PREDICTIVE RATIO CLOSED-LOOP POWER CONTROL FOR CDMA WIRELESS SYSTEMS

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ABSTRACT

In this work, we discuss the limitations of conventional closed loop power control (CLPC). We derive a closed-form expression for the control error. We then propose two algorithms that reduce this error. Simulations show a reduced power error compared to current CLPC techniques.

1. INTRODUCTION

The requirement of Power Control (PC) in the up-link DS-CDMA system is a critical limitation. Power control is needed in CDMA systems because users share the same bandwidth to transmit data and therefore inter-user interference occurs. The signal received by the Base Station (BS) from a near Mobile Station (MS) dominates that received from a far MS. The objective of power control is to control the transmission power of the mobile units to maximize the capacity of the overall system. Power control reduces inter-user interference by overcoming the near-far effect, which results in capacity increase of the overall CDMA system. Power control combats the Rayleigh fading channel effect on the transmitted signal by compensating for the fast fading of the wireless channel. It also minimizes the power consumption of the mobile units. Instead of using a fixed maximum power by the mobile station, it will now use an adaptive transmission power based on the power control requirements. Power control can be classified into two main categories, open loop power control (OLPC) and closed loop power control (CLPC). While OLPC is used to suppress slow fading, CLPC deals with faster channel fading.

A block diagram of conventional CLPC is shown in Figure 1. The transmission power $P_t(t)$ used by the MS is attenuated by the channel fading $\phi(t)$. At the BS, the received power $P_r(n)$ is measured (we assume an exact power measurement). The received power $P_r(n)$ is then compared to a desired fixed power level P_d.

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The error $e_a(n)$ is given by

$$e_a(n) = P_d - P_r(n) = P_d - \phi(n)P_t(n-1). \quad (1)$$

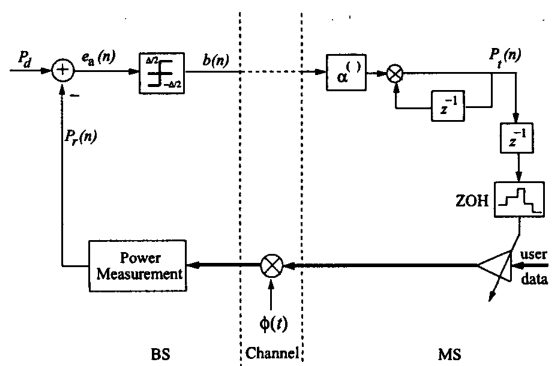

Fig. 1. *Conventional closed loop power control.*

The power error $e_a(n)$ is quantized using a one-bit quantizer to produce the power command bit $b(n)$ scaled by half the step-size of the quantizer Δ, i.e.,

$$b(n) = \frac{\Delta}{2}\text{sign}[e_a(n)]. \quad (2)$$

This PCB is transmitted to the MS. The mobile station then increments or decrements its transmission power by a fixed amount (in dB). This process is mathematically expressed as

$$P_t(n) = \alpha^{b(n)}P_t(n-1). \quad (3)$$

In other words,

$$\overline{P}_t(n) = b(n)\overline{\alpha} + \overline{P}_t(n-1) \quad (4)$$

where the following notation is used:

$$\boxed{\overline{(.)} = 10\log_{10}(.).} \quad (5)$$

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In closed loop power control, the tracking ability of the control loop is slow compared to fast variations in the channel fading. This imposes a limitation on the power control performance. There have been many studies proposed in the literature to overcome this problem [3, 4]. In this work, we first describe a model for the power control error. This model discloses the limitations of conventional CLPC. Based on this model, two algorithms are developed in an effort to "minimize" the power control error.

2. POWER CONTROL ERROR

In this study, we consider the effect of the uplink channel on the power envelope of the received signal. We assume a multi-path channel with Rayleigh fading reflections that are optimally combined using a RAKE receiver with M fingers. The discrete-time received power $P_r(n)$ at the BS can be expressed as [1, 5]:

$$P_r(n) = \frac{1}{T_p}\int_{(n-1)T_p}^{nT_p} P_t(t)Q(t)dt \qquad (6)$$

where T_p is the power control period, $P_t(t)$ is the transmission power, and $Q(t)$ is the power gain of the channel. This gain contains all effects of the multipath reflections on the signal power. In [1], the gain $Q(t)$ is given by

$$Q(t) = \sum_{p=0}^{L-1} a_p^2(t) \qquad (7)$$

where a_p is the tap weight coefficient relative to the pth finger of the channel. In (7) it is assumed that the channel AWGN is taken care of by the receiver and that any slow shadow fading by the channel is accounted for by the open loop power control.

The transmission power $P_t(t)$ is kept unchanged during a power control period, so that

$$P_r(n) = P_t(n-1)\left[\frac{1}{T_p}\int_{(n-1)T_p}^{nT_p} Q(t)dt\right]. \qquad (8)$$

Let us denote

$$\phi(n) \triangleq \frac{1}{T_p}\int_{(n-1)T_p}^{nT_p} Q(t)dt. \qquad (9)$$

Then the received power is modeled by

$$P_r(n) = \phi(n)P_t(n-1). \qquad (10)$$

We shall further assume in this study that the power bit is transmitted from the BS to the MS through the down-link channel with zero BER.

It can be shown that, in a logarithmic scale, the received power of Figure 1 can be expressed as (*the proof is omitted for brevity*)

$$\boxed{\overline{P}_r(n) = \overline{\phi}(n) - \overline{\phi}(n-1) + \overline{P}_d + \overline{\alpha}e_d(n-1)}. \qquad (11)$$

The signal $e_d(n)$ is the quantization noise introduced by the one bit quantizer. This noise is generally assumed to be uniformly distributed within $[-\frac{\Delta}{2}, \frac{\Delta}{2}]$, where Δ is the step-size of the quantizer.

Let us define the closed loop control error (PCE) in dB as[1]

$$e(n) \triangleq \overline{P}_r(n) - \overline{P}_d. \qquad (12)$$

Then, from (11),

$$\boxed{e(n) = \overline{\phi}(n) - \overline{\phi}(n-1) + \overline{\alpha}e_d(n-1)} \qquad (13)$$

3. ADAPTIVE METHODS FOR CLOSED LOOP POWER CONTROL

Referring to (13), we see that the power error, $e(n)$, is affected by two factors:

1. The variation in the channel fading power, namely, $\overline{\phi}(n) - \overline{\phi}(n-1)$.
2. The quantization noise, $e_d(n)$, that is introduced by the one-bit quantizer of Figure 1.

These facts suggest new strategies for reducing the power control error $e(n)$, and consequently improving the performance of the closed loop power control mechanism. In this work, we propose two algorithms for closed loop power control.

3.1. Algorithm 1: Predictive Ratio CLPC (PR-CLPC)

In this algorithm, we replace $\overline{\phi}(n-1)$ by the prediction $\overline{\phi_p}(n|n-1)$. The block diagram of the proposed scheme is shown in Figure 2. The only modification to the conventional CLPC of Figure 1 is the introduction of the ratio block $\frac{\phi_p(n+1|n)}{\phi(n)}$. This will cancel the fading $\phi(n)$ caused by the channel and replace it by the prediction $\phi_p(n+1|n)$. Everything else is the same as in the conventional CLPC of Figure 1.

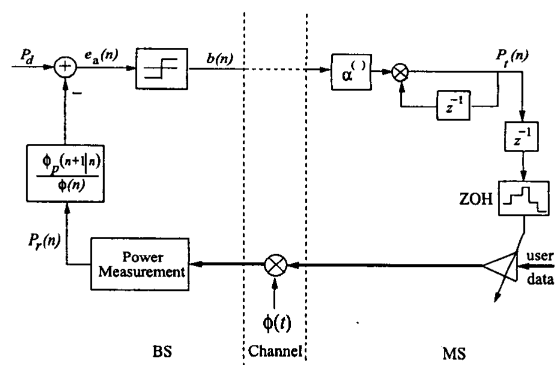

Fig. 2. *Block diagram of Predictive Ratio CLPC.*

The prediction could be obtained via an adaptive upsampled scheme as in Figure 3. The signal $\phi(n)$ is upsampled and then passed through a delay as shown in Figure 3, where m refers to the oversampling index. The delayed samples $\phi(m-1)$ are fed into an adaptive filter of order M. The output of the adaptive filter is compared to $\phi(m)$. The comparison error is fed back to the

[1] This error is just another way of measuring the difference between $P_r(n)$ and P_d. It employs a logarithmic scale, while the earlier error $e_a(n)$, defined in Figure 1, employs a linear scale.

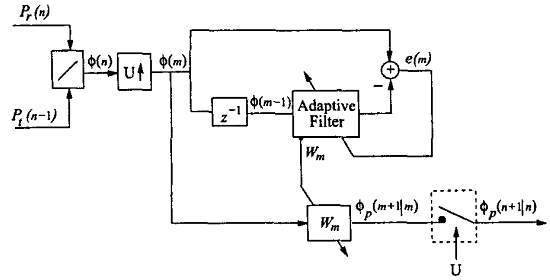

Fig. 3. *Prediction scheme for channel power fading.*

adaptive filter for online training. The taps of the adaptive filter, W_m, extract the correlation between the fading samples. The tap values are carried out online and used to adapt the taps of an FIR filter as shown in the figure. The input to this FIR filter is $\phi(m)$ and its output is the prediction of $\phi(m+1)$ denoted by $\phi_p(m+1|m)$. This signal is then down-sampled by the factor U to produce the required prediction value

$$\phi_p(n+1|n) \approx \phi(n+1). \tag{14}$$

If we follow the same derivation as in the conventional case, we can verify that

$$P_t(n) = \frac{P_d}{\phi_p(n+1|n)} K(n) \tag{15}$$

so that the received power is

$$P_r(n) = \phi(n) P_t(n-1) = \frac{\phi(n)}{\phi_p(n|n-1)} P_d(n-1) K(n-1). \tag{16}$$

In the logarithmic scale,

$$\overline{P}_r(n) = \overline{\phi}(n) - \overline{\phi}_p(n|n-1) + \overline{P}_d + \overline{\alpha} e_d(n-1) \tag{17}$$

and, hence, the power error is now given by

$$e(n) = \overline{\phi}(n) - \overline{\phi}_p(n|n-1) + \overline{\alpha} e_d(n-1). \tag{18}$$

Notice that the only difference between (13) and (18) is that the term $\overline{\phi}(n-1)$ is replaced by $\overline{\phi}_p(n|n-1)$. The power error is now dependent on the difference $[\overline{\phi}(n) - \overline{\phi}_p(n|n-1)]$ instead of $[\overline{\phi}(n) - \overline{\phi}(n-1)]$, as in conventional CLPC. Since for reasonable prediction, $\overline{\phi}_p(n|n-1)$ is usually closer to $\overline{\phi}(n)$ than $\overline{\phi}(n-1)$, we expect this algorithm to result in lower PCE. The prediction term $\overline{\phi}_p(n+1|n)$ can be evaluated by resorting to the scheme of Figure 3. In this way, the power measurement and ratio blocks on the left-hand side of Figure 2 (at BS side) can be more explicitly detailed as shown in Figure 4.

The error mean is zero since

$$E\{e(n)\} = E\{\overline{\phi}(n)\} - E\{\overline{\phi}_p(n|n-1)\} + \overline{\alpha} E\{e_d(n-1)\} \tag{19}$$

and the error variance is

$$E\{e^2(n)\} = E\{(\overline{\phi}(n) - \overline{\phi}_p(n|n-1))^2\} + \overline{\alpha}^2 E\{e_d^2(n-1)\}. \tag{20}$$

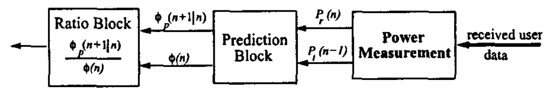

Fig. 4. *Evaluation of the predictive ratio. The prediction scheme used here is the one of Figure 3.*

When the uniformity assumption on the quantization noise $e_d(n)$ holds, we get

$$E\{e^2(n)\} = E\{(\overline{\phi}(n) - \overline{\phi}_p(n|n-1))^2\} + \overline{\alpha}^2 \frac{\Delta^2}{12}. \tag{21}$$

Therefore, the variance of the PCE is now dependent on the second moment $E\{(\overline{\phi}(n) - \overline{\phi}_p(n|n-1))^2\}$ instead of the quantity $E\{(\overline{\phi}(n) - \overline{\phi}(n-1))^2\}$, as in the conventional case. Thus, any prediction with acceptable accuracy will improve the power control error.

3.2. Algorithm 2: Adaptive Predictive Ratio CLPC (APR-CLPC)

This algorithm is an extension to the Predictive Ratio CLPC algorithm. Here, we use an adaptation technique to vary the exponent term α (which determines the value of $\overline{\alpha}$). The motivation behind this algorithm is the following. When the power fading variations are small, the predictor performs well. Therefore, we can decrease α to further decrease the power error of (13). When the variations are large, α is increased to boost the tracking capabilities of the power control loop. The adaptation scheme used for α is

$$\alpha(n) = \alpha(n-1) + \lambda(n) C \tag{22}$$

where C is a positive constant, usually $C < 1$ (e.g., $C = 0.2$). The signal $\lambda(n)$ is chosen as follows:

$$\lambda(n) = \begin{cases} +1 & \text{if } b(n) = b(n-1) = b(n-2) \\ -1 & \text{if } b(n) \neq b(n-1) \\ 0 & \text{otherwise.} \end{cases} \tag{23}$$

Furthermore, the exponent term $\alpha(n)$ is limited by lower and upper bounds, i.e.,

$$\alpha(n) = \begin{cases} \alpha_{max} & \text{if } \alpha(n) > \alpha_{max} \\ \alpha_{min} & \text{if } \alpha(n) < \alpha_{min}. \end{cases} \tag{24}$$

The bounds α_{max} and α_{min} are chosen in the interval $(1, 3]$.

4. SIMULATIONS

The PR-CLPC and APR-CLPC algorithms are simulated using Matlab and Simulink. The simulations are performed on a frequency selective channel with multi-path Rayleigh fading, where the channel fading data is obtained from Simulink. The desired power P_d is set to 0dB. The standard deviation of the power control error is used as a measure of how well the power control algorithms achieve the desired received power.

We start our tests by investigating the effect of choosing the exponent term α on the performance of the PR-CLPC algorithm. Figure 5 shows the PCE versus α for different mobile speeds. The optimal PCE changes in a nonlinear fashion with respect to α. When the Doppler frequency of the mobile unit can be measured, then we can refer to Figure 5 for the optimal choice of α. However, if the Doppler frequency cannot be measured accurately, then a choice of $\alpha = 1.3$ seems to be reasonable as indicated by the vertical arrow in the figure.

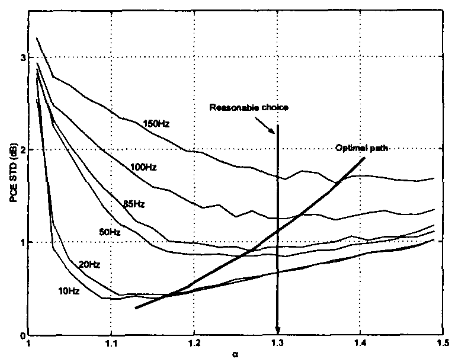

Fig. 5. *Effect of choosing α on PCE for the PR-CLPC algorithm.*

The APR-CLPC algorithm is tested via simulations. Figure 6 shows the STD of the PCE for two different values of the adaptation constant C. The saturation limits for α are chosen as $\alpha_{min} = 1.1$ and $\alpha_{max} = 2$. Increasing C will improve the performance of the CLPC algorithm at high vehicle speeds but will degrade it at low speeds. Choosing $C = 0.1$ was found reasonable for all tested applications.

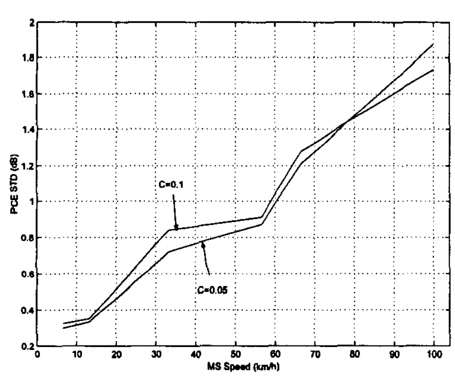

Fig. 6. *Power errors for the APR-CLPC algorithm for two values of the adaptation constant C.*

Finally, Figure 7 shows the PCE performance of the PR-CLPC and APR-CLPC. The parameters C, α_{min}, α_{max} for the APR-CLPC algorithm are set to 0.1, 1.1, and 2, respectively. Figure 7 includes also the performance of the conventional CLPC and that of an adaptive CLPC developed in [6], for the sake of comparison. The APR-CLPC demonstrates the best performance over all other algorithms, in terms of minimizing the power control error.

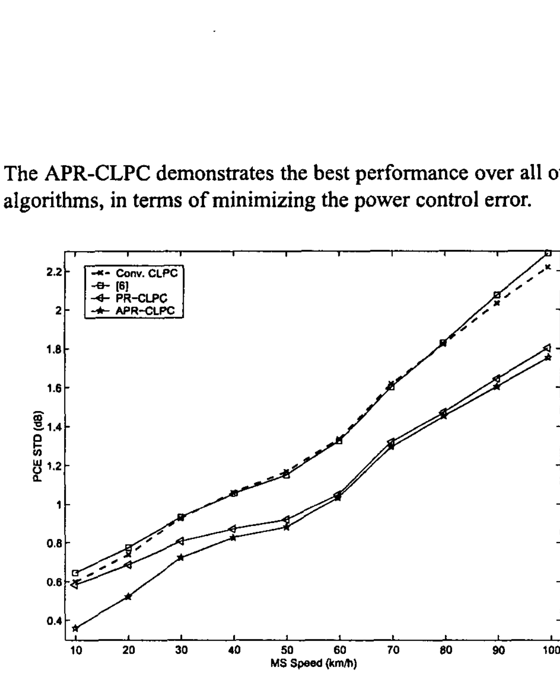

Fig. 7. *Performance of the developed algorithms compared to conventional CLPC and an adaptive CLPC developed in [6].*

5. CONCLUSION

The power control error for conventional CLPC was analyzed. Based on that, two new algorithms for CLPC were proposed. The algorithms aim to "minimize" the CLPC error expression. Simulations of the algorithms show improved power control performance.

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