Design and Analysis of a Modified Algorithm for the Maximum Likelihood Parallel Search Technique for DSSS Signals

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Abstract: - This paper investigates the problems of pseudorandom noise (PN) code acquisition techniques in direct-sequence code division multiple access (DS-CDMA) communication systems. PN code acquisition (or PN code synchronization) is the most essential first-stage processing in a DS-CDMA receiver. To speed up the multiple access process, initial synchronization should be performed in minimal time. PN code acquisition refers to the operation of synchronizing the locally generated PN code with the received PN code within one chip interval, beyond which the tracking process takes charge. This paper presents the interesting characteristics of effective PN code acquisition techniques for DS-CDMA systems. The techniques described in this paper are generally capable of determining the received PN code phase to within an accuracy of $\pm 1/2$ to $\pm 1/4$ of a chip. The aim of this paper is to propose the modified algorithm for parallel search realization of the maximum likelihood search technique for direct-sequence spread spectrum (DSSS) signals in MATLAB. In addition, the universal autonomous algorithm in MATLAB for PN code generation using a linear feedback shift register is proposed.

Key-Words: - Direct-Sequence Code Division Multiple Access (DS-CDMA), Synchronization, PN Code Acquisition, Search Techniques, MATLAB

1 Introduction

A spread-spectrum communication system requires that the locally generated PN code sequence (PN code) used in the receiver to despread the received PN code signal (PN code) be synchronized to the PN code used to spread the transmitted signal at the transmitter. The basic synchronization subsystem is shown in Fig. 1 [1]. In this subsystem, the process of synchronizing the local and received PN codes is done in two phases, called acquisition [1]-[7], consists of bringing the two PN codes into coarse alignment with one another within one chip interval T_c and tracking [1], [8], [9] performs a fine synchronization within a small fraction of a chip, and maintains the PN code generator at the receiver in synchronism with the incoming PN code while the demodulator is in progress. Finally, the data are demodulated.

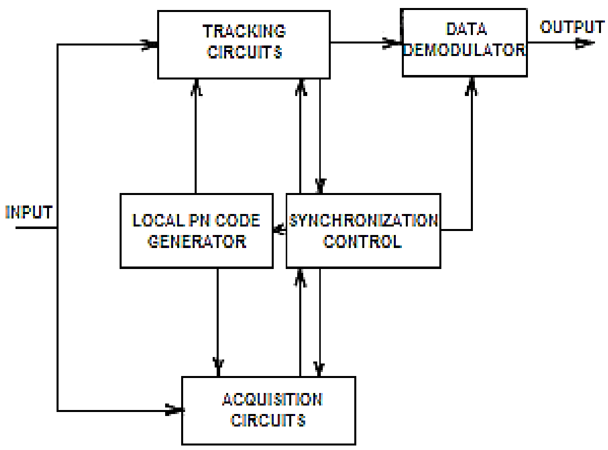


Fig. 1. Functional diagram of synchronization subsystem.

2 Search Techniques for the Acquisition of DSSS Signals

The acquisition problem is one of searching throughout a region of time and frequency uncertainty in order to synchronize the received DSSS signal with the locally generated PN code. PN code acquisition schemes can be classified as coherent or noncoherent. The most current acquisition schemes utilize noncoherent detection because the PN despreading process typically takes place before carrier synchronization, and thus the carrier phase is not exactly known a priori. Acquisition can be realized in principle by a filter matched to the PN code or cross-correlation, which are optimum methods. The classification of PN code acquisition schemes and structure of detectors used for PN code acquisition purposes is illustrated in Figs. 2 and 3, respectively [8].

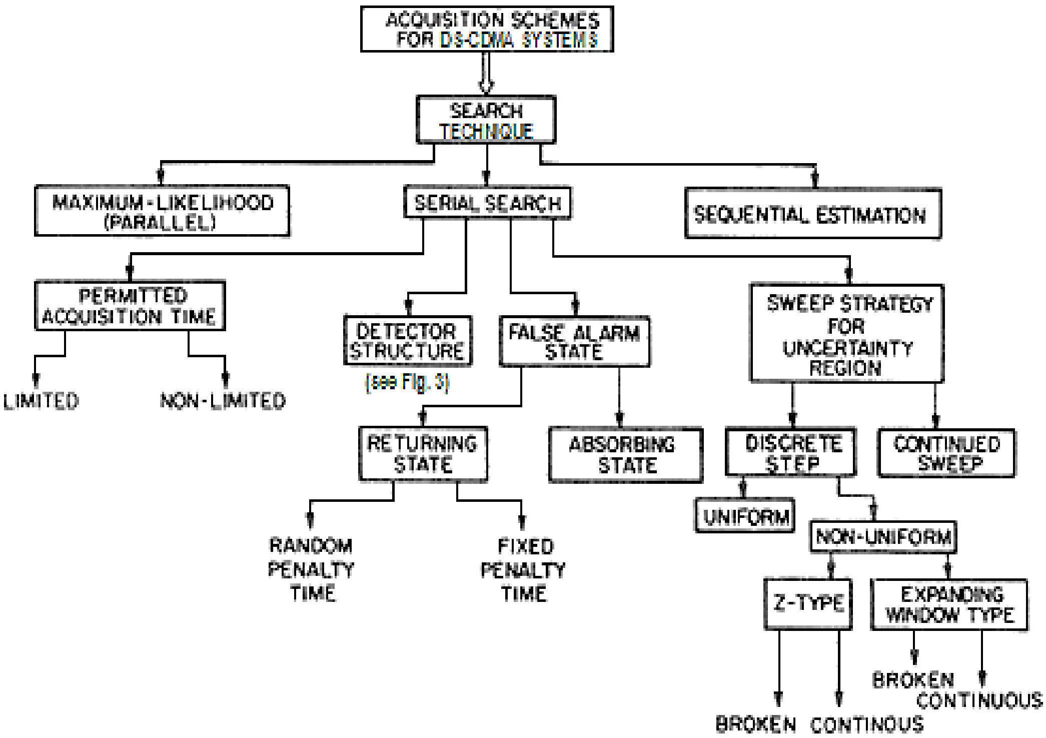


Fig. 2. Classification of PN code acquisition schemes.

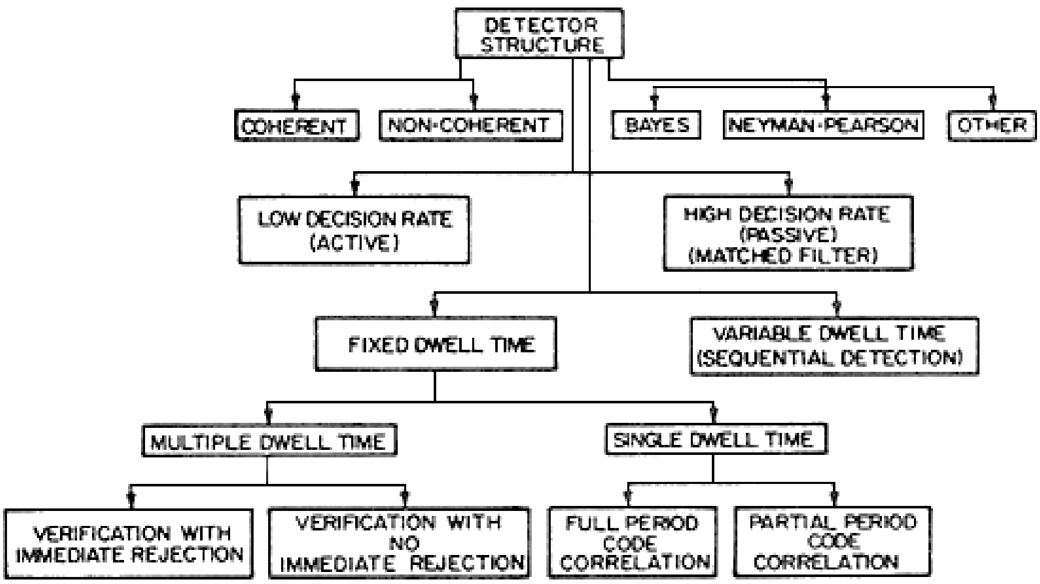


Fig. 3. Classification of structure of detectors for PN code acquisition purposes.

2.1 Fundamental PN Code Acquisition Techniques

2.1.1 Parallel Search Technique

Consider the direct-sequence parallel search acquisition system in Fig. 4 [1], [10], [11]. We observe that the locally generated PN code $g(t)$ is available with delays spaced one-half of a chip $(T_c/2)$ apart to ensure correlation. If the region of uncertainty of the PN code phase is N_c chips, then $2N_c$ correlators to make complete parallel search in a single search time are employed. Each correlator simultaneously examines a sequence of λ chips, after which the $2N_c$ correlator outputs are compared. The locally generated PN code corresponding to the correlator with the largest output is chosen.

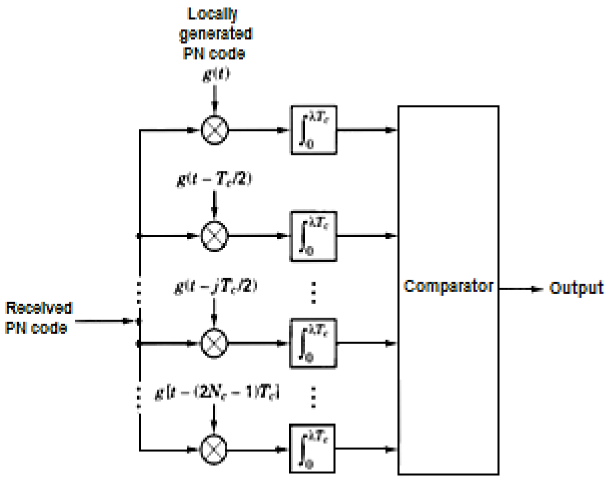


Fig. 4. A direct-sequence parallel search acquisition system.

As the number of chips λ increases, the probability of choosing the incorrect PN code alignment (synchronization error) decreases, and the maximum PN code acquisition time given by [1]

$$(T_{acq})_{max} = \lambda T_c \,, \qquad (1)$$

increases. Thus, λ is chosen as a compromise between the probability of a synchronization error and the time to acquire PN code phase. The mean PN code acquisition time of a parallel search system is

$$\bar{T}_{acq} = \frac{\lambda T_c}{P_D} \,. \qquad (2)$$

It means that the mean PN code acquisition time can be approximated by noting that after integrating over λ chips, a correct decision will be made with probability P_D, called the probability of detection. If an incorrect output is chosen, an additional λ chips are again examined to make a determination of the correct output.

2.1.2 Serial Search Technique

The other technique for the acquisition of DSSS signals is the use of a sliding correlator as shown in Fig. 5 [1], [5], [8].

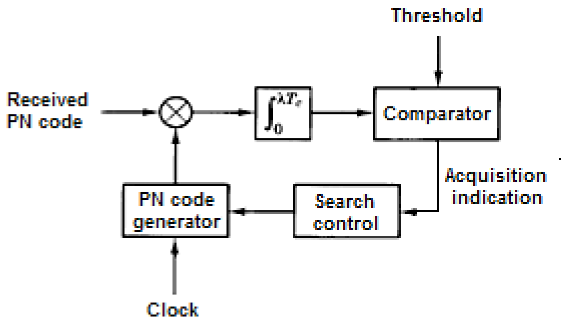


Fig. 5. A direct-sequence serial search acquisition system.

In this direct-sequence serial search acquisition system, the incoming PN code is correlated with the locally generated PN code in discrete time instants, usually in time intervals of $T_c/2$. In order to test synchronism at each time instant, the cross-correlation is performed over fixed intervals of λT_c, called search dwell time. The correlator output is compared to a preset threshold. If the correlator output falls below the threshold and therefore is deemed too small, the correlation process is repeated.

The maximum PN code acquisition time required for a fully direct-sequence serial search acquisition system, assuming that the search proceeds in half-chip increments, is [1]

$$(T_{acq})_{max} = 2N_c \lambda T_c \,, \qquad (3)$$

where the time uncertainty between locally generated PN code and the received PN code to be searched is N_c chips long. The mean PN code acquisition time of a fully direct-sequence serial search acquisition system can be shown, for $N_c \gg T_c/2$, to be

$$\bar{T}_{acq} = \frac{(2 - P_D)(1 + KP_{FA})}{P_D} (N_c \lambda T_c) \,, \qquad (4)$$

where P_D is the probability of detection, P_{FA} is the probability of false alarm, and $K\lambda T_c$ $(K \gg 1)$ is the time interval needed to verify a detection.

2.1.3 Z-Search Strategies of a Serial Search Technique

The Z-search strategies [6], [7], [8], [10] illustrated in Fig. 6 are used to achieve a rapid synchronization where the sweep lengths are equal to the number of q-cells in the whole uncertainty region.

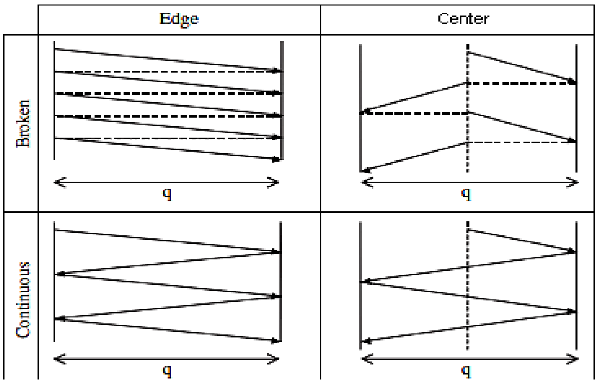


Fig. 6. Illustration of Z-search strategies.

The starting cell position for the Z-search strategy may be specified at the most probable position (center) or the least probable position (edge) and the search path may be made broken or continuous. The broken-center Z-search is appropriate when a priori information makes part of the timing uncertainty more likely to contain the correct cell than the rest of the region. The edge Z-search has an intermediate level of performance but does not effectively utilize the available a priori information.

2.1.4 Comparison of Serial (Straight Line Strategy) Search, Parallel Search and Serial (Z-Strategy) Search Techniques

Three different types of search techniques (straight line strategy applied in a serial search technique, parallel search technique and Z-search strategy applied in a serial search technique) are implemented using a computer simulation, and the evaluation between them is shown in Fig. 7. From this figure we conclude that the parallel search is the superior one as it provides the shortest mean PN code acquisition time where the Z-search is moderate and the simple serial search has the longest mean PN code acquisition time.

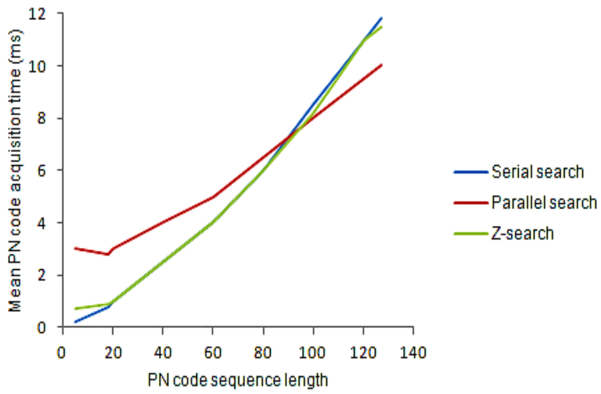


Fig. 7. Mean PN code acquisition time for different search techniques.

3 Simulated Parallel Search Realization of the Maximum Likelihood Search Technique for DSSS Signals in MATLAB

The parallel search technique considers all possible PN code positions (or fractional PN code positions) in parallel and uses a maximum likelihood algorithm for acquiring the PN code. The PN code phase that yields the maximum correlation value among all those despread output signals is determined as the correct PN code phase in the final stage.

We have proposed the modified algorithm for parallel search realization of the maximum likelihood search technique for DSSS signals in MATLAB. In addition, the universal autonomous algorithm using MATLAB for PN code generation using a linear feedback shift register has been proposed. Implementation of the modified algorithm for parallel search realization of the maximum likelihood search technique for DSSS signals is illustrated in the flowchart of Fig. 8. In our simulation, proposed MATLAB/Simulink realization of the PN generator model based on the 6-stage linear feedback shift register for PN code generation is illustrated in Fig. 9. The PN code sequence used for scrambling user-coded data is characterized by the characteristic polynomial $p(x) = x^6 + x + 1$. The most important characteristics of the generated PN code, i.e., the autocorrelation function and its corresponding power spectral density are depicted in Figs. 10 and 11, respectively. For transmitter-side signal processing, the algorithm for DSSS signal generation has been proposed. Here, the most important signal waveforms and their corresponding power spectral densities (PSDs) have been plotted (see Figs. 12(a) and (b), respectively). For receiver-side signal processing, the despreading algorithm for the demodulated PN code signal with implementation consideration of time synchronization using a parallel search technique has been proposed. Here also, the most important signal waveforms and their corresponding PSDs have been plotted (see Figs. 12(c)-(f)).

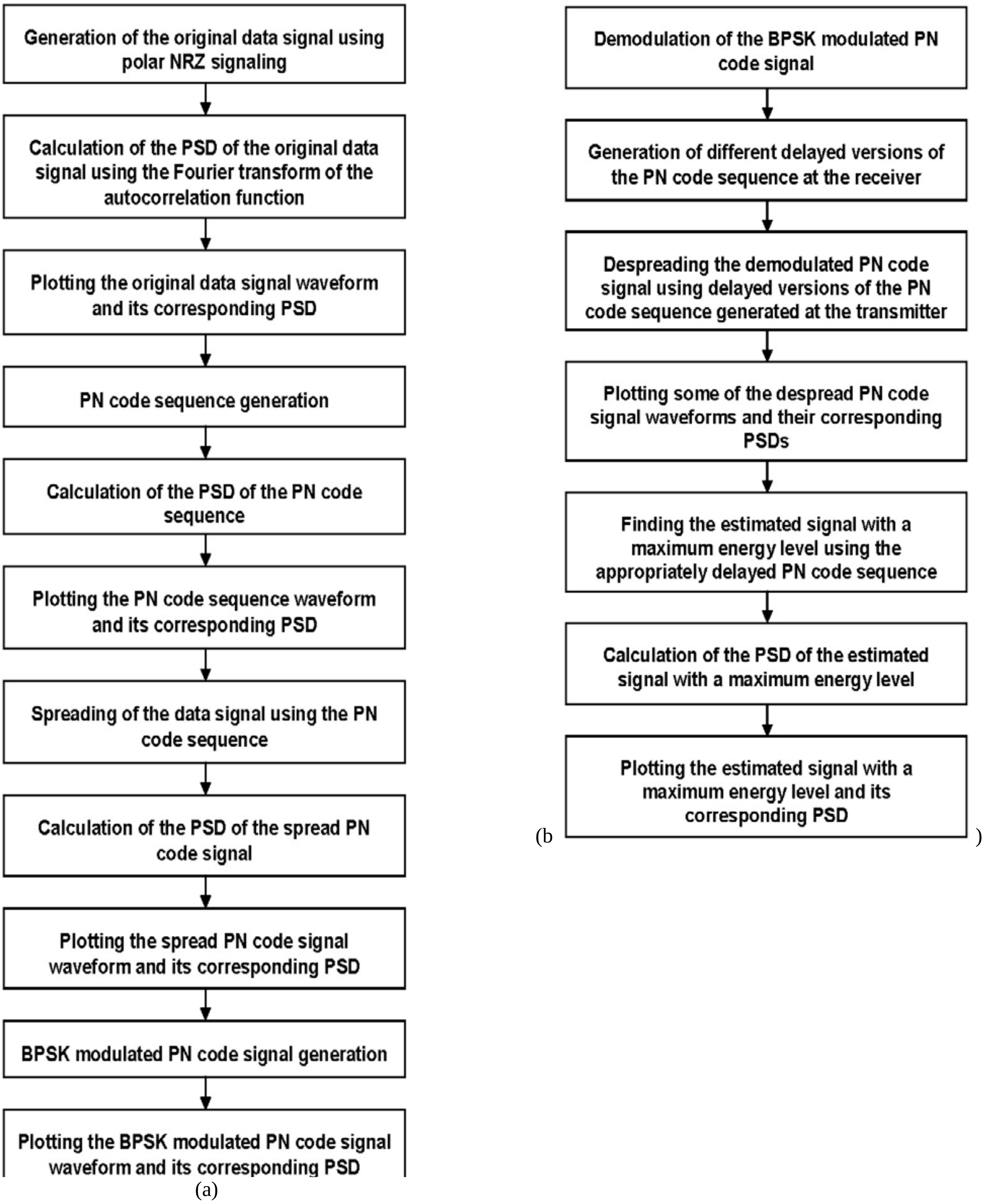


Fig. 8. Flowchart of the simulation procedure of parallel search realization of the maximum likelihood search technique for DSSS signals in MATLAB. (a) The simulation procedure for DSSS signal generation at the transmitter side; (b) The simulation procedure for despreading the demodulated PN code signal with implementation consideration of time synchronization using a parallel search technique at the receiver side.

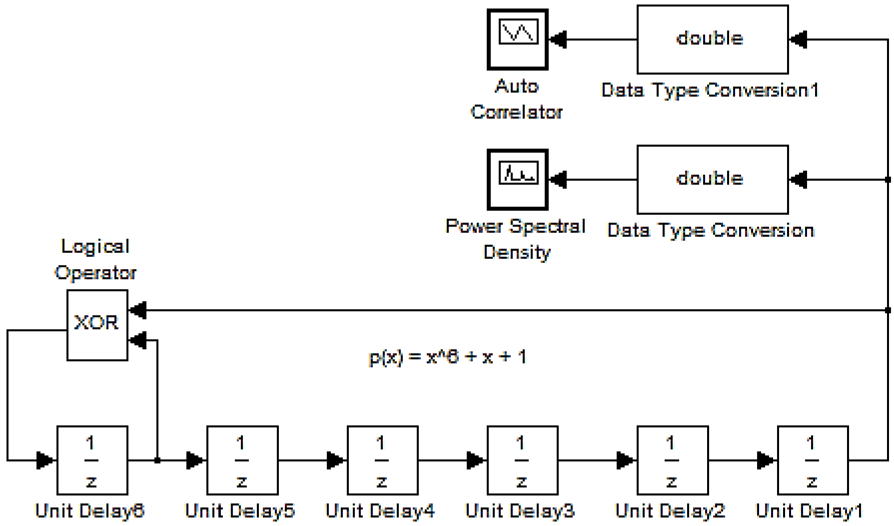


Fig. 9. Proposed and simulated PN generator based on the 6-stage linear feedback shift register for PN code generation in MATLAB/Simulink.

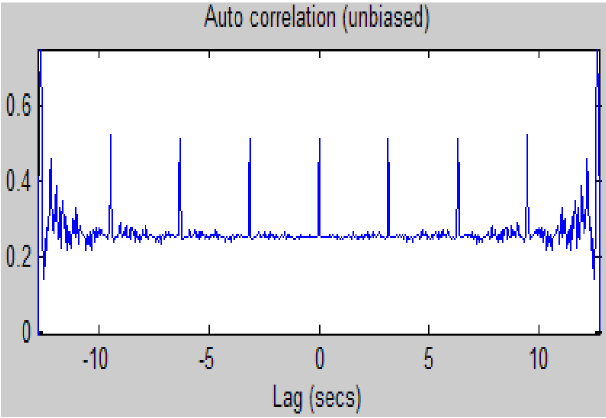


Fig. 10. Autocorrelation function of the generated PN code.

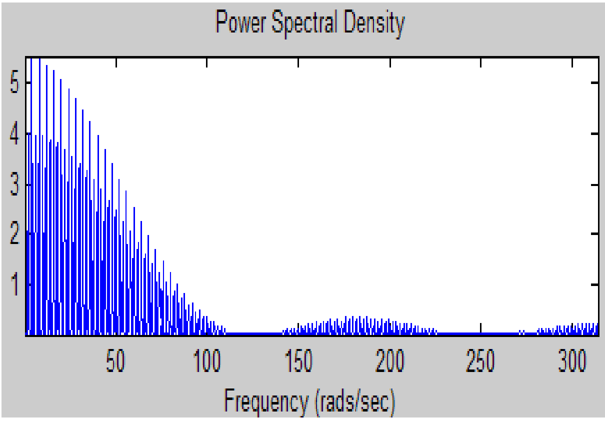
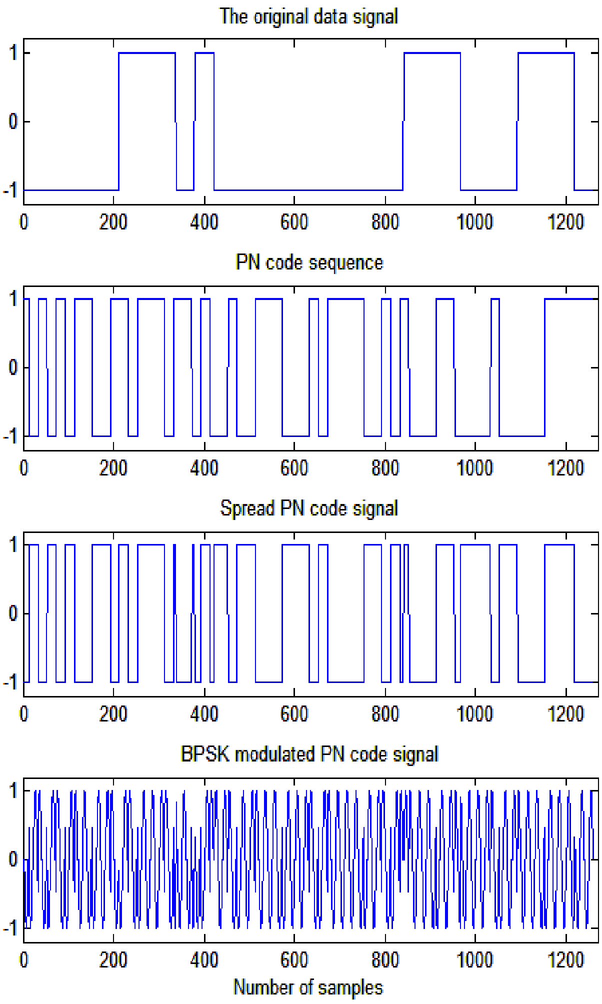
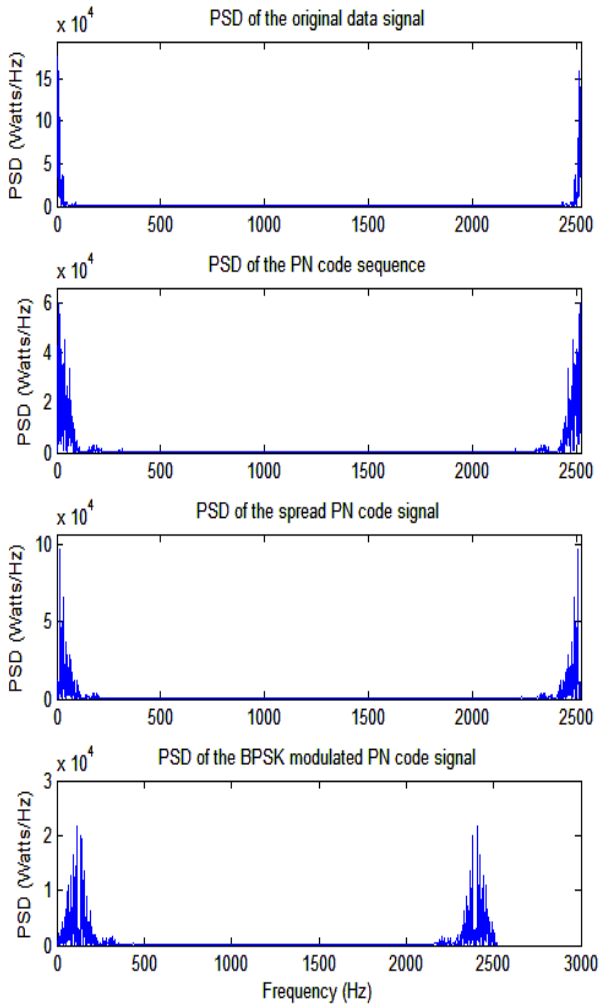


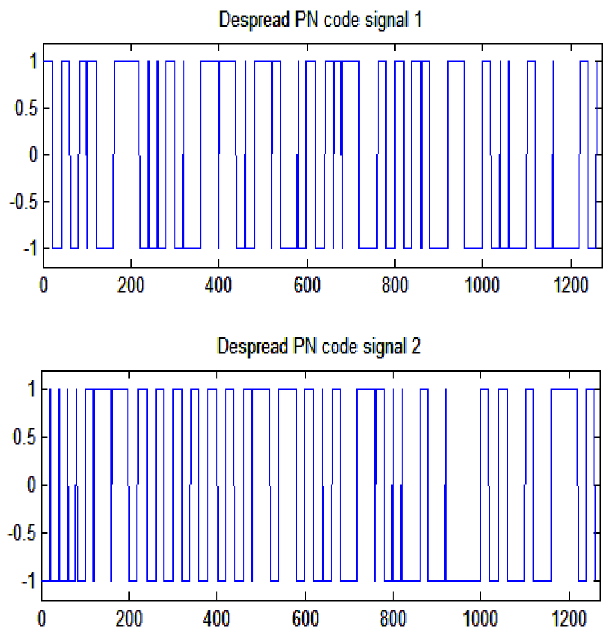
Fig. 11. Power spectral density of the generated PN code.

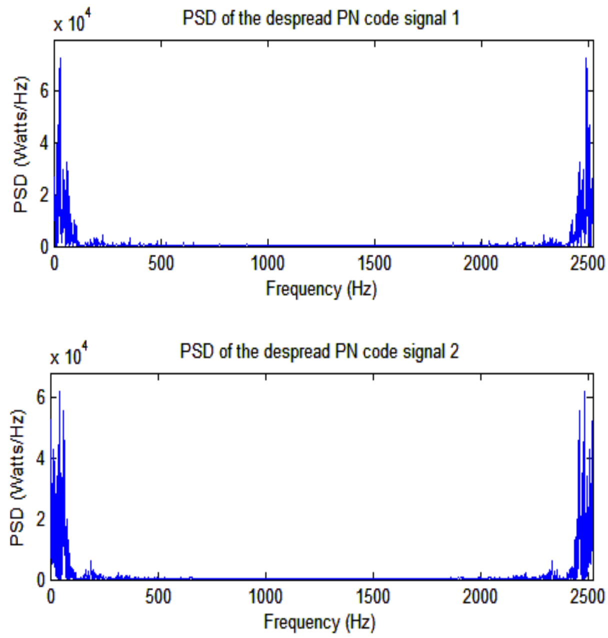


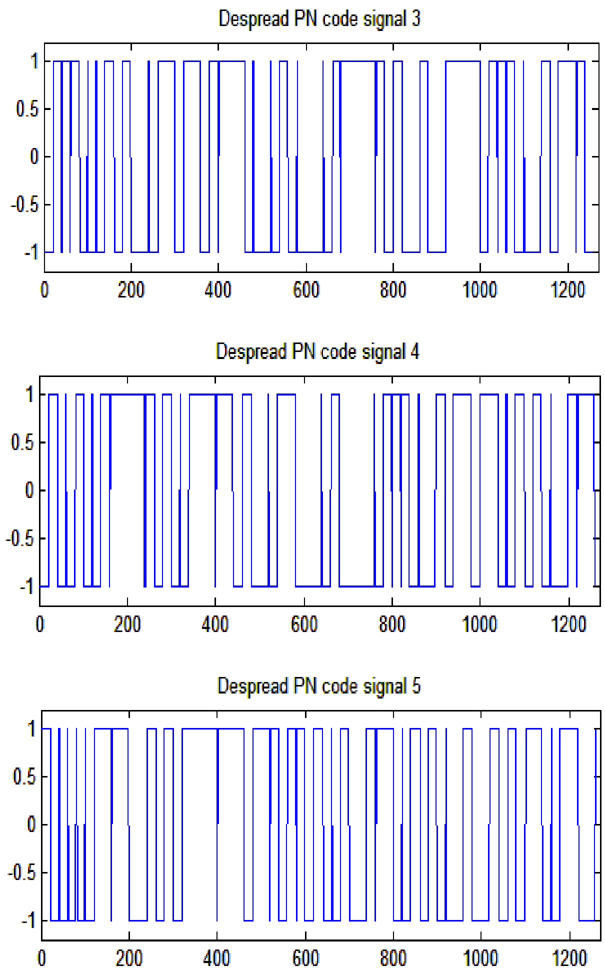
(a) Waveforms of the original data signal, the PN code sequence, the spread PN code signal and the BPSK modulated PN code signal, respectively, generated at the transmitter side.



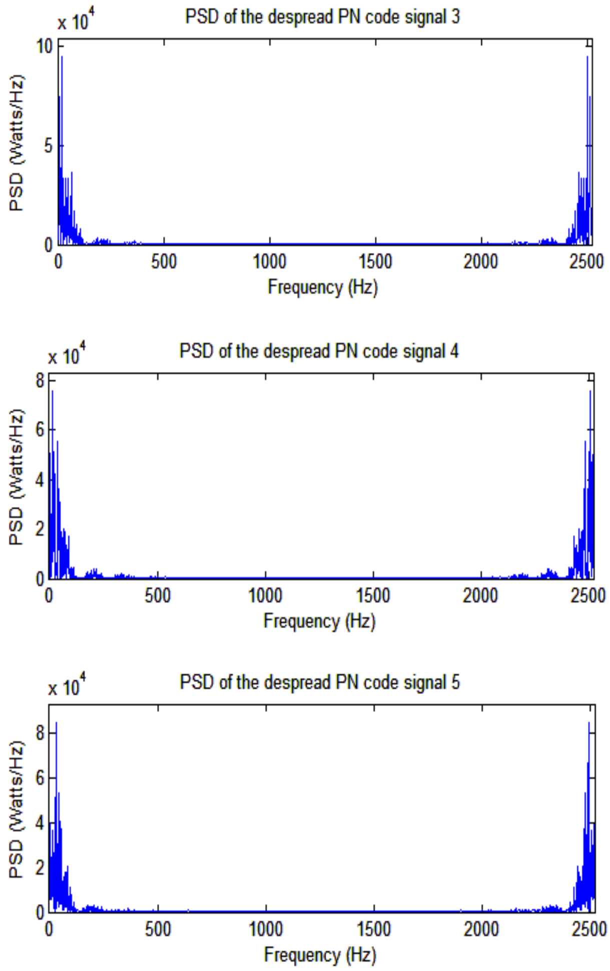
(b) Power spectral densities of the original data signal, PN code sequence, the spread signal and the BPSK modulated PN code signal, respectively, generated at the transmitter side.



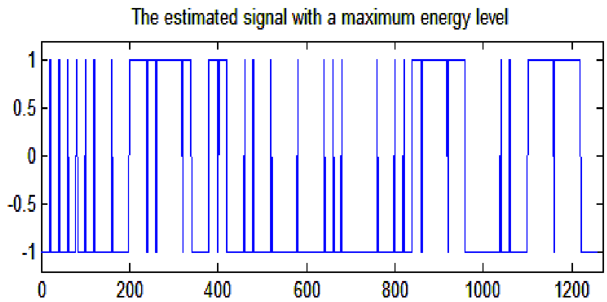




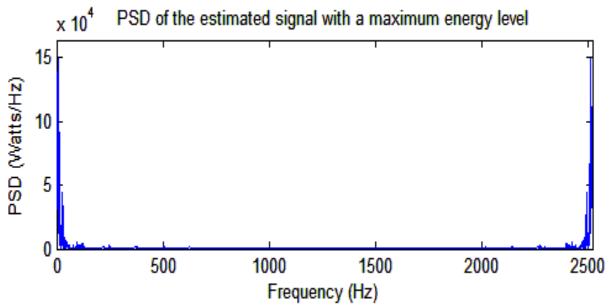
(c) Some waveforms of the despread PN code signals at the receiver side.



(d) Power spectral densities of some despread PN code signals at the receiver side.



(e) Waveform of the estimated signal with a maximum energy level at the receiver side.



(f) Power spectral density of the estimated signal with a maximum energy level at the receiver side.

Fig. 12. The simulation results of parallel search realization of the maximum likelihood search technique for DSSS signals in MATLAB. (a) Waveforms of the original data signal, the PN code sequence, the spread PN code signal and the BPSK modulated PN code signal, respectively, generated at the transmitter side; (b) Power spectral densities of the original data signal, the PN code sequence, the spread PN code signal and the BPSK modulated PN code signal, respectively, generated at the transmitter side; (c) Some waveforms of the despread PN code signals at the receiver side; (d) Power spectral densities of some despread PN code signals at the receiver side; (e) Waveform of the estimated signal with a maximum energy level at the receiver side; (f) Power spectral density of the estimated signal with a maximum energy level at the receiver side.

4 Conclusion

In this paper, we have investigated effective PN code acquisition techniques for DS-CDMA systems. First, we have described the direct-sequence parallel search acquisition system which has more complex hardware, but can achieve a faster acquisition. Another strategy for the acquisition of DSSS signals is the use of a sliding correlator or matched filter that serially search until synchronization is achieved. The serial search acquisition system can be implemented with low complexity but at the expense of long acquisition time. Effective Z-search strategies of a serial search technique have also been described. In the practical section, the modified algorithm for parallel search realization of the maximum likelihood search technique for DSSS signals in MATLAB has been proposed. In addition, the universal autonomous algorithm in MATLAB for PN code generation using a linear feedback shift register has been proposed. Finally, the procedure of parallel search realization of the maximum likelihood search technique for DSSS signals in MATLAB has been simulated and analyzed.

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