EE 382C Literature Survey

Adaptive Power Control Module in Cellular Radio System

Jianhua Gan

Abstract

Several power control methods in cellular radio system are reviewed. Adaptive power control scheme based on the adaptive optimization of transmitter power and receiver filter coefficients is analyzed. The scheme can be mapped to power control algorithm, adaptive receiver digital filter, RAKE receiver power estimator and analog RF power amplifier. The implementation, co-simulation and co-synthesis in HP Advanced Design System are proposed.

I. Introduction

Accurate power control can reduce the interference in both Global System Mobile (GSM) and CDMA system. When the mobile is close to the base station, it can use lower power since the signal loss is smaller. For GSM, interference to other cells using the same frequency is reduced when the power control is accurate. For CDMA, accurate power control is vital because all CDMA signals interfere with each other. Lack of accurate power control reduces the capacity for CDMA. Moreover, power control can reduce battery drain and increase possible talk time. The major objective of power control is to alleviate the co-channel and cross-channel interference [1]. Cross-channel interference results from imperfect technology, Doppler shift and multi-path propagation. The capacity maximization and fair allocation of resources among different users largely depend on the effectiveness of the power control scheme. Due to the effects of fast fading, shadowing and distance loss, an adaptive power control (APC) scheme is needed [2]. Adaptive power control attempts to maintain a constant average performance among the users, minimize the required transmitter power at each mobile, and reduce the multiple-access interference effect. Adaptive power control is a difficult problem to be solved. While there are some simple power control algorithms deployed in real cellular radio systems and there are many quasi-analytical simulation results published, we try to summarize some of the important results and propose the implementation, co-simulation and co-synthesis in HP Advanced Design System, which is closer to real CMOS implementation.

II. Open-loop and closed-loop adaptive power control

There are two types of adaptive power control: open-loop [2] and closed-loop [3] APC. In closed-loop implementations, the reverse link (mobile-to-base station link) channel state is estimated by the base station, then the base station issues power control command on the forward link (base station-to-mobile link) based on the estimation. In open-loop implementations, the channel state on the forward link is estimated by the mobile itself, and this information is used by mobile as a measure of the channel state on the reverse link. The mobile adjusts its transmitter power accordingly. This scheme works well if the forward and reverse links are perfectly correlated. Closed-loop APC outperforms open-loop APC in a terrestrial environment where the round-trip delay is small. The close-loop APC is sensitive to round-trip delay and therefore it is not effective in a land mobile satellite system. Closed-loop APC is more complex in implementation and needs extra bandwidth for power control command. Open-loop APC can compensate for large-scale variations such as shadowing, and it provides a fast, inexpensive methods to equalize average received power at the base station. A better solution is to user both open-loop and closed-loop power control. For simplicity, we will concentrate on open-loop power control.

In order to get a better estimation of the received power, the received power at the mobile can be estimated by using RAKE receiver [2] as shown in Figure 1. After RF demodulation the outputs of the taps of the RAKE receiver are correlated with the de-spreading sequence $c(t)$ over one bit time, then squared and summed to generate $X(k)$ at time kT. $X(k)$ is averaged over m bits to form an estimate of the received power. These processes are typical DSP processes. By adaptively adjust the transmitter power level, we can minimize the interference that users create to each other while maintaining the desired signal to interference ratio (SIR) or bit error rate (BER) and increasing the throughput of cellular radio systems [3, 4, 5, 6].

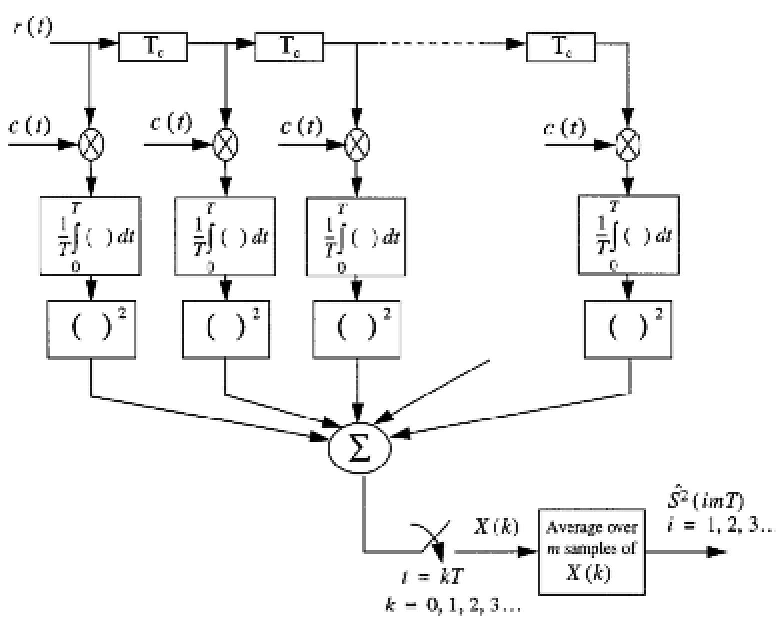

Figure 1. Power estimation diagram using RAKE [2]

An open-loop APC algorithm attempts to minimize the effect of multi-path fading by averaging it out. So there is a randomly varying power control error (PCE) that causes performance degradation. A quasi-analytical approach was used to estimate the reverse link capacity of the open-loop power control scheme in both a single cell and a multi-cell environment for both a fixed base station and a moving base station scenario [2]. For a single cell environment, the upper bound on the coded BER performance of the open-loop power control as a function of the number of interfering users (J) and the standard deviation of the power control error (σ_e) is shown in Figure 2. For a targeted coded BER of 10^{-3}, a maximum of 33 users can be accommodated in a system with perfect open-loop power control (i.e. σ_e = 0dB). The capacity degrades by 18% (27 users) and 36% (21 users) when σ_e = 2dB and 3dB, respectively. This clearly shows the importance of accurate power control.

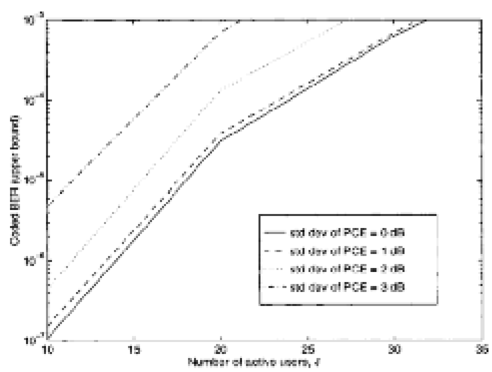

Figure 2. Upper bound on the coded BER performance of the open-loop power control scheme on a flat Rayleigh fading channel for single cell [2].

III. Integration of transmitter power control with receiver interference suppression

The simple power control approach was concerned with assigning the transmitter powers to the users optimally with the assumption that the receiver filters of the users were fixed to single user detector [5]. Multi-user detection was concerned with designing receiver filters to suppress the interference seen by each user with the assumption that the received powers of the users were fixed. The minimum mean squared error (MMSE) detector is an example of multi-user detector [7]. If the transmitter powers and receiver filters of the users are optimized jointly, the performance of a CDMA system can be improved greatly. We can use an iterative and distributed algorithm. At each iteration the receiver filter coefficients of the mobiles are updated to suppress the interference optimally and then the transmitter powers of the mobiles are determined so that each mobile creates the minimum possible interference to other mobiles while satisfying the quality of service requirements (SIR-based or BER-based). This method will require interference measurement at each receiver. It is shown that the resulting power control algorithm converges to a global fixed-point power vector where all mobiles meet their SIR-based quality of service requirements and that the linear receiver converges to the MMSE multi-user detector.

A simple measurement based adaptive power control algorithm can be implemented in a distributed manner using only local measurements to get a sample average, but the substitution of stochastic measurements does not preserve the deterministic convergence properties. The block diagram of the adaptive power control scheme is shown in Figure 3. The SIR information is obtained from RAKE receiver. Based on this information, each mobile adapts its receiver filter coefficients the MMSE detector coefficients to suppress interference and performs iterative transmitter power level adjustment for fixed filter coefficients. The convergence of this two step iteration may be slow.

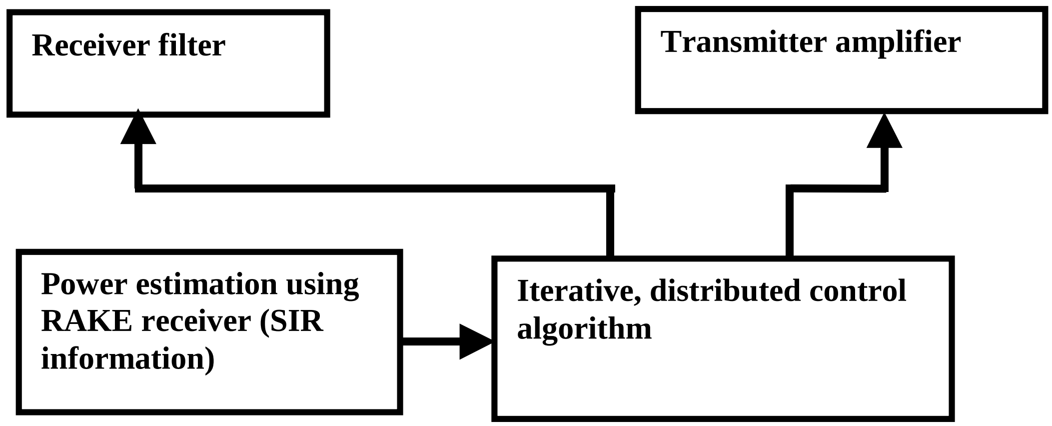

Figure 3. Block diagram of the adaptive power control scheme

The simulation results for 25 base stations are shown in Figure 4. N is the total number of mobiles. It is clear that the MMSE adaptive power control is better than the conventional power control in terms of total power and convergence rate. Using MMSE adaptive power control, the total power is less than that needed for conventional power control. The savings in total power for the same number of users are equivalent to increased capacity for the same level of SIR.

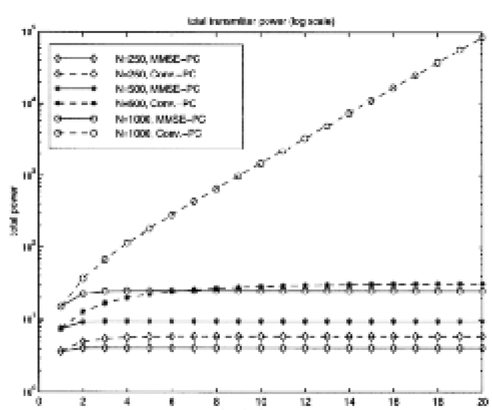

Figure 4. Total transmitter power for the conventional power control (Conv.-PC) and the MMSE adaptive power control algorithm (MMSE-PC) for N=250, 500 and 1000 [5]

IV. Implementation, simulation and synthesis

HP Advanced Design System (ADS) [8] is a new electronic-design-automation (EDA) software system that helps speed communications products to market. It provides the integrated, end-to-end signal path design solution for cellular and potable phones, pagers, wireless networks, and radar and satellite communications systems. HP ADS permits the co-simulation and co-synthesis of heterogeneous system including DSP applications and analog RF circuits. HP Ptolemy is a module in HP ADS. There are several forms of dataflow models defined in HP Ptolemy. The simulation results mentioned above were obtained through quasi-analytical approach. We intend to use HP ADS to implement the adaptive power control algorithm, RAKE receiver power estimator, adaptive MMSE receiver filters and possibly the CDMA digital and RF modulator and demodulator. More specifically, power control algorithm may be implemented in C language. RAKE receiver power estimator and adaptive receiver filter may be implemented with synchronous dataflow (SDF) in HP Ptolemy. Co-simulation and co-synthesis of this heterogeneous system can then be done within ADS. The performance of the adaptive power control may be evaluated from the results of co-simulation.

References

[1] Z. Rosberg and J. Zander, “Towards a framework for power control in cellular systems,” *Wireless Networks*, vol. 4, no. 3, pp. 215-222, Apr. 1998.

[2] A. Chockalingam, and L. B. Milstein, “Open-loop power control performance in DS-CDMA networks with frequency selective fading and non-stationary base stations,” *Wireless Networks*, vol. 4, no. 3, pp. 249-261, Apr. 1998.

[3] A. Chockalingam, L.B. Milstein, P. Dietrich and R.R. Rao, “Performance of closed-loop power control in DS-CDMA cellular systems,” *IEEE Transactions on Vehicular Technology*, vol. 47, no. 3, pp. 774-789, Aug. 1998.

[4] A. Sheikh, Y. Yao, and S. Cheng, “Throughput enhancement of direct-sequence spread-spectrum packet radio networks by adaptive power control,” *IEEE Transactions on Communications*, vol. 42, no. 2-4, pp. 884-890, Feb-Apr. 1994.

[5] S. Ulukus and R. D. Yates, “Adaptive power control and MMSE interference suppression,” *Wireless Networks*, vol. 4, no. 6, pp. 489-496, Nov. 1998.

[6] P. -R. Chang, B. -C. Wang, “Adaptive fuzzy power control for CDMA mobile radio systems,” *IEEE Transactions on Vehicular Technology*, vol. 45, no. 2, pp. 225- 236, May 1996.

[7] U. Madhow and M.L. Honig, “MMSE interference suppression for direct-sequence spread-spectrum CDMA,” *IEEE Transactions on Communications*, vol. 42, no. 12, pp. 3178–3188, December 1994.

[8] HP Advanced Design System, Hewlett Packard, *HP EEsof Division*, http://www.tmo.hp.com/tmo/hpeesof