DS-SS Code Acquisition Based on Simultaneous Search and Verification

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***Abstract*—A double-dwell acquisition system that can simultaneously operate search and verification processes, by employing two correlation blocks, is proposed. The search block continuously looks for threshold-crossing instants, and at those instants, the verification block is reset and reinitiated. The threshold is time varying and updated depending on the partial correlation. Computer simulation results indicate that the proposed technique can perform better than existing double-dwell systems which alternate between search and verification modes.**

***Index Terms*—Code acquisition, DS-SS, multipath fading channels.**

I. INTRODUCTION

IN direct-sequence spread-spectrum (DS-SS) systems, the goal of code acquisition is to achieve a coarse time alignment between the received pseudonoise (PN) code and the locally generated code to an accuracy of a fraction of one PN sequence chip. A popular approach to code acquisition is serial search techniques [1]–[5], which correlate the received and locally generated code sequences and then test the synchronization based on either the crossing of a threshold or the maximum correlation. A threshold value is determined depending on the signal-to-noise ratio at the matched-filter output [2], and it may be adjusted according to either the noise power [3] or the partial correlation [4]. A search technique that employs both the maximum criterion as well as the threshold-crossing criterion is introduced in [5].

In many practical code acquisition systems, the reduction of the false alarm probability for a given overall acquisition time involves the use of search techniques in conjunction with a verification algorithm [2]–[5]. The verification process alternates with the search process and is started whenever an acquisition is declared. The search is then placed on hold during verification and resumed when a false alarm is declared. An acquisition algorithm that employs both search and verification is called a *double-dwell* system.

This paper attempts to improve the performance of a double-dwell acquisition system with a serial search. Specifically, an algorithm that can simultaneously operate search and verification is introduced, and its performance is examined. It will be shown that the proposed algorithm can perform better than conventional double-dwell acquisitions which alternate between search and verification modes.

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II. CODE ACQUISITION USING SIMULTANEOUS SEARCH AND VERIFICATION

Simultaneous search and verification requires two correlation blocks, one for search and the other for verification, as shown in Fig. 1. For the search block, either a matched filter (equivalently, a passive correlator) or an active correlator can be utilized. In this work, a matched filter was used for fast acquisition. For the verification block, an active correlator is sufficient.[1] In Fig. 1, the continuous input signal $r_a(t)$ is frequency-down converted and sampled with period ΔT_C, where Δ is a constant, typically $\Delta = 2^{-n}$ for a nonnegative integer n, and T_C is the chip period. Assuming a multipath fading channel, the input signal $r[k]$ to the correlators is given by

$$r[k] = \sqrt{S}e^{j\theta}\int_{(k-1)\Delta T_C}^{k\Delta T_C}\int_0^{T_m} h(\tau;t)\,c\,(t-\tau-\xi)\,d\tau\,dt + n[k], \quad k = 1, 2, 3, \cdots \tag{1}$$

where S is the signal power, θ represents the carrier phase offset, $h(\tau;t)$ is the equivalent low-pass representation of the time-variant channel impulse response, T_m is the multipath spread of the channel, $c(t)$ represents the code sequence of length L-chips, ξ is the delay with respect to a time reference, and $n[k]$ is zero-mean Gaussian noise with the variance $\sigma_n^2 = \Delta T_C N_0/2$. Here, it is assumed that data are absent and that the frequency offset is negligible.[2] In addition, $c(t)$ is assumed to be ± 1-valued (rectangular pulse shape).

The matched-filter output in the search block is given by

$$g[k] = \sum_{i=0}^{L_P/\Delta - 1} r[k-i]c[L_P/\Delta - i] \tag{2}$$

where L_P is the partial correlation length in chips and $c[i]$ can be obtained by sampling $c(t)$ with the period ΔT_C, i.e., $c[i] = c(t)|_{t=i\Delta T_C}$. In the search block, the magnitude $|g[k]|^2$ is compared with a time-varying threshold $\eta[k]$, which is defined as

$$\eta[k] = \begin{cases} \eta_0, & \text{at } k = 1 \text{ and at time instants} \\ & \text{where a false alarm is declared} \\ & \text{by verification} \\ \max\{\eta_0, \eta[k-1], |g[k-1]|^2\}, & \text{otherwise} \end{cases} \tag{3}$$

where η_0 is the initial threshold which is determined depending on the input statistics. This $\eta[k]$ is nondecreasing, unless a false alarm is declared by the verification block. The search block

[1] Use of a verification correlator can be avoided when a matched filter evaluating the full period correlation is employed for searching, because the correlation values for verification can be obtained by decimating the matched-filter output by a factor of the code period.

[2] The presence of data and/or frequency offset can severely degrade the performance. Techniques for overcoming these difficulties are discussed in [2] and [6].

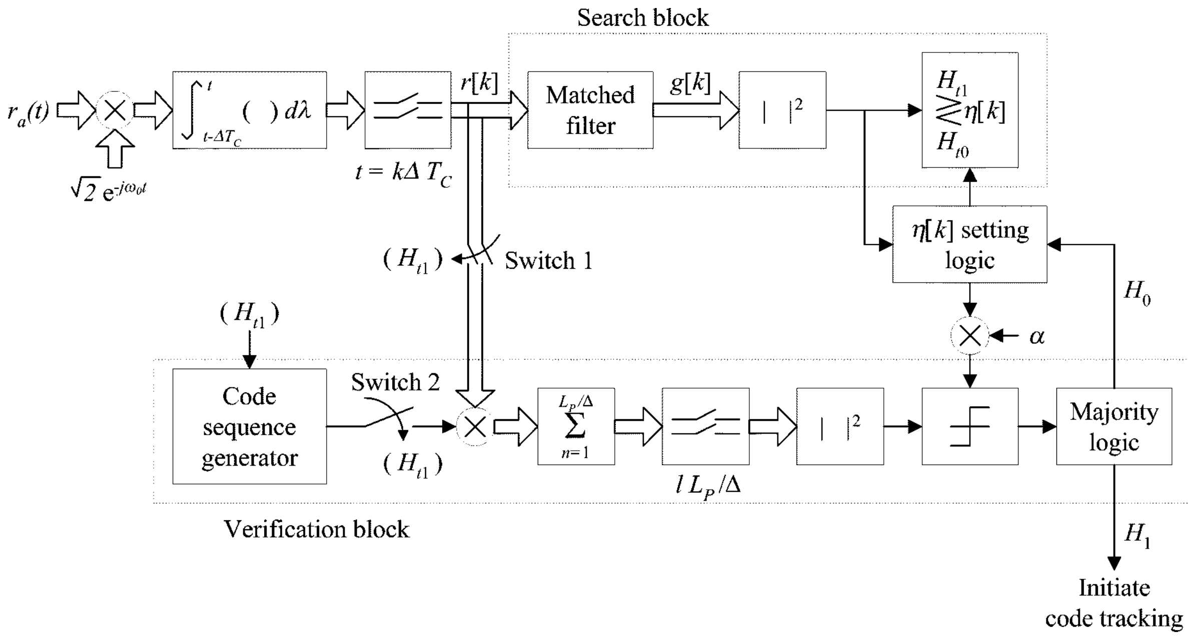

Fig. 1. Proposed code acquisition system.

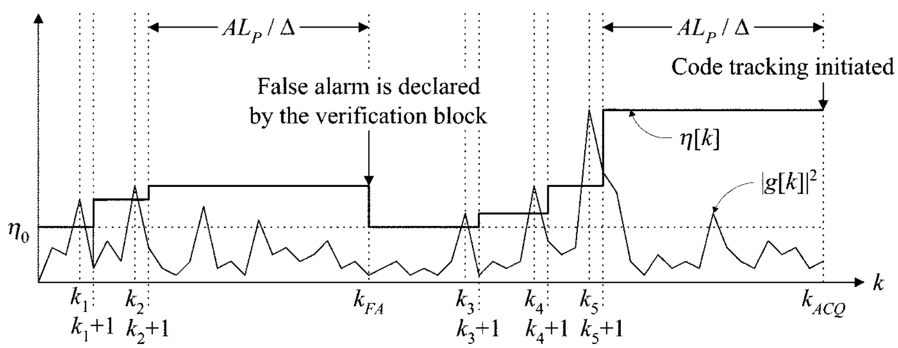

Fig. 2. Typical trajectories of $\eta[k]$ and $|g[k]|^2$. Verification is started at k_1 and k_3, and it is reset and reinitiated at k_2, k_4, and k_5.

in Fig. 1 declares a tentative acquisition, say hypothesis H_{t1}, whenever $|g[k]|^2 > \eta[k]$. When referring to Fig. 2, which shows the typical trajectories of $\eta[k]$ and $|g[k]|^2$, the proposed algorithm can be described as follows. At $k = k_1$, $|g[k_1]|^2 > \eta[k_1]$. Then, H_{t1} is declared and verification is activated. The threshold at k_1+1 becomes $\eta[k_1+1] = |g[k_1]|^2$. When $k > k_1$, both search and verification processes are in motion. The search block then continues to identify instants at which the threshold is crossed. Suppose that the threshold crossing occurs at $k = k_2$, before the verification is completed. In this case, verification is reset. The verification process is restarted at $k = k_2 + 1$, ignoring the results between $k_1 + 1 \leq k \leq k_2$. This is because $|g[k_2]|^2 \geq |g[k_1]|^2$. In this manner, the search and verification blocks can operate simultaneously until verification is completed.

The procedure for verification is essentially identical to those in [2], [3], and [5]. Upon H_{t1}, switches 1 and 2 in Fig. 1 are closed, and the code sequence $c[i]$ is generated starting with $i = L_P/\Delta$ at the same rate as the incoming code. The active correlator produces an independent partial correlation at every L_P/Δ and a number of tests, say A, are performed by comparing the correlation value with the threshold $\alpha\eta[k]$, where α is the scaling factor. If at least B out of the A tests indicate synchronization, a code acquisition H_1 is declared and code tracking is initiated. Otherwise, a false alarm H_0 is declared, and the threshold $\eta[k]$ is reset to η_0.

The proposed code acquisition algorithm can be summarized as follows. 1) The search block continuously looks for time instants, say $k_1, k_2, k_3, \cdots (k_1 < k_2 < k_3 \cdots)$ at which $|g[k_j]|^2 > \eta[k_j]$, by serially evaluating partial correlation values, where the time-varying threshold $\eta[k]$ is given by (3). 2) At k_1, verification is started; at each k_j, $j \geq 2$, verification is reset and reinitiated. 3) The search and verification continues until a code acquisition is declared by the verification block.

Before concluding this section, the proposed algorithm is compared with the double-dwell system in [4] whose threshold-setting policy is similar to that in (3). Using the notations in this paper, the threshold for the search mode in [4] can be written as $\eta[k] = \max\{\eta[k-1], |g[k-1]|^2\}$ when $k > 1$ and $\eta[1] = 0$. In this case, $\eta[k]$ is always nondecreasing. The method in [4] then alternates the search and verification modes exploiting this threshold. One drawback of this method is that the switching between the search and verification modes occurs frequently, especially at the beginning of acquisition when the threshold values are small. The proposed system does not suffer from this switching, because it can perform the search and verification processes simultaneously.

III. Performance Evaluation

In order to evaluate the performance of the proposed system, its mean acquisition time was obtained by computer simulation and then compared with those of the double-dwell systems in [3] and [5] which alternate between search and verification. In the simulation, a PN code of length $L = 2^{15} - 1$ chips was considered, $\Delta = 1/2$, the partial correlation length $L_P = 256$ chips, and the initial threshold η_0 was given by $\eta_0 = \beta|b|^2$, where β was a constant and b was the partial correlation value when a perfect code alignment was achieved in the absence of noise. Experimental results indicated that the performance of the proposed scheme was rather insensitive to the choice of β; any value in between 0.2 and 0.6 could be chosen as β. Accordingly, in the simulation, β was set to 0.6. For verification, the parameters A and B were set at 4 and 2, respectively, as suggested in [2]. For the verification threshold $\alpha\eta[k]$, it was found that the value $\alpha = 0.3$ produced good results over the possible values of E_C/N_0, ranging from 0 dB to -25 dB.[3] Thus, α was set to 0.3.

Two types of channels were considered. One was an additive white Gaussian noise (AWGN) channel, expressed as $h(\tau;t) = \delta(\tau)$ in (1). The other was the frequency-selective fading channel in [3], which is characterized by

$$\phi_h(\tau_1,\tau_2;t') \cong \begin{cases} \left(\dfrac{\mu T_m}{1-e^{-\mu T_m^2}}\right) e^{-\tau_1 \mu T_m} \delta(\tau_1 - \tau_2) J_0(2\pi f_d t'), \\ \qquad 0 \le \tau \le T_m \\ 0, \qquad \text{otherwise} \end{cases} \tag{4}$$

where $\phi_h(\tau_1,\tau_2;t')$ is the autocorrelation function of $h(\tau;t)$ defined as $\phi_h(\tau_1,\tau_2;t') = (1/2)\,E[h^*(\tau_1;t)h(\tau_2;t+t')]$, $\delta(\cdot)$ is the Dirac-delta function, $J_0(\cdot)$ represents the zeroth-order Bessel function, T_m denotes the multipath spread, f_d is the Doppler spread, and μ is a constant. In the simulation, $T_m = 5T_C$, $f_d T_C = 1.0 \times 10^{-4}$, and $\mu = 0.138\,15$.

The time required for the tracking loop to indicate a false lock and the acquisition system to resume the search was set to $25\,000\,T_C$ [5].[4] The mean acquisition time was normalized with LT_C and denoted by $E\{T_{ACQ}\}/LT_C$. It was assumed that the received chip sequences and locally generated chip sequences were aligned, so that the residual code phase offset after acquisition was zero.

For comparison, the normalized mean acquisition times of the methods in [3] and [5] were also evaluated. In [3], the *variable threshold* η_v is given by $\eta_v = \gamma\hat{\sigma}^2$, where γ is a variable which is determined depending on E_C/N_0, and $\hat{\sigma}^2$ is an estimate of the disturbance variance. In the simulation, the optimal η_v value for each E_C/N_0 was obtained following the procedure in [3]. In [5], a *maximum/threshold-crossing* (*MAX/TC*) *criterion* is employed for a serial search. After observing the correlation values of the first W code phase offsets, the maximum correlation is selected and compared with the threshold. If the threshold is crossed, verification is initiated; otherwise, the next W code phase offsets are examined. In the simulation, $W = 4681$ and the threshold was $0.6|b|^2$, as suggested in [5].

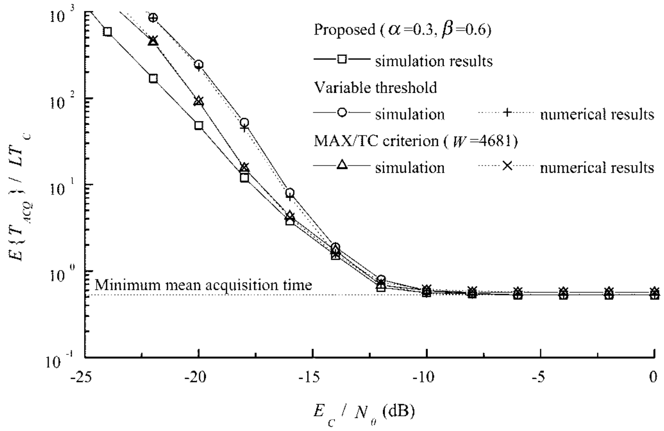

Fig. 3. Performance comparison between proposed and conventional methods in AWGN channel, when $L = 32\,767$.

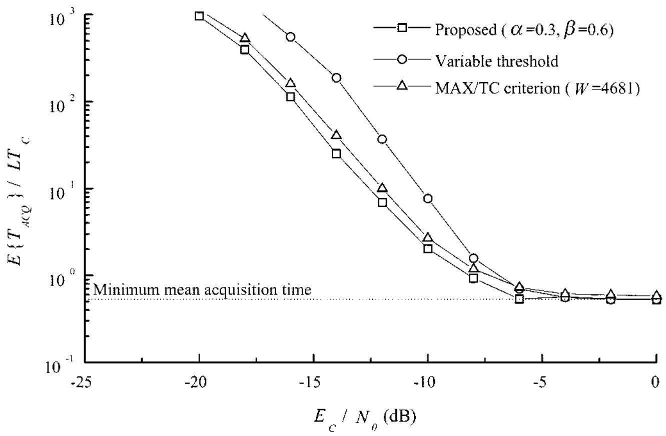

Fig. 4. Performance comparison between proposed and conventional methods in multipath fading channel ($T_m = 5T_C$, $f_d T_C = 1.0 \times 10^{-4}$), when $L = 32\,767$.

Fig. 3 compares the performances of the acquisition techniques in an AWGN channel. The mean acquisition time was estimated by averaging the results for 4096 possible code phase offsets. (For the techniques in [3] and [5], results from a numerical integration are also shown.) The achievable minimum mean acquisition time is given by $(L/2 + AL_P)/L$. It should be noted that for both the variable threshold and the MAX/TC criterion, the results from the simulation were very close to those from the numerical integration. The performances of the proposed, MAX/TC with $W = 4681$, and variable threshold methods were comparable when $E_C/N_0 > -10$ dB. The proposed method, however, exhibited a better performance than the others when E_C/N_0 was lower than -10 dB. The multipath fading channel characterized by (4) is considered in Fig. 4. In this case, the proposed method started to perform better than the others when $E_C/N_0 = -5$ dB.

[3]After the correlation peak, $\eta[k] \simeq |b|^2$ at a high E_C/N_0, and $\eta[k]$ tends to increase as E_C/N_0 decreases. Therefore, by using $\alpha\eta[k]$, the threshold for verification is automatically adjusted for each E_C/N_0.

[4]$25\,000\,T_C$ is an approximate acquisition time for the tracking loop when *one-delta* DLL with a loop bandwidth of 100 Hz is employed and $T_C = 1\ \mu$s [7]

TABLE I
PERFORMANCE GAIN OF PROPOSED METHOD OVER CONVENTIONAL METHODS

Channel	AWGN			Fading		
$E\{T_{ACQ}\}/LT_C$	10^1	10^2	10^3	10^1	10^2	10^3
Gain over variable threshold (dB)	1.4	2.3	2.5	2.2	2.6	3.0
Gain over MAX/TC (dB)	0.4	1.0	1.3	0.6	0.5	0.4

Table I summarizes the performance gain of the proposed scheme in terms of E_C/N_0 for several $E\{T_{ACQ}\}/LT_C$ values. It was observed that the gain over the variable threshold method was substantial; however, the gain over the MAX/TC method was less significant, particularly with the multipath fading channel.

IV. CONCLUSION

A double-dwell acquisition system based on simultaneous search and verification was proposed, and its performance examined through computer simulation. The simulation results demonstrate that the proposed technique outperforms the methods in [3] and [5]. One drawback of the proposed method is that its theoretical analysis is formidable due to its time-varying threshold. Further work will concentrate on analyzing the behavior of the proposed algorithm.

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