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PREDICTIVE CLOSED LOOP POWER CONTROL FOR MOBILE CDMA SYSTEMS

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Abstract—In this paper, a predictive closed power control loop for mobile communication systems is simulated employing actual multiuser interference. The system parameters are derived from those used in a CDMA system uplink transmission at urban mobile speeds. It is shown by COSSAP (Communications Simulation and System Analysis Program of CADIS GmbH, Germany) simulations that when the estimates of the received power level are noisy, and the control loop response is inherently delay-limited, predictive lowpass filtering can be applied to improve the received power level estimates and overall system performance. In this paper, comparative bit error rate, relative transmitter power consumption, received power level estimate behavior and power control action simulation results between a predictive and a conventional control scheme are presented.

I. INTRODUCTION

As the CDMA systems are inherently interference limited, it is of paramount importance to keep the transmission power of each mobile user as low as possible [1]. This is crucial in the uplink transmission (from mobile to base station), where all the mobile units need to be controlled by the base station to keep the *received power level* from each mobile unit constant in the average. The need for power control has been widely studied, and the capacity of a CDMA system is found to greatly depend on the power control function [1], [2]. In this study, the mobile transmitter power control, used to counteract Rayleigh fading, is achieved through a closed power control loop for which it is necessary to estimate the received power level.

The function of predictive filtering is twofold: to predict future values of the power signal, and to reduce the additive noise and interferences corrupting the power signal. An additional requirement in a control application like this is that the control loop should remain *stable* in all conditions; this sets explicit requirements for the predictive filter as well.

The simulator is described in detail in Section II. The simulation results are given in Section III, and the main results are shortly summarized in Section IV.

II. CLOSED LOOP POWER CONTROL SIMULATOR

To clearly demonstrate the effects of the predictive power controller, other simulator components are kept as simple as possible. Thus, no corrective coding nor interleaving is used, for example. The simulator applies complex lowpass equivalent signal presentation. Simulation parameters are derived from those presented for the Qualcomm CDMA system in [3]. Some parameters are adjusted for simulation purposes. Both data and spreading code are random binary sequences produced by maximum length shift registers with periods of $2^{31}-1$ and 127, respectively. 127 is also the number of chips per bit, while the Qualcomm system uses 128 chips per bit [3]. To further simplify the simulator, the same spreading code is used for both in-phase and quadrature components. The carries frequency is 1.8 GHz and the chip frequency 1.2244 MHz, as in [3]. In our simulator, the sampling rate is one sample per chip. To clarify the power control effects, and to reduce simulation execution time, the power control frequency is double that given in [3]. In our simulator, transmission power is controlled every 6 bits, resulting in a power control interval of approximately 0.6 ms. At each control instant, the transmission power is either increased or reduced by 1 dB, which is also one of the possible settings in the Qualcomm system. A single user simulator module with the interference summation point is depicted in Fig. 1.

In the simulations, there are altogether 5 or 10 users which are connected to a common base station and interfere with each other. All the users are identically power controlled but have different data and spreading code initializations. All the other interfering users have their total control loop delay set to 2 chip durations, while the observed mobile experiences a total control loop delay of either 2, 50 or 127 chip durations. Mobile speeds v_i, i=1, …, 9, of the interfering users are set to $v_i=i\cdot 5$ km/h, in the 10 user simulations, and to $v_i=i\cdot 10$ km/h in the 5 user simulations. The observed mobile is moving with the speed of 10 km/h or 30 km/h. The average fading power in the radio channels of all the users is set to unity, i.e., if the transmitter was set to constant unity transmission level, the received signal would have unit average. In all simulation runs 100000 bits are transmitted and received. Also, a white Gaussian noise (WGN) interference model is used. The complex interfering WGN is zero mean with component variance set to 1 or 5.

A. *Transmitter Model*

The transmitter applies differential encoding and binary phase shift keying (BPSK) to the data before applying the spreading code. This naturally leads to all real transmitted signal, but the simulator still employs full complex baseband signal presentation. In this study, the effects other than those of power control, are minimized, though. Also, the additive noise is always complex-valued. Next, the transmitter power is set by multiplying the chip sequence by a power control multiplier. Nominally, the powers of both in-phase and quadrature components are set to unity.

After each power control interval, a new power control multiplier is calculated according to the previous power control multiplier and the power control bit B_c received from the power controller in the base station. Subscript c is the control period index. When the received power control bit is "1", the previous transmitter power control multiplier is decremented by -1 dB, and in the case of a power control bit "0", incremented by +1 dB:

$$p_{trans,c}(n) = \begin{cases} p_{trans,c-1}(n-1) \cdot 10^{-1/20}, & \text{when } B_c = 1 \\ p_{trans,c-1}(n-1) \cdot 10^{1/20}, & \text{when } B_c = 0 \end{cases} \quad (1)$$

with $p_{trans}(n)$ within the limits

$$\left(10^{-1/20}\right)^{15} \le p_{trans}(n) \le \left(10^{1/20}\right)^{15}, \quad (2)$$

i.e., the overall dynamic range is set to ±15 dB from the nominal transmitter level. In the beginning of the transmission, the transmission level is set to $p(0) = -15\,\text{dB}$ from the nominal transmission level. In the transmitter, the transmitter power setting is monitored.

In the transmitter, the normalized transmitter power setting is monitored, and cumulative transmitter power setting over each complete simulation run is used as a measure of relative transmitter power consumption.

B. *Radio Channel Model*

In the channel, Rayleigh fading is applied to the transmitted signal [4]. The average fading power is set to 0 dB in all the users' channels. Complex additive white Gaussian noise (AWGN) of component variance 0.05 is added to simulate receiver noise. Also, identically power controlled interfering users are added after the user's fading is applied. All the users receive interference from all the other users through the interfering users' fading channels, i.e., all the users are connected to the same base station. On the other hand, also WGN interference approximation is simulated. The WGN is added in the channel after the fading has been applied. In the radio channel model, the channel power response is monitored along with the channel output variance. This monitoring is done after the fading is applied but before adding the interference.

C. *Receiver Model*

Receiver model is exactly synchronized, and the spreading code is perfectly known. The receiver correlates the correct spreading code with the received signal, and integrates the despread signal over the bit period, after which BPSK decoding and differential decoding are applied. Achieved bit error rate is recorded using the knowledge of the actual transmitted data. From the receiver, the despread and integrated, but not yet differentially decoded, signal is fed to the controller as the input.

D. *Power Controller Model*

The control is based on the estimated received signal power level originated from the mobile being controlled. The aim of the controller is to maintain the desired received power level irrespective of the fading and interference. It is assumed that the power control and data modulations of the received signal can be completely removed in order to obtain a predictable radio channel estimate which is then scaled by the number of chips per bit. The prediction is independently applied to the in-phase and quadrature components of this estimate. After prediction, the transmitter power level

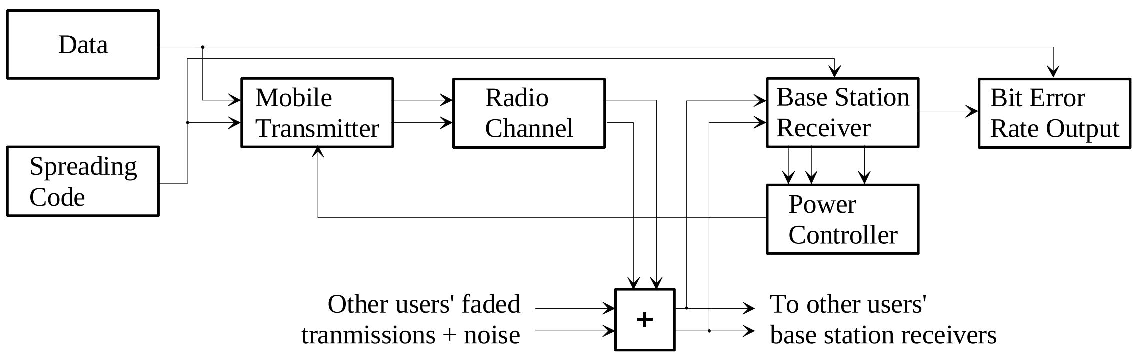

Fig. 1. Block diagram of a single user simulator module. In the other users, different data and spreading code initializations are used. The transmitted signals are added together after the application of mobile specific fading in the radio channel, and total signal is fed to all the receivers.

information is restored by multiplying the predicted chip components with the corresponding transmitter power level setting. Signal power is calculated by computing the sum of squared in-phase and quadrature components, the power is integrated over the control period in bits, and scaled by the number of bits in a control period. This presents the predictive estimate $\hat{p}_{rec}$ (3) of the average signal power originating from the particular user's mobile transmitter. The scalings are performed in order to be able to set the desired signal threshold level to unity. The power control command bit is send to the mobile transmitter accordingly.

$$\hat{p}_{rec,c} = \frac{1}{M}\sum_{m=1}^{M}\left[p_{trans}(n)\sum_{k=1}^{K}h(k)\frac{x_i(n-k)}{p_{trans}(n-k)} + p_{trans}(n)\sum_{k=1}^{K}h(k)\frac{x_q(n-k)}{p_{trans}(n-k)}\right]^2 \quad (3)$$

where n is the bit time index, M the number of bits per control interval, $p_{trans}(n)$ the transmitter power level setting, $h(k)$ the coefficients of the predictive finite impulse response filter, and x_i and x_q the in-phase and quadrature components of the controller input from which the power control and data modulations have been removed, respectively. $\hat{p}_{rec,c}$ is calculated once in a control period. The control bit to be send is calculated by thresholding the received power level estimate

$$B_c = \mathrm{t_c}(\hat{p}_{rec,c}), \text{ with } \mathrm{t_c}\left(\hat{p}_{rec,c}\right) = \begin{cases} 1, & \text{when } \hat{p}_{rec,c} \geq 1 \\ 0, & \text{when } \hat{p}_{rec,c} < 1 \end{cases} \quad (4)$$

The reference controller is exactly identical with the described predictive controller, except that the predictors are omitted.

E. *The Predictor*

The first degree lowpass Heinonen-Neuvo polynomial predictor [5] of length 15, analyzed in [6], is used in this study. It is to be noted that this particular predictor may not be the optimum choice for the application, but is selected for ease of implementation, and existence of optimized closed form coefficients for exact prediction of polynomial signals in white Gaussian noise [5]. From [6] it is seen that the predictor of the selected degree and length is a reasonable compromise with the simulation parameters used also in this paper. Also, as FIRs, these predictors are naturally stable. At urban mobile speeds, the Rayleigh fading can be accurately modeled as piecewise polynomial, and the power control loop accuracy is inherently delay limited.

III. SIMULATION RESULTS

In [7] it was clearly shown by simulations that predictive filtering could successfully be used in a single user system in which the power control was performed based on the total received power. The predictive low-pass filtering made it possible for the controller to function appropriately under such input noise conditions that the non-filtering controller failed completely. Even though controlling the transmitter power as per user is naturally very different, as it requires the computation of the particular user's received bit energy before the prediction can be applied, the results encouraged to extend the research to actual multiuser simulations presented in this paper.

A. *Behavior of the Received Power Level Estimate and the Transmitter Power Level Setting*

A control action plot of a half a second is shown in Fig. 2, in which channel power response, received power level estimate, i.e., the control variable, and the transmitter power level setting are plotted from a 10 user simulation with the non-predictive reference controller with the total control loop delay set to 2 chip durations. It is seen from Fig. 2 that always once and a while the control dynamics is not sufficient for maintaining the received power level estimate close to the unit level. With the predictive controller, this figure remains very much the same, except in some occasions the transmitter power level setting is reduced one control period earlier, or increased one control period later than with the non-predictive controller. The earlier power level reduction results in lower received power level estimate peaks, but on the other hand the delayed power level increase results in a slightly faster collapse of the received power level estimate. Almost exactly the same behavior is observed with the total control

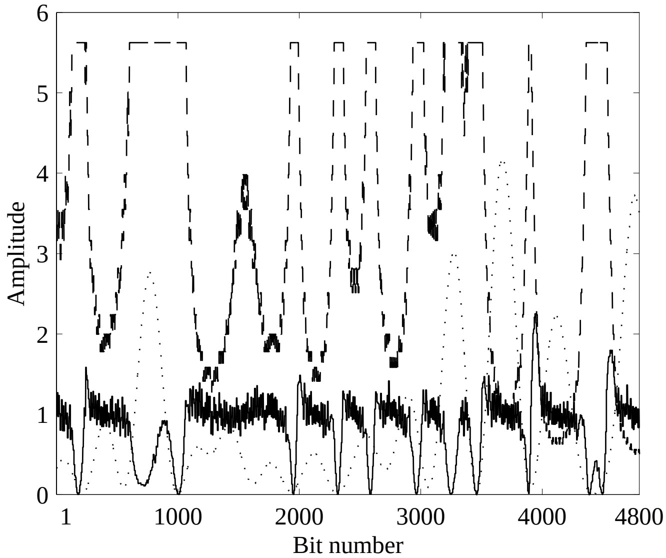

Fig. 2. A plot of a half a second of channel power response (dotted), received power level estimate (solid) and mobile transmission level setting (dashed). Speed of the mobile observed is 10 km/h, its total loop delay 2 chip durations, and the controller is non-predictive.

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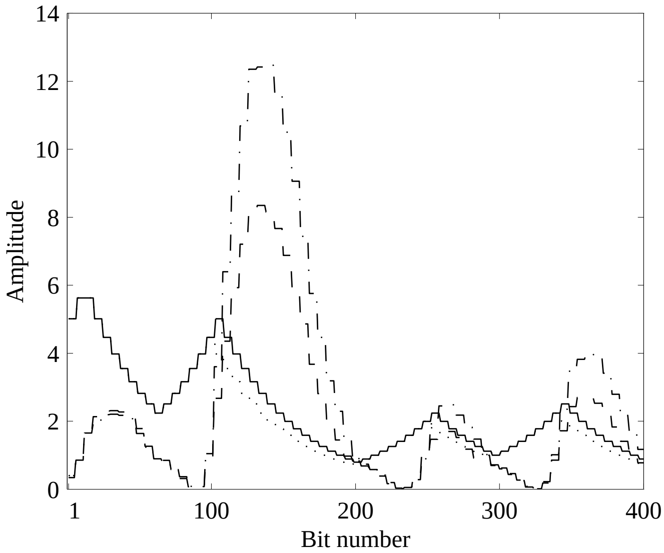

Fig. 3. A plot of the received power level estimates using the predictive (dashed) and the reference (dash-dot) controllers, along with the transmitter power level setting with the predictive (dotted) and the reference (solid) power controller. Speed of the observed mobile is 30 km/h and the total control loop delay is 127 chip durations.

loop delays of 50 and 127 chip durations. The observed mobile moving at 30 km/h, the control fails almost complete, regardless of the total control loop delay, and the received power level estimate oscillates violently for most of the time. Still, the timing changes of the transmitter power level changes remain similar to those observed at the lower mobile speed, resulting in more pronounced decrease of the peaks in the received power level estimate, Fig. 3.

Very similar results are visible in the simulations using the WGN interference model. With 5 users in the system, there is little difference in the received power level estimates and the transmitter power level settings between the reference and the predictive systems.

B. *BER*

A little surprisingly, application of the prediction does not have much effect on the achieved bit error rates, given in Table 1, for the total control loop delay of all the users set to 2 chip durations. Varying the delay also makes little difference. The same simulations were run with the total power control loop delays of 50 and 127 chip durations, and the BER results differ at most by $0.1\cdot10^{-3}$ from those given in Table 1.

C. *Power Consumption*

In all the cases with actual multiuser interference, cumulative power consumptions are consistently a little lower when employing predictive received power level estimation, though the improvement is actually only marginal. Employing the WGN interference model, power consumptions of the predictive systems are equal or a little higher than those with the reference system. The power savings are listed in Table 2 for the cases also mentioned in Table 1.

D. *Channel Output Variance*

Although the variance of the user's radio channel output is not the variable that is actually controlled, it directly affects the interference experienced by the other users. The channel output variance is calculated after the fading has been applied but before adding the interference. The variance reductions achieved though applying the prediction are listed in Table 3. From Table 3 it is seen that in most cases the channel output variance is reduced by 2 % - 3 %.

Table 1. BERs from the simulations of 100000 bits with the total control loop delay of 2 chip durations.
In the WGN interference simulations the mobile speed was 10 km/h.

Controller	5 users, 10 km/h	5 users, 30 km/h	10 users, 10 km/h	10 users, 30 km/h	noise interf., var = 1	noise interf., var = 5
reference	$7.6\cdot10^{-3}$	$13.6\cdot10^{-3}$	$5.2\cdot10^{-3}$	$9.5\cdot10^{-3}$	$9.6\cdot10^{-3}$	$22.8\cdot10^{-3}$
predictive	$7.6\cdot10^{-3}$	$13.6\cdot10^{-3}$	$5.1\cdot10^{-3}$	$9.6\cdot10^{-3}$	$9.6\cdot10^{-3}$	$22.6\cdot10^{-3}$

Table 2. Power savings achieved employing the prediction from the simulations with the total control loop delay of 2 or 127 chip durations. In the WGN interference simulations the mobile speed was 10 km/h.

Loop delay	5 users, 10 km/h	5 users, 30 km/h	10 users, 10 km/h	10 users, 30 km/h	noise interf., var = 1	noise interf., var = 5
2 chips	0.3 %	1.3 %	0.3 %	1.3 %	0.3 %	-0.4 %
127 chips	0.2 %	1.1 %	0.3 %	1.2 %	0 %	-0.6 %

Table 3. Channel output variance reductions achieved by applying the prediction.
In the WGN interference simulations the mobile speed was 10 km/h.

Loop delay	5 users, 10 km/h	5 users, 30 km/h	10 users, 10 km/h	10 users, 30 km/h	noise interf., var = 1	noise interf., var = 5
2 chips	4.0 %	2.3 %	-0.2 %	4.1 %	3.2 %	3.3 %
127 chips	1.8 %	3.2 %	0.2 %	4.5 %	2.2 %	0.0 %

IV. CONCLUSIONS

In this paper, it is shown by simulations that the predictive filtering can be successfully applied to the as pre user received power level based closed loop power control. The results show that in most cases transmitter power consumption may be slightly reduced, and the channel fading is slightly better counteracted with the predictive control, while maintaining the same BER as with the non-predictive control. The lower transmitter power and improved control functionality naturally results in lower interference to the other users, and thus the system capacity may be increased, though most of the results achieved employing the methods presented in this paper may be considered marginal. Considering the fixed power control dynamics and the duration of the delays as compared to the power control period and fading rate, and that the received signal is anyway integrated over hundreds of chips before making power control decisions, it actually feels natural that this kind of simple prediction scheme can help only a little. On the other hand, the cost of applying the predictive filtering is very small.

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