Chapter 1

Introduction

Spread spectrum (SS) system was originally invented to be used in military applications. A completed history of SS system can be found in [1, 2]. It has properties of anti-jamming, anti-interference, low probability of intercept etc., which are desirable properties in military communications. Until two decades ago, it began to step into commercial mobile communications [3]. Its performance was expected to be superior to other conventional multiple access techniques, i.e., frequency and time division multiple accesses (FDMA and TDMA).

There are some problems in designing mobile communications. First, a mobile channel is rather hostile. The received signal can be severely degraded by multipath and fading[1] [4-9]. In addition to using adaptive antenna arrays[2] to mitigate the multipath and fading [15], SS systems can alleviate such degradation by exploiting the rake structure [5, 16]. Second, [17] showed that the capacity (number of users) in a SS multiple access (SSMA) system is limited by the multiple access interference (MAI). So, an SSMA system provides a soft-limited capacity, whereas FDMA and TDMA have a hard-limited capacity. Last, an SSMA system has the undesired near-far[3] effect, which can be alleviated by a power control technique [18]. The receiver can also be designed to alleviate the near-far problem [19, 20]. In the last decade, many techniques have been explored, e.g., multiuser detector [17, 21, 22], adaptive detector [23], diversity (i.e., multipath diversity [5, 16], frequency diversity [24], antenna diversity [13, 14]), etc. Besides its use in the IS-95 mobile system, SS technique has been adopted for terrestrial air interface of the third generation (3G) mobile communications [25]. Additionally, SS system is also anticipated to be a candidate for the fourth generation (4G) mobile communications [26, 27].

In an SS system, the transmitted bandwidth is many times wider than the original data bandwidth. Generally, there are three basic kinds of SS techniques: direct sequence (DS), frequency hopping (FH), and time hopping (TH) [1]. However, in this thesis, we are only interested in direct sequence SS (DS/SS) systems. At the transmitter of a DS/SS system, the data signal modulates the pseudonoise (PN) signal (called spreading process) before it modulates the carrier and gets transmitted. A PN signal is a deterministic periodic binary sequence exhibiting random properties. The time duration of one bit of the PN

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[1] Characterization, properties, and models of multipath and fading can be found in many books and articles, for examples, [4-9].

[2] Adaptive antenna arrays are common techniques for wireless systems, i.e., FDMA, TDMA, code division multiple access (CDMA). Their performance improvements are mentioned in [10]. They are also used for space division multiple access or SDMA system [11]. The benefits of antenna arrays are various, including reduction of the effect due to multipath and fading, as well as interference [12]. Details of adaptive antenna arrays can be found in [13, 14].

[3] The received signal from a closer transmitter has a higher power than a faraway transmitter, due to lower path loss. This situation only occurs in the reverse link, i.e., signal transmission from mobile station to base station.

signal is called a chip. Several PN signals have been developed. They possess different properties of autocorrelation and cross-correlation functions. Each is suitable for different applications [1, 28-30].

At the receiver, data is recovered by modulating the received signal with a synchronous replica of the PN signal. This process is called despreading. Therefore, the receiver must obtain PN code synchronization which must be accomplished before despreading.

Traditionally, the code synchronization comprises of two processes, initial acquisition and tracking. The former is performed first in order to reduce the difference between the code phase of the incoming and the local signals to a fraction of chip, typically a half or one chip. Then, the tracking process begins to perform fine adjustment and maintain the difference of code phase to zero or near zero.

At the beginning of the acquisition process, the acquisition system has to know the uncertainty region, which is the region where the incoming code phase can lie[4]. The uncertainty region is divided into a finite number of tested code phases (cells) for searching. The number of cells[5] is dictated by the step size of the alignment detector and the pull-in range of the tracking process. Each cell is examined by the alignment detector, using the output of the correlation between the incoming signal and a local PN signal with a phase being the code phase under inspection. Either "in alignment" or "out of alignment"[6] is decided by the decision device. In a parallel search, there are parallel correlators for all the cells under test and the outputs are compared to determine the most possible code phase of the incoming signal. In a sequential search scheme, there is one correlation for testing one cell at a time. The output is compared with a threshold. The process is repeated for each new cell until the output is larger than the threshold. Then, "in alignment" will be declared and the tracking process starts.

The performance of an acquisition process is usually measured as the mean and variance of the acquisition time, which is the time spent until acquisition is achieved. They can be computed from the probability density function of the acquisition time [31]. However, a more powerful and favorite method is to use the probability generating function of the acquisition time [1, 32], which can be obtained from the process's flow graph [1, 32-33].

Once the acquisition process declares coarse alignment, fine adjustment is started and maintained by the code tracking process. This functionality is accomplished by using an early-late type loop, which utilizes the difference between the advanced and retarded correlation results to adjust the local PN phase.

Traditionally, there are two types of code tracking loops [1, 29]: delay-locked loop (DLL) and tau-dither loop (TDL) or time-shared loop. However, both adopt the same

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[4] Actually, the uncertain region is a two dimensional time-frequency uncertainty region. The frequency uncertainty occurs due to Doppler effect, while the time uncertainty is the unknown timing of the code phase due to propagation delay. However, we consider only time uncertainty region.

[5] The number of cells is equal to N/Δ, where N is the length of the considered uncertainty region, Δ is the step size of local code phase update, typically, 0.5 or 1 chip. The value of the step size is selected depending on the value of pull-in range of the tracking circuit. In our thesis, we use the step size of one chip, which is enough. Therefore, uncertainty region is divided into N cells.

[6] "In alignment" means that the code phase difference between the incoming and local code phase is less than or equal to a specific values. Usually, such specific value is equal to the pull-in range of the tracking circuit. "Out of alignment" means otherwise. Therefore, it is possible that more than one cell can give "in alignment", especially, when the step size is small (fractional number), or the pull-in range is large. However, in our thesis, only one cell may correspond to "in alignment".

principle as described above. The difference occurs only that the former uses two active correlators, while the latter uses only one active correlator in a time sharing mode. The performance of a tracking process is evaluated by the tracking jitter, the acquisition (transient) behavior, and slip time (mean time to lose lock) [1, 29].

1.1 Motivation and Scope

As mentioned above, the code synchronization process usually requires two successive processes. However, in the situation that the range of uncertainty is very small, i.e., a few chip durations, the step of acquisition can be skipped, and only the code phase tracking circuit can be used to obtain the code phase synchronization. The pull-in range of such tracking circuit has to be extended to cover the uncertainty region under consideration. Several extended range tracking circuits have been proposed in the literature [1, 34-35]. All of them suffer from either the limited range extension or increasing the noise jitter. A solution was proposed in [36] by applying a branch selection algorithm. Two consecutive active correlators from a bank of M correlators are selected to form a conventional tracking circuit. By using the branch selection algorithm, the pull-in range can be extended as desired without increasing the noise jitter. However, the scheme suffers from a low probability of correct branch selection. Consequently, in this thesis, we propose modified schemes to improve the probability of correct branch selection.

Furthermore, we are also interested in the acquisition process. Traditionally, the fully parallel search acquisition scheme provides the fastest acquisition but it needs extensive hardware, i.e., the number of correlators is equal to the number of considered cells, which can be prohibitive for practical implementation. On the other hand, a serial search acquisition scheme has minimum hardware, but it is slow. A compromise of these two approaches leads to hybrid search schemes. Recently, a serial search acquisition scheme with an auxiliary signal was proposed [37]. It shows significant improvement. Then, the idea was extended to various cases [38-43]. The auxiliary signal is used in order to either obtain the direction for updating the code phase or estimate the incoming code phase. In this thesis, we propose an acquisition system with a set of auxiliary signals for estimating the section of uncertainty region that the incoming code phase is located. The estimated section is then supplied to the serial search detector. A new estimated section will be provided until the incoming code phase is detected.

We assume that the carrier phase is known a priori, so our systems can use coherent carrier demodulation. We also assume that no data is transmitted during the code synchronization. The transmitted signal is a DS/SS signal with m-sequence spreading code [28].

1.2 Thesis Outline

The entire thesis is organized into seven chapters. Chapter 2 reviews many interesting papers which have appeared in the literature in the area of code acquisition and tracking.

Chapter 3 begins with a description of the delay-locked loop (DLL) with correlation branch selection [36]. Subsequently, we propose two modified schemes, called parallel early-late DLL and parallel extended range DLL. Their performances are analyzed in terms of the probability of correct selection. Performance evaluations under various parameters are presented. Results confirm the improvement obtained by the modified schemes.

Chapter 4 concentrates on a proposed acquisition system using a set of auxiliary signals. The detail of the overall system is described. We also mention and discuss important parameters of the proposed system. The performance of the sectional estimate is derived in term of the probability of correct estimate. Other related probabilities are also obtained.

Chapter 5 is dedicated to analyzing the probability mass function and the mean of the acquisition time of the proposed system described in Chapter 4. The signal flow graph technique [32] is used here.

Chapter 6 shows the performance results of the proposed acquisition system presented in Chapter 4. The performance is evaluated by obtaining numerical results of various probabilities and the acquisition time. Both simulation and analytical results are presented. The effects of various parameters are also considered and discussed.

Chapter 7 concludes this thesis. Some issues for further research are also suggested.