# Effect of Imperfect Power Control on Performance of a PN Code Tracking Loop for a DS/CDMA System

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## ABSTRACT

In this paper, effect of imperfect power control on performance of a pseudonoise (PN) code tracking loop is analyzed and simulated for a direct-sequence/code-division multiple access (DS/CDMA) system. The multipath fading channel is modeled as a two-ray Rayleigh fading model. Power control error is modeled as a lognormally distributed random variable. The tracking performance of DLL (delay-locked-loop) is evaluated in terms of tracking jitter and mean-time-to-lose-lock (MTLL). From the simulation results, it is shown that the PN tracking performance is very sensitive to the power control error.

## I. INTRODUCTION

DS/CDMA (direct-sequence/code-division-multiple-access) is a promising technique for mobile and personal communication systems because of anti-interference, random access capability, and increased capacity etc. To exploit the advantages of a DS/CDMA technique, a CDMA receiver must synchronize a locally generated pseudonoise (PN) code with the incoming one [1]. The synchronization of a DS/CDMA system consists of two steps: acquisition (coarse alignment) and tracking (fine alignment). PN tracking is necessary to detect the timing with maximum energy. PN code tracking in a multipath fading channel is a critical issue in the design of DS/CDMA receivers since the service disconnection can be caused by the failure of code tracking [2]. This situation results in reducing the channel utilization, which corresponds to capacity decrease of mobile communication system.

Power control is a major design criterion in a DS/CDMA system for two reasons: 1) to make received power less dependent on fading and shadowing, and 2) to combat near-far problem and cochannel interference. A number of power control schemes have been proposed to minimize the effects of fading, shadowing, and near-far problems. In a power control scheme, the transmitted power from all mobile stations is adjusted such that all signals are received with equal power at the base station. In the most previous researches on the CDMA, perfect power control has been assumed by employing the adaptive power control. However, the field test on a CDMA performance demonstrates that a power control error determined by lognormal distribution is more realistic in the practical case. The effect of imperfect power control on PN acquisition performance has already been considered. However, the impact of power control error and shadowing on PN tracking performance has not been taken into account so far.

In this paper, the performance of noncoherent first-order DLL (Delay-Locked-Loop) is analyzed and simulated for a DS/CDMA system with imperfect power control in a multipath fading channel. The multipath fading channel is modeled as a two-ray Rayleigh fading model that is typically applied to land mobile communication environment. The performance of DLL is evaluated in terms of tracking jitter and mean-time-to-lose-lock (MTLL) [3,4]. In a DS/CDMA system, the signal can be degraded or distorted by multipath fading, shadowing, imperfect power control, and MAI (multiple access interference) etc. For effective and reliable PN tracking, the combined effect of above factors is considered in the analysis of PN tracking performance. The imperfection of power control system is well modeled by the logarithmic standard deviation of the lognormal power distribution of the received signal.

The rest of the paper is organized as follows: In Section II, PN tracking model is described in the two-ray multipath fading model. In Section III, the PN tracking performance of DLL is in terms of tracking jitter and MTLL. In Section IV, simulation results are presented and, finally, the conclusions are drawn in Section V.

## II. SYSTEM MODEL

In a noncoherent first-order DLL shown in Fig. 1, the received signal is first correlated with locally generated early and late PN sequences, that is, $c(t-\hat{\tau}_1+\Delta T_c)$ and $c(t-\hat{\tau}_1-\Delta T_c)$. Then the error signal is obtained by bandpass filtering, squaring, and differencing the correlator outputs. The loop is closed by lowpass filtering of the error signal and the output of loop filter is used to drive voltage control clock (VCC). The output of VCC is used to correct the code phase error of local PN code. The parameter $\Delta$ $(0<\Delta<1)$ is called the early-late *discriminator offset*. The acquisition unit continually adjusts the phase of the local code until the incoming and local are aligned, so that the code phase error is within the permissible range ($\varepsilon_{\min,}\varepsilon_{\max}$).

For a PN tracking loop, this permissible range is usually the range of the discriminator characteristic or S-curve. The code phase error is defined as the normalized phase difference between the incoming and local codes and given by [5]

$$\varepsilon(t)=\frac{[\tau_1(t)-\hat{\tau}_1(t)]}{T_c}, \qquad (1)$$

where $\tau_1(t)$ and $\hat{\tau}_1(t)$ are the phases of the incoming and local codes, respectively, and $T_c$ is a chip duration.

## III. PERFORMANCE ANALYSIS

In the analysis of PN tracking performance, the followings are assumed: 1) data sequence, spreading sequence, and AWGN are mutually independent, 2) tracking boundaries are absorbing, 3) individual tracking process is statistically identical, 4) both reverse and forward links suffer from identical shadowing, and 5) mobile user estimates signal strength by measuring pilot signal and controls its transmission power. For the multipath in terms of primary and dominant interfering rays.

In the most previous researches on the PN tracking loop, perfect power control ($P_k=P$, $(1\le k\le K)$ has been generally assumed by employing adaptive power control. However, the field measurements on CDMA performance demonstrate that a power control error determined by lognormal distribution is more realistic in the practical operating environment. The probability density function *(p.d.f).* of received signal power is modeled by [6-8]

$$f(P_k)=\frac{1}{\sqrt{2\pi}\sigma_P P_k}\exp(-\frac{\ln^2 P_k}{2\sigma_P^2}), \qquad (2)$$

where $\sigma_P$ is the logarithmic variance and $P_k$ is assumed to have logarithmic mean of zero.

The major factors affecting the received signal power are the distance and shadowing loss. The received power at the base station for the $kth$ user is given by

$$P_k=P_0 d_k^{-\varsigma}\cdot 10^{\xi_k/10}, \qquad (3)$$

where $P_0$ is a constant which depends on the parameters of transmitter and receiver, $d_k$ is distance between the $kth$ mobile user and base station, $\varsigma$ is path loss exponent, and $\xi_k$ is a random variable corresponding to shadowing and power control error which is lognormally distributed with standard deviation of $\sigma_s$ dB and $\sigma_P$ dB for shadowing and power control error, respectively.

Then, the received signal at the receiver in a two-ray fading model is given by

$$\begin{aligned}r(t)&=\sum_{k=1}^{K}\sqrt{2P_{k,1}}g_{k,1}a_k(t-\tau_{k,1})c_k(t-\tau_{k,1})\cos(2\pi f_c t+\phi_{k,1})\\&+\sum_{k=1}^{K}\sqrt{2P_{k,2}}g_{k,2}a_k(t-\tau_{k,1}-\tau_{d_k})c_k(t-\tau_{k,1}-\tau_{d_k})\cos(2\pi f_c t+\phi_{k,2})+n(t)\end{aligned} \qquad (4)$$

where $\tau_{d_k}=\tau_{k,2}-\tau_{k,1}$ is delay difference between the first and second paths, $g_{k,i}$ is a path gain with Rayleigh distribution, $\tau_{k,1}$ is propagation delay of the first path of the $kth$ user, $\phi_{k,1}$ is carrier phase offset of the first path, $\phi_{k,2}=\phi_{k,1}-2\pi f_c\tau_{d_k}$, and $n(t)$ is AWGN with power spectral density $N_0/2$. The $\phi_{i,1}$ and the $\phi_{i,2}$

($i = 2,\cdots,K$) are *i.i.d.* (independent identically distributed) random variables uniformly distributed in [0, $2\pi$], and $\tau_{i,1}(i = 2,\cdots,K)$ are *i.i.d.* random variables. Therefore, $\tau_{1,1}$ is the time delay to be tracked by the tracking loop. The decision statistic of reference user is given by

$$Z_1 = D + I_1 + I_2, \tag{5}$$

where $D$ is the sum of desired user's component and self-interference, $I_1$ is the MAI component, and $I_2$ is AWGN component.

Since the *p.d.f.* of MAI and self-interference is difficult to obtain, the DS/CDMA system analysis has been evaluated using approximations. The effect of AWGN, MAI, and fading is incorporated into analysis of PN tracking performance simply by increasing variance of interference. For MAI modeling in this paper, Gaussian approximation is employed. The variances of $I_1$ and $I_2$ are derived. We adopt the results for variances of to find the PN tracking performance.

The overall discriminator characteristic is shown in Fig. 2, and given by [9]

$$C(\varepsilon) = C_s(\varepsilon) + C_i(\varepsilon), \tag{6}$$

where $C_s(\varepsilon)$ is desired discriminator component and $C_i(\varepsilon)$ is interference discriminator component due to the effect of the second path. The overall discriminator characteristic in a two-ray multipath fading channel is shown in Fig. 2. When there is a multipath effect, there may not exist the linear region near $\varepsilon = 0$. In this case, the nonlinear analysis is more appropriate than the linear approach for analyzing the tracking performance.

## IV. SIMULATION RESULTS

For simulation examples, the binary non-return-to-zero (NRZ) pulse for a chip pulse shape, path loss exponent $\varsigma$ = 4, chip rate = 1.2288 Mcps (IS-95 CDMA system specification), processing gain = 128, carrier frequency $f_c$ = 900MHz, the number of user $K$ = 15, the number of multipath = 2 (*i.e.* two-ray multipath fading model), and Doppler frequency $f_D = f_c v / c$ = 30 Hz ($c$ is speed of light and $v$ is vehicle speed) are assumed. The ideal BPF is used with cutoff frequency of $R_b (= 1/T)$.

In the simulations of the power control scheme, 1) power control step size of 1dB is used, 2) feedback power control scheme is employed with power control feedback delay (the delay from when power control command is sent to when power is adjusted). It is also assumed that there is a very accurate acquisition unit in a DS/CDMA synchronization block, and boundary absorption occurs at $\varepsilon(t) = \pm 1$ where $\varepsilon(t)$ is the phase difference between the incoming and local PN sequences normalized by chip duration.

In Fig. 3, tracking jitter vs. discriminator offset is shown for varying standard deviation of power control error. It is shown that the tracking jitter becomes larger with the discriminator offset. It is also shown that power control error substantially degrades the tracking jitter performance. As the power control error becomes larger, the performance degradation becomes higher.

In Fig. 4, MTLL vs. discriminator offset is shown for varying standard deviation of power control error. It is shown that MTLL becomes larger with the discriminator offset. It is shown that the MTLL performance is also severely degraded by power control error. The degree of MTLL performance degradation becomes higher with the power control error.

## V. CONCLUSIONS

The PN code tracking performance of the noncoherent first-order DLL was evaluated for a DS/CDMA system with imperfect power control in a multipath fading channel. It is shown that large power control error substantially degrades the PN tracking performance. Therefore, it is concluded that a very accurate power control scheme is required to compensate for fading and shadowing. In this paper, the IS-95 CDMA system parameters are mainly employed. In the future simulations, the wideband-CDMA system parameters will be considered for applications to IMT-2000 system. The extension of analysis to higher-order loop models is very straightforward. The results of this paper can be applied to the design of a PN code tracking loop for a DS/CDMA system.

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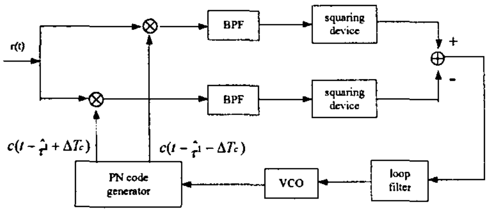

Fig. 1. Block diagram of PN code tracking loop.

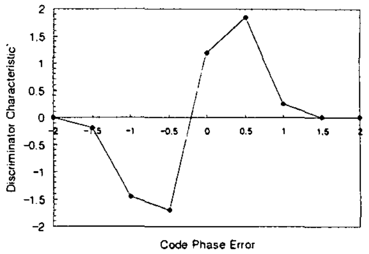

Fig. 2. Discriminator characteristics in a multipath fading channel.

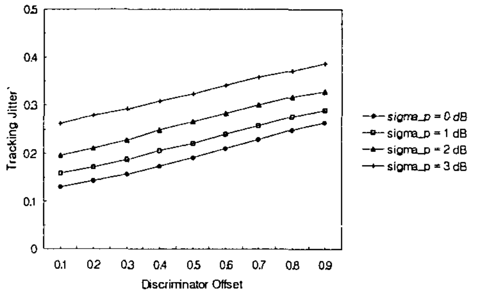

Fig. 3. Tracking jitter vs. discriminator offset for power control error.

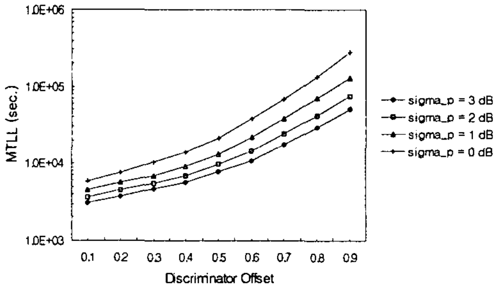

Fig. 4. MTLL vs. discriminator offset for power control error.