PN Code Acquisition in a DS/CDMA Overlay Environment

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ABSTRACT

In this paper, performance of a PN code acquisition scheme is analyzed and simulated for a DS/CDMA overlay system where a CDMA user and a narrowband user coexist in the same frequency band. To suppress the NBI, an interference suppression filter is employed at the receiver front-end. From the simulation results, it is shown that the interference suppression filter is very effective for suppression of the NBI and rapid PN code acquisition in a DS/CDMA overlay environment. It is also shown that the one-sided tap number of 5 for interference suppression filter is sufficient to suppress the NBI.

I. INTRODUCTION

One of the most critical aspects in a DS/CDMA (direct-sequence/code-division-multiple-access) system is synchronization of an incoming PN sequence and a locally generated PN sequence. PN synchronization is usually done in two stages [1]: PN acquisition stage where the phase of incoming PN sequence is coarsely aligned with that of locally generated PN sequence within a chip, followed by PN tracking stage where the coarse alignment is maintained throughout demodulation. The acquisition stage mainly determines the code synchronization time, so it should be as fast as possible for rapid initial link setup and smooth handoffs in a mobile cellular environment. Since in any spread spectrum system, data transmission is not possible before PN code acquisition is achieved, the rapid and effective acquisition scheme is required for successful operation of a DS/CDMA system.

To enhance spectrum efficiency, a CDMA overlay system has been proposed. In a DS/CDMA overlay system, a set of mobile DS/CDMA users communicates with a base station, while other narrowband users simultaneously transmit in the same frequency band. The basic principle of a DS/CDMA overlay is that because DS/CDMA power is diffused over a much wider bandwidth than that of narrowband users, this leaves only a fraction of the CDMA power in any given subband occupied by a given narrowband user. Since the DS/CDMA signal spreads their power over a large bandwidth, the effect of such a transmission on a narrowband receiver is often just an imperceptible rise in its noise level. Hence, it may possible to overlay a DS/CDMA system on an existing set of narrowband users without severely affecting either. Moreover, because of the broadband noise-like characteristics of DS/CDMA signals, it is possible to use signal processing technique to reduce narrowband interference (NBI).

In this paper, the PN acquisition performance is analyzed and simulated for a DS/CDMA overlay system. To reduce the effect of narrowband users, the interference suppression filter is placed prior to the acquisition stage. The taps of interference suppression filter is updated based on MMSE (minimum-mean-square-error) criterion.

The rest of the paper is organized as follows: In Section II, a system model of a noncoherent parallel MF acquisition scheme with interference suppression filter and a NBI model are described. In Section III, interference of a DS/CDMA system is modeled. Simulation examples are presented in Section IV, and conclusions are drawn in Section V.

II. SYSTEM MODEL

II. 1. PN Acquisition Model

A noncoherent parallel MF acquisition scheme with interference suppression filter is shown in Fig. 1(a) [2]. It consists of an interference suppression filter and a parallel MF acquisition scheme. The received signal is first filtered through interference suppression filter shown in Fig. 1 (b) to reduce the effect of the NBI. A parallel MF acquisition scheme is composed of a bank of N noncoherent parallel I-

Q MF's shown in Fig. 1 (c). The parallel scheme is employed to provide faster acquisition than the serial acquisition scheme. In a conventional parallel acquisition scheme, the test statistics corresponding to all of the possible received code phases are computed and the largest output is chosen [3].

II. 2. Narrowband Interference Model

A narrowband user is modeled as narrowband interference located at the fraction of the desired CDMA user's bandwidth (BW) as shown in Fig. 2. The interference signal is given by

$$I_i(t) = \sqrt{2I}\hat{a}_i(t)\cos[2\pi(f_0 + \Delta)t + \theta], \qquad (1)$$

where Δf is frequency offset from f_0, carrier frequency of the CDMA signal, I is interference power, θ is phase of interference signal, and $\hat{a}_i(t)$ is data sequence of interference signal. The interference BW is approximated as $B_i = 2/T_i$ where T_i is data bit duration of interference signal. The NBI is characterized by the following two parameters which are narrowband BW ratio p and frequency offset ratio q, and given by

$$p = \frac{B_i}{B_s} = \frac{T_c}{T_i}, \qquad (2)$$

$$q = \frac{\Delta f}{B_s/2}, \qquad (3)$$

where B_s is spreading BW of a CDMA user and T_c is chip duration of spreading sequence.

III. PERFORMANCE ANALYSIS

To apply for a mobile cellular environment, the followings are assumed in the analysis: 1) cell pattern is hexagonal which is typically employed in performance evaluation of a mobile cellular system, 2) adjacent cell interference comes from only adjacent cells of first-tier and second-tier, that is, the number of adjacent cells is 18 in a cluster of 19 cells. 3) desired user is located at the cell-of-interest surrounded by 18 adjacent cells. In-cell users are the users who are located at the same cell as the desired user. Out-of-cell users are the users who are located at the 18 adjacent cells, 4) code uncertainty region is a full code length, 5) multipath delay spread is much less than one data symbol period, so that intersymbol interference can be ignored, and 6) each of 19 cells has the uniform user distribution within a cell.

The received signal of the reference user (without loss of generality, user 1) is given by

$$r(t) = \mathrm{Re}[\sum_{i=0}^{CK}\sqrt{2P_k}\left(\frac{d_{c_k,k}}{d_{1,k}}\right)^{\gamma/2} \cdot \sum_{l=1}^{L}[H_{kl}\exp(j\phi_{kl}) + \beta_{kl}\exp(j\varphi_{kl})]$$

$$a_k(t-\tau_{kl})c_k(t-\tau_{kl})\cdot\exp(j2\pi f_0 t) + I(t) + n(t), \qquad (4)$$

where $d_{1,i}$ is distance from the ith mobile to base station of interest, $d_{j,i}$ is distance from the ith mobile to the jth base station ($2 \le j \le 19$), γ is path loss exponent which describes how the received power falls off with distance, C is the number of cells in the system, τ_{kl} is propagation delay of kth user's lth path, L is the number of multipath, c_k is the cell number ($c_k = 1,2,\cdots,C$), H_{kl} and β_{kl} are specular and diffuse components' power with $E[\beta_{kl}^2] = 2\rho_{kl}$, and $n(t)$ is AWGN with two-sided power spectral density $N_0/2$. The propagation delays τ_{kl} are uniformly distributed in $[0, T_b]$, T_b is data bit duration, and the carrier phases $\{\phi_{kl}\}$ and $\{\varphi_{kl}\}$ are uniformly distributed in $[0, 2\pi]$. All delays and phases are assumed to be independent of one another and independent of the data.

The output of double-sided interference suppression filter is given by [4]

$$r_0(t) = \sum_{m=-Q}^{Q} b_m r(t - mT_c), \qquad (5)$$

where b_m is filter coefficient and Q is the one-sided tap number. The interference suppression filter is double-sided so that $b_0 = 1$ and $b_m = b_{-m}$.

IV. SIMULATION RESULTS

For simulation examples, the following parameters are assumed: 1) penalty time due to a false alarm in the verification mode $J = 10^6$ (chips), 2) the number of tests in the verification mode $A = 4$ and the number of successful tests in the verification mode $B = 2$, 3) phase updating parameter $\Delta = 1/2$, 4) path loss exponent γ = 3.8, and 5) the number of each out-of-cell user is 30.

The tap coefficient of the interference suppression filter is determined to satisfy the following Wiener-Hopf equation [5]:

$$\sum_{m=-Q, m\neq 0}^{Q} b_m \hat{R}[(n-m)T_c] + \hat{R}[nT_c] = 0, \qquad (6)$$

where $\hat{R}(\cdot)$ is autocorrelation function of input signal to interference suppression filter. The fading channel model used in this paper is as follows: 1) Rician factor (specular-to-diffuse power ratio) R_f = 10dB, 2) type of delay profile = exponentially decaying multipath intensity profile, 3) moving vehicle with 30km/h, and 4) the number of multipath L = 2 (two-ray fading model).

To assess the effectiveness of the interference suppression filter, we define *SINR improvement factor* (SIF) as a measure of effectiveness in a following form:

$$\eta = \frac{SINR \quad at \quad filter \quad output}{SINR \quad at \quad filter \quad input}, \qquad (7)$$

where $SINR$ is signal-to-interference-and-noise ratio.

In Fig. 3, the SIF vs. SNR/chip is shown for varying one-sided number of taps for interference suppression filter (Q). It is shown that the SIF is drastically improved as the number of filter taps. So, it is confirmed that the use of interference suppression filter is an effective way to suppress the NBI.

In Fig. 4, normalized mean acquisition time vs. narrowband BW ratio of NBI with respect to a desired CDMA user is shown for varying the Q. The simulation examples are shown for SNR/chip = -5 dB, q = 0.4, and K = 30. It is shown that the acquisition performance is significantly improved with the use of interference suppression filter. It can be noted that a very slight improvement on acquisition performance is achieved for the tap number larger than 5. That is, the diminishing returns on acquisition performance are found with the number of taps larger than 5.

In Fig. 5, normalized mean acquisition time vs. frequency offset ratio of narrowband interference signal from the desired CDMA user is shown for varying the Q. The simulation examples are shown for SNR/chip = -5 dB, p = 0.1, and K = 30. It is shown that acquisition performance is improved as the separation of center frequency between narrowband interference and a desired CDMA user increases.

V. CONCLUSIONS

The acquisition performance was evaluated for a non-coherent parallel MF acquisition scheme with interference suppression filter in a DS/CDMA overlay environment. It was shown that the interference suppression filter is very effective for suppression of the NBI and enhancement of PN code acquisition performance. The results in this paper can be applied to the design of radio link for a DS/CDMA overlay environment with other narrowband systems.

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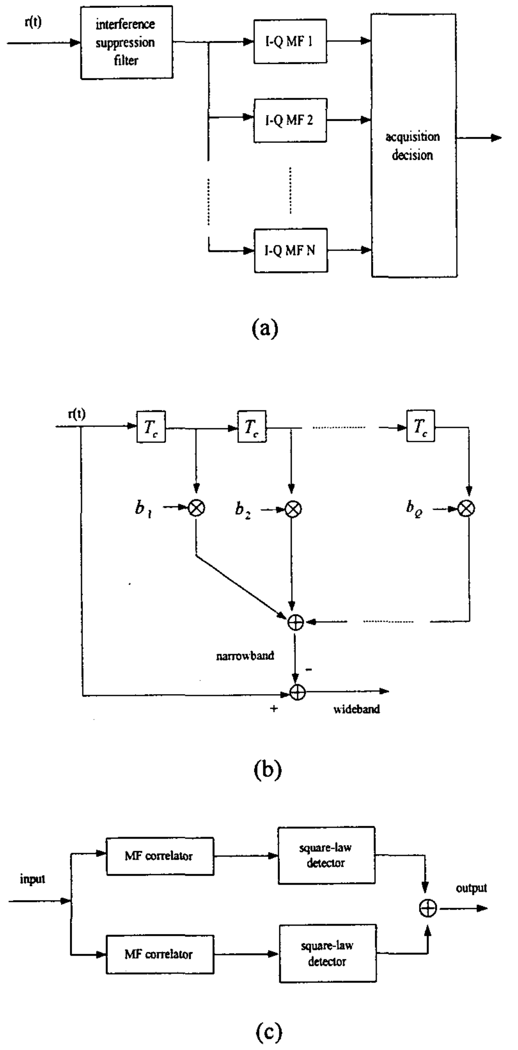

Fig. 1. Block diagram of acquisition scheme with NBI suppression filter. (a) Parallel acquisition scheme with interference suppression filter. (b) Structure of NBI suppression filter. (c) I-Q MF of N parallel I-Q MF's.

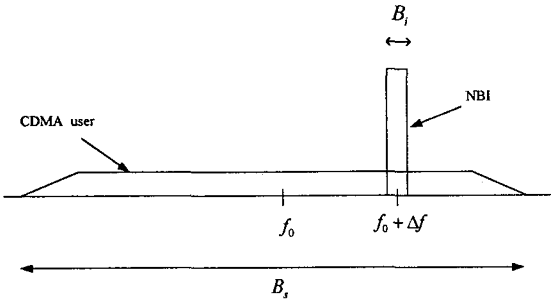

Fig. 2. Narrowband interference model.

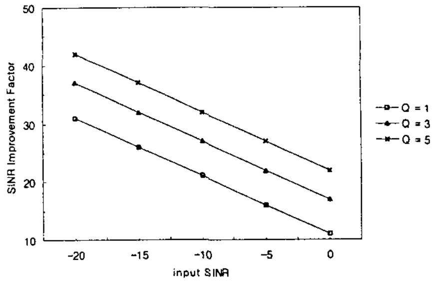

Fig. 3. SINR improvement through interference suppression filter.

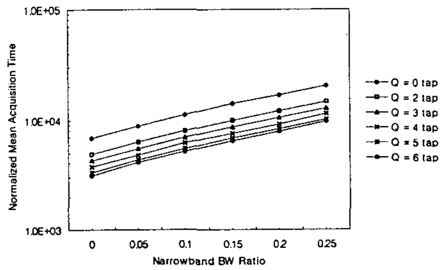

Fig. 4. Normalized mean acquisition time vs. narrowband bandwidth ratio.

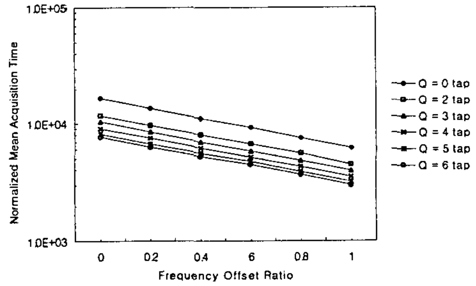

Fig. 5. Normalized mean acquisition time vs. frequency offset ratio.