Proceedings of **ITC-CSCC 2000**, Pusan, Korea

Performance of PN Code Tracking Loop for a DS/CDMA System with Imperfect Power Control and Shadowing

Jin Young Kim, Ph. D.

Central Research and Development Center,
SK Telecom,
9-1, Sunae-dong, Pundang-gu, Sungnam City
Kyunggi-do 464-020, Korea

ABSTRACT

In this paper, performance of a pseudonoise (PN) code tracking loop is analyzed and simulated for a direct-sequence/code-division multiple access (DS/CDMA) system with imperfect power control in a multipath fading channel. A noncoherent first-order delay-locked loop (DLL) is considered as a PN code tracking loop. Power control error is modeled as a log-normally distributed random variable. From the simulation results, it is shown that for smaller discriminator offset, tracking jitter performance is improved while MTLL performance is degraded. It is shown that large power control error and heavy shadowing substantially degrade the PN tracking performance. The analysis in this paper can be applicable to design of PN code tracking loop for a DS/CDMA system.

I . INTRODUCTION

The synchronization of a DS/CDMA system consists of two steps: acquisition (coarse alignment) and tracking (fine alignment) [1,2]. 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. This situation results in reducing the channel utilization, which corresponds to capacity decrease of mobile communication system.

Conventionally, the noncoherent tracking loop is preferred because it is insensitive to data modulation and presumes a reliable carrier tracking prior to PN code synchronization. Delay-locked loop (DLL) and tau-dither loop (TDL) are extensively considered in the literatures [3,4]. Although TDL overcomes gain imbalance problem of DLL, it suffers from degradation in noise performance. The DLL and the TDL can be applied to the coherent and noncoherent detection schemes. In most of CDMA applications, the noncoherent tracking loops are more often employed than coherent loops because spread signal-to-noise ratio (SNR) is typically too low to achieve carrier recovery before code synchronization [5,6]. In an AWGN channel, linear and nonlinear approaches have been employed to analyze tracking performance.

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 [7]. A number of power control schemes have been proposed to minimize the effects of fading, shadowing, and near-far problems. 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 [8]. 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 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) by the method of RPA.

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 Δ ($0 < \Delta < 1$) 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 ($\varepsilon_{\min,}\varepsilon_{\max}$).

The code phase error is defined as the normalized phase difference between the incoming and local codes and given by

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

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 fading channel, the two-ray fading model is employed. It is widely used to represent the dispersive component of fading, and describes the multipath propagation in terms of primary and dominant interfering rays.

III. 1. Power Control Error Modeling

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

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

where σ_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

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

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, ς is path loss exponent, and ξ_k is a random variable corresponding to shadowing and power control error which is lognormally distributed with standard deviation of σ_s dB and σ_p dB for shadowing and power control error, respectively.

The decision statistic of reference user is given by [9]

$$Z_1 = D + I_1 + I_2, \tag{4}$$

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.

III. 2. PN Tracking Performance

To describe the dynamic behavior of DLL, the stochastic differential equation is given by

$$\frac{de(t)}{dt} = f_D - G_v\sum_{k=1}^{K}[P_{k,1}H_k(0)C(\varepsilon) + n_T(\varepsilon,t)] * l(t), \tag{5}$$

where G_v is VCC gain, $l(t)$ is impulse response of loop filter, and f_D is Doppler shift.

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

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

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.

Let $p(\varepsilon \mid \vec{g})$ be the stationary *p.d.f.* of the tracking jitter conditioned on the channel impulse response $\vec{g}$. In a RPA, the $p(\varepsilon \mid \vec{g})$ satisfies the following Fokker-Plank equation with boundary conditions $p(\varepsilon_{\min} \mid \vec{g}) = p(\varepsilon_{\max} \mid \vec{g}) = 0$.

$$\frac{\partial}{\partial\varepsilon}[\frac{z_{k,1}(\varepsilon)p(\varepsilon\,|\,\vec{\mathbf{g}})}{P_D(\varepsilon)}]-\frac{1}{2}\frac{\partial^2}{\partial\varepsilon^2}[\frac{z_2(\varepsilon)p(\varepsilon\,|\,\vec{\mathbf{g}})}{P_D(\varepsilon)}]=\frac{\pi(\varepsilon)}{\bar{\tau}_{l|\vec{\mathbf{g}}}}, \tag{7}$$

where $\pi(\varepsilon)$ is the *p.d.f.* of the initial code phase error and depends on acquisition process,

$$P_D(\varepsilon)=1-P_L(\varepsilon), \tag{8}$$

$$z_{k,1}=-G_v\sum_{k=1}^{K}H_k(0)C(\varepsilon)+\frac{1}{4}\frac{dz_2(\varepsilon)}{d\varepsilon}, \tag{9}$$

$$z_2(\varepsilon)=G_v^2\int_{-\infty}^{\infty}R_{n_T}(\varepsilon,\xi)d\xi, \tag{10}$$

and $\bar{\tau}_{l|\vec{\mathbf{g}}}$ is conditional MTLL.

The tracking jitter and MTLL is obtained by [9]

$$\sigma_\varepsilon=\int_{\vec{\mathbf{g}}}\sigma_{\varepsilon|\vec{\mathbf{g}}}\,p(\vec{\mathbf{g}})d\vec{\mathbf{g}}, \tag{11}$$

$$\bar{\tau}_l=\int_{\vec{\mathbf{g}}}\bar{\tau}_{l|\vec{\mathbf{g}}}\,p(\vec{\mathbf{g}})d\vec{\mathbf{g}}, \tag{12}$$

where $\sigma_{\varepsilon|\vec{\mathbf{g}}}$ is the conditional tracking jitter, and $p(\vec{\mathbf{g}})$ is the joint *p.d.f.* of the channel impulse response.

IV. SIMULATION RESULTS

For simulation examples, the binary non-return-to-zero (NRZ) pulse for a chip pulse shape, path loss exponent ς = 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.

In Fig. 3, tracking jitter vs. discriminator offset is shown for the various values of power control errors with variance of shadowing σ_s^2 = 5dB. It is shown that the tracking jitter becomes larger as 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 the various values of power control errors with variance of shadowing σ_s^2 = 5dB. It is shown that MTLL becomes larger as 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 as the power control error.

In Fig. 5, tracking jitter vs. discriminator offset is shown for the various values of power control error and shadowing deviations. It is shown that shadowing affects the tracking jitter performance in the whole range of discriminator offset.

In Fig. 6, MTLL robustness vs. discriminator offset is shown for the various values of power control error and shadowing deviations. It is shown that the MTLL performance is also degraded due to shadowing in the whole range of discriminator offset.

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. The extension of analysis to higher-order loop models is very straightforward. The considerations in this paper can be applied to the design of a PN code tracking loop for a reverse link of a DS/CDMA system.

REFERENCE

[1] R. E. Ziemer, and R. L. Peterson, *Digital Communications and Spread Spectrum Systems*, Macmillan, 1985.

[2] M. K. Simon, J. K. Omura, R. K. Scholtz, and B. K. Levitt, *Spread Spectrum Communications vol. I-III*, Computer Science Press, 1985.

[3] H. Meyr, "Delay-lock tracking of stochastic signal," *IEEE Trans. Commun.*, vol. 24, Mar. 1976.

[4] M. K. Simon, "Noncoherent pseudonoise code tracking performance of spread spectrum receivers," *IEEE Trans. Commun.*, vol. 25, pp. 327-345, Mar. 1977.

[5] A. Polydoros and C. L. Weber, "Analysis and optimization of correlative code-tracking loops in spread spectrum systems," *IEEE Trans. Commun.*, vol. COM-33, pp. 30-43, Jan. 1985.

[6] H. Meyr, "Nonlinear analysis of correlative tracking systems using renewal process theory," *IEEE Trans. Commun.*, vol. 23, pp. 192-203, Feb. 1975.

[7] A. J. Viterbi, A. M. Viterbi, and E. Zehavi, "Performance of power-controlled wideband terrestrial digital communication," *IEEE Trans. Commun.*, vol. 41, no. 4, pp. 559-569, Apr. 1993.

[8] J. Y. Kim and J. H. Lee, "Effect of imperfect power control on acquisition performance in a DS/CDMA system," *IEE Electronics Letters*, vol. 32, no. 14, pp. 1255-1256, July 1996.

[9] J. Y. Kim and J. H. Lee, "Performance analysis of TDL for tracking of a direct-sequence spread-spectrum system in a multipath fading channel," *Journal of IEEK*, vol. 33-A, no. 3, pp. 10-17, Mar. 1996.

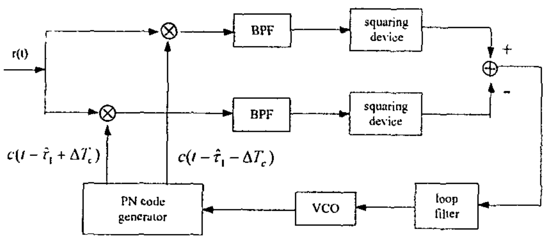

Fig. 1. Block diagram of PN code tracking loop.

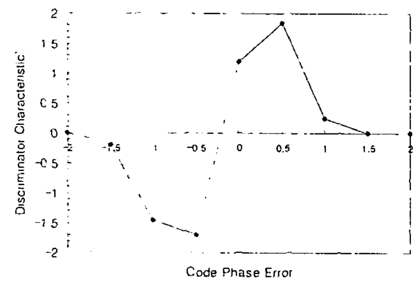

Fig. 2. Discriminator characteristics in a multipath fading channel.

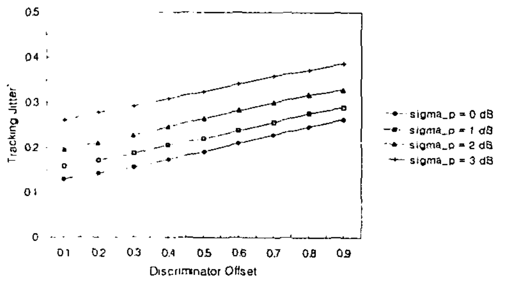

Fig. 3. Tracking jitter vs. discriminator offset for power control error.

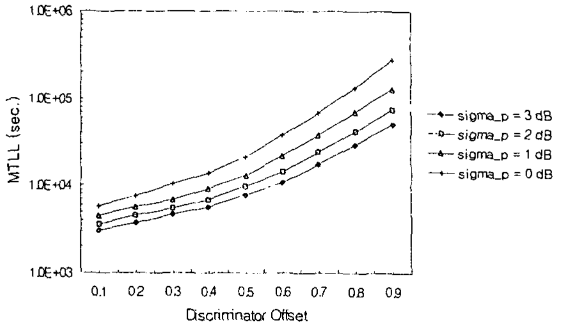

Fig. 4. MTLL vs. discriminator offset for power control error.

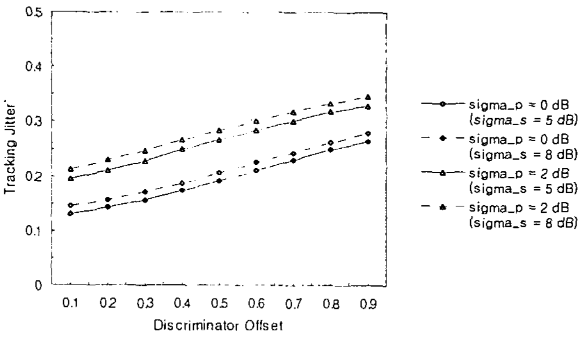

Fig. 5. Tracking jitter vs. discriminator offset for shadowing deviations.

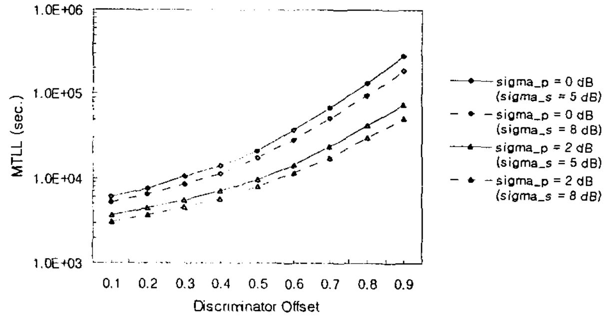

Fig. 6. MTLL vs. discriminator offset for shadowing deviations.