7. Summary of the Publications

P1 J. M. A. Tanskanen, A. Huang, T. I. Laakso, and S. J. Ovaska, “Polynomial prediction of noise shaping Rayleigh fading,” in *Proc. 1995 Finnish Signal Processing Symposium*, Espoo, Finland, June 1995, pp. 26–29.

In [P1], predictivity of delayed and noisy Rayleigh fading signals with Heinonen-Neuvo polynomial predictors of several lengths and degrees is presented in the sense of achievable SNR gains. Rayleigh fading signal generation from WGN by noise shaping, and the applied predictors, are reviewed in the paper. Two prediction schemes for complex-valued signals are presented and an appropriate complex signal SNR definition is developed. The Rayleigh fading process parameters are derived partially from a CDMA communications system point of view, and the prediction is found to be a potential tool for received fading power level estimation in CDMA power control systems. The results are shortly compared with those employing prediction of Rayleigh fading generated by Jakes’ fader. Also, the prediction of low frequency parts of the fading signals with regard to utilizing ‘slow’ fading information is considered, i.e., the signal used as the reference in SNR calculations can be band-limited. Anyway, the main emphasis in the paper is on the total fading signal prediction.

The main results of the paper are the polynomial predictor performance evaluation and H-N length and degree selection criteria for Rayleigh fading signals used at urban mobile speeds.

P2 J. M. A. Tanskanen, A. Huang, T. I. Laakso, and S. J. Ovaska, “Prediction of received signal power in CDMA cellular systems,” in *Proc. 45th IEEE Vehicular Technology Conference*, Chicago, IL, July 1995, pp. 922–926.

In [P2], the predictivity of delayed and noisy Rayleigh fading signals with Heinonen-Neuvo polynomial predictors of several lengths and degrees is presented in the sense of achievable SNR gains. Jakes’ Rayleigh fader and the applied predictors are reviewed in the paper. As compared to [P1], [P2] addresses the prediction of low frequency parts of the fading signals, whereas the emphasis of [P1] is in the complete signal prediction. [P2] thus emphasizes prediction of the frequency components of the Rayleigh fading received power level that is actually relevant to the CDMA power control function. For this, an appropriate complex signal SNR employing lowpass filtered reference signals is developed with special attention is paid to the reference signal generation. The applied H-N predictors and the complex-valued signal prediction schemes are reviewed.

The main results of the paper are the polynomial predictor performance evaluation and length and degree selection criteria for Rayleigh fading signals used. The differences between the noise shaping Rayleigh fader [P1] and the Jakes’ fader [P2] affecting the prediction are analyzed in the introductory part of this Thesis.

P3 J. M. A. Tanskanen, J. Mattila, M. Hall, T. O. Korhonen, and S. J. Ovaska, "Predictive closed loop transmitter power control," in *Proc. 1996 IEEE Nordic Signal Processing Symposium*, Espoo, Finland, Sept. 1996, pp. 5-8.

In [P3], a single user CDMA closed loop power control simulator is constructed and H-N predictive control is compared with the corresponding non-filtered reference control. The system parameters are derived from Qualcomm CDMA system parameters with some modifications to speedup and simplify simulations. In the simulator, the input to the controller is the total unprocessed complex-valued received baseband signal. The results clearly demonstrate the effect of excess noise to the operation of the closed power control loop, with the main emphasis on the noise reduction capabilities of the filter used within the closed power control loop. The prediction mechanism of the H-N predictors is present but negligible with regard to the results shown.

In [P3], the selected total closed power control loop delay, 1 chip duration, is too short to be reality. This delay as a propagation delay would mean that the cell radius would be approximately only 122 m. Still, part of the delay consist of signal processing delays.

The main result is that this kind of closed loop power control, and thus also the data transmission, fails completely under too noisy conditions unless filtering is applied. The results illustratively show the definitive deed for filtering within the closed control loop based on the total received power estimation.

P4 J. M. A. Tanskanen, J. Mattila, M. Hall, T. Korhonen, and S. J. Ovaska "Predictive closed loop power control for mobile CDMA systems," in *Proc. 47th IEEE Vehicular Technology Conference*, Phoenix, Arizona, USA, May 1997, pp. 934-938.

In [P4], complete multiuser CDMA closed loop power control simulators are constructed with 5 or 10 users, one of which is the user under observation. The users are connected to a single base station, and interfere with each others. Also, a WGN multiuser interference model is simulated. In this simulator, the input to the controller is the complex-valued received signal after despreading and integration over the bit duration. This is the main difference with the controller employed in [P3]. As the result of the integration, noise power at the controller input has already been reduced, and the predictive function of the applied H-N lowpass predictors is more pronounced. The multiuser interference is clearly apparent in the control action results shown in the paper. It is shown, that the predictive controller is capable of commanding to reduce transmitter power earlier than the non-predictive controller. BER comparisons between the predictive and non-predictive controllers give no consistent results as the mobile speed and the number of users is varied. Though, as the BERs given in the paper, are raw BERs, i.e., e.g., no error correction coding is applied, the BER difference to one direction or to the other may not have any effect on the BER performance of an actual communications system. The predictive control results in consistent reduction in transmitter power consumption, though the achieved savings are very low, actually marginal, and statistically not very meaningful. However, the control objective, minimizing the variance of the received power level is consistently a little better achieved with the predictive controller than with the non-predictive reference controller. The WGN interference model results agree with the actual multiuser interference results in most of the cases.

The main result is that the closed power control loop can be fine tuned by application of proper predictive filtering, and H-N prediction is seen to be able to slightly adjust control timing.

P5 J. M. A. Tanskanen, A. Huang, and I. O. Hartimo “Predictive power estimators in CDMA closed loop power control,” in *Proc. 48th IEEE Vehicular Technology Conference*, Ottawa, Ontario, Canada, May 1998, in press.

In [P5] two optimum predictor design methods based on the Wiener model are presented by A. Huang, and they are applied in single user, 5-user, 10-user, and AWGN interuser interference model closed power control loop simulators. Thus [P5] also offers a quick look at the actual multiuser simulator vs. the commonly used AWGN interuser interference model, as does [P4], too. Also, H-N polynomial predictors are employed as well as non-predictive power measurement based systems. The latter of which is used as the reference case. The simulation results are given in the form of achieved BERs, mobile transmitter power savings, and received power level variance reductions. The reduction of the received power level variance, or the variance of the user’s channel output power, is the actual control variable whose quality is the main motivation behind the whole research work presented since the CDMA communications system capacity is greatly dependent on the power control system’s capability of providing for equal and constant power levels at the base station receivers from all individual mobile users.

The single user results very clearly show the need for (predictive) filtering in this type of power controllers, as also concluded in [P3]. The multiuser simulation results show that even though the simulated power control system is inherently very restrictive, it is possible to fine tune the closed power control loop by application of proper predictors.