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ภาคผนวก

บทความทางวิชาการที่ได้นำเสนอในที่ประชุมวิชาการระหว่างประเทศ
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MULTI-BIT CONSTRAINED SECOND-ORDER POWER CONTROL AND QUADRATIC EQUATION LINK GAIN ESTIMATION IN DS-CDMA CELLULAR MOBILE COMMUNICATION SYSTEMS

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Abstract

This paper presents a modified version of Constrained Second-Order Power Control (CSOPC) algorithm with Quadratic Equation link gain estimation added. The purpose of the modified algorithm is to reduce outage probability in DS-CDMA cellular mobile communication system. The simulation results show that the proposed algorithm can improve the system performance compared to the CSOPC and Signal to Interference Ratio (SIR) – based Pulse Code Modulation (PCM) power control at the same number of power control bits.

Keywords: Power Control, Link Gain Estimation, CDMA

1. Introduction

In the uplink of a DS-CDMA system, the requirement for power control is the most serious. The power control problem arises because of the multiple access interference. All Mobile Stations (MSs) in a DS-CDMA system transmit the message by using the same bandwidth at the same time and therefore MSs interfere with one another. Due to the propagation mechanism, the signal received by the Base Station (BS) from an MS close to the BS will be stronger than the signal received from another MS located at the cell boundary. Hence, the distant MSs will be dominated by the close MS. This is called the near-far effect. A solution to this problem is power control, which attempts to achieve a constant received Signal to Interference Ratio (SIR) for each MS. Therefore, the performance of the Transmitter Power Control (TPC) is one of the several dependent factors when deciding on the capacity of a DS-CDMA system.

In this paper, combining CSOPC and the link gain estimation method using a quadratic equation is proposed. CSOPC can iterate transmitted power to converge to a desired power, P_d. However, in real system, Rayleigh fading is a main factor that causes outage probability of the system high. Thus, in this paper, link gain estimation method using a quadratic equation, is proposed to reduce outage probability of the system which is mostly affected by Rayleigh fading. Quadratic equation link gain equation was used due to its rather low computational complexity.

2 Previous Power Control Schemes

2.1 PCMPC [1]

This scheme is an SIR-based multi-bit PC. The BS measures received SIR, compares with the desired SIR then generate a power control command (cmd) according to the error between received SIR and desired SIR and sends this cmd to the MS as shown in Figure 1. Pt(t) is the transmitted power of the MS, G(t) is the link gain of the reverse link and I(t) is the interference power from all other MSs in the system. The control mode n of this scheme is defined as follows. Given n is a positive integer, q=err/p where p is the power control step size, err is the difference between desired SIR and received SIR, then cmd is given by

$$cmd = \begin{cases} -n, & q > n - 0.5 \\ \lfloor 0.5 - q \rfloor, & -n + 0.5 < q < n - 0.5 \\ n, & q < -n + 0.5 \end{cases} \qquad (1)$$

where $\lfloor \cdot \rfloor$ is the floor function, i.e., if l is the largest integer less than or equal to x, $\lfloor x \rfloor = l$.

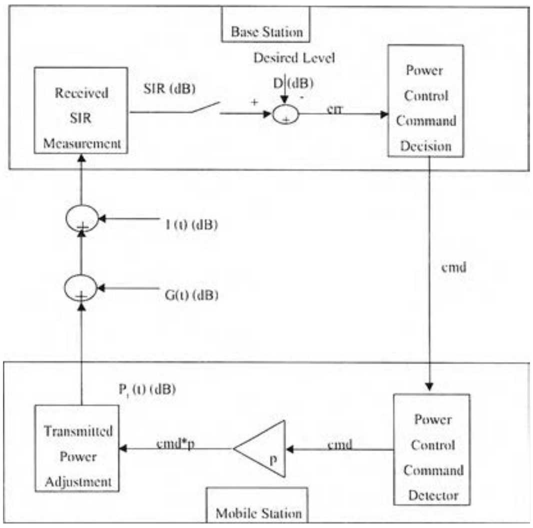

Figure 1. Block diagram of the SIR-based PCM power control scheme.

When the MS receives cmd, Pt(t) is updated by an amount of $cmd \cdot p$.

2.2 Centralized PC [2]

Centralized PC assumes that all information about all link gains is available and in one step, the maximum achievable SIR level can be computed. In fact, let

$$A = \begin{bmatrix} 0 & A_{12} & \cdots & A_{1N} \\ A_{21} & \ddots & & A_{2N} \\ \vdots & & \ddots & \vdots \\ A_{N1} & \cdots & \cdots & 0 \end{bmatrix} \qquad (2)$$

where $A_{ij}=G_{ij}/G_{ii}$, G_{ij} is link gain between BS of the ith MS to the jth MS.

$$P = \begin{bmatrix} P_1 \\ \vdots \\ P_N \end{bmatrix} \qquad (3)$$

where P_i is the transmitted power of the ith MS, N is the number of MSs in the system

The largest achievable SIR level of the system, γ^* is related to the matrix, A, by $\gamma^*=1/\lambda^*$ where λ^* is the largest real eigenvalue of matrix A. The optimal power vector, P*, achieving this maximum level is given by eigenvector corresponding to λ^*. Thus, the power control problem is reduced to eigenvalue problem. The main limitation of this scheme is the fact that it is centralized. The information of all other MSs has to be available to compute the power for a given ith MS. From a practical point of view, as the number of MSs grows, this scheme becomes computationally costly.

In feasible system [2] ($\gamma^t < \gamma^*$) where γ^t is the desired SIR level, the power vector that makes SIR of all MSs equal to the desired SIR level is [3]

$$P_d = [\frac{1}{\gamma^t} I - A]^{-1} \eta \qquad (4)$$

where $\eta_i = \frac{\upsilon_i}{G_{ii}}$, υ_i is background noise

2.3 CSOPC [3]

CSOPC can compute desired power P_d distributively. This scheme is an iterative procedure to achieve P_d. It has faster convergence speed compared to DCPC [4]. The scheme was developed by applying the successive overrelaxation iterative method [5] to the power control problem. The transmitted power adjustment made by the ith MS at the (t+Td)th time instant is given by

$$\begin{aligned} p_i^{(n+1)} &= \min\left\{p_{\max}, \max\left\{0, \omega \frac{\gamma_i^t}{\gamma_i^{(n)}} p_i^{(n)} + (1-\omega) p_i^{(n-1)}\right\}\right\} \quad (5) \\ p_i^{(t+Td)} &= p_i^{(M+1)} \end{aligned}$$

where n=1, 2, ..., M, $p_{\max}$ is the maximum transmitted power of the MS, ω is relaxation factor, $\gamma_i^{(n)}$ is SIR of the ith MS at nth iterations, γ_i^t is desired SIR, ω is a decreasing sequence. The following sequence was used

$$\omega^{(n)} = \frac{1}{1+1.5^n}, \text{ n=1, 2, ..., M} \qquad (6)$$

2.4 Intelligent Closed-Loop PC [6]

Intelligent Closed-Loop PC scheme is a fixed-step power control that does not take power control threshold into account when making its power control decision, but uses link gain estimation method at the BS for determining the adjustment of the transmitted power of the MSs.

$$G_i^{(k+1)} = a_0^{(k)} + a_1^{(k)}(k+1) + a_2^{(k)}(k+1)^2 \qquad (7)$$

where the coefficients, $a_0^{(k)}$, $a_1^{(k)}$ and $a_2^{(k)}$, are estimated from

$$\begin{aligned} G_i^{(k)} &= a_0^{(k)} + a_1^{(k)}(k) + a_2^{(k)}(k)^2 \\ G_i^{(k-1)} &= a_0^{(k)} + a_1^{(k)}(k-1) + a_2^{(k)}(k-1)^2 \qquad (8) \\ G_i^{(k-2)} &= a_0^{(k)} + a_1^{(k)}(k-2) + a_2^{(k)}(k-2)^2 \end{aligned}$$

k is the time index of loop delay, e.g. k-2, k-1 and k are refered to t-2Td, t-Td and t respectively, where t is time and Td is a period of loop delay [1]. Each MS can either increase or decrease the power by one step size (fixed-step). Hence there will be 2^N possible sets of power control command (cmd) for N MSs in a cell. For each cmd set, the transmitted power of the MS for the next period can be evaluated. Together with the estimated $G_i^{(k+1)}$, $SIR_i^{(k+1)}$ can be calculated. The BS can then choose an appropriate cmd set that satisfies algorithm with certain decision rules.

3. Proposed scheme

The proposed scheme is a modified version of CSOPC algorithm with Quadratic Equation link gain estimation added. In real system, link gain is time-varying. In [3], the BS uses the current-time link gain, G(t) to compute SIR level for calculating next-time transmitted power of the MS, Pt(t+Td), with its value converging to $P_d(t)$ by CSOPC in Equation (5).

Because link gain is time-varying, P_d is also time-varying, thus, Equation (4) becomes

$$P_d(t) = [\frac{1}{\gamma'} I - A(t)]^{-1} \eta \qquad (9)$$

The error will occur because $P_d(t)$ is according to link gain G(t) but the MS will transmit power at time t+Td. However, link gain that should be used to update the power at time t+Td, is G(t+Td) which is not according to $P_d(t)$. The transmitted power that is according to link gain G(t+Td) is $P_d(t+Td)$. The method to achieve $P_d(t+Td)$ is to estimate link gain at time t+Td, $\hat{G}(t+Td)$, by Quadratic Equations (7) and (8), calculate estimated SIR, $\hat{\gamma}(t+Td)$ and modify Equation (5) of CSOPC as

$$p_i^{(n+1)} = \min\left\{ p_{\max}, \max\left\{0,\ \omega \frac{\gamma_i'}{\hat{\gamma}_i^{(t+Td)}} p_i^{(n)} + (1-\omega) p_i^{(n-1)} \right\}\right\}$$
$$p_i^{(t+Td)} = p_i^{(M+1)} \qquad (10)$$

where n=1, 2, …, M, and computed transmitted power, Pt(t+Td), of the MS distributively with its value converging to $P_d(t+Td) \mid \hat{A}(t+Td)$, where

$$P_d(t+Td) \mid \hat{A}(t+Td) = [\frac{1}{\gamma'} I - \hat{A}(t+Td)]^{-1} \eta \qquad (11)$$

In [3], 9 iterations are performed on average to calculate Pt(t+Td). To obtain power control command bit, transmitted power of time t+Td, Pt(t+Td), is devided by transmitted power of time t, Pt(t), then this value is quantized to obtain power control command (cmd) of P bits. The BS sends cmd to the MS, the MS updates transmitted power from PC command. The block diagram of the proposed scheme is shown in Figure 2

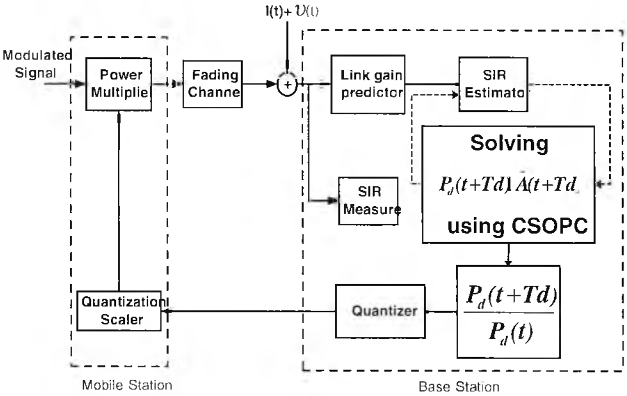

Figure 2. Block diagram of multi-bit constrained second-order power control and quadratic equation link gain estimation scheme.

I(t) is the interference power from all other MSs in the system, υ(t) is background noise. To obtain cmd in practice, upper boundary, $Q_{\max}$, and lower boundary, $Q_{\min}$ of quantization must be defined. If cmd has P bits, then there are 2^P cmd's and step size between two adjacent cmd's is $\frac{Q_{\max} - Q_{\min}}{2^P - 1}$. This cmd was sent to the MS to update its transmitted power.

4. Simulation Model

In simulations, only the reverse links in 19 cells in a DS-CDMA cellular mobile radio system were considered [1]. The MSs in these 19 cells were assumed to be randomly located with uniform distribution and with the same number of MSs, N_u, in all BSs. The radio signal at time t in the uplink of the center cell was assumed to be attenuated by a channel gain G(t) containing long-term fading, denoted by L(t), which describes the local mean signal power, and short-term fading, denoted by S(t) [7], which accounts for multipath fading. Given a transmitted power of MS as Pt(t), the received power at the BS B(t) can be obtained by

$$B(t)=Pt(t).G(t)=Pt(t).L(t).S(t) \qquad (12)$$

The long-term fading L(t) is a function as shown in Equation (13),

$$L(t) = \kappa \cdot r^{-\alpha} 10^{\frac{\xi}{10}} \qquad (13)$$

where κ is a constant, r is the distance between the BS and the MS, α is called the path loss exponent, ξ is a normal-distributed random variable with zero mean and variance σ_L^2. In simulations, let κ =1, α=4 and σ_L=8 [8]. The short-term fading S(t) is also a function with probability density function (pdf) being Rayleigh distribution as shown in Equation (14),

$$p(r) = \frac{r}{p_0} \exp\left[\frac{-r^2}{2p_0}\right] \quad \text{for } 0 \le r \le \infty$$
$$= 0 \qquad \text{for } r < 0 \qquad (14)$$

where r is the amplitude of the received signal, p_0 is the local mean power. In simulations, carrier frequency is 800 MHz, processing gain is 128, maximum and minimum transmitted power from MS is 1 and 10^{-5} watt, respectively, background noise is 10^{-10} watt. In this paper, outage probability is used as performance indicator. The outage probability for a given communication link i, denoted by P_0^i, defined as

$$P_0^i = \Pr\{SIR_i < SIR_0\} \qquad (15)$$

where SIR_i is the average SIR of the uplink i and SIR_0 is the minimum SIR required to achieve a desired bit error rate. The outage probability for the system, denoted by P_0

is defined as the average outage probability over all the in-cell links located in different positions of the center cell. P_0 is given by

$$P_0 = \frac{1}{|L_k|}\sum_{i\in L_k} P_0^{(i)} = \frac{1}{|L_k|}\sum_{i\in L_k}\Pr\{SIR_i < SIR_0\} \tag{16}$$

SIR can be expressed in terms of E_b/I_0 as

$$SIR = \frac{E_b}{I_0}\cdot\left(\frac{W}{R}\right)^{-1} \tag{17}$$

where E_b is the energy per information bit, I_0 is the interference power per hertz, R is the information bit rate and W is the channel bandwidth. In simulation, it is assumed that required performance in terms of the bit error rate is less than 10^{-3} , thus E_b/I_0 should be larger than 7 dB, using spread spectrum processing gain W/R =128 then the minimum required SIR_0 = -14 dB

A total of 500 simulation cycles was executed in the study. The number of observation periods in each simulation cycle is 600, where the measured data was collected from the last 400 observation periods to evaluate P_0.

5. Simulation Results

Figure 3 shows outage probability of PCMPC, CSOPC and the proposed PC scheme as a function of desired SIR when the number of MSs = 12 in all BSs, Q_{max} = 2, Q_{min} = 0.6 and PC bits = 5 bits. The minimum value of outage probability of CSOPC, PCMPC and the proposed PC schemes are $9.96\text{x}10^{-3}$, $1.22\text{x}10^{-2}$ and $4.95\text{x}10^{-3}$, respectively, at desired SIR = -11 dB.

The proposed PC scheme has outage probability less than CSOPC and PCMPC at most case of the number of MSs as illustrated in Figure 4. when Desired SIR = -11 dB. Q_{max}=2, Q_{min}=0.6 and PC bits=5bits.

To obtain cmd of the proposed PC scheme, appropriate number of PC bits should be investigated. Figure 5 shows outage probability of three algorithms as a functions of the number of PC bits. The results show that the sufficient PC bits is 5 bits for the proposed PC scheme. The proposed PC scheme has system performance superior to CSOPC at most case of the number of PC bits and superior to PCMPC when the number of PC bits is more than 1.

Figure 6 depict outage probability of the proposed PC scheme as a function of Q_{max}, The optimal value of Q_{max} is 2. From Figure 7, the optimal value of Q_{min} is 0.6.

In Figure 8, probability density function (pdf) of received SIR is shown. The proposed PC has pdf of the received SIR higher at desired SIR and narrower than CSOPC and PCMPC, indicating that the received SIR of the proposed PC is less variable.

6. Conclusion

The results show that the proposed PC scheme gives system performance, which is measured by outage probability, better than CSOPC and PCMPC at most case of the number of MSs and desired SIR when the number of PC bits is more than 1. To obtain cmd of the proposed PC, the optimal value of Q_{max} and Q_{min} are investigated, which are found to be 2 and 0.6 respectively. The system reliability of the proposed PC, which is measured by pdf of received SIR, is superior to CSOPC and PCMPC. Thus, when using the number of PC bits more than 1, the proposed PC scheme is shown to be an effective algorithm in controlling power in the DS-CDMA systems.

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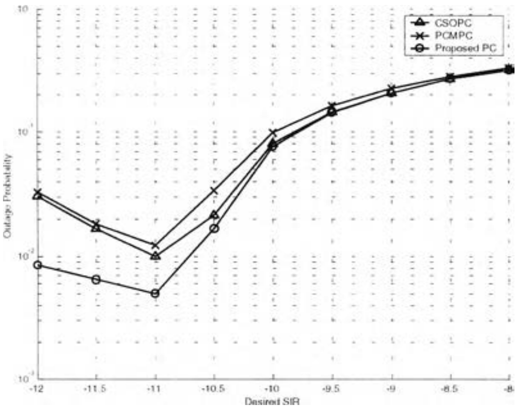

Figure 3. Outage probability of CSOPC, PCMPC and the proposed PC as a function of the desired SIR, given that the number of PC bits=5, the number of MSs=12, Q_{max}=2 and Q_{min}=0.6.

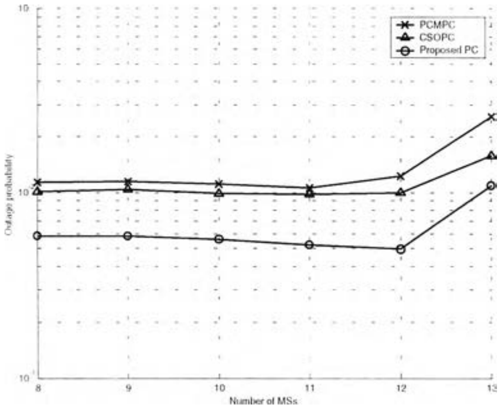

Figure 4. Outage probability of CSOPC, PCMPC and the proposed PC as a function of the number of MSs, given that the number of PC bits=5, the desired SIR= -11dB. Q_{max}=2 and Q_{min}=0.6.

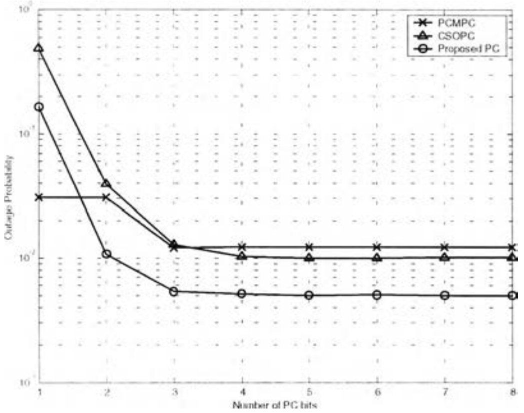

Figure 5. Outage probability of CSOPC, PCMPC and the proposed PC as a function of the number of PC bits, given that the number of MSs=12, the desired SIR= -11dB. Q_{max}=2 and Q_{min}=0.6.

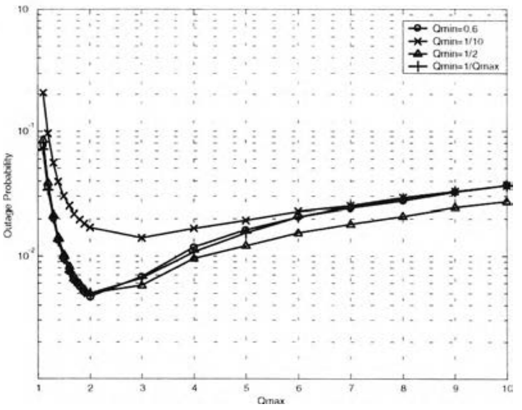

Figure 6. Outage probability of the proposed PC when Q_{min}=0.6, 1/10, 1/2 and $1/Q_{max}$, as a function of Q_{max}, given that the desired SIR=-11dB, the number of MSs=12 and the number of PC bits=5.

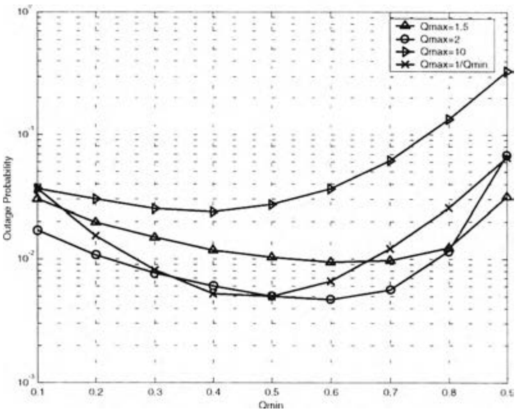

Figure 7. Outage probability of the proposed PC when Q_{max}=1.5, 2, 10 and $1/Q_{min}$, as a function of Q_{min}, given that the desired SIR=-11dB, the number of MSs=12 and the number of PC bits=5.

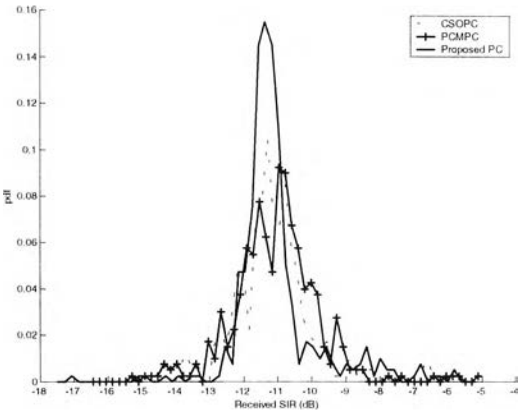

Figure 8. Probability density function (pdf) of CSOPC, PCMPC and the proposed PC as a function of the received SIR (dB), given that the number of MSs=12, the desired SIR=-11 dB, the number of PC bits=5, Q_{max}=2 and Q_{min}=0.6.

ประวัติผู้เขียนวิทยานิพนธ์

นาย เจษฎา โลหะวิวัฒนกุล เกิดวันที่ 11 มิถุนายน 2521 ที่กรุงเทพมหานคร เข้ารับการศึกษาในหลักสูตรวิศวกรรมศาสตรบัณฑิต จุฬาลงกรณ์มหาวิทยาลัย ในปีการศึกษา 2538 สำเร็จการศึกษาปริญญาตรีวิศวกรรมศาสตรบัณฑิต สาขาวิศวกรรมไฟฟ้า จากจุฬาลงกรณ์มหาวิทยาลัย ในปีการศึกษา 2541 และเข้าศึกษาต่อในหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต สาขาวิศวกรรมไฟฟ้าที่จุฬาลงกรณ์มหาวิทยาลัยในปีการศึกษา 2542