The Overview of Synchronization in DS-UWB

Jun Chen, Zheng Zhou
Wireless Network Lab, Beijing University of Posts and Telecommunications
Inner Box.96, Beijing University of Posts and Telecommunications, Beijing 100876, P.R.China
Email: c_pony@163.com and zzhou@bupt.edu.cn

Abstract--[1]**Ultra-Wide band (UWB) radio, transmits data using nanosecond level impulses, is gaining increasing attention own to its attractive features that include low-complexity hardware and high transmission rate. However, UWB system has to cope with great design challenges, including synchronization, multi-path energy combining. A review of acquisition methods in Direct Sequence-Spread Spectrum (DS-SS) communication system is given in detail at first and analysis of their performance with evaluating parameters, which is the essential reference to DS-SS acquisition algorithm is shown next. Then, several acquisition scheme used specially in DS-UWB system is analyzed. Hardware complexity and acquisition performance in DS-UWB is still the two sides of one contradiction needed to be tradeoff.**

Keywords: **UWB, DS, Synchronization, Acquisition**

I. INTRODUCTION

Ultra-Wideband (UWB) technology has emerged as a promising one for many applications in high speed wireless communication, location, and tracking etc. Adapted to these applications owe to its attractive features that include low-power low-complexity base band operation and ample multi-path diversity. Meanwhile, to realize these unique features of UWB radio, clock synchronization constitutes a major challenge, the difficulty of which is emphasized due to the impulse-like low-power UWB transmit-waveforms.

The process of synchronization algorithm in UWB communication system typically includes two successive stages same as traditional spread spectrum communication system. Step1 is acquisition, it make a coarse alignment (less than a fraction of a chip) between the received signal and local generated template signal. Step2 is tracking. This process maintains the two codes in fine synchronization by means of a closed loop operation [1].

According to the definition of UWB given by Federal Communications Commission (FCC), several communication schemes discussed in vogue. There are Time Hopping-Pulse Position Modulation (TH-PPM), Direct Sequence-Pulse Amplitude Modulation (DS-PAM) and Multi Band-Orthogonal Frequency Division Multiplexing (MB-OFDM). Among them, TH-PPM scheme attracts more interesting in academic analysis rather than industry field. The transmitted information in the form of pulse position different appears in each frame of symbol, time hopping code is used as multi-user access. Another scheme transmits information by BPSK modulated bi-phase or monocycle pulses and spreads signal spectrum in whole bandwidth with PN code. The final approach is multi-band scheme. Like original OFDM communication system is applied overwhelming, this scheme divide available spectrum into many sub-bands, each occupies at least larger than 500 MHz. Multi-carrier-modulation using OFDM technology is employed. The transmission rate can be improved by simply multiplexing more bands at the expense of system complexity. Aims at different scheme the synchronization algorithm is different respectively.

This paper mainly focuses on the DS-PAM scheme. Synchronization problem about common DS-SS communication system have been investigated a lot. A rapid acquisition methods using PN code for spread spectrum communication system are developed in [1]. In Section II, history overview about PN based acquisition is given. However it is general PN code timing acquisition scheme which take into account neither the extremely short pulse nor the channel effect. In other words, it is not dedicated for UWB pulse synchronization. The most important performance analysis about PN based acquisition will be discussed in Section III. In Section IV, acquisition methods in UWB scheme will be discussed. Finally, some concluding remarks are made in Section V.

II. ACQUISITION METHODS IN CLASSICAL DS-SS COMMUNICATION SYSTEM

In DS-SS communication system, classical peak-picking method finding the maximum output of a sliding correlator with the transmit-waveform template (local generated) is not only suboptimum in the presence of dense multi-path, but also results in unacceptably slow acquisition speed and prohibitive complexity. This situation will be worsening especially when UWB has to perform exhaustive search over thousands of bins (chips) [4]. Based on this algorithm, several methods are deduced to make a tradeoff between costs and precision. The classification of rapid acquisition methods according to search strategy can be divided into

[1] This research was supported by:
National Natural Science Fund of China (60372097)
National Natural Science Fund of China-key project (60432040),
Beijing Municipal Natural Science Fund (4052021)
University IT Research Center Project (INHA UWB-ITRC), Korea.

three parts: maximum-likelihood algorithm (MLA), serial search and sequential estimation.

A Maximum-likelihood algorithm (MLA)

Maximum-likelihood algorithm perhaps is the simplest, at least conceptually method which has strictest form and requires that the input serial signal be correlated with all possible pulse positions (or the every each step positions) of local generated signal replica. All of these correlators operate simultaneous and respectively with identical observation of received signal plus noise. Under this compulsive force acquisition procedure, a definite decision will be made after only a single examination of all code phase positions. The advantage of MLA is the rapidest acquisition speed and the simplest method in theory but requires the most complex receiver structure or the most expensive cost.

B Serial search

Aimed at making the progress of MLA, the serial search scheme is proposed as a less strict version of maximum-likelihood algorithm. Here the input signal is serially correlated with all possible pulse position (or perhaps fractional pulse position) of the local generated pulse replica. The corresponding detector outputs are stored until the maximum detector output is chosen as the correct pulse alignment described by local pulse phase position. The delay between received signal and local template is:

$$Delay = \arg_i(\max(Z_i)) \times \Delta t \qquad (1)$$

Same as form which it derived, the definite decision will be made after a single search through the entire pulse period. Since the limits of FFC mask, UWB system may transmit a train of impulses with very short duration in the order of nano-seconds [5]. A single data symbol is associated to several consecutive impulses for reliable communication, each located in its own sub-frame. The process of synchronization decision in serial scheme needed search the entire frame is too long to tolerance especially in real time communication. Thus, many improvements made to decrease the search time at acceptable hardware complexity. One of the improved ways is the test for synchronization is based on the output Z_i whether cross the preset threshold. The search can stop anywhere within the sequence area rather than having to wait till the end of the entire sequence period. This scheme trade off shorter acquisition time against reduced accuracy in detection of synchronization. Next discussion is mainly based on this threshold-comparison structure.

C Sequential estimation [1]

Another scheme, named RASE (Rapid Acquisition by Sequential estimation) based on the property that the next combination of register states of PN sequence depends only on the present combination of the states. So, the acquisition system makes the best estimate of the first n (the number of stages in the PN code generator) received PN code chips, if this n code chips are correctly estimated, all the following states can be predicted based on the knowledge of only this initial condition. If the correct estimate is made, the PN code generation register is then closed within the PN tracking loop which is responsible for maintain code phase from that time on. Because the estimation process is performed on a chip-by-chip basis, it does not take advantage of the interference rejection capabilities of PN signals, the RASE technique has not the immunity of noise and ISI (inter signal interference). A modification scheme also proposed named: RARASE (Recursion-Aided Rapid Acquisition Sequential Estimation).

D Adaptive threshold acquisition system

Maximum likelihood algorithm discussed previously is basic approach for PN sequence acquisition in noise environment. If choosing long PN code with large procession gain, its parallel form have fast acquisition speed with most complex hardware, its serial implementation have simplest hardware but acquisition time is the longest for the search process of entire sequence space. Conventional serial search algorithm uses a fixed threshold to decide the occurrence of acquisition. However, in a practical communication environment, the channel is time-various; the signal to noise ratio (SNR) in receiver is not a fix value. So, the threshold selection becomes a deliberate task. Many articles propose their approach to improve the performance of acquisition, but how to select an optimized threshold is a black box. Aims at this difficult, another articles propose the algorithm exploit the adaptive threshold to control the search process. In order to use different threshold for acquisition, all known methods, in one form or another, must estimate the background power level or exploit the statistics of noise characteristics to control the preset threshold. In [9], an adaptive threshold acquisition system with the constant false alarm rate (CFAR) was proposed. The correlator bank can search N chip positions at one time. Threshold ($T□X = T□f(\overline{Z(M)})$) changed depends on the correlator bank output except the maximum correlator output $\overline{Z(M)}$. If the maximum correlator output over the threshold TX, the chip position of maximum correlation occurs is the synchronization position. On the contrary, the PN sequence steps into next N chip positions for search. In [10], the author proposes an adaptive threshold acquisition system named: Automatic decision threshold level control (ADTLC). In [11], an adaptive signal detection threshold for signal detection and an adaptive signal classification threshold for classifying a signal versus noise, and a noisy bin threshold used to indicate the number of integrator output does not exceed the signal classification threshold are defined in a maximum likelihood approach combining with a serial search approach acquisition system.

E Blind acquisition

Until now, the methods discussed in previous section have a common feature; all those algorithms operate in the preamble included in the data frame. In other words, they are data-aided acquisition schemes. Own to the judiciously designed training sequence in preamble, the acquisition get a high performance. Moreover, in time-various channel, the training sequence may have to be transmitted periodically for fine acquisition. This would cause the undesirable throughput or bandwidth reduction. Furthermore, the performance of data-assisted schemes degrades a lot when they do not work in stationary or slow-fading channels.

Recently, non-data aided or blind schemes, which do not suffer form such drawbacks, have been receiving substantial interest. A MUSIC (MUltiple SIgnal Classification) algorithm proposed in [13], it decomposes the observation space into orthogonal signal subspace and noise subspace, and the orthogonality is exploited for parameter estimation. However, the MUSIC need the number of transmitted signal and sensitive to colored noise or unknown interference in which it difficult to distinguish the signal subspace from the noise subspace.

Another blind acquisition scheme proposed in [14], which refer to the Capon algorithm, design a bank of filters, each of which passed one user signal of interest without distortion, meanwhile suppressing the overall interference as much as possible. It only needs the spreading code of the desired user. The author also proves than this scheme can be used in many kinds of communication environments, such as: ISI, MAI and colored noise.

III. Performance Analysis of Single-Dwell Serial Search Acquisition System

In order to evaluate the performance of single-dwell serial search acquisition system, well comprehension about the whole search process is necessary at first. No matter what kind of search algorithm used in acquisition system, the basic idea is similar. At each test position, the sampled output compare with the preset threshold. If the sampling above the threshold, a hypothesized position is defined. If this hypothesized position represents the true acquisition position, then the acquisition process comes to an end. If the hypothesized position is a false alarm, then after the verification process the search must continue. Generally, the verification process can be regarded as the "penalty time" (assume: $K\tau_d$ sec; K_P>>1) of obtaining a false alarm. If the sampling fall s below the preset threshold, then the local sequence generator steps to its next position and the search continue. Thus, except the true acquisition position, one of the two events can take place, namely, false alarm indicate the acquisition occurred when the sequences are actually misaligned and on the contrary, no false alarm. With the point of view of statistical, a false alarm happens with a probability P_{fa} and causes a penalty of $K\tau_d$ sec; no false alarm occurs with probability (1- P_{fa}) and results a single dwell time of τ_d sec. Furthermore, at the true acquisition position, a correct detection happens with probability P_d and no detection occurs with probability (1- P_d).

A Markov chain acquisition model

With those priori definitions, a whole acquisition process can be modeled as a discrete Markov chain. The only one acquisition position, denoted with H_1, can appears in anyplace within the uncertain region and the rest positions are the misalignments, denoted with H_0. Without loss of generality, N search position is defined in uncertain region (if search proceeds in half-chip increments, then $N=2N_u$, N_u is the number of chip in pseudorandom sequence).

B Mean acquisition time $E(T_{acq})$ and acquisition time variance σ_{acq}^2

In generally, the acquisition time T_{acq} is a random variable and depends on the initial code phase position of the local PN generator relative to that of the receiver code. The only way to describe the T_{acq} is its probability density function. Conventional, we use mean acquisition time $E(T_{acq})$ and acquisition time variance σ_{acq}^2 for the serial acquisition to evaluate the probability of successful acquisition for the system. As is discussed in [1], Mean acquisition time and acquisition time variance are all function of the detection probability P_d, false alarm probability P_{fa} and dwell time τ_d, it means: $\overline{T}_{acq},\sigma_{acq}^2 = f(P_d,P_{fa},\tau_d)$. Without less generalization, we assume that the initial position of serial search begin at anyplace of the uncertain region with equal probability. That is the initial position with a uniform distribution, $P_{C(i)}=1/N, (j=1,2,\dots N)$. Then, we can get:

$$\overline{T}_{acq} = \frac{(2-P_d)(1+KP_{fa})}{2P_d}(N\tau_d) \tag{2}$$

$$\sigma_{acq}^2 = \tau_d^2(1+KP_{fa})^2 N^2\left(\frac{1}{12}+\frac{1}{P_d^2}-\frac{1}{P_d}\right) \tag{3}$$

These equation only apply to the single dwell serial acquisition scheme, other can get derive the formulas form this basic idea.

IV. Rapid Acquisition Methods in UWB Communication System

Unlike the DSSS communication system, UWB system uses the impulse in nanosecond level to communicate. Fortunately, the DS-UWB system uses PN code for modulation or multi-user access, all of acquisition scheme applied in DSSS communication system can be referred to DS-UWB system. The challenge in DS-UWB acquisition is more acquisition position need to be searched or more precise acquisition needed.

A combination of serial timing searching and parallel phase matching algorithm is proposed in [12]. Own to its unique structure, the acquisition speed and accuracy is improved significantly. The stimulation result indicates that the acquisition time can achieve less than 3 μs. There are also blind acquisition [5] proposed for bandwidth or power efficiency. Besides these improvements for conventional acquisition schemes, many novel algorithms proposed for UWB system.

A Sequential Block Search (SBS) [6].

This search algorithm aims at reducing the mean acquisition time, while maintaining the receiver complexity comparable to the serial search approach. The whole search process can divided into two steps. Firstly, the SBS determine a subregion where the signal delay is likely to exist. Then, the exact position of synchronization would be extracted form this subregion with a more deliberate search process. According to this method, a new template signal is defined for quickly search in first step. Given the K is the number of search position in the block then the whole uncertainty region N is divided into B=N/K block. New defined template includes K search position rather than the conventional serial search algorithm the local template only includes one search position. The output from the block template used as a criterion to decide if the block contains the synchronization position or not. If the block output exceeds the preset threshold, normal serial search methods used in the subregion to find the exact acquisition position.

From the simulation experiments results, the mean acquisition time of SBS is shorter then serial search.

$$\overline{T}_{acq} = \frac{(2 - P_s P_d)[\tau_{SBS} + KP_N(\tau_d + CP_{fa})]B}{2P_s P_d} \quad (4)$$

Where: C is the penalty time and τ_{SBS} is the dwell time in SBS block. P_s is the probability of a signal block output exceeds the threshold.

B Bit reversal search (BRS) [7, 8].

Bit reversal search algorithm attempt to improve sliding-correlator based acquisition speed over a noiseless no-modulated pulse sequence. Unlike the traditional serial search used linear sweeping the uncertain region cause longer average search times, BRS use nonconsecutive serial search strategy make a more efficient search process. In [10], the author compares the BRS performance with other serial search order, such as: linear search, truly random search, look and jump by K bins' search. The mean stopping time of the BRS is:

$$\overline{T}_{acq} = \frac{1}{2} \cdot (\frac{N}{K} + 1) \quad (5)$$

Where: N is the entire search position including in uncertain region, K is the consecutive position for one search. It is the shortest mean acquisition time among these serial search strategies. In [9], a hybrid parallel/serial search scheme which uses multiple correlators in the receiver is given. The estimation result shows that the performance of BRS is better then linear serial search strategy.

V. CONCLUDING REMARKS

Acquisition proves to be a significantly important issue for UWB communication systems due to the using of extremely short impulse with high speed transmission rate. We review the main acquisition schemes to help reader have a bird's-eye viewpoint about DS-UWB acquisition algorithm. It is also indicate that hardware complexity and acquisition performance in DS-UWB is still the two sides of one contradiction needed to be tradeoff.

REFERENCE:

[1]. M.K. Simon, J. K. Omura, R. A. Scholtz, and B. K. Levitt, Spread Spectrum Communications Handbook, volume III, McGraw-Hill, 1985.

[2]. Homier, E.A.; Scholtz, R.A.; "Rapid acquisition of ultra-wideband signals in the dense multipath channel Ultra Wideband Systems and Technologies", 2002. Digest of Papers. 2002 IEEE Conference on, 21-23 May 2002, Pages: 105 – 109.

[3]. Z.Tian, L.Yang, and G.B.Giannakis, "Non-data aided timing acquisition of ultra-wideband transmissions using cyclostationarity", IEEE Trans. On communications, submitted March 2003.

[4]. Liuqing Yang, and G.B.Giannakis, "Blind UWB Timing With a Dirty Template", ICASSP, 2004, Page(s): 509- 512. vol.4.

[5]. Aiello G.R., Rogerson G.D. "Ultra-wideband wireless systems", Microwave Magazine, IEEE , Volume: 4 , Issue: 2 , June 2003, Pages:36 – 47

[6]. S. Gezici, et al., "A rapid acquisition technique for impulse radio," Communications, Computers and signal Processing, 2003. PACRIM. 2003 IEEE Pacific Rim Conference on Volume: 2. 28-30 Aug. 2003. Page(s): 627- 630. vol.2.

[7]. E. A. Homier and R. A. Scholtz, "Hybrid fixed-dwell-time search techniques for rapid acquisition of Ultra-WideBand signals," the Department of Defense under MURI Grant No. DAAD19-01-1-0477 and NGST Doctoral Fellowship

[8]. E. A. Homier and R. A. Scholtz, "Rapid acquisition of ultra-wideband signals in the dense multipath channel," Ultra Wideband Systems and Technologies, 2002. Digest of Papers. 2002 IEEE Conference on 2002. Page(s): 105- 109

[9]. K. Chang-Joo, et al., "Adaptive hybrid acquisition of PN sequences for DS/SS communications," Electronics Letters. Volume: 34 Issue: 10, 14 May 1998. Page(s): 939-940

[10]. S. G. Glisic, "Automatic decision threshold level control in direct-sequence spread-spectrum systems," Communications, IEEE Transactions on. Volume: 39 Issue: 2, Feb 1991. Page(s): 187-192

[11]. C. Sanguoon, "A new serial search acquisition approach with automatic decision threshold control," Vehicular Technology Conference, 1995 IEEE 45th. Volume: 2, 25-28 Jul 1995. Page(s): 530-536

[12]. Z. Yuanjin, R. Cao and Y. Lian, "A new synchronization algorithm for UWB impulse radio communication systems," Communications Systems, 2004. ICCS 2004. The Ninth International Conference on, 6-8 Sept. 2004, Page(s): 25- 29

[13]. E. G Strom, S. Parkvall, S. L. Miller and B. E. Ottersten, "Propagation delay estimation in asynchronous direct-sequence code-division multiple access systems," Communications, IEEE Transactions on, Volume: 44, Issue: 1, Jan 1996, Page(s): 84-93

[14]. L. Hongbin and W. Rensheng, "Interference resistant blind code synchronization for DS-CDMA systems," Vehicular Technology Conference, 2001. VTC 2001 Fall. IEEE VTS 54th, Volume: 1, 2001, Page(s): 318- 322