TIME VARIANT POWER CONTROL IN CELLULAR NETWORKS

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Abstract

We study the transmission power control in a cellular network where users mobility results in a time varying gain matrix. A framework for evaluating the channel quality is specified, and an asymptotic representation of the link gain evolution in time is obtained. Then, a variant of a standard Distributed Constrained Power Control (DCPC) which copes with user mobility is derived. These two power controls, as well as constant-received power and constant-transmitted power controls are compared with respect to their outage probabilities in a Manhattan-like microcellular system. The comparison reveals that the classical DCPC algorithm has an outage probability close to one, unless some counter-measures are taken. The time variant algorithm however, copes well with users mobility and provides a close to an optimal scale up factor for the Signal to Interference Ratio (SIR) target. Furthermore, the time variant algorithm provides a substantial reduction in outage probability compared to the other algorithms above.

Keywords: PCS, Wireless, Power Control, Time Variant Gain Matrix, Mobility.

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1 Introduction

Transmitter power control has proven to be an efficient method to control cochannel interference in cellular PCS, and to increase bandwidth utilization. Power control can also improve channel quality, lower the power consumption, and facilitate network management functions such as mobile disconnection, hand-offs, base-station selection and admission control.

Power control algorithms can be sub-divided into two main classes. One is the *constant-received-power* control, where transmitters adapt their power to meet some *received power target* at the receiver. The other is the *quality-based* power control, where the transmitters adapt their power to meet some *signal quality target* at the receiver. Quality-based power control has been shown to outperform constant-received-power control [32], and it has been extensively studied for narrow-band and wide-band systems.

Centralized and distributed algorithms with *continuous power levels, non-random interferers, and Signal to Interference (SIR) quality measure*, have been developed and their convergence properties have been investigated in [1, 2, 8, 12, 13, 14, 15, 18, 22, 23, 25, 32, 33]. Distributed algorithms with *continuous power levels, random interferers, and Signal to Interference (SIR) objectives*, have been studied in [24, 27]. Distributed power control with *discrete power levels and SIR quality measure*, has been studied in [4, 31], and with *continuous power control and Bit Error Rate (BER) quality measure*, in [20]. Resource management functions combined with power control have been also investigated. A combination with *mobile admission* has been studied in [5, 9]; a combination with *base station selection* in [19, 29]; and a combination with *mobile disconnection and hand-off* in [4]. Notably is the study in [30], where sufficient conditions have been derived for the convergence of power control algorithms, which unifies most of the known converging results.

In all the studies above, it has been assumed that the **power control converges much faster compared to the changes in the link gains due to mobility**. This assumption has motivated a snapshot evaluation of the algorithms (where link gains are fixed in time), which implies an under estimation of the quality measure target. (see e.g., [6]). To compensate this under estimation, coarse over-allocation of bandwidth is being used for designing a cellular network. In future PCS environments, bandwidth would be more carefully allocated and users mobility will have a greater impact on the system performance. Hence, the snapshot analysis will not provide the desired system design parameters, and users mobility should be taken into account.

A preliminary study of time variant power control in [6], reveals that the quality measure target must be set significantly higher than the target which is determined under the snapshot assumption. The study however, does not provide any concrete rule to determine the actually required quality target. Determining this value is a primary engineering problem in power control and it is the main objective of the current paper. The authors are not aware of any previous results on this design problem.

This paper studies the "slow" power control problem in a cellular network where link gains vary in time according to a slow fading process which is exponentially correlated in time, [17]. An asymptotic representation of the link gain evolution in time is derived, and a framework to evaluate the channel quality in a time varying system is specified. In spite of the dynamic problem complexity, we derive a simple distributed time-dependent power control algorithm which successfully copes with users mobility. The algorithm enhances a previously proposed Distributed Constrained Power Control (DCPC) algorithm, [15], and requires only three additional system parameters. One is the maximum velocity of a mobile, the second is the log normal variance of the shadow fading, and the third is the correlation distance of the shadow fading. These three parameters can be a priori estimated by the system operator, therefore resulting in an algorithm that can be applied in practice.

Our numerical examples reveal that the DCPC algorithm has an outage probability close to one, unless some counter-measures are taken. One possible counter-measure is to bound the transmission power from below. Another, is to scale up the quality measure target. In the latter case, it is not clear however, with how much to scale up. The time dependent algorithm which we develop, copes with this situation and provides a close to an optimal scale up factor. The algorithm also provides a substantial improvement in the spectrum utilization compared to the DCPC algorithm enhanced with a lower bound on the transmission power, the constant-transmitted power algorithm, and the constant-received power algorithm.

In Section 2 we present the time variant system model, and in Section 3 we derive the power control algorithm. Numerical results are evaluated in Section 4, and final conclusions are given in Section 5.

2 System Model

Consider a generic channel in a cellular network which is being accessed by N transmitters, where each one of them is communicating with exactly one receiver. For the uplink case, the transmitters are the mobiles and the receivers are their corresponding base stations. For the downlink case, their roles are reversed.

When transmitter j $(1 \leq j \leq N)$ is transmitting at time t, it uses a power of $p_j(t) \leq \overline{p}_j$, where $\overline{p}_j$ is the maximum transmission power for transmitter j. Given that at time t, the link gain between transmitter j and receiver i is $g_{ij}(t)$ $(1 \leq i, j \leq N)$, the received signal power at receiver i is $g_{ii}(t)\ p_i(t)$. The interference power experienced by receiver i at time t, is $\nu_i + \sum_{j:j \neq i} g_{ij}(t)\ p_j(t)$, $(1 \leq i \leq N)$, where $\nu_i > 0$ is a time independent background noise power.

Define the Signal to Interference Ratio at receiver i at time t, $SIR_i(t)$, by

$$SIR_i(t) = \frac{g_{ii}(t)\ p_i(t)}{\nu_i + \sum_{j:j \neq i}\ g_{ij}(t)\ p_j(t)}\ , \quad (1 \leq i \leq N)\ . \tag{1}$$

The SIR is a standard measure for channel quality, which is highly correlated with its error rate. Let γ_i be the SIR target for the channel between transmitter i and its corresponding receiver. We say that channel i is *supported at time* t, if

$$SIR_i(t) \geq \gamma_i\ . \tag{2}$$

To incorporate mobility of the transmitters or the receivers (uplink or downlink), which results in time variant link gains, we have to specify the link gain processes $(g_{ij}(t) \mid\ t \geq 0)$, $(1 \leq i, j \leq N)$.

We focus on a relatively slow power control algorithms with 1-100 power updates per second. Such rates are too slow to track fast multipath fading (usually modeled by a fast time varying Rayleigh process). Hence, we assume that the multipath fading is resolved by appropriate coding and interleaving techniques. Power control algorithms with update rates of 100-10000 updates per second (which includes multipath fading) has been studied in [26].

For every time instant t, the link gain is modeled as a product of a distance dependent propagation loss, and a slow shadow fading component. That is,

$$g_{ij}(t) = L_{ij}(t) \cdot S_{ij}(t) \ . \tag{3}$$

i The factor $L_{ij}(t)$ is modeled as,

$$L_{ij}(t) = D_{ij}^{-\alpha}(t) \ , \tag{4}$$

where $D_{ij}(t)$ is the distance between transmitter j and receiver i at time t, and α is a propagation constant. The factor $S_{ij}(t)$ is assumed to be log-normally distributed with a log-mean of 0 dB, and a log-variance of σ^2 dB. That is,

$$Z_{ij}(t) \overset{\text{def}}{=} \frac{10}{\sigma} \log_{10} S_{ij}(t) \ ,$$

is the standard normal random variable.

We assume that the link gain processes are mutually independent, and the evolution of each process $(g_{ij}(t) \mid \ t \geq 0)$ is governed by the following correlated process.

Let v be the average mobile velocity, and t_0 be an arbitrary time reference. For every $t > 0$, we assume that $(Z_{ij}(t) \mid \ t \geq 0)$ is a stationary Gaussian process with an exponential correlation function given by,

$$E[Z_{ij}(t_0 + t) Z_{ij}(t_0)] = e^{-\frac{vt}{X}} \ , \tag{5}$$

where X is the effective correlation distance of the shadow fading. The parameter X is environment dependent and describes how rapid the fading correlation is decreasing as a function of distance.

From (5), we can represent the evolution of $(Z_{ij}(t) \mid \ t \geq 0)$ by

$$Z_{ij}(t_0 + t) = Z_{ij}(t_0) \cdot e^{-\frac{vt}{X}} + N_{ij}(t) \cdot \left(1 - e^{-\frac{2vt}{X}}\right)^{\frac{1}{2}} \ , \tag{6}$$

where $\{N_{ij}(t)\}$ are independent standard normal random variables. variables,

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