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Letter

Combined fuzzy-based power control with window-based transmission rate management in multimedia CDMA cellular systems

Young-Long Chen[a,*], Jyu-Wei Wang[b], Yung-Sheng Lin[c], Jyh-Horng Wen[d]

[a] Department of Computer Science and Information Engineering, National Taichung Institute of Technology, No. 129, Sec. 3, Sanmin Rd., Taichung 404, Taiwan
[b] Department of Photonics and Communication Engineering, Asia University, Taiwan
[c] Quanta Computer Incorporation, Taiwan
[d] Department of Electrical Engineering, Tunghai University, Taiwan

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ABSTRACT

Power control and transmission rate management play vital roles in multimedia CDMA cellular systems. To support multimedia services in CDMA cellular systems, different quality of service (QoS) requirements, such as minimum transmission rate or bit energy to interference spectral density ratio, should be set for different services. In this paper, we propose a novel scheme which combines fuzzy-based power control with window-based transmission rate management for use in multimedia CDMA cellular systems. We use window-based measurements to adjust transmission power by using fuzzy logic control (FLC) so that each service can maintain its signal-to-interference ratio (*SIR*). Simulation results show that the new proposed method outperforms the original SPC (selective power control) and LRPC (Lagrangian relaxation technique and power control) methods in various measurements, such as outage probability, average transmission rate, probability of unsuccessful transmission, and probability of changes in transmission rates.

1. Introduction

A power control mechanism is essential to any CDMA wireless communication system to combat the near–far effect and to compensate for multi-path fading. In CDMA systems the transmission rate is closely related to the received signal-to-interference ratio (*SIR*), and in general, using power control can efficiently control the *SIR*. It has been previously shown that the system capacity of any CDMA system can be significantly improved by using power control as well [1]. For feasible implementation, a two-level hierarchical power control structure was proposed in [2] to carry out the eigen-decomposition required for the *SIR*-balanced optimum power control (OPC) scheme. The algorithm discussed in [2] requires global information and, as a consequence, is usually called centralized schemes. Furthermore, those discussed in [3,4] are distributed algorithms and require only local information. In [3], a distributed fixed-step power control algorithm with single bit control command was proposed for short-term fading channels. A simple received *SIR* model was adopted to derive the sufficient conditions that ensure system stability. A distributed multi-step power control algorithm [4] was proposed for cellular systems. Extensive studies were carried out to derive the sufficient conditions that ensure system stability and to obtain the general formula for the bound of the received *SIR*. It was shown that the bound of the received *SIR* is a function of the number of power control steps, the step size, and the dead factor.

However, most of the previous studies only concentrated on the systems that have a single transmission rate. Since today's CDMA systems support multimedia services, an effective power control algorithm has to take different transmissions into account so as to achieve a higher transmission rate than a single transmission rate system.

Multimedia services are characterized by different quality of service (QoS) requirements, such as minimum transmission rates, bit energy to interference spectral density ratio (E_b/I_o), and effective transmission rates. In general, multimedia systems are able to manage such things as voice, compressed video, data, and others. Some of them require real time delivery and others require stringent bit error rate (BER) constraints. Therefore, when a power control scheme is applied to a multimedia system, it has to take different QoS requirements into account. The QoS requirements must be met, while at the same time the available bandwidth must be used as efficiently as possible.

Since delay is not a crucial measurement for non-real time services, they can be transmitted by using variable rates based on a best-effort basis. On the other hand, in CDMA systems, different transmission rates have different impacts on *SIR* s, which in turn affect the power control adjustments. This fact raises the problem

* Corresponding author.
E-mail address: ylchen@cm5.tinp.net.tw (Y.-L. Chen).

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of how to adjust both the transmission power and rates for individual users so that a higher spectral efficiency can be achieved. Therefore, a mechanism, which combines power control and rate control, is necessary in a multi-rate multimedia system. Recently, this issue has received much attention [5–8].

DS-CDMA systems may use one of the following techniques to support multi-rate transmissions. One technique uses different chip rates to achieve multi-rate transmission. Another technique spreads different transmission signals with different transmission rates over the same amount of bandwidth. This is the system considered in this paper. Although many researchers assumed the various transmission rates are real values, in practical applications, feasible transmission rates are limited to some discrete values. Thus, in this paper, we will focus on a distributed power control scheme with rates that are discrete values.

In [7,8], the authors adopted the *Lagrangian multiplier* to find the solution to the problem of combining power control and transmission rate while limiting feasible transmission rates to certain discrete values. In [8], two distributed multi-rate power control algorithms were suggested. One is based on the *Lagrangian relaxation technique*, called the LRPC method, and the other is the *selective power control* (SPC) scheme. The SPC algorithm tries to maximize the transmission rate in each communication link and may occasionally result in unsuccessful transmissions. In [9], the authors combined SPC with the active link protection (ALP) scheme to maintain a minimum transmission rate for each user while minimizing the number of rate changes by smoothing the realized *SIR* s. A problem of how to control the transmission rates for maximizing system throughput while simultaneously minimizing the transmission powers was studied in [10]. In [11], the authors proposed adaptive QoS for wireless multimedia networks using power control and smart antennas. They showed that this method significantly increases the average *SIR* levels for multimedia users.

In the fuzzy control context, to the best of our knowledge, Chang and Wang [12,13] were the first ones to apply the fuzzy logic controller (FLC) to strength-based power control. They proposed using the FLC in power control mechanisms and showed that FLC is suitable for channels with non-linear and time variant characteristics. In [14], the authors combined a fuzzy network with a neural network in a strength-based power control method, and showed that the fuzzy-neural scheme was applicable to on-line system identification and adaptive control through neural network training. However, in comparison with the *SIR*-based power control method, the weakness of the strength-based power control method is its lack of ability to meet different QoS requirements. Because all of the above-mentioned fuzzy-based algorithms consider only a fixed transmission rate, they cannot be directly applied to multimedia systems. To avoid frequently changing the transmission rates while simultaneously maximizing the system throughput, we propose in this paper a novel power control scheme, which combines fuzzy-based power control with window-based transmission rate management for multi-rate systems.

The rest of this paper is organized as follows. Section 2 describes the system model. The combined fuzzy-based power control and window-based transmission rate management method is described in Section 3. The simulation model and the results are presented in Section 4. Finally, conclusions are given in Section 5.

2. System model

In this paper, we assume that the chip rate R_c for different service types is the same and that all users are spread over the same amount of bandwidth W_s so that different processing gains can be mapped onto different transmission rates. Accordingly, with a common modulation scheme, the BER requirement for different rates of a service type s can be related to a bit energy to interference spectral density ratio $(E_b/I_o)_s$. We also assume that there are S types of services in the system, each of which has K different transmission rates. We use the notation $R_s^{(k)}$ to denote the k th transmission rate of service type s. Then, for a rate $R_s^{(k)}$, the required minimum *SIR* can be expressed as given in [14]

$$SIR_s^{(k)} = \frac{R_s^{(k)}}{W_s} \cdot \left(\frac{E_b}{I_o}\right)_s. \tag{1}$$

Obviously, an increase in the transmission rate requires an increase in transmission power and thus introduces more interference to other users.

We assume that the multimedia CDMA system consists of B cells with Q active MSs. The notation N_j represents the number of active MSs in cell j and $M_{h,j}$ denotes the MS h in cell j, where $1 \le j \le B$ and $1 \le h \le N_j$. For convenience, we map the two-dimensional expression for h th mobile in cell j, (h, j), onto a one-dimensional expression, i, as in [5]:

$$i = \sum_{t=1}^{j} N_{t-1} + h, \quad 1 \le h \le N_j, \tag{2}$$

where $N_0 = 0$. Obviously, $1 \le i \le Q$. The measured uplink *SIR* at base station (BS) i may be expressed as

$$SIR_i = \frac{P_i G_{ii}}{\sum_{j \ne i} P_j G_{ij}}, \tag{3}$$

where G_{ij} denotes the link gain from MS j to the BS that serves MS i and where P_i is the uplink transmission power from MS i.

3. Combined fuzzy-based power control with window-based rate management

We use $SIR_{i,s}(n)$ and $R_{i,s}(n)$ to denote the received *SIR* value and the transmission rate, respectively, at iteration n for service type s of MS i. We also use $SIR_{i,s}^{(k)}$ and $SIR_{i,s}^{k*}$ to denote the minimum *SIR* required and the *SIR* set point, respectively, at the k th rate for service type s of MS i. Practically, the *SIR* set point is set to $SIR_{i,s}^{k*} = SIR_{i,s}^{(k)} + D$, where D is a protection margin for the received SIR_i. If $SIR_{i,s}(n) \ge SIR_{i,s}^{(k)}$, then the transmission of service type s using the k th rate is considered to be successful; otherwise, it would not be considered successful. We assume that the feasible transmission rates for service type s of MS i are $R_{i,s}^{(1)}, \quad R_{i,s}^{(2)}, \ldots, R_{i,s}^{(K)}$, with $R_{i,s}^{(k)} = 2^{k-1} R_{i,s}^{(1)}$, for $k = 2, 3, \ldots, K$.

In Fig. 1 we show the block diagram of the proposed system. The *SIR* error $(e(n))$ and *SIR* error change $(\Delta e(n))$ are used to adjust the power and transmission rate. The major idea behind the system is to use a sliding window to average the $e(n)$ over W consecutive intervals. In addition, an FLC function is used to maintain $SIR_{i,s}(n)$. The system operation is described below.

3.1. Window-based measurement

We define the moving average of *SIR* errors over the previous W intervals as $\bar{m}_W(n) = \frac{\sum_{i=-W}^{-1} e(n+i)}{W}$, where $e(n)$ is defined as

$$e(n) = SIR_{i,s}^{k*} - SIR_{i,s}(n). \tag{4}$$