Improving Synchronization Performance in Ultra-wideband Communication Systems Using Two-Section Algorithm Based on Energy Detection Receiver

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Received: November 2013 Revised: March 2014 Accepted: May 2014

ABSTRACT:
This article aims to investigate synchronization of UWB signals between transmitter and receiver in communication networks. In Ultra wideband technology, synchronization consists of two sections. In the former section coarse synchronization has been accomplished which leads to fine one at the end. In first section of coarse synchronization, maximum detection was utilized. In order to improve the performance of the synchronization algorithm and decreasing the complexity of calculation, in second section of coarse synchronization search back algorithm was presented. Synchronizations were performed in MATLAB and the results were the indication of a decrease in calculation and improvement in synchronization performance. To evaluate the performance of synchronization algorithms MAE, RMSE were utilized as two criteria and the results obtained explains the fact that RMSE criterion in search back algorithm has better performance for lower SNR.

KEYWORDS: Energy Detection Receiver, Maximum Detection Algorithm, Synchronization, UWB Pulse, Coarse Synchronization, Fine Synchronization, RMSE, MAE, Coherent, Non-Coherent.

1. INTRODUCTION

Synchronization between transmitter and receiver signals has been very crucial. In the previous studies has focused on synchronization of narrow band signals. Increasing the number of communication users as well as the tendency toward using more band width in data transmission and using different utilities of these systems necessitate ultra wideband systems application [1]. Synchronization methods in UWB systems differ from narrow band ones. Exact demodulation and precise nomination of lock point synchronization would be of importance. In ultra wideband communication, narrow pulses (to Nano seconds extent) with low power is used compared to other wireless systems. These two characteristics causes decrease in power consumption and precise processing on received signal in time domain. To design the receiver for these systems, coherent and non-coherent procedure can be used [2-4]. The coherent one uses the correlation between received signals with the produced signal version in receiver. Rake receiver is usually utilized for coherent receivers. In spite of high precision in Rake receiver, this receiver wouldn't be suitable for low power applications. To simplify the receiver structures non-coherent procedure was used in which there is no estimation of channel so these receivers can perform with low power. Among these receivers, energy detection needs the lowest power and the least complexity [5].

Coarse synchronization algorithms for energy detection receivers can utilize simple methods to calculate TOA [6-8]. One of the most common synchronization algorithms is to use sliding integration windows in which the maximum energy moment is detected [9]. The window lengths would be considered about tens Nano seconds so as to make conformity between channel and integral windows. Also in fine synchronization section the window length changes to improve in synchronization.

Other synchronization methods are based on the estimation TOA of the first path. This kind of estimation is done using search back algorithm (further explanation in reference [10]).

This article aimed to investigate coarse synchronization using energy detection and used search back algorithm to improve synchronization. The current article has been organized as follows: Second section deals with

the introduction of a general model for the structure of ultra wideband receivers.
Regarding the focus of the study on coarse synchronization, this method has been divided into two sections. The first one has been investigated completely in third section. The second step of coarse synchronization as well as introduction to search back algorithm are in section 4. Section 5 consists of MATLAB simulations and finally conclusion will be in section 6.

2. GENERAL MODEL OF RECEIVER STRUCTURE

Usual receivers in ultra wideband communication which act based on energy detection include the following sections: Low noise amplifier, squaring unit, Integral block, Temporary saving and Analog to digital convertor presented in **Fig.** (1) [11].

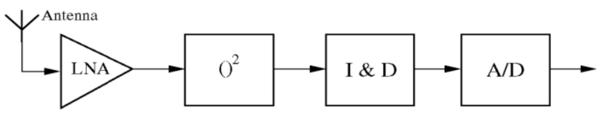

Fig.1. Typical Energy Detection Receiver [11]

According to above figure, received UWB signal is amplified in first step and then in order to capture energy, signal will reach to the power of 2 and will be integrated in different time intervals. Finally to synchronize and demodulate, the amount obtained change to digital samples. In the current article modulation has been done through 2PPM method in which pulses are located in first or second half of pulse repetition interval [12].
Energy detection receiver in pulse interval does integral in both halves and obtains received signal energies which results in analog to digital conversion. Totally, each transmitted packet includes specific information. There is a fix complex of UWB signals at the beginning of each packet including the information from non-modulated pulses which is repeated in pulse transmission interval. The received signal is modeled as follows:

$$r(t) = \sum_{i=-\infty}^{+\infty} p\left(t - iTs - \tau\right) + n(t) \qquad (1)$$

In the above equation Ts represents pulse interval, $p(t)$ represents UWB signal, τ is the representative of delay between transmitter and receiver. Received signal $r(t)$ includes AWGN[1].
In this article the integral block performs similar to differential energy detector. This block calculates two integrals using 4 control signals and saves obtained amounts temporarily to be compared. The aim of this integrator is to capture the energy difference between two consecutive pulses from beginning information of each packet which should be converted into a bit and represents the energy difference of two pulses. To perform this, it integrates from two adjacent ultra wideband pulses using two integral windows delayed to t_{synch} extent. At the end of process two energy amounts obtained have been compared and output bit is a result. The amount of which will be assessed through comparing received energies.

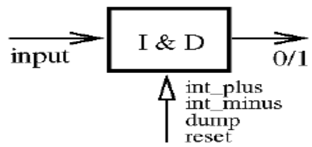

Fig.2. Integral and Dump step

Coarse synchronization algorithm consists of two consecutive sections. In the first section named energy calculation, the energy between two consecutive pulses is calculated in different times and the location of the point in which the maximum energy happen will be identified. In the second one, in order to more precise and better synchronization, search back algorithm was accomplished.

3. THE FIRST STEP OF COARSE SYNCHRONIZATION

Fig. 3 shows the first step of synchronization in energy detection entrance.

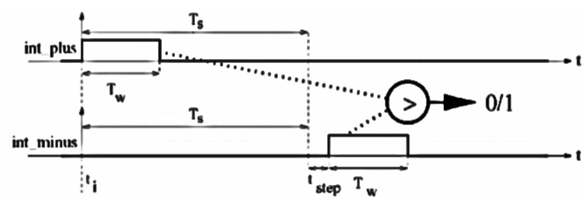

Fig.3. The first step of synchronization in energy detection entrance

In above figure t_{step} parameter indicates synchronization exactness. t_i , T_ω parameters show integral reference and integral time interval respectively. Calculated energies for two consecutive pulses in different times are represented as follows:

$$I_0(i) = \int_{t_i}^{t_i+T_\omega} r(t)^2 dt \qquad (2)$$

$$I_1(i) = \int_{t_i+t_{step}+T_s}^{t_i+t_{step}+T_s+T_\omega} r(t)^2 dt \qquad (3)$$

[1] Additive White Gaussian Noise

In above equations i is the representative of the number of calculated integrals in a specific time and $i \in [0, \dots, N-1]$. Also $t_{i+1} = t_i + t_{step}$ in which t_{step} identifies synchronization exactness. N indicates the number of steps and is calculated via $N = t_s / t_{step}$. Differential energy detection compares two energies based on $I_0(i) - I_1(i)$. If it was more than zero, output would be zero otherwise it would be 1. Dou to narrowness of UWB pulses T_ω is supposed to be big enough so as to investigate UWB pulse with zero average. It is also possible to simplify the square of received signal as follows:

$$\int r(t)^2 \simeq \int p^2(t) + \int n^2\,(t) \tag{4}$$

Received signal is approximately the sum of two components of main signal and the AWGN one. According to reference [13] it is proved that AWGN is in a Gaussian function form with Mean of $\mu_{ed} = 2B_\omega T_\omega \sigma_n^2$ and variance $\sigma_{ed}^2 = 4B_\omega T_\omega \sigma_n^4$ is modeled. B_ω and σ_n represent noise bandwidth and standard deviation of n(t) respectively. These equations would be true in that $2B_\omega T_\omega > 4$. On the basis of these assumptions, it would be possible to consider a parameter by which the output bit will be assessed. The second and third equations can be written as follows:

$$I_0(i) \simeq E_0(i) + N_0(i) \tag{5}$$

$$I_1(i) \simeq E_1(i) + N_1(i) \tag{6}$$

In above equations $E_0(i) = \int_{t_i}^{t_i+T_\omega} p(t)^2$, $E_1(i) = \int_{t_i+t_{step}+T_s}^{t_i+t_{step}+T_s+T_\omega} p(t)^2$. $N_0(i)$, $N_1(i)$ are representative of cumulative Gaussian process with σ_{ed}^2 variance and μ_{ed} mean. Comparator output can be identified as $R(i) = I_0(i) - I_1(i) = (E_0(i) - E_1(i)) + (N_0(i) - N_1(i))$.
$R(i)$ consists of two parts. The first step is the result of UWB signal and the second one is identified by noise. These amounts can be summarized as $E(i) + N(i)$ in which $E(i) = E_0(i) - E_1(i)$, $N(i) = N_0(i) - N_1(i)$.
After integral from the main signal along with noise, energy detector digitalized $R(i)$ to $D\{R(i)\}$. $D\{\,\}$ is the digitalize operator which compares amounts with zero threshold during the algorithm accomplishment both integrals extend from zero to N-1 and the digital bits obtained are classified and stored in one vector. DE vector is defined as follows:

$$DE = [DE_0, DE_1, DE_2, \dots, DE_i, \dots, DE_{N-1}] \tag{7}$$

In above equation DE_i is exactly the same as $D\{R(i)\}$. The probability of zero or one for each component is calculated via following equation:

$$P(DE_i = 0) = 1 - \frac{1}{2} erfc(\frac{-E(i)}{\sqrt{2}\sigma_N}) \tag{8}$$

$$P(DE_i = 1) = \frac{1}{2} erfc(\frac{-E(i)}{\sqrt{2}\sigma_N}) \tag{9}$$

In above equations erfc(x) is error function which is defined as $erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{+\infty} (e^{-t^2})$. The mentioned equations indicate that how the probabilities from energy steps affected on i location.
In order to decrease the noise effect, a processing gain can be utilized in calculations. This would be realized via repetition of processing for PG times and calculation of DE vectors and summing them together. The obtained vector is as follows:

$$ADE = \left[\sum_{j=1}^{PG} DE_0^j, \dots, \sum_{j=1}^{PG} DE_i^j, \dots, \sum_{j=1}^{PG} DE_{N-1}^j\right] \tag{10}$$

In above equation DE_i^j , is the i element in j repetition. Each vector ADE consists of an exact amount between zero to PG. Since DE vectors are statistically independent, it would be proved that for each i column the probability of detection [0, PG] follows a Bernoli distribution. The total probability of the result of integral amounts in each i column are reported as (11):

$$P(ADE_i = K) = \binom{PG}{K} \left(\frac{1}{2} erfc\left(\frac{-E(i)}{\sqrt{2}\sigma_N}\right)\right)^K \times (1 - \frac{1}{2} erfc(\frac{-E(i)}{\sqrt{2}\sigma_N}))^{PG-K} \tag{11}$$

4. THE SECOND STEP OF COARSE SYNCHRONIZATION

Due to short time of interval of UWB pulse and the fact that UWB channel is full of multipath components, received signal would be completely different from transmitted signal. Because of the statistical nature of signal, a constant figure for received signal can't be represented. For real UWB signal, the probability of simple diagnosis depends on E(i) energy. The detection probability of real UWB signal is obtained from the following equation:

$$P_d = \frac{1}{2^{PG}} erfc^{PG}\left(\frac{-E(i)}{\sqrt{2}\sigma_N}\right). \prod_{i \neq m} (1 - \frac{1}{2^{PG}} erfc^{PG}\left(\frac{-E(m)}{\sqrt{2}\sigma_N}\right)) \tag{12}$$

Regarding the nature of UWB pulses, the first path of signal cannot be easily detected. In order to more precise and better synchronization, concentration on previous maximums was used in this article. A collection of ADE matrix can be processed starting from i index (which shows maximum amount of ADE) then after ADE matrix comparison in adjacent areas of proposed i algorithm can be performed.

4.1. Search back Algorithm

In search back approach, the algorithm has been started search backward from maximum amount and then compares samples one by one to threshold. The most crucial problem in this algorithm is that there might be various clusters of multipath components with maximum amount in UWB channel. It shows that there are probably noise samples among different clusters and it may continue its search to find primary edge. So in this algorithm as searching continues, the algorithm allows some of the noise samples to pass so the cluster problem will be solved.

The threshold level when there are K number consecutive pure noise samples will be calculated by the following equation: $\xi = \tilde{\sigma} Q^{-1}\left(1-\left(1-P_{fa}\right)^{\frac{1}{K}}\right)+\tilde{\mu}$.

As it's obvious, the optimum threshold level is a function of k parameter. The k amount will be obtained from averaging channel parameters. This algorithm is based on 3 parameters of the probability of false alarm, The number of adjacent noise sample and the window length of this algorithm each of which is selected related to channel characteristics. The search back algorithm is obvious in the following figure.

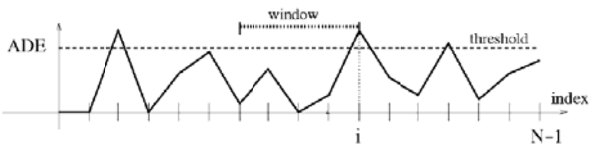

Fig.4. Search back Algorithm

The function of the algorithm is that it finds the maximum energy point in ADE vector and search back algorithm with suitable window length is done to find previous maximums (Maximum are certainly under threshold).It will be continue to the extent that all samples place under the threshold. Fulfilling all the circumstances, the maximum sample will be stored. If search untread to first amount in ADE vector, the window length should be decreased to that of one sample and the locked space would be stored as zero.

5. SIMULATION

In this section the synchronization performed in Matlab software has been represented to investigate the performance of the algorithm. In this simulation, transmitted signals are the second derivative of Gaussian pulse.

$$\omega(t) = \left(1-\frac{4\pi t^2}{\theta^2}\right)e^{-2\pi t^2/\theta^2} \qquad (13)$$

In above equation θ determine the time length of each chip. The UWB pulse figure in equation (13) is shown in **Fig.** (5).

The synchronization algorithm has been assessed with regards to MAE criterion. This process has been repeated for 200 times and as a result the outputs obtained were averaged.

The simulation procedure has been divided into two steps. In the former step maximum detection were accomplished in the later one the presented algorithm in (**4.1**) has been investigated.

The first step maximums were obtained through following equation:

$$i_{synch} = \arg\max_i \{ADE\} \qquad (14)$$

The above equation determines the location of maximums in ADE vector.

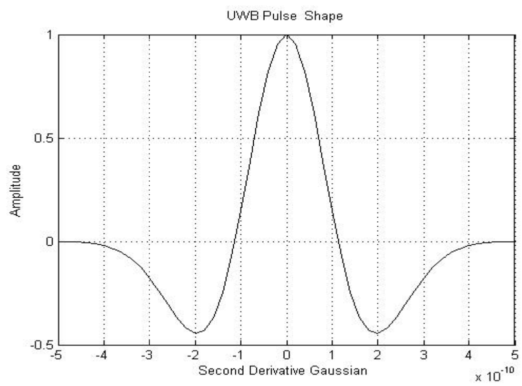

Fig.5. UWB Pulses

In second step, two windows with 4 and 9 symbol lengths have been utilized respectively to measure 12ns and 6ns paces in which the selected threshold level is 1 unit less than maximum energy obtained in first step.

The noise bandwidth considered for all simulations was 8 GHz with uniform channel delay in zero to pulse repetition interval range. Integral lasted for 30ns using CM1, CM4 channels standardized by IEEE.802.15.4a. The following figure represents the synchronization performance for real UWB pulses using maximum detection algorithm and search back algorithm in CM1, CM4 channels.

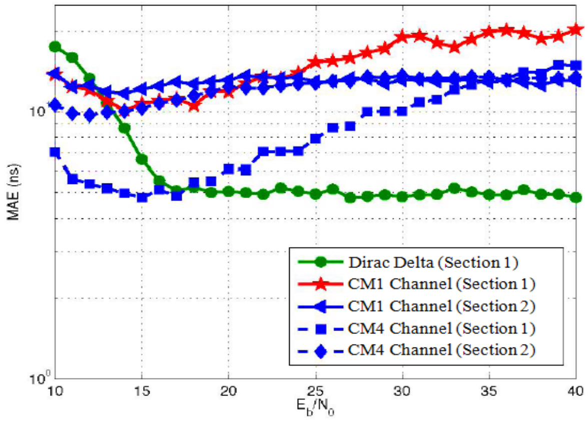

Fig.6. Performance of Synchronization Algorithm (Step: 12ns)

It is observed that performing the first step of this algorithm does perfect synchronization when the Dirac Delta pulse is considered as input signal, whereas using UWB pulses leads to multipath phenomenon which is the agent of changing the exactness in synchronization point.

The following figure shows high processed simulation in step conversion to 6ns from 12ns.

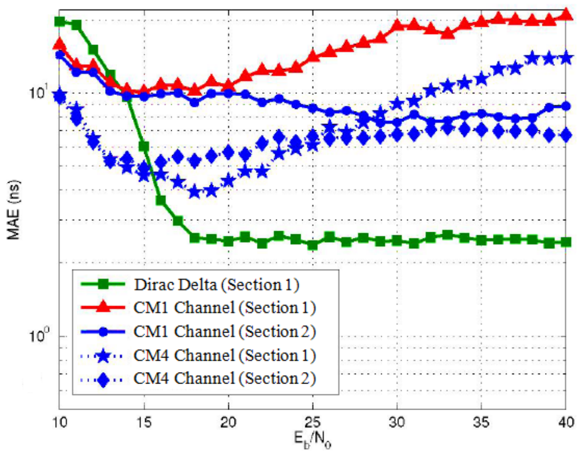

Fig.7. Performance of Synchronization Algorithm (Step: 6ns)

Another criterion used for assessing algorithm performance is RMSE. The following figure represents RMSE for maximum detection and search back algorithms. According to the figure it is obvious that search back algorithm outperforms compared to other algorithms.

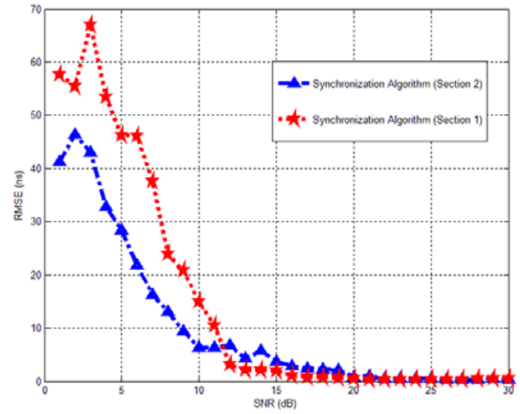

Fig.8. RMSE Criterion for Maximum Detection and Search back Algorithm

6. CONCLUSION

The current article aimed to investigate the synchronization algorithms for UWB signals to be synchronized in coarse section. The proposed algorithm caused reduction the complexity in energy detection receiver. The mentioned algorithm consists of two steps, in the former the maximums of square transmitted signals vector were determined and in the later one the fine point of synchronization is identified using search back algorithm. Comparing the results obtained from simulations, it is observed that the search back algorithm outperforms in SNRs less than 12dB with regard to RMSE criterion and also regarding the MAE criterion it is obvious that it has better performances for real UWB signal in different channels.

REFERENCES

1) N., Beaulieu , D., Young, "**Designing time-hopping ultrawide bandwidth receivers for multiuser interference environments**," *Proc. IEEE*, Vol. 97, No. 2, pp. 255–284, Feb. 2009.
2) A., Spaulding , D., Middleton, "**Optimum reception in an impulsive interference environment-part I: Coherent detection**," *IEEE Trans. Commun.*, Vol. 25, No. 9, pp. 910–923, 1977.
3) K., Witrisal, G., Leus, G., Janssen, M., Pausini, F., Troesch, T., Zasowski, and J., Romme, "**Noncoherent ultra-wideband systems**," *IEEE Signal Process. Mag.*, Vol. 26, No. 4, pp. 48–66, Jul. 2009.
4) Z., Sahinoglu , I., Guvenc, "**Multiuser interference itigation in noncoherent UWB ranging via nonlinear filtering,**" *EURASIP J. Wireless Commun. Netw*., pp. 1–10, 2006.
5) S., Cui , F., Xiong, "**UWB system based on energy detection of derivatives of the Gaussian pulse**," *EURASIP Journal on Wireless Communications and Networking*, pp: 1-18, 2011.

6) J., Youssef, B., Denis, C., Godin, and S., Lesecq, **"New TOA estimators within energy-based receivers under realistic UWB channel statistics,"** in *Proc. IEEE VTC – Spring*, pp. 1–5, 2010.
7) I., Khosu, Z., Sahinoglu , P., Orlik, and H., Arslan, **"TOA estimation in non-coherent low-rate IR-UWB systems,"** *Wireless Personal Communication*., Vol. 48, No.4, pp. 585–603, 2009.
8) A., D'Amico, U., Mengali, and L., Taponecco**, "TOA estimation with the IEEE 802.15.4a standard,"** *IEEE Trans. Wireless Communication*., Vol. 9,No. 7, pp. 2238–2247, 2001.
9) A.A., D'Amico, U., Mengali, and E., Arias-De-Reyna, "**Energy-detection UWB receivers with multiple energy measurements**," *IEEE Trans. Wireless Commun*., Vol. 6, No. 7, pp. 2652–2659, 2007.
10) I., Guvenc, "**Towards Practical Design of Impulse Radio Ultra wideband systems: Parameter Estimation and Adaptation, Interference Mitigation, and Performance Analysis,**" *A issertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Department of lectrical Engineering College of Engineering University of South Florida*, March. 2006.
11) Y., Tang, Y., Ruan, "**Research on a Novel Synchronization and Detection Scheme used in Energy Detection UWB Receiver**," *The 11th International Symposium on Communication & Information Technologies (ISCIT 2011)*, pp.109-113, 2011.
12) F., xiong, " **Digital Modulation Techniques**," *Aretech House, INK*, 2000.
13) Y., Ying, M., Ghogho, and A., Swami, **"synchronization for UWB-IR systems: Algorithms and analysis,"** *IEEE Trans. on Sig. Process.*, Vol. 56, No. 10, pp. 5169–5180, 2008.