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A constrained minimum mean square error code tracking loop for synchronous DS-CDMA systems

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Abstract

A constrained minimum mean square error code tracking loop (CMMSE-CTL) is proposed in this paper for synchronous direct sequence code division multiple access (DS-CDMA) systems in a multiuser environment. By introducing assistant weighted despreading signals into the local reference signals of the loop, we exploit the resultant extra degrees of freedom to improve the tracking performance under multiuser environment. The derived mean square tracking error is taken as the cost function and minimized with respect to the weight parameters, under the constraints which ensure an odd-symmetric bias-free *S*-curve with enhanced tracking range. Simulations based on Gold codes compare the *S*-curve, root-mean-square (rms) tracking error, mean-time-to-lose-lock (MTLL) performance of CMMSE-CTL and the traditional modified code tracking loop (T-MCTL). It is shown that CMMSE-CTL outperforms T-MCTL greatly in that it provides unbiased stable code tracking with reduced mean square tracking error, an enhanced tracking range, and near–far resistance.

Keywords: Code tracking; Synchronization; DS-CDMA; Multiple access interference (MAI); Delay lock loop

1. Introduction

Synchronization between the local despreading pseudo-noise (PN) sequence and the incoming sequence contained in the received signal is of critical importance to direct sequence code division multiple access (DS-CDMA) communication systems, which is an important technology for 3G wireless communication systems. The synchronization comprises two stages: code acquisition, which coarsely aligns the incoming and local PN codes to a small range, usually within one chip duration or less, followed by code tracking, which achieves and continuously maintains fine alignment [1]. After the initial acquisition, code tracking takes over and reacquisition will be triggered once out-of-lock situation is detected. This combined tracking/reacquisition procedure is repeated throughout the synchronization process [2]. In this paper, we assume that acquisition has been achieved and focus on the code tracking stage.

Traditional delay lock loop (T-DLL) [1–3] shown in Fig. 1(a) is a well-recognized code tracking technique for DS-CDMA systems. Many improved variants have been reported over the years [4–8], among which is the traditional modified code tracking loop (T-MCTL) [5]. T-MCTL shown in Fig. 1(b) combines the early and late reference signals in one branch and generates the error signal by a multiplier, thus eliminating the squaring and subtraction operations. In this way, T-MCTL combats the gain imbalance problem of T-DLL under additive white Gaussian noise (AWGN) condition with superior tracking performance and hardware simplicity.

In a multiuser environment, the nonorthogonality between the signature waveforms of the users causes multiple access

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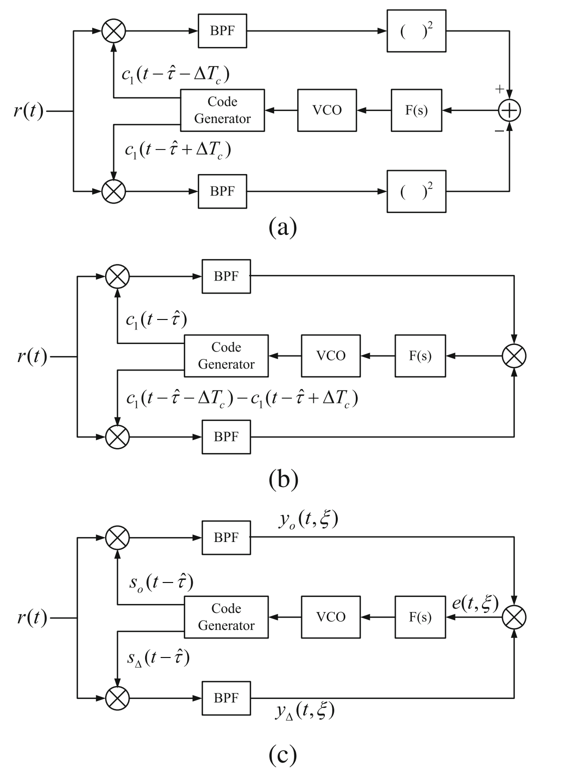

Fig. 1. Block diagram of (a) T-DLL, (b) T-MCTL and (c) CMMSE-CTL.

inference (MAI) which degrades the system performance. In view of the impairment that MAI places on CDMA systems, substantial efforts have been devoted to multiuser receivers. However, the most discussed multiuser receivers, such as the decorrelator and the parallel/successive interference cancellation receiver, are all sensitive to timing errors, since any inaccuracy in the delay estimate will lead to inaccurate interference cancellation as well as a loss in the correlation energy [9–11]. On the other hand, T-DLL and T-MCTL, although well suited for code tracking under AWGN channel, suffer significant performance degradation in the presence of MAI [12–16]. Our previous work [15–18] shows that strong MAI not only severely distorts the S-curves of the traditional schemes and creates a tracking bias, but may also cause a stability problem.

Multiuser detection techniques like successive interference cancellation [19,20] and parallel interference cancellation [21] have been applied to T-DLL to combat MAI. Both require knowledge of the data symbols and amplitudes of all users, which are obtained via adaptive channel estimation or tentative decision feedbacks, and the hardware complexity increases with the number of interferers.

In this paper, we propose a constrained minimum mean square error code tracking loop (CMMSE-CTL) that keeps the major hardware structure of T-MCTL unchanged, aside from the fact that assistant weighted despreading signals are introduced into the local reference signals, which facilitates the easy migration of T-MCTL to our scheme. By exploiting the extra degrees of freedom provided by the weight parameters, the constrained optimization based on the minimum mean square tracking error criterion is performed, subject to the constraints that ensure an odd-symmetric bias-free S-curve with enhanced tracking range. CMMSE-CTL is shown to be able to mitigate the MAI effects and provide unbiased stable tracking with reduced mean square error and enhanced pull-in capability in a multiuser environment. It is shown that the mean square tracking error of our proposed tracking loop converges to zero as the noise vanishes for an arbitrary number of users.

The rest of the paper is organized as follows. In Section 2, we introduce the channel and signal model, and describe the proposed code tracking loop. The key signals of the tracking loop are given. In Section 3, we carry out performance analysis to derive the analytical expressions of the S-curve and the mean square error. Constrained optimization based on minimum mean square error (MMSE) criterion is then performed. The numerical results are reported in Section 4, where CMMSE-CTL is shown to outperform T-MCTL greatly. Finally, conclusions are drawn in Section 5.

2. System model

2.1. Signal and channel model

Consider a DS-CDMA system with K users under AWGN channel. The received signal is given by

$$r(t)=\sum_{k=1}^{K}\sqrt{2P_k}\,b_k(t-\tau_k)c_k(t-\tau_k)\cos(\omega_c t+\theta_k)+n(t) \tag{1}$$

where P_k is the kth user's received signal power, $b_k(t)$ is the data waveform with bit duration T_b, and $c_k(t)$ is the spreading waveform with chip time T_c. ω_c and θ_k are the carrier frequency and phase, respectively. τ_k is the unknown delay that we desire to track. The noise has the bandpass representation

$$n(t)=\sqrt{2}[n_c(t)\cos(\omega_c t)-n_s(t)\sin(\omega_c t)] \tag{2}$$

where $n_c(t)$ and $n_s(t)$ are two independent low-pass zero-mean Gaussian processes with a double-sided power spectral density (PSD) of $N_0/2$ W/Hz.

In this paper, we focus on the effects of MAI and AWGN in a synchronous channel, and thus other channel distortions are not considered. Hence, we have $\tau_1=\tau_2=\cdots=\tau_k=\tau$. This work can be extended to an asynchronous channel if the relative delays between users are known. Without loss of generality, we assume user 1 to be the desired user.

2.2. The proposed code tracking loop

In T-MCTL, as shown in Fig. 1(b) for reference, the received signal is cross-correlated with the on-time signal and the early–late difference signal separately, where $\hat{\tau}$ is the