Chapter 2

Literature Review

2.1 PN Code Acquisition Systems

In this section we review the literature on PN code acquisition.

2.1.1 Classification of PN Code Acquisition Systems

Acquisition systems can be classified according to detector structure and search strategy, as shown in [1].

Consider the detector structure. It uses either a matched filter (passive correlator) or an active correlator. In the correlation process, the dwell time can be designed to be fixed or variable. Fixed dwell schemes can be classified as single dwell or multiple dwell, where the latter consists of two or more dwells. A variable dwell or sequential scheme means the elapsed time for examining the alignment in each possible cell is not fixed in advance. It depends on the actual received signal. Matched filter with variable dwell achieves acquisition faster, at the expense of increasing complexity. If the carrier phase is unknown during the acquisition, the system has to use a noncoherent detector. If carrier phase is known, the system may use a coherent detector.

The acquisition time also depends on the search strategy. The fastest acquisition is obtained by a fully parallel search, in which all possible correct cells are examined simultaneously. However, this requires extensive hardware. On the other hand, a serial search examines each cell sequentially using minimum hardware, but the acquisition time is long. Compromise can be made using a hybrid scheme which consists of a serial search that examines several cells at a time. In a serial search scheme, we can use one of several kinds of search strategy, depending on the priori knowledge about the correct phase. If all code phases are equally likely, the system should perform straight-line search. On the other hand, if the likely location of the correct code phase is known, either a Z or expanding window search is recommended. In a very high signal-to-noise ratio environment, a sequential estimate technique [1, 29] is preferable because of its simplicity and fast acquisition. The code phase is obtained by feeding an estimate of the state of the shift register of the local PN generator. With the correct value of the state, the shift register generates the PN sequence with the correct phase.

2.1.2 Performance Analysis Techniques for PN Code Acquisition

The performance of PN acquisition system is usually measured using one or more of the following: probability of density function (pdf) of acquisition time, mean acquisition time, and variance of the acquisition time. There are four techniques[1] for evaluating the acquisition performance: signal flow graph, time domain approach, circular diagram, and

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[1] Here, it is assumed that an active correlator is used. For passive correlator (matched filter), some suitable modification should be applied but it is straightforward.

direct approach. However, it is observed that the third and fourth techniques are modified versions of the first and second techniques, respectively.

In 1977, the signal flow graph technique was applied in [32] to obtain the overall generating function, as well as the mean and variance of the acquisition time. The single and double dwell serial search schemes were shown as examples. In this technique, nodes, arrows, probabilities of transition, and elapsed time z^k are used to represent the process of the system under consideration. The diagram can be drawn straightforwardly by using node S (starting node), one node for each cell, and node F (final node when acquisition is achieved), which are connected by arrows labeled with probability of transition and elapsed time. The transfer function from node S to F called overall acquisition-time probability-generating function can then be calculated. Consequently, the mean and variance of the acquisition time can be obtained respectively by multiplying the dwell time with the first and second derivatives of the generating function evaluated at z=1. Later, in 1980, [44] exploited the signal flow graph technique to calculate the pdf of the acquisition time for the single dwell serial search scheme.

In 1983, [45] proposed the technique called time domain approach. The pdf, mean, and variance of the acquisition time were represented as infinite summations of the products between the elapsed times (in time domain) and the corresponding probabilities which were obtained algebraically. In this technique, a flow graph is not needed.

In the following year, [33, 46] proposed a modified signal flow graph technique which was easier and more compact for analyzing the performance of many acquisition systems. It is called circular diagram technique. Here, the performances of single and multiple dwell were analyzed. Instead of drawing a signal flow graph of the cells in a linear manner, the circular diagram technique connects all cells in a circle. Only one cell specified as the correct cell can flow to the node F, while the others are incorrect cells which can lead to a false-alarm. The starting node can be one of the candidate cells with some probability depending on a priori information. The calculation of pdf, mean, and variance of the acquisition time are similar to those presented in [32]. This technique has been used in many papers.

Lately, in 1988, [31] proposed a technique called direct approach which is the combination between time domain [45] and z transform domain. Similar to [45], no flow graph is used. This technique finds the characteristic function (i.e., z transform) of the acquisition time. The function is the infinite summation of the products between elapsed times represented in the z domain and the corresponding probabilities. Such function can be used to calculate the pdf, mean, and variance of the acquisition time. The mean and variance of the single dwell serial search and the mean acquisition time of several kinds of Z searches were shown as examples.

2.1.3 PN Code Acquisition in Multipath and Fading

The effects of multipath and fading on code acquisition have been studied in many papers. In [47], the performance of the hybrid acquisition scheme was evaluated in a Rayleigh fading channel. The structure comprises N in-phase/quadrature-phase (I/Q) matched filters. It showed that the fading degrades the mean acquisition time significantly, especially, for fast fading[2]. Results suggested that, a reduction of dwell time can alleviate the effect of fast fading. An extension of this paper to the nonselective and frequency selective Rician fading can be found in [48].

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[2] The amplitude and phase of the fading can vary during the dwell time.

The optimal decision strategy for the fully parallel acquisition scheme in a frequency-selective fading was proposed in [49]. In the conventional fully parallel scheme, test statistics from all branches are compared and the code phase of the maximum test statistic is selected as the correct code phase. From the analysis in [49], it was suggested that, for a frequency-selective Rayleigh fading, a new test statistic be used. The i^{th} test statistic is obtained from the i^{th} branch to the $(i+L)^{\text{th}}$ branch for the case that there are L paths in the channel. This is similar to the rake structure. The performance evaluation showed that the proposed scheme outperforms the conventional one, especially for increasing L.

Traditionally, in a multipath and fading channel, we assume that the test statistics of the candidate code phases are independent of each other. This assumption is justifiable only when an active correlator is used and the dwell time is sufficiently long. However, for a passive correlator, such as a matched filter, this is not true. An analysis of the acquisition time with dependent fading for one path was considered in [50], where the acquisition scheme is the serial search with I/Q matched filters. It showed that the test statistics due to code phases under H_0 (incorrect code phase) are independent, while the present test statistic due to code phase under H_1 (correct code phase) is dependent of past test statistics due to code phases under H_1. The acquisition time analysis for dependent fading was given.

2.1.4 PN Code Acquisition with Automatic Threshold Setting

For a dynamic environment, due to causes such as multipath and fading, multiple access, or unknown signal-to-noise ratio, although the structure of the acquisition based on the maximum likelihood criterion is very suitable; to remedy the effect of the dynamic environment, the threshold value should be able to adapt automatically. An automatic decision threshold control for acquisition using an active correlator was proposed in [51]. The structure used two correlator branches working in parallel, with a time difference between the first and second local signals. Two algorithms were considered, called instantaneous threshold setting (ITS) and constant false alarm rate (CFAR). The threshold based on ITS was obtained by averaging the minimum value between the outputs of the first and second branch. For CFAR, the threshold was increased if the number of threshold crossing is larger than a specific number; otherwise, the threshold was decreased. The minimum value between the first and second branch was compared with the threshold.

Similarly, in [52], additional detectors were used to adjust the threshold. These additional detectors were designed so that they were orthogonal to the code phase detector. The output values of the orthogonal detectors were used for periodic adjustment of the threshold.

An improvement of the double dwell serial search with automatic threshold setting was proposed in [53]. In a double dwell acquisition, the first dwell is used to obtain a preliminary detection of the correct code phase, while the second dwell is used to verify the code phase specified by the first dwell. Therefore, the first and second dwells are called search and verification modes, respectively. Usually, they are performed one after another. However, in [53], they were designed to work in parallel. If the output of the search detector was larger than Γ_s, the current Γ_s and Γ_v were changed according to the output of the search detector, where Γ_s and Γ_v are the thresholds of the search and verification modes, respectively.

2.1.5 PN Code Acquisition with Diversity

In an L resolvable[3] multipath environment, it is usually assumed that there are L correct code phases in the uncertainty region. With this fact, two improved acquisition schemes for multipath were proposed in [54]. The first one was a single-dwell serial-search scheme with step size equal to L chips, while the second scheme was a serial search scheme using multipath diversity with step size equal to L chips, where the multipath diversity is a rake with three fingers and equal-gain combining. In the second scheme, the signal-to-noise ratio can be improved considerably without increasing the dwell time. The fading was assumed to be slow enough so that it was constant over the dwell time. Results showed that both schemes provided lower mean acquisition time when compared with the conventional serial search for either uniform or exponentially decaying multipath intensity profile (MIP). More improvement was observed for uniform MIP with exponential decaying MIP. In the case of high signal-to-noise ratio, both offered improvement for increasing L. The mean acquisition time slightly improved for increasing L when the signal-to-noise ratio was low and the first scheme provides almost the same mean acquisition time as the conventional scheme.

In addition to using multipath diversity, frequency and antenna diversities can alleviate the degradation from multipath as well. Frequency diversity can be achieved if the same signal is transmitted in many frequencies simultaneously, for example, in multicarrier DS-CDMA[4] (MC-DS-CDMA) systems [24]. The effect of multipath can be reduced since degradation is not equal in all frequencies. An acquisition scheme with frequency diversity was analyzed in [56]. M noncoherent detectors were used for M frequencies. The code phases were sequentially examined. The test statistic of the current inspected code phase was obtained by either the equal-gain combining or maximum-selective algorithm from the M outputs and then stored. After the scheme obtained the test statistics for all the considered code phases, the code phase corresponding to the largest test statistic would be declared as the correct code phase. Results showed that both acquisition schemes were useful when the channels were additive white Gaussian noise (AWGN) with partial-band interference (PBI), Rayleigh fading, and Rayleigh fading with PBI. In addition, the performance improved for increasing M and the structure using equal-gain combining always outperformed the one using selective algorithm. Conversely, in a pure AWGN environment, the performances of both became worse than the acquisition scheme without frequency diversity.

An analysis of acquisition system using antenna diversity was given in [57]. Similar to other diversities, the signal-to-noise ratio can be improved by summing the outputs from several antennas. In [57], it was assumed that the received signals from the antennas were independent since they were positioned so that the distance between two antennas was more than one carrier wavelength. The acquisition structure corresponding to each antenna was fully parallel. The test statistics were obtained from summing the outputs of the same branch numbers at different antennas together. Thereafter, the code phase due to the largest value was declared as the correct code phase. As expected, the performance improved as the number of antennas increased. An extension to the case of dependent signals was analyzed in [58].

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3 For SS systems, the time delay between two resolvable paths is larger than or equal to one chip duration.

4 In the literature, many models of the multicarrier for SS system was proposed, they are described in [55].

2.1.6 PN Code Acquisition in Multi-Dimensional Uncertainty Region

In additional to one-dimensional uncertainty region, i.e. code timing uncertainty region due to the propagation delay, the Doppler effect due to the movement of the transmitter or/and receiver causes additional uncertainty regions, i.e. frequency Doppler and code Doppler. Therefore, the uncertainty region of an acquisition system can be formulated as a three-dimensional uncertainty region: code timing-code Doppler-frequency Doppler. The code timing acquisition in this three-dimensional uncertainty region can be found in [59]. While [60] and [61] considered the code timing acquisition in the code timing-frequency Doppler uncertainty region and the code timing-code Doppler uncertainty region, respectively.

In using an adaptive antenna, one more additional uncertainty region is present, i.e. angular uncertainty region. [62] analyzed two-dimensional acquisition in the code timing-angular uncertainty region. The objective was to find both the correct code phase and angular dimension. The acquisition structure was the single dwell serial search. The correct cell in the two-dimensional uncertainty region was searched sequentially. Two search algorithms were considered in [62]. The first one was a fixed angle/sweep delay procedure, while the second one was a fixed delay/sweep angle procedure. Their performances were evaluated in many situations: AWGN, multipath, spatial interference.

2.1.7 PN Code Acquisition Using Auxiliary Signal

A new technique of acquisition was proposed in [37]. It consisted of two parts: an alignment detector (which is a conventional serial search) and a voltage controlled clock (VCC) loop. The direction of the search of the alignment detector was updated toward the correct code phase, as directed by the output of the VCC. In the VCC, there was a signal called auxiliary signal for correlation with the received signal. The auxiliary signal was designed so that its cross-correlation with the received signal in a noise-free environment had a triangular shape covering the whole uncertainty region. An improvement of at least two folds over the conventional serial search was shown. The auxiliary signal was obtained as a weighted sum of the PN code at different phases.

An extension of [37] to noncoherent acquisition was presented in [38]. Improvements on both the mean and variance of the acquisition time were observed. In addition to using an auxiliary signal to direct the code phase update, it can also be used to estimate the location of the incoming code phase. In [40], an initial estimate of the code phase was obtained using an auxiliary signal. Thereafter, the same process in [37] was used to find the correct code phase. Similarly, [41] also used an auxiliary signal to obtain the initial code phase of the local code phase generator. However, in [41], the code phase estimate was more accurate than that in [37] at the cost of increased hardware. In the alignment detector, [41] used the two single-dwell serial searches with opposite code phase update.

2.1.8 Further Topics in PN Code Acquisition

In additional to the above subsections, acquisition in the presence of data modulation [63, 64] have been considered in the literature as well. For the case of multiple access environment, interfering signals can be modeled as a zero mean white Gaussian random variable; therefore, a longer dwell time is required as the number of users increases. Similar to multiuser detection (MUD), many acquisition schemes in CDMA environment [65, 66] treat the interfering signal as a deterministic signal. They proposed algorithms to estimate (not detect) the correct code phase, with all candidate code phases being examined simultaneously. However, such algorithms require numerous computations.

Usually, a fixed dwell detection scheme is used in the alignment detector. Since it is well known that sequential detector generally reduces the sample sizes on the average, as compared to the fixed size sample (FSS) detector. Therefore, instead of using a FSS detector, many papers analyzed applications of the sequential detector in PN code acquisition [67-71].

2.2 PN Code Tracking Circuit

There are not many recent papers in the literature on PN code tracking, perhaps due to maturity of the subject. In addition to designing tracking circuits to overcome the effect of noise, robustness to the effect of multipath fading and multiple access interference (MAI) should also be important. The effect of multipath fading to PN code tracking was considered in [72], where a noncoherent DLL was used. Multipath fading changes the discriminator characteristic of a tracking loop due to time-variant amplitude and phase and the delay spread. Therefore, the shape of the discriminator characteristic is distorted and the locking point is moved. Consequently, multipath fading increases the tracking error. On the other hand, a multipath extends the pull-in range, which improves the mean time to lose lock.

The effect of MAI on the performance of a noncoherent delay locked loop (NC-DLL) was investigated in [73]. The paper analyzed the NC-DLL in an MAI environment. The near-far effect and capacity load were also shown. Unlike the mulipath, an MAI can delay or advance the locking point. It was found that the near-far effect degraded the performance of NC-DLL significantly even when there were only a few users in the system. Therefore, the power control is necessary.

The performance degradation of a CDMA system due to code timing error was discussed in [74]. Two reasons that cause a code timing error, i.e. multipath and MAI, were explained. It showed the degradation on bit error probability, packet success probability, throughput, and time delay of successful transmission. It was recommended that a coherent DLL (C-DLL) should be used instead of NC-DLL when possible.

As we know, data detection in SSMA is significantly improved if an MUD is used. However, an MUD requires code timing synchronization. The effect of code timing error on the decorrelating detector was investigated in [75]. Results showed that the decorrelating cannot preserve its near-far resistance in the presence of timing error. In [76], the effect of timing error on the parallel interference cancellation (PIC) detector was investigated. It was found that the PIC was considerably robust to the timing error.

A tracking circuit to overcome a multipath fading was proposed in [77]. The proposed scheme consisted of a C-DLL and a channel estimator. The channel estimator comprised several branches, each branch was used to estimate the channel gain and phase of each path. The C-DLL also consisted of several branches, each branch correlated its local code sequence with the received signal. The outputs were adjusted by the estimated gain and phase before summing in order to produce an error signal. The structure of the C-DLL used here was similar to the rake structure.

In addition to weighting the correlation output of each branch in a DLL with the estimated gain and phase, another attempt to eliminate the effect of multipath in a DLL was proposed in [78]. The proposed scheme consisted of a rake-like NC-DLL and a multipath reproduction unit. The multipath in the received signal was removed by the estimated mutipath interference before entering the NC-DLL. The estimated multipath interference was obtained from the multipath reproduction unit.

The two schemes in the previous paragraphs were decision directed algorithms. In [79], a scheme was proposed to overcome the unknown data-bearing received signal and carrier phase, also using a decision directed algorithm. Additional hardware was needed to estimate the tentative data and carrier phase, which were supplied to the C-DLL.