# 1. Introduction

Always has communications played an important role in the history of mankind. Besides development of means of traveling, which actually can be considered to have been also the only means of data transport, it can be considered the single most efficient agent that has changed the views of vast numbers of people with methods ranging from continent-wide propaganda to very personal communications [Li95]. In the sense of reaching everybody on the globe, the modern communications is still far from being truly global but the growing commercialism requires more efficient communications technologies to keep on growing, and also the wireless communications technology itself is making itself affordable, desirable, and finally, indispensable. This technological evolution is investigated in [Sha97] and [Vit94b].

Increasing density of active cellular telephone users is a well-known problem in the field of mobile communications. With the existing systems, this has to be taken care of by network planning, and reorganizing the existing networks, for example, by reducing cell sizes in dense mobile user environments. It is well understood that a future mobile communication system should possess profoundly more user capacity in order to be successful. Direct-sequence spread-spectrum code-division multiple-access (DS/SS/CDMA) system technology is one of such new technologies which is already trying to penetrate the markets [Sch90], [Mag94]. Several differing analyses on the user capacities of CDMA systems have been conducted [Gil91], [Vit93b], [JaM94], [Lee97], [Ada96]. Although there are many opinions on the achievable user capacity increase, the importance of power control system in CDMA systems has been well established [Gil91], [Vit93a], [Sim93], [Vit95], [Vit94a], [Cam96]. It is generally accepted that the user capacity of a CDMA system is crucially interference limited, and thus the mobile power control function plays a major role in maximizing the capacity. The effects of imperfect power control are studied in [Pra92], [Kim97], and [Pri96].

The motivation for the work presented in this Thesis arises from these power control needs of mobile CDMA communications systems. In this Thesis, the power control system aims to maintain the received power levels from all the mobile users at equal and constant level at the base station receiver. This is one of the actual possible basis for the power control [Qua92]. The power control is to minimize the near-far effect [Lin92], i.e., the phenomenon that without proper power control mobiles close to the base station cause overly large interference levels to the reception of the users further away. Also, the power control systems should be able to counteract fast Rayleigh fading at least to the extend that the bit errors caused by the Rayleigh fading are randomized [Qua92], i.e., there are not many errors caused by the same long lasting and deep fade. This error randomization occurs when the mobile speed is sufficiently high, and the fades correspondingly of sufficiently short duration. Below that mobile speed, the power control systems should must be able to compensate for the fading in order to ensure sufficient transmission quality. In [Qua92], the field trials had shown that the power control, described in [Qua92], is able to compensate for fading at mobile speeds of 0 miles/h, …, 10 miles/h. At the speeds over 20 miles/h, the fades were short enough for the interleaver [Sim93] to make it possible for the Viterbi decoder [Vit95] to function properly. Within the mobile speed range from 10 miles/h to 20 miles/h, the power control system was not able to compensate for fading, nor was the errors sufficiently randomized in order to provide for good error correction performance.

Now, the aim of applying predictive lowpass filtering in a closed power control loop starts to unfold. First, the lowpass filtering itself is necessary in a systems which measures the received power level, as otherwise also much of the noise power would be accounted into the received power level estimate causing severe received power level estimation errors. Secondly, closed control loop response is always delay limited. In the loop there are several sources of signal processing delays, as well as the radio propagation delays (estimation of propagation delays, [Str96]) both ways. Thus, it would be intuitively desirable to be able to predict radio channel behavior in advance so that the control action could be taken at a correct time despite of the control loop delays. Next, as mentioned, it is not helpful to try to maintain perfect power control above a certain mobile speed. Thus, the lowpass filtering could be designed so that the power controller would actually never need to see the fading which is too fast, and unnecessary for it to compensate anyway. In *the Publications* [P1], [P2], [P3], [P4], [P5], included into this Thesis, predictive filtering methods for improving received power level estimates are proposed and simulated. The received power level estimate is a naturally essential input to any transmitter power control system, and it is expected that any improvement in the quality of the received power level estimate directly contributes to the user capacity. The methods take advantage of any polynomial-like behavior, or of statistical properties in general, of the power response of a fading transmission path. Employing predictive polynomial estimation [Hei88] or optimum power estimation by A. Huang [Hua95], [Hua96], [Hua97], [Hua98], it is possible to reduce the effects of propagation and processing delays within a closed power control loop, and at the same time delaylessly reduce both interference and noise present in the received power level estimates.

In the first publications [P1], [P2], the predictability of radio channel power responses is investigated by applying predictive filters to noisy delayed Rayleigh fading signals. The noisy delayed Rayleigh fading signals are found well predictable, and criteria for selecting the right polynomial predictors for difference environments, i.e., for different noise levels and mobile speeds, are found. Next, predictors are employed into a closed power control loop of a single user CDMA communications systems [P3]. The results from the single user system are naturally not of great practical interest but they very clearly state the definite need for filtering in general within an interference, or noise, limited power control system. Finally, the system evolves into a full multiuser simulator [P4], [P5], with 5 or 10 users. In this context, also additive white[†] Gaussian noise (AWGN) multiuser interference model simulations are performed. It is seen that with the selected Qualcomm’s power control system parameters [Qua92], the power control system is inherently very restrictive and does not leave much room for improvements from simple predictive filtering. Anyway, the results state that the closed power control loop can be fine tuned with proper predictive filtering.

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[†] Note: The terms white Gaussian noise (WGN), and additive white Gaussian noise (AWGN), used in the Thesis and in *the Publications*, refer to Gaussian noise whose spectrum is flat within a limited frequency band determined by the sampling frequency, and zero outside this frequency band. Thus, WGN, and AWGN, can be associated with a finite variance.