize a cell is equal sectoring, in which all sectors have the same coverage angle. In this paper, we assume three sectors for each base station with sector angle 120° for the ES method.

VI. SIMULATION RESULTS

We consider \( M = 4 \) base stations for a four-cell CDMA system on a 2×2 grid and size (40×40) . We assume a uniform linear array of \( S \) omni-directional antennas in each base station with antenna spacing \( d = \lambda/2 \). Also, we assume BPSK m-sequence code spreading with processing gain \( G = 64 \); the input data rate \( T_b = 9.6 \text{ Kbps} \); the number of antenna weights \( N = 3 \); the number of antenna sensors \( S = 5 \); threshold value \( \varepsilon_0 = 0.1 \text{dB} \); frequency-selective fading channel with \( L = 2 \) resolvable propagation paths; variance of the complex Gaussian fading channel coefficient \( \sigma_x^2 = 4 \text{dB} \); fixed step size for SSPC, FSPC, and VSPC algorithms \( \delta = 0.01 \); mode \( q_v = 4 \) for VSPC algorithm [15]; path-loss component \( L_\alpha = 4 \); variance of the log-normal shadow fading \( \sigma_z^2 = 8 \text{dB} \); resolution \( R = 1 \); initial value for weight vectors in the CG algorithm \( \mathbf{w}(0) = \mathbf{0} \); initial value for transmitted power vectors \( \mathbf{p}_m^0 = \mathbf{0} \). The SINR target value is the same for all users and is set...
to $\gamma^* = 5(7 \text{dB})$. It also is assumed that the distribution of users in all cells is uniform.

Fig. 2 shows the comparison of the average SINR achieved over $K_u = 32$ users versus the power control iteration index ($n'$) for the SSPC, VSPC and FSPC algorithms. In this simulation, the three-stage RAKE receiver uses CGBF, SB, or ES methods in the first stage. Also, we assumed that each user to have a maximum power constraint of 1 watt. Accordingly, we observe that the convergence speed of the SSPC algorithm is faster than the VSPC and FSPC algorithms. This figure also shows that the SSPC algorithm with the SB technique converges faster than the SSPC algorithm with the CGBF and ES techniques. Also observe that the average SINR level achieved is below the target SINR value for the ES method, because in this method the MAI is higher than CGBF and SB methods. Fig. 3 shows the comparison of the average SINR achieved over $K_u = 32$ users versus the power control iteration index ($n'$) when there are $K_u = 32$ users in all cells according to Fig. 2. But in this simulation, we assume that users have maximum power constraints. Similar to Fig. 2, we see that the ES method never can achieve the target SINR value. Also it can be seen that the SSPC algorithm offers more savings in the TTP as compared to the FSPC and VSPC algorithms. Also we observe that the TTP for the SB technique is lower than other cases, because in this technique the MAI is lower than CGBF algorithm.

VII. CONCLUSIONS

In this paper, we studied the RAKE receiver performance of multiple-cell DS-CDMA system with the space diversity processing, Rayleigh frequency-selective channel model, and closed-loop power control. Accordingly, we proposed the SSPC algorithm to reduce the CCI and the MAI. It has been shown that, by using antenna arrays at the base stations, the SSPC algorithm will decrease the interference in all cells. In addition, it can be seen that the TTP in the SSPC algorithm is less than the FSPC and VSPC algorithms. Thus, it decreases the BER by allowing the SINR targets for the users to be higher, or by increasing the number of users supportable at a fixed SINR target level. Also, it has been shown that the convergence speed of the proposed algorithm is increased in comparison with the VSPC and FSPC algorithms.