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A New Power Control Algorithm for Cellular CDMA Systems

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Abstract. The conventional closed-loop power control in cellular code division multiple access systems can only achieve limited performance due to its inability to track channel variations quickly. In this paper, we present a new power control algorithm which is able to increase the speed of convergence to track the changes in radio channel efficiently. Simulation results show that it outperforms the conventional algorithms.

Keywords: Code division multiple access (CDMA), power control, adaptive algorithm, step size.

1. Introduction

It has been shown that Code Division Multiple Access (CDMA) improves the performance of cellular systems significantly [1]. However, some factors such as path loss, shadowing, multipath fading and interference can degrade system performance.

Power control has a significant role in maintaining the communication link quality under fading and interference conditions. It is responsible for ensuring that transmit power is kept at minimal while the signal to interference plus noise ratio (SINR) target is achieved.

In practical CDMA systems, power control is a fixed step-size algorithm where transmission power will either increase or decrease by a fixed step-size [2]. This approach, although is simple to implement, is not capable of tracking rapid changes in radio channel efficiently. Therefore, use of variable step could improve power control performance. In this paper, we propose an adaptive step algorithm to increase the system capabilities. This algorithm calculates step-sizes based on power control command (PCC) history.

The rest of the paper is organized as follows: Section 2 reviews the conventional power control loop including mobile radio channel model. We introduce our proposed adaptive step power control in section 3. Performance analysis and simulation results are presented in section 4 which is followed by conclusion in section 5.

2. System Model

This section reviews conventional closed-loop power control used in CDMA systems which is a fixed step controller based on SINR measurements [2]. Fig. 1 shows the Fixed Step Power Control (FSPC) algorithm. Power Control Command $(u(k))$ is computed based on the difference between SINR target value $(t(k))$ and measured SINR $(y(k))$ in the base station (BS). A mobile station (MS) receives $u(k)$ to update its transmitting power $p(k)$ using fixed step-size δ:

$$p(k) = p(k-1) + \delta sign(t(k) - y(k)) \tag{1}$$

$f(k)$ and $m(k)$ in Fig. 1 are channel fading and interference respectively and are explained later in this section. The target SINR is specified by an outer loop power control [3]. In practical systems, the PCCs must be minimized and typically only one or two Power Control Bits (PCB) is available for transmission. The step-size for conventional FSPC is usually about 1dB.

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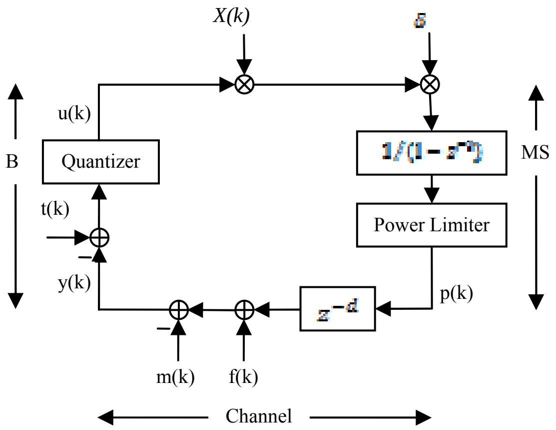

Fig. 1: fixed closed-loop power control

The power gain of a time-varying channel consists of long-term and short-term fading [4]:

$$f(k) = f_{long}(k) + f_{short}(k)\ [dB] \tag{2}$$

Long-term fading, the slowly varying components such as path loss and shadowing, can be expressed [4, 5] as:

$$f_{long}(k) = K_0 - 10n\log_{10}(D) + X_\sigma(k) \tag{3}$$

where K_0 is a constant, D is the distance between the base station and the mobile station and n is the path loss exponent. The parameter $X_\sigma(k)$ describes shadow fading and typically follows a log-normal distribution with zero mean and variance σ_s^2 which depends on the environment [5].

Short-term fading is fast fading over the radio channel, where the signal strength varies because of rapid scattering around a moving mobile. Short-term fading is widely modeled as Rayleigh fading [5] and generated according to Jakes model [6] represented by:

$$z(t) = R(t)e^{-j\theta(t)} = U(t) + jV(t) \tag{4}$$

where $\theta(t)$ is a random phase uniformly distributed on $[0,2\pi)$ and $R(t)$ is a Rayleigh distributed random process, independent of $\theta(t)$. $U(t)$ and $V(t)$ are independent Gaussian processes with zero mean and variance σ^2, given by:

$$2\sigma^2 = 2E[U^2(t)] = 2E[V^2(t)] = E[R^2(t)] \tag{5}$$

The envelope process $R(t)$ follows the Rayleigh probability density function:

$$f_R(x) = \frac{x}{\sigma^2}exp\left(-\frac{x^2}{2\sigma^2}\right)\ ;\quad x \geq 0 \tag{6}$$

As shown in Fig. 1, PCC is then transmitted to the mobile station. Since the downlink channel is noisy, the channel bit error rate should be taken into account. The power control commands may be corrupted by some disturbances. This is modeled by $x(k)$ with probability function [7]:

$$P_x(x) = (1 - P_{CE})\delta(x-1) + P_{CE}\delta(x+1) \tag{7}$$

where P_{CE} is command error probability.

At mobile station, PCC is multiplied by the step-size and then is directed to the integrator resulting in the transmission power expressed in equation (1). Obviously power $(p(k))$ is bounded in interval $[P_{min}, P_{max}]$. For simplicity, we show uplink and downlink delays in total with round-trip delay d.

Combining the transmitted power level and fading, the interference for each user can be computed. Let's $p_i(k)$ denote linear-scale transmitted power level of the *i*th user, $f_i(k)$ linear scale fading of the *i*th user and $n_{c,i}(k)$ linear scale power level of the Additive White Gaussian Noise (AWGN) then interference for *i*th user can be expressed as [8]:

$$m_i(k) = 10\log_{10}\left(\sum_{\substack{j=1 \\ j\neq i}}^{N} p_j(k-d)\cdot f_j(k) + n_{o,i}(k)\right)\ [dB] \tag{8}$$

is the number of users. Therefore, the received SINR at the base station can be computed as:

$$y(k) = p(k-d) + f(k) - m(k)\ [dB] \tag{9}$$

As we mentioned earlier, use of fixed step-size is not the most efficient because it is unable to track rapid changes in radio channel quickly. Use of adaptive step-size, which is the main focus of the next section, would improve this problem.

3. Proposed Adaptive Step Power Control

The Adaptive Step Power Control (ASPC) algorithm which is the main contribution of this paper is shown in Fig. 2. This algorithm is designed to be able of tracking both smooth and deep fading.

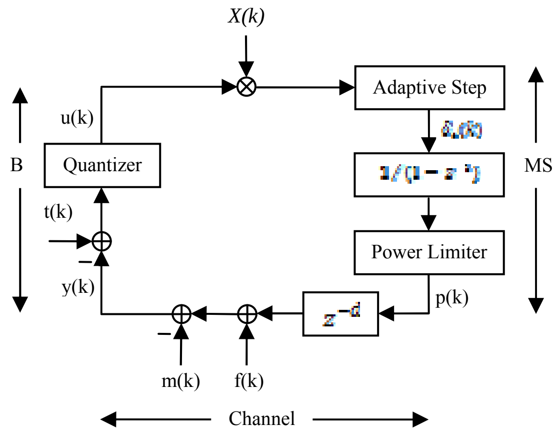

Fig. 2: Adaptive step closed-loop power control

The ASPC algorithm adjusts the transmit power based on the following equation:

$$p(k) = p(k-1) + \delta_a(k). \tag{10}$$

We define $\delta_a(k)$ for one PCB power control (i.e. $u(k) \in \{-1,1\}$) as:

$$\delta_a(k) = \alpha(k)\cdot\left(\frac{1+u(k)\cdot u(k-1)}{2}\right)\cdot\delta_a(k-1) + \beta(k).u(k).\delta_{tune} \tag{11}$$

and for two PCBs power control

(i.e. $u(k) = (u_1(k), u_2(k)) \in \{(-1,-1),(-1,1),(1,1),(1,-1)\}$ as:

$$\delta_a(k) = \alpha(k)\cdot\left(\frac{1+u_1(k)\cdot u_2(k-1)}{2}\right)\cdot\delta_a(k-1)$$

$$+\beta(k)\cdot u_1(k)\cdot\left(\frac{1+u_2(k)}{4}+\frac{1-u_2(k)}{2}\right)\cdot\delta_{tune} \tag{12}$$

where δ_{tune} is a constant. In general, $\alpha(k)$ and $\beta(k)$ are parameters which will increase if the two latest PCCs are the same and will stay same as their initial values if they are different. Therefore $\delta_a(k)$ will increase or decrease in the same manner. Note that the step-size $\delta_a(k)$ is always limited to the interval $[\delta_{min}, \delta_{max}]$ in dB scale and the performance of the ASPC method naturally depends on the selection of the parameters such as (k) , $\beta(k)$ and δ_{tune}.

Also, in power control algorithm, SINR under the target value is a more serious threat than when it is above the target value due to the higher chance of outage. One way to make a more rapid recovery from these situations is to use a larger update parameter when receiving power increase command than receiving power decrease command.

For one PCB this can be expressed as bellow:

$$\delta_a(k) = \alpha(k)\cdot\left(\frac{1+u(k)\cdot u(k-1)}{2}\right)\cdot\delta_a(k-1) + \beta(k)\cdot\left(\frac{1+u(k)}{2}\cdot\delta_{in} - \frac{1-u(k)}{2}\cdot\delta_{dec}\right). \quad (13)$$

And for two PCBs:

$$\delta_a(k) = \alpha(k)\cdot\left(\frac{1+u_1(k)\cdot u_1(k-1)}{2}\right)\cdot\delta_a(k-1) + \beta(k)\cdot\frac{1+u_1(k)}{2}\cdot\left(\frac{1+u_2(k)}{4}+\frac{1-u_2(k)}{2}\right)\cdot\delta_{in} - \beta(k)\cdot\frac{1-u_1(k)}{2}\cdot\left(\frac{1+u_2(k)}{4}+\frac{1-u_2(k)}{2}\right)\cdot\delta_{dec} \quad (14)$$

where δ_{in} and δ_{dec} are step-size increase and decrease respectively. We call this method ASPC2.

We examine the performances of our proposed algorithms and compare them with FSPC algorithm in the next section.

4. Simulation and Performance Analysis

The simulation is based on setting the carrier frequency at 900 MHz and power control update rate at 800 Hz. A typical minimum value for SINR is −14 dB to guarantee an acceptable communication quality [4]. In practice, the target SINR $(t(k))$ is set by the outer loop power control. For simplicity, the target SINR $(y(k))$ is set at −10 dB. The command error probability is set at $P_{CE} = 10^{-3}$. The shadowing log-standard deviation (σ_s) is chosen as 4 dB [5].

We compared performances of proposed methods with conventional FSPC algorithm while using one and two PCBs. We define standard deviation of SINR tracking error as our performance criterion:

$$\sigma_e = \left\{\frac{1}{K}\sum_{k=1}^{K}[t(k) - y(k)]^2\right\}^{\frac{1}{2}} \quad (15)$$

where $y(k)$ is given by equation (9), K is the total transmission data bit, and k is the index of bits.

We present simulation results of the power control for a cell with 10 users and mobile speed ranging from 10 to 80 km/h in Fig. 3. This figure illustrates standard deviation of SINR tracking error versus mobile speed for different methods. It is obvious that proposed adaptive step algorithms have better performance than FSPC algorithm.

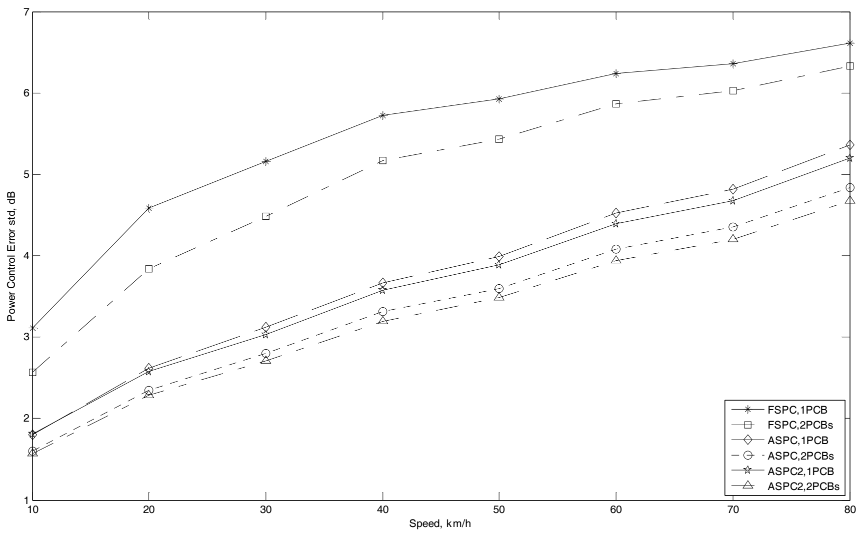

Fig. 3: Performance comparison versus mobile speed

As long as the measured SINR in equation (9) falls below minimum SINR, the system performance is instantaneously degraded and outage occurs. The outage probability $P_{o,i}$ for the ith receiver/transmitter pair is given by [9]:

$$P_{o,i} = prob[SINR_i < SINR_{min}] \tag{16}$$

By averaging $P_{o,i}$ for all the users in the considered cell, the outage probability P_o versus mobile speed is compared between the methods for both one and two PCBs. The results are in Fig 4, which clearly shows that new algorithms are more reliable than FSPC algorithm especially at high mobile speeds.

We now consider the effect of round-trip delay on power control algorithms. It is obvious that additional loop delays will affect the performance of any power control methods. The standard deviation of SINR tracking error versus total delay is shown in Fig. 5. It is expected that ASPC algorithm where the step-size is adjusted based on power control command history be more sensitive to loop delay than fixed step-size algorithm. The use of a delay compensation technique such as those proposed in [7] and [10] could be a possible solution for this problem.

5. Conclusion

We proposed an adaptive step power control (ASPC) algorithm for cellular CDMA systems. Performance of proposed algorithm is studied and compared with the conventional fixed step power control (FSPC) algorithm. Simulation results show that it outperforms FSPC algorithms without any requirements for additional information. The ASPC algorithm has better performance and lower outage probability than FSPC algorithm. However, not surprisingly, performance of our proposed algorithm in the presence of additional loop delay is worse than fixed step algorithm. We intend to investigate using time delay compensation techniques as a possible solution.

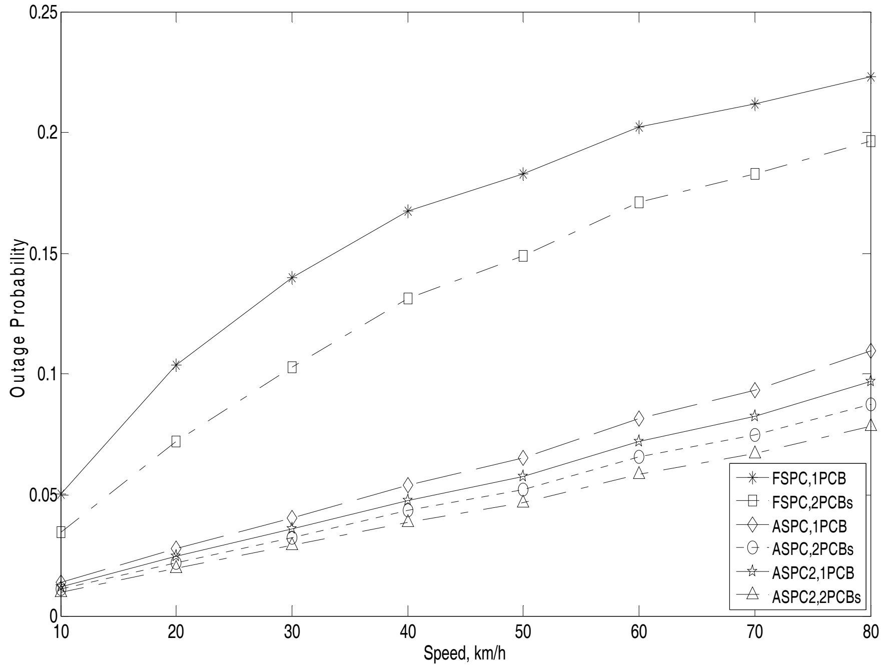

Fig. 4: Outage probability versus mobile speed

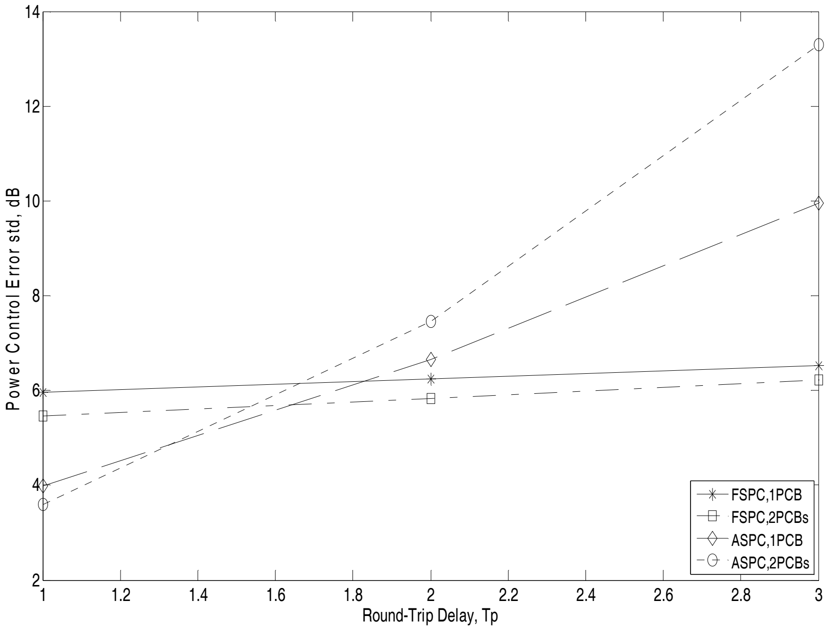

Fig. 5: Performance versus round-trip delay

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