Adaptive Autocorrelation Transmitted Reference Receivers for Ultra-Wideband Systems

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Abstract—**Transmitted reference (TR) modulation schemes, initially proposed for spread spectrums in 1920's, have regained popularity in the context of ultra wideband (UWB) communications, where accurate channel estimation is a challenging task. Conventional RAKE receivers can capture only a fraction of the received signal energy under practical implementation and channel estimation requirements. Transmit reference and autocorrelation receivers can efficiently collect energy from all the received multi path components without explicit channel estimation and with a simpler structure. Performance analysis of these schemes is investigated herein and verified via simulations. UWB systems are likely to be employed in wireless indoor environments with different channel characteristics for different locations. Since the length of the integration interval is an important design parameter with respect to the achievable performance, a new algorithm for adaptive adjustment of integration interval parameter is proposed in the autocorrelation receivers. According to this method, integration time is restricted to those intervals with more received signal components. This time is almost equal the multi path delay spread time of channel, in other words, by using the adaptive algorithm, the effect of the added noise to the received signal in the autocorrelation receiver is suppressed. Simulations are performed to evaluate the error performance of the proposed algorithm in indoor UWB standard channels and on different transmitted reference schemes, also at higher data rates, in the present of ISI, we notice performance improvements.**

Index Terms – ultra wideband communications, autocorrelation, transmit-reference, integration interval, multi path delay spread time, Inter Symbol Interference (ISI).

I. INTRODUCTION

Ultra-wideband (UWB) communication system has received great attention recently specially for high data rate digital communication in short range communication. In these kinds of systems data have been sent by ultra narrow width pulses. Such a system has huge bandwidth and also ability to handle very high data rate. UWB system received more attention in 2002 after Federal Communication Committee (FCC) released a standard to specify power limits and frequency range of the system. According to this standard, UWB systems should use relatively low power in comparison to narrow band systems. Because of this restriction, UWB systems can be used in short range applications such as Wireless Personal Area Networks (WPAN) [1]. In the indoor applications, there are so many reflection paths lead in a huge number of multi path components in the received signal, so effective extracting and collecting of multi path energy is the most important problem in UWB system design [2]. RAKE receivers are a common method in wireless communication systems to deal with multi path. But in UWB system, because of a large number of multi path components, there are some implementation difficulties for RAKE receivers. Also this method could not detect all of signal components. Meanwhile it needs to extract synchronization and channel estimation. Due to mentioned problem, a transmitted reference scheme has been proposed. In this method a reference signal is transmitted besides a data signal. The main idea is that by transmission of a reference signal, the receiver can estimate channel response in order to recover information from data signal, assuming that channel response to both signals are almost the same. In the other words, TR system in conjunction with autocorrelation receivers can be employed, offering an important energy capture without explicit channel estimation [3]-[5]. Although these benefits, TR-UWB method has some drawbacks. The main problem is using the reference signal increases transmission overhead and reduces data rate, which results in reduced transmission efficiency. The bit error rate (BER) performance of the system is also limited by the noise term in the reference signal. To deal with such problems a Differential TR UWB system (DTR) proposed in [6]-[8]. In this method the reference signal is not transmitted separately, but instead the pulse previously sent is used as a reference. By using this method, a 3 dB improvement in performance is gained. The receiver of DTR is the same as TR and the only difference is in the transmitter.

As suggested in [9], the accuracy of determining the optimal integration length increases with E_b / N_0. In [10] the correlation interval is split up to a number of smaller correlations, which are then linearly combined, taking into account the received SNR at the output of each of these smaller correlations. In [11], the received signal is demodulated using a fractionally sampled autocorrelation receiver, which means that the symbol period is divided into several intervals, and each interval takes adaptive weighting factors in integration.

In this paper, considering all above, complete bit time is divided into small intervals and with an adaptive method; the integration is limited to those times with sufficient signal components.

This paper is organized as follows. After introduction in section I, the TR system and the standard channel model is introduced, and the DTR system structure and its performance is presented in section II, the proposed algorithm and its flow chart and the self tuning of the decision threshold are introduced and discussed in section III. The simulation results are presented and discussed in section IV, followed by conclusion in section V.

II. System And Channel Model

We consider a single user UWB system employing antipodal signaling in an indoor multi path channel with additive white Gaussian noise (AWGN). In binary PAM UWB signaling, information bits b[i] $\in\{1,-1\}$ are transmitted over a train of ultra-short pulses $p(t)$ of pulse width T_p. The bit interval T_f (Frame Time) is much larger than T_p, resulting in a low duty cycle transmission form. With energy E_b per bit, the transmitted PAM UWB waveform is given by:

$$S_{tr}(t) = \sum_{i=-\infty}^{\infty} g_{tr}(t - iT_f) + b_{\lfloor i/N_s \rfloor} g_{tr}(t - iT_f - T_d) \quad (1)$$

Here $g_{tr}(.)$ is a transmitted monocycle waveform that is nonzero only for $t \in (0; T_p)$.Each frame contains two monocycle waveforms. The first is a reference and the second, T_d seconds later, is a data modulated waveform. The data bits are $b_{\lfloor i/N_s \rfloor} \in \{1,-1\}$ with equal probability. The index $\lfloor i/N_s \rfloor$ is the integer part of i/N_s and represents the index of the data bit modulating the data waveform in the ith frame. Hence each bit is transmitted in N_s successive frames to achieve adequate bit energy in the receiver, and the channel is assumed invariant over this bit time. In this TR system, T_d is greater than the multi path delay spread T_{mds} to assure that there is no interference between reference signal and data signal. The frame time is designed to be T_f , $2T_d > 2T_{mds}$ so that no inter frame interference exists.

Pulsed UWB signaling gives rise to frequency selective channels, whose impulse responses can be modeled as tapped delay line filters.

The aggregate channel after convolving with the transmitted pulse is given by [5].

$$h(t) = \sum_{l=0}^{L-1} \alpha_l g_{tr}(t - \tau_l) \quad (2)$$

Where L is the total number of multi path components, each with path fading gain α_l and delay τ_l relative to the first path. Perfect timing is assumed by setting $\tau_l = 0$, for l = 0,…, L-1.

A.DTR System Structure

It is possible to construct a UWB DTR system in which no references are transmitted, but instead, the data signal in the previous frame is used as reference. A block diagram of a UWB DTR system is plotted in Fig.1. Here the differentially modulated UWB transmitted signal is:

$$S_{tr}(t) = \sum_{i=-\infty}^{\infty} m_i g_{tr}(t - iT_f) \quad (3)$$

where $m_i = m_{i-1} b_{\lfloor i/N_s \rfloor}$.

All the other parameters are the same as defined in the TR system. Because there is no extra reference signal imbedded in each frame, the requirement for no inters frame interference is simply that $T_f > T_{mds}$. It is not easy for this differential receiver to average several signals to produce a cleaner reference because the data is transmitted as the difference of two consecutive signals.

B. Performance of a DTR receiver

The received signal of this differential system is:

$$r(t) = \sum_{i=-\infty}^{\infty} \sum_{l=0}^{L-1} \alpha_l m_{i-1} b_{\lfloor i/N_s \rfloor} g_{tr}(t - iT_f - \tau_l) + n(t) \quad (4)$$

With this development, it can be verified that the BEP of the differential system is [6]:

$$P_e = Q\left(\left[\left(\frac{N_0}{E_p}\right) \frac{(2N_s - 1)}{N_s^2} + \left(\frac{N_0}{E_p}\right)^2 \frac{T_{mds} W}{2N_s} \right]^{-1/2} \right) \quad (5)$$

Where W is the receiver bandwidth and E_p is the pulse energy.

III. Proposed Algorithm

According to above considerations and references, it can be seen that integration interval has an important role in precise detection of received bits so performance of the receiver can be considerably improved if there is a suitable selection of integration interval. In order to optimize this parameter an adaptive algorithm has been proposed (Fig.2). In this algorithm integration interval has been continuously adjusted according to received information and other parameters of the system. If integration interval is greater than the multi path delay spread time (T_{mds}) then effects of noise increase in the integrator output and this will lead the system to greater BER. In fact in these cases integrator processes received signal in the times that there is no signal components and noise is dominant so the output is inaccurate. On the other hand if integration interval is smaller than Spreading Delay Time some of signal component will be suppressed on this will result of error. In the proposed Algorithm, complete bit time is divided into small intervals. Integration then will be done on these intervals. If absolute value of integration is less than a decision threshold for a certain successive times (Ns) then it will be supposed that there is no more signal component in the received signal so the integration will be stopped until start of the next bit time. In fact by this method, integration will be limited to those times that there are sufficient signal components. Ns is an important parameter that affects on sensitivity of the method. Increasing of Ns will lead the algorithm to be less sensitive. Flow chart of the proposed algorithm is presented in Fig.2.

According to the flow chart, receiver checks the partial interval times and calculates partial integrals. If partial integrals are less than a decision threshold then a counter increases, and finally if the counter reaches to Ns then algorithm stops integration in current bit time and will wait for the next bit time start. Decision threshold is an important parameter in the proposed algorithm. Increasing of this parameter will result in more interference of the algorithm in

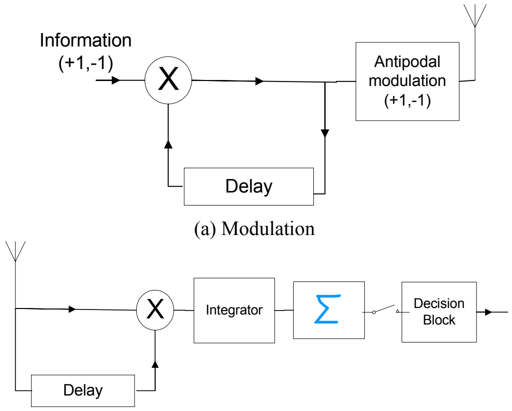

Fig.1. Block diagram of the modulator and demodulator in UWB DTR system.

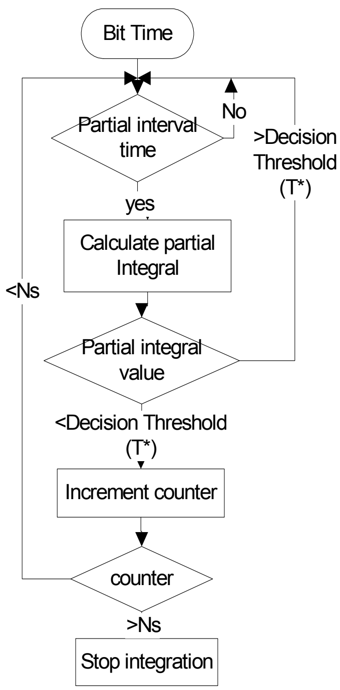

Fig.2. Flow chart of Adaptive Algorithm For Integration Interval

the determination of the final output. In fact ideal value of this parameter is the maximum value of the existing noise that is difficult to identify. The number of *partial time interval* also can determine the resolution of the algorithm. Decreasing of this parameter leads to higher precision in the algorithm but by the cost of more computational complexity.

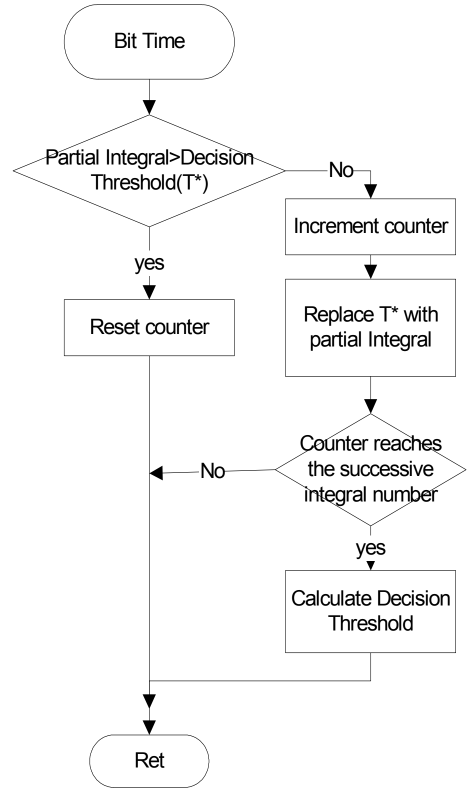

Fig.3. Flow chart for Self Tuning Of the decision Threshold

IV. Simulation Results

The proposed algorithm has been applied to a DTR UWB system. IEEE802.15.3a [12],[13] channel model has been used to simulate the UWB channel effects.

Estimation of Adaptive Integral Time of a DTR receiver by using the proposed algorithm is shown in Fig.4 and Fig.5 for CM1 and CM2 UWB channel respectively. There is no noise in the channel to evaluate behavior of the algorithm and as it can be seen in these figures, values of the parameter approximately converge to Multi path Delay Spread Time of the channel. Actually these figures show that integration only done if there is enough signal components in the receiver input. The algorithm stops integration when partial integral value decreases from a decision threshold and therefore total integral times converge to T_{mds} . (Table1.)

Table1. Multi path Delay Spread time for Standard UWB Channels

Channel	CM1	CM2	CM3	CM4
T_{mds} (ns)	40	60	122	200

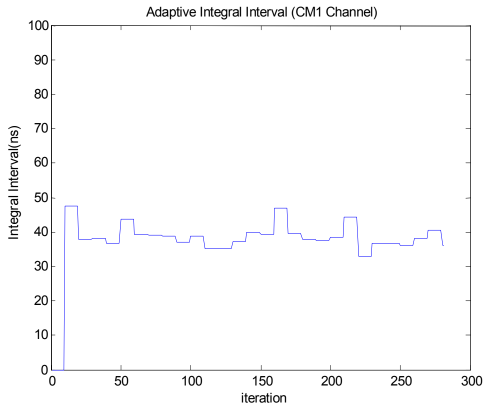

Fig.4. Adaptive estimation of Integral Interval for CM1 channel model using adaptive proposed algorithm

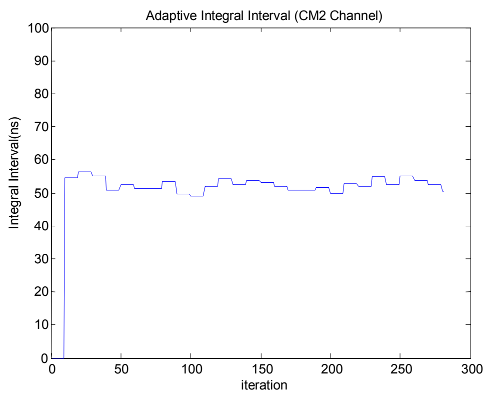

Fig5. Adaptive estimation of Integral Interval for CM2 channel model using adaptive proposed algorithm

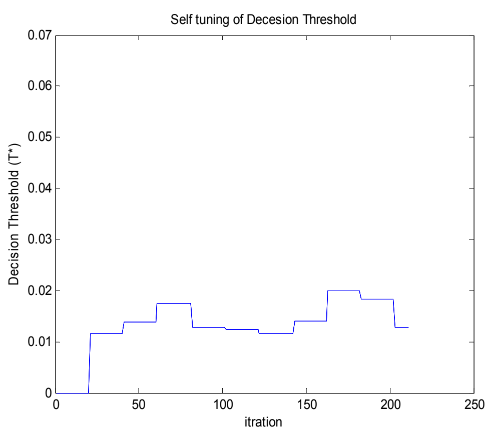

Fig.6. Self tuned decision threshold of the proposed algorithm

Fig.6 shows the decision threshold parameters of the algorithm. This parameter has been self tuned according to method described before (Fig.3).

By using Monte Carlo method to estimate of bit error rate (BER), performance of the system has been simulated and shown in Fig.7. The simulation has performed for a 100ns bit time and IEEE CM1 UWB channel model. Analytical and simulated BER of DTR system as well as proposed adaptive algorithm BER has been shown in this figure. Decision thresholds of the algorithm considered as 0 in first simulation and then self tuning method applied for estimation of the parameter. The results show that for Decision threshold 0, adaptive algorithm reduces to regular DTR system. For self tuned Decision Threshold, the figure shows an approximately 2dB performance improvement in comparison to DTR system.

Fig.8. shows the simulation results of the system performance in the case of Inter Symbol Interference. Bit time of the system has chosen 25ns and so there is ISI. DTR and proposed adaptive algorithm BER performance can be seen in this figure. As shown in this figure, performance of the system by the proposed adaptive algorithm improves more than 1 dB. This is because of noise suppression capability of the algorithm by using of adaptive adjustment of Integration Interval for receiver correlator.

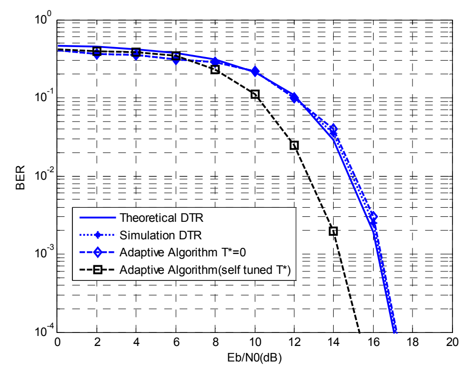

Fig.7. BER performance for DTR system model using adaptive algorithm

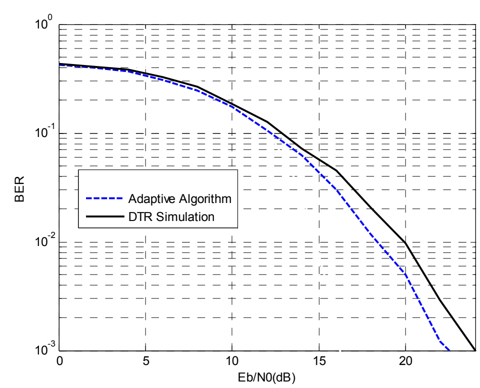

Fig.8. BER performance in the case of ISI

V. CONCLUSION

An adaptive autocorrelation approach for TR UWB system has been proposed in this paper. For UWB communication systems, conventional RAKE receiver encounters some problems such as huge complexity and no complete receive signal energy capture because of so many multi path components in the channel. Transmitted Reference method in conjunction with autocorrelation receiver can improve the performance of the system. Differential TR system (DTR) method uses information signal as reference pulse for next data to be sent and can save more energy by sending pure information pulses via channel. Analytical results and simulations shows that Integral interval of the receiver correlator have an important role in the performance of the system so an adaptive approach for self adjustment of this parameter has been developed. The main idea of the approach is based on stopping of integration if the signal components reduce from a decision threshold.

Simulation results show at least 2 dB performance improvement of the system by using of adaptive algorithm in both non ISI and ISI cases.

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