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A scheme to design power controller in wireless network systems [☆]

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Abstract

In this Letter, power control problem is firstly studied at an angle of LQG measurement-feedback control problem. A stochastic uplink power control problem is considered for CDMA systems. An effective distributed algorithm is proposed based on stochastic linear quadratic optimal control theory assuming SIR measurements contain white noise. The presented scheme minimizes the sum of the power and the error of SIR. A measurement-feedback power controller is designed by constructing an optimization problem of a stochastic linear quadratic type in Krein space and solving the Kalman filter problem for the systems.

Keywords: Power control; CDMA; Measurement-feedback; LQG; Kalman filter

1. Introduction

Power control is an important component of resource management in a cellular communication system. The aim is to assign to each user a transmitter power level so that a global quality-of-service (QoS) performance index of the system is optimized. This is particularly crucial in code division multiple access (CDMA) systems for suppression of multi-user interference. QoS can be measured in terms of the signal-to-interference ratio (SIR), the bit error rate (BER) or other quantities. Usually, for voice traffic, the QoS is specified in terms of SIR. There has been a rich literature on the topic of power control. Many approaches are proposed in various classes of power control problems that can be formulated depending on the optimization objective. In multiuser model, an early approach is called power balancing, in which the system aims at optimizing the worst-case signal quality, such as [1–3]. The algorithms used in these papers are non-iterative, synchronous and centralized, and the link gains are given a priori. However, it is an arduous task to obtain the gains in real time in a large cellular system. In practical implementations, distributed methods have been proposed by [4–6]. The computation of global information for some factors needed among users weakens the distributed nature of these algorithms. So it can accommodate estimation error in the observation. Instead of optimizing the worst-case signal quality, another approach for power control called QoS tracking [7] aims at finding a feasible solution which minimizes the power consumption. This approach has been investigated in papers [8–10], where the new algorithm developed in [10] is based on the technique of stochastic approximation, and overcomes the shortcoming of the deterministic algorithms in the above papers.

In cellular telephone systems, a discrete algorithm is more applicable in practice since transmitter power outputs are typically quantized into discrete levels. Another practical issue that needs to be addressed is measurement error, which could seriously affect the performance of the algorithm, including system stability. Recently, a new distributed fixed-step algorithm has been proposed in [11] building on the papers [6,12,13]. Under the algorithm, the SIR of each user converges to a target region, which only depends

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on the variances of the link gains and the measurement errors. It modifies the upper threshold of the target region in [6], and its convergence property is more effective than that in [10].

In stochastic framework, extensive research has been devoted to the topic, for example [14–16]. In these papers, power control for lognormal fading channels has been considered as a stochastic control problem with unbounded or bounded controls and quadratic type costs and the associated optimal control is analyzed by viscosity solutions or classical solutions of Hamilton–Jacobi–Bellman equations, and suboptimal or optimal control laws are computed using a perturbation technique. However, for systems with large population, there exists the basic limitation of computational complexity associated with this approach. Hence it is desirable to develop new techniques for obtaining simplified and efficient control laws.

An explicit and simple optimal feedback control law is developed by computing Kalman filter gains in this work. Power control problem is formulated as LQG problem and studied at an angle of LQG measurement-feedback control problem at the first time. A new power control model is proposed based on the work mentioned above. Since in practical power control problem systems are often driven by an exogenous input (driving disturbance), the rate-based power control model in [14–16] is replaced by a state equation with one control input and an exogenous input for the power adjustment of fading channels by taking into account existing wireless technology [17]. In many applications one has at most access to a certain measurement signal that is related to the exogenous input. Therefore, in our research work, we assume that measurements of SIR from SIR measurement module at a base station contain white noise and adopt the model in [18]. Moreover a performance function with minimizing the sum of mobile user's transmission power and SIR error is introduced. It makes an attempt to construct a power controller according to the past and current mobile's SIR observations, which are the only information available to the controller. Then power control problem is formulated as a linear quadratic optimal control problem, where the time-varying system is driven by white noise. A control law can be found by constructing an optimization problem of a stochastic linear quadratic type in Krein space and solving the Kalman filter problem for an associated forward Riccati recursion.

In wireless CDMA systems, the SIR is an important parameter to measure channel (link) quality. In this Letter, we assume stochastic measurements of SIR at the base station according to the SIR measurement module, implemented in both [19] and bandwidth CDMA proposed for the third generation wireless system [20]. At the base station receiver, SIR measurements are done after Rake combining. The frame structure using time-multiplexed pilots well supports SIR measurements [21].

The rest of the Letter is organized as follows. System model and cost function are formulated in Section 2. In Section 3, the power control problem is transformed to a projection problem in Krein space by solving the backward-time Krein space Kalman filter and the measurement feedback control law is computed by solving the forward-time Riccati recursions of Kalman filter. Finally, some concluding remarks are drawn in Section 4.

2. System model and cost function

In this section, power control problem is formulated as a stochastic linear quadratic optimal control problem, where the time-varying system is driven by white noise.

The stochastic SIR measurements of mobiles at time instant i at the base station can be modeled in [18] as

$$y_i = \gamma_i + v_i, \tag{2.1}$$

where y_i denotes the measurement of the SIR of the mobile at time instant i, v_i is a disturbance which can be regarded as measurement noise and a zero-mean, mutually uncorrelated stochastic process. γ_i is the actual value of the SIR.

Let x_i, $1 \leqslant i \leqslant N$, denote the transmitted power of mobiles at time instant i. We model the stepwise adjustments of the transmitted power update x_{i+1} (in dB scale) with the following equation, which takes the place of the model by the so-called rate adjustment model ($x_{i+1} = x_i + \alpha_i u_i$) in [14]

$$x_{i+1} = x_i + \alpha_i u_i + w_i, \tag{2.2}$$

where $\{u_i\}$ is the control input, α_i is a given time-varying value, $\{w_i\}$ is the exogenous input.

We denote the minimum acceptable SIR by γ, which is a prescribed value of individual SIR by the required error performance and the coding/modulation method. Recall the definition of channel variation $\sigma_i : \gamma_i = \sigma_i x_i$. The SIR error is given by $e_i = \gamma - \gamma_i = \gamma - \sigma_i x_i$.

Consider the time-variant system model formed by state–space equation (2.1) and the output equation (2.2)

$$\begin{cases} x_{i+1} = x_i + \alpha_i u_i + w_i, \\ y_i = \gamma_i + v_i, \end{cases} \tag{2.3}$$

where it assumes that the initial condition x_0 and the disturbances $\{w_i\}_{i=0}^{N}$ are zero-mean random variables with variances given by

$$\left\langle \begin{bmatrix} x_0 \\ w_i \\ v_i \end{bmatrix}, \begin{bmatrix} x_0 \\ w_j \\ v_j \end{bmatrix} \right\rangle = \begin{bmatrix} \pi_0 & 0 & 0 \\ 0 & Q_i^w \delta_{ij} & 0 \\ 0 & 0 & Q_i^v \delta_{ij} \end{bmatrix}. \tag{2.4}$$