Time Delay Compensation in Power Controlled Cellular Radio Systems

Fredrik Gunnarsson, Fredrik Gustafsson

Division of Communication Systems
Department of Electrical Engineering
Linköpings universitet, SE-581 83 Linköping, Sweden
WWW: <http://www.comsys.isy.liu.se>
Email: fred@isy.liu.se, fredrik@isy.liu.se

5th February 2001

Report No.: [LiTH-ISY-R-2334](#)

Submitted to IEEE Communications Letters

Technical reports from the Communication Systems group in Linköping are available by anonymous ftp at the address [ftp.control.isy.liu.se](ftp://control.isy.liu.se). This report is contained in the file 2334.pdf.

Abstract

Transmission power control is an important means to manage the radio resources in wireless communications. The performance, however, may be reduced due to time delays as in any controlled system. Most controllers to date are designed without considering time delays, which may result in oscillatory or unstable systems. To overcome these problems, Time Delay Compensation (TDC) is introduced. The main idea is to adjust the measurements (e.g. SIR) to include the effects of issued but not yet applied power control commands. TDC thereby improves the stability and performance of an arbitrary power control algorithm. The benefits are illustrated by simulations using some popular power control algorithms.

Keywords: Power control, Wireless networks, Time delays, Delay compensation, DS-CDMA, GSM

Time Delay Compensation in Power Controlled Cellular Radio Systems

Fredrik Gunnarsson and Fredrik Gustafsson

Abstract

Transmission power control is an important means to manage the radio resources in wireless communications. The performance, however, may be reduced due to time delays as in any controlled system. Most controllers to date are designed without considering time delays, which may result in oscillatory or unstable systems. To overcome these problems, Time Delay Compensation (TDC) is introduced. The main idea is to adjust the measurements (e.g., SIR) to include the effects of issued but not yet applied power control commands. TDC thereby improves the stability and performance of an arbitrary power control algorithm. The benefits are illustrated by simulations using some popular power control algorithms

I. INTRODUCTION

Closed-loop power control is widely discussed as a means to maintain acceptable quality of service in cellular radio systems. The objective is to compensate for varying channel gains and to control the multiple access interference (MAI). A common strategy is to control each link individually and distributedly, based only on local information. An outer loop provides an inner loop with a target value (e.g., target SIR). The inner loop then issues transmission powers or transmission power control commands to meet this target.

This works well under ideal assumptions, but in real situations, time delays in the control loops reduce the performance. These delays are typically round-trip delays in the inner loop. As concluded in [1], the delays result in oscillative and possibly unstable systems. This in turn affect the spectral efficiency of the system [2].

In Section III in this Letter, we propose a general technique, referred to as Time Delay Compensation (TDC), to compensate for the delays. The technique can be used together with a wide range of power control algorithms, as described in a general framework in Section II. To exemplify its merits, it is applied to two popular power control algorithms in illuminating simulations in Section IV, followed by some concluding remarks.

II. SYSTEM MODEL

It will be assumed that each mobile station is connected to only one base station, and soft handover schemes are discussed in the end of Section III. Moreover, the nomenclature is settled to focus on the uplink (reverse link). However, the downlink (forward link) is treated analogously.

A. Notation

All values will be represented by values in logarithmic scale (e.g., dB or dBW). The m active mobile stations are transmitting using the powers $p_i(t)$, $i = 1, \dots, m$. Let i identify each link, so that e.g., receiver i is located in the base station to which mobile station i is connected. The signal from mobile station i to receiver j is attenuated by the power gain $g_{ij}(t)$ (< 0). Thus receiver i will experience a desired carrier power

$$C_i(t) = p_i(t) + g_{ii}(t)$$

and an interference plus noise $I_i(t)$. The *signal-to-interference ratio* (SIR)¹ at base station i is defined by

$$\gamma_i(t) = p_i(t) + g_{ii}(t) - I_i(t).$$

Processing and signaling takes time, introducing time delays in the control loops. Due to specified signaling protocols, it is relevant to describe time delays in terms of the sampling interval or power update interval. Hence, the delayed signals can be described using the *delay operator* q , defined by

This work was supported by the Swedish National Board for Industrial and Technical Development (NUTEK) and has been carried out in cooperation with Ericsson Radio Systems AB, which both are acknowledged.

¹Sometimes the term *carrier-to-interference ratio* (C/I) is used. The actual difference is whether the *processing gain* (PG) is included in the interference or not. From a dynamical point of view, this is irrelevant.

$$q^{-n}p_i(t) = p_i(t - n).$$

Assume that issued powers or power control commands are delayed by n_p samples before they take effect. Furthermore, assume that a measurement is used in the control algorithm n_m samples after it is collected (for example if the measurement is sent over the radio interface). Furthermore, the power control algorithm itself includes a processing delay of one sample. A typical situation is $n_p = 1$ and $n_m = 0$, which will be used in the simulations.

B. Power Control Algorithms

Two popular power control algorithms will be described below, together with a generic description of a general power control algorithm. In the emerging WCDMA-standards, up/down power control will be employed [3].

$$\begin{aligned} \text{Receiver:} \quad & s_i(t) = \text{sign}(\gamma_i^t(t) - \gamma_i(t)) \\ \text{Transmitter:} \quad & p_i(t+1) = p_i(t) + \Delta_i s_i(t) \iff p_i(t) = \frac{\Delta_i}{q-1} \text{sign}(\gamma_i^t(t) - \gamma_i(t)), \end{aligned} \quad (1)$$

where $\gamma_i^t(t)$ is the target value provided by an outer loop. The algorithm will be referred to as *Fixed-Step Power Control*, (*FSPC*). Taking the delays into consideration, the local dynamics of this link can be depicted as in Figure 1. A similar algorithm is the Distributed Power Control (DPC) algorithm [4], [1]

$$p_i(t+1) = p_i(t) + (\gamma_i^t(t) - \gamma_i(t)) \iff p_i(t) = \frac{1}{q-1} (\gamma_i^t(t) - \gamma_i(t))$$

Fig. 1

LOCAL DYNAMICS OF THE WCDMA UP/DOWN POWER CONTROL ALGORITHM (FSPC). THE POWER CONTROL COMMANDS MAY BE CORRUPTED, DESCRIBED BY THE DISTURBANCE $x_i(t)$. THE TIME DELAY COMPENSATION IMPLEMENTATION IS DESCRIBED BY THE PROCESS H_i .

In a general and generic setting, the issued powers or control commands depend on measurements, normally either SIR or received carrier power. These measurements, denoted $m_i(t)$, may be filtered by a filtering operation F_i (assumed additive and time-invariant). The filtered measurements (outdated by n_m samples) together with corresponding target values $m_i^t(t)$ from an outer loop are used in the control mechanism R_i (resulting in a time delay of one sample) to issue power control commands $s_i(t)$, which are sent over the radio interface. The control commands (outdated by n_p samples) are decoded by the device D_i on the transmitter side into updated transmission powers $p_i(t+1)$. Note that D_i include physical constraints, such as limited dynamic range and quantization. This generic case is depicted in Figure 2.

III. TIME DELAY COMPENSATION

The main idea is to adjust the measurements to also reflect issued commands that not yet have taken effect. In practice this involves monitoring the power to be used. This can be formalized for the generic case in the previous section as the following algorithm

Algorithm: Time Delay Compensation (TDC)

- i) Adjust measurements: $\tilde{m}_i(t) = m_i(t) + F_i\{\tilde{p}_i(t)\} - F_i\{\tilde{p}_i(t - n_p - n_m)\}$.
 - ii) Issue power control command: $s_i(t) = R_i\{m_i^t(t), \tilde{m}_i(t)\}$.
 - iii) Monitor output powers to be used: $\tilde{p}_i(t + 1) = D_i\{s_i(t)\}$.
-

Schematically, this is implemented as in Figure 2, where H_i represents the time delay compensation as described above.

Fig. 3

SIGNAL-TO-INTERFERENCE RATIO $\gamma_i(t)$ FOR THE TYPICAL CASE OF ONE SLOT DELAY WITH AND WITHOUT TIME DELAY COMPENSATION (TDC). THE TARGET VALUE IN ALL CASES IS $\gamma_i^t(t) = 12$ dB.

REFERENCES

- [1] F. Gunnarsson, J. Blom, and F. Gustafsson. Power control in cellular systems subject to constraints and time delays. In *Proc. IEEE Global Telecommunications Conference*, Sydney, Australia, November 1998.
- [2] J.H. Jr. Gass, D.L. Neneaker, and M.B. Pursley. Spectral efficiency of a power-controlled CDMA mobile personal communication system. *IEEE Journal on Selected Areas in Communications*, 14(3), April 1996.
- [3] S. Ariyavistakul. Signal and interference statistics of a CDMA system with feedback power control - part II. *IEEE Transactions on Communications*, 42(2/3/4), 1994.
- [4] G.J. Foschini and Z. Miljanic. A simple distributed autonomous power control algorithm and its convergence. *IEEE Transactions on Vehicular Technology*, 42(4), 1993.
- [5] F. Gunnarsson. *Power Control in Cellular Radio System: Analysis, Design and Estimation*. PhD thesis, Linköpings universitet, Linköping, Sweden, April 2000. Available at <http://www.control.isy.liu.se>.