Original Research Article

Robust matched-filter acquisition for direct-sequence ultrawideband systems

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Abstract: In this paper, we propose and analyze a rapid acquisition loop for a direct-sequence ultrawideband (DS-UWB) system called robust matched-filter acquisition, which is mainly aimed at eliminating the cases of false alarm in signal acquisition. Moreover, we present a study on the acquisition performances of the serial search, conventional matched filter, and robust matched filter in UWB dense multipath environments. The mean acquisition time, the acquisition probability, and the mean number of false alarms are evaluated for CM1-CM4 channel models. We find that the robust matched-filter acquisition provides a significant improvement in performances over the conventional matched-filter algorithm for the specific UWB channel model. UWB (Ultra Wideband) wireless communication system is very suitable to short-distance and high-data-rate wireless communication, because it has the characters of higher data rate, shorter communication distance, and low average transmission power. UWB systems ensure certain fixed synchronized error between the transmitted and received ends. In the thesis, we will focus on the issue of synchronization performance analysis to do further discuss and study. In real communication channel environment, multipath factor contributes a lot of severe interference to data transmission whereas it happens more severely in dense metropolitan area. Conventionally, we use Rake receiver to receive the signal in order to reduce such multipath-caused interference. However, using Rake receiver, we required to know the delay time and attenuated amount of each transmitted route in advance. Furthermore if we needs to gather more signal energy, it is necessary for us to add more "fingers" at Rake receiver. Nevertheless it will increase complexity of the hardware. To avoid such situation happening, we adopt the concept of DHTR (Delay-Hopped Transmitted- reference) that correlates the delayed signal with original one to avoid the design issue of template signal. In the proposed scheme, we are able to reduce the complexity problem of the Rake receiver system. Besides, we further present the performance analysis of such system to make the study more complete, also provide a convincing proof to the simulation.

Keywords: DS-UWB(Direct-Sequence UltraWide Band); Acquisition; automatic gain control (AGC); complexity

1. Direct-sequence ultrawideband systems

Ultra-wideband wireless communications techniques have many merits, including an extremely simple radio that inherently leads to low-cost design, large processing gain for robust operations in the presence of narrowband interference, covert operations, and fine time resolution for accurate position sensing. However, there are a number of challenges in UWB receiver design, such as capturing multipath energy, intersymbol interference especially in a non-line-of-sight environment, and the need for high-sampling-rate analog-to-digital converters. In this article, we provide a comprehensive review of UWB multiple access and modulation schemes, and their comparison with narrowband radios. We also outline the issues with UWB signal reception and detection, and explore various suboptimal low-complexity receiving schemes.

2. DS- ultrawideband systems

Traditional synchronization techniques applied to impulse-radio ultra-wideband (UWB) result in prohibitively long acquisition times, due to the extremely large search space. Additionally, in dense multipath environments, there exist a larger number of cells within the uncertainty region that can lead to acquisition lock. Locking to an arbitrary multipath component may result in unacceptable performance for many applications (range error in positioning systems for example). In this paper, we present a modified framework for the analysis of UWB acquisition which accommodates multiple lock cells. The framework divides the acquisition process into two distinct phases. The two phases are termed "coarse" and "fine" acquisition. The coarse acquisition phase is a fast implementation of traditional serial search which takes advantage of the large number of cells which can terminate the search process. Fine acquisition exploits statistics derived from the first phase and the clustered nature of multipath arrivals to determine the earliest arriving path, even when it is severely attenuated. We show that the first phase provides a substantial improvement in mean acquisition time compared with traditional serial search and that the second phase provides robust estimation of the first arriving path in ranging applications.

3. Robust matched-filter

The automatic gain control (AGC) loops are usually used in communication systems to stabilize the performance. In this paper, the combined performance of digital delay-locked loop (DDLL) and AGC loop for direct-sequence spread-spectrum systems is analyzed. Especially, the inherent coupling effects between DDLL and AGC loop are developed. The numerical results show that the DDLL with AGC loop can offer a reliable and satisfactory performance.

4. Rapid acquisition loop for ultrawide band

Ultrawideband (UWB) impulse radio is an emerging technology suitable for high-rate tactical wireless communications. One of the crucial challenges for a connecting station remains the initial code acquisition, in a hostile propagation environment (e.g., urban combat). In this paper, we address the coarse acquisition of pseudonoise (PN) codes and propose algorithms for speeding up the acquisition process and/or reducing the complexity of the acquisition algorithm itself. Also, in the case of energy detection, we show that the front-end sampling rate may be reduced. An in-depth analysis, supported by simulations in the presence of multipath is presented, and the results discussed. The frequency offset is estimated based on

the training symbol defined by the coarse-timing estimation. Frequency-offset compensation is then performed on the training symbol. Next, the channel impulse response is esti- mated based on the frequency offset compensated received training symbol. Given the channel estimation, the delay of the first channel path is found and added to the coarse-timing estimate to give a fine-timing estimate. The new training symbol defined by the fine-timing estimate is used to estimate the fine frequency offset. Hence, the fine synchronization part contains frequency-offset compensation, channel impulse response estimation, fine-timing offset estimation, and fine fre- quency-offset estimation. This fine synchronization procedure can be repeated in order to achieve further improvements. The channel impulse response can then be estimated again after per- forming frequency-offset compensation on the training symbol defined by the fine-timing estimate. It may be directly used or further processed for employment in channel equalization, but further processing on the channel response estimate will not be considered in this paper. It is also noted that the proposed synchronization method is applicable to both continuous-mode transmission and burst-mode transmission since it does not utilize any property specific to a particular transmission mode such as null interval in the burst-mode transmission. In our simulations, we use a burst-mode transmission where the training symbol is preceded by noise samples and followed by data symbols.

5. Signal model

In this thesis, a BPSK random time-hopping (TH) IR system is considered. Each information bit is modulated by BPSK. Then the data symbol $d_i \in \{+1,-1\}$, where i is the data symbol index, is transmitted via N_f frames. Each frame conveys one pulse waveform. Commonly, the polarities of N_f pulses representing an information symbol are always the same. Recently, the pulse-based polarity randomization scheme was investigated. In addition to the modulation, each pulse has a random polarity code $b_j \in \{+1,-1\}$. The use of random polarity codes can help fit the spectral shape according to the FCC constrain by eliminating the power spectral lines in UWB IR systems. It also can provide further robustness against multiple access interferences.

As stated above, a known random polarity sequence $b_j \in \{+1,-1\}$ is differentially modulated with the transmitted pulses, where $j \in \{0,1,2,...,N_f-1\}$ is the pulse index within a symbol. By using super-imposing BPSK and the random polarity code, each pulse is differentially modulated by both BPSK and random polarity sequence, so the differentially modulated pulse-polarities are obtained as $a_{i,j+1} = a_{i,j}d_ib_j$ and $a_{i+1,0} = a_{i,N_f-1}d_ib_{N_f-1}$. The transmitted signal from the user k is given by [2]:

$$s_k(t) = \sum_{i=-\infty}^{\infty}\sum_{j=0}^{N_f-1} a_{i,j}w(t - iT_s - jT_f - c_{k,j}T_c),$$

6. Performance analyses

In many DHTR related papers, they all mentioned that the integration output noise term of TR-UWB is Gaussian distribution. In these papers, they not only described this phenomenon but also had their theoretical derivation. We also proposed a reasonable assumption that the output of SLD is Gaussian distribution. And its mathematic expression is as follows:

$$f_{z_j}(z) = \frac{1}{\sqrt{2\pi}\sqrt{Var\left[z_j\right]}} e^{-\frac{\left(z-E\left[z_j\right]\right)^2}{2Var\left[z_j\right]}}, -\infty < z < \infty,$$

where $E\left[z_j\right]$ is the expected value of the output, $Var\left[z_j\right]$ is the variance of the output, $f_{z_j}(z)$ is the P.D.F. of its output end.

Assuming the distance from the target step position to the symbol boundary is denoted as ε, which is uniform distribution. By defining

$$E_b(\varepsilon) = (N_f)\sum_{l=1}^{L_k}\int_0^{SIW} E\{\alpha_{k,l}^2\}w^2(t-(l-1)T_c-\varepsilon)dt,$$

we can derive as:

$$E[z_j] = d_{2k-2}E_b[(c_{k,0} - c_{\mathrm{mod}(j+1,N_f)})T_c - (k-1)\Delta + \sum_{p=0}^{\mathrm{mod}(j+1,N_f)} D_{k,p}],$$

and $Var\left[z_j\right]$ as:

$$Var\left[z_j\right]=\left[\frac{1}{N_f}(e^{4\sigma^2}-1)E_b^2\left((c_{k,0}-c_{\mathrm{mod}(j+1,N_f)})T_c-(k-1)\Delta+\sum_{p=0}^{\mathrm{mod}(j+1,N_f)}D_{k,p}\right)\right]^2$$
$$+2\left[(1-e^{-\sigma^2})E_b\left((c_{k,0}-c_{\mathrm{mod}(j+1,N_f)})T_c-(k-1)\Delta+\sum_{p=0}^{\mathrm{mod}(j+1,N_f)}D_{k,p}\right)\right]^2 .$$
$$+2\left[\sqrt{N_f}\times e^{-\frac{\sigma^2}{2}}\sqrt{E_b\left((c_{k,0}-c_{\mathrm{mod}(j+1,N_f)})T_c-(k-1)\Delta+\sum_{p=0}^{\mathrm{mod}(j+1,N_f)}D_{k,p}\right)}\right]^2+\left(N_f\times SIW\right)^2$$

7. Simulation results

simulation are: CM4, Nu=1, SNR=0, and total outcomes=20000. As shown, the most of statistics are centralized at the integration output one point and symmetrically decreased toward two sides from the one point. Such simulation output is in accordance with the behavior of Gaussian distribution, which verifies that our assumption is correct as shown.

The horizontal line represents the shift value of the symbol boundary, while the vertical line represents the mean value of the integrator output. Parameters employed in the simulation are: CM4 and total outcomes=20000. The peak occurred when the correlated value reached its maximum, which means the two symbol boundaries (original signal and its delayed one) were perfectly matched. The exponentially increased and decreased curves were shown when their partial correlation occurred. The other flat curves represent that the average values were around zero, which means the correlation did not nearly occur during the simulation process. The plot of Variance of SLD (Share Loop Delayed-line) output is shown.

8. Conclusions

In this paper, we propose and analyze a rapid acquisition loop for a direct-sequence ultrawideband (DS-UWB) system moreover, we present a study on the acquisition performances in UWB dense multipath environments. The mean acquisition time, the acquisition probability, and the mean number of false alarms are evaluated for CM1-CM4 channel models will be future works. According to viewpoint above, we have derived the theoretical performance in the thesis. The theoretically derived consequence, PDF of SLD receiver output, was proved to be Gaussian distribution through the simulation. We also derived the mean and variance of SLD integration output, which were proved to be correct through the simulation.

However, those who are interested in the further studies in the same field can follow up to derive P_d , P_{fa} , and the mean acquisition time. After that, they are recommended to continue their research to work on the architecture of “ Markov chain model”.

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