Original Research Article

Time of arrival estimation with DLC receivers for IEEE 802.15.4a UWB systems

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Abstract: In many conditions, it is necessary for a node in a WSN to be aware of its location in the physical world. If tracking or event-detection functions are not useful if the WSN cannot provide any information where the event has happened. Some location procedures have been proposed in the IEEE 802.15.4a standard, including the TOA estimation, the location estimation, and network location algorithms. In this paper, we discuss an effective TOA estimation scheme with the DLC receiver [7], which employs impulse radio UWB signals compliant with the IEEE 802.15.4a standard. By modifying the synchronization algorithm with the DLC receiver, the TOA can be obtained straightly.

Keywords: TOA estimation; Localization; Impulse radio (IR); Ultra wideband (UWB)

1. Introduction

Recently, a not-for-profit open industry association, the WiMedia Alliance leads the market in commercializing UWB by enabling and promoting the standardization and multi-vendor compliance and interoperability of UWB worldwide. The WiMedia UWB common radio platform based on MB-OFDM that enables high-speed (480Mbps and beyond), low power consumption multimedia data transfers in a WPAN. For a low rate WPAN, the 802.15.4a standard uses IR-UWB as an alternative physical layer to enable data communications and precision ranging. The large bandwidth of the IR-UWB signals enables highly accurately ranging.

The range between a pair of transmitter and receiver devices can be estimated from the measured multipath profile characterizing the wireless channel between them. The peaks of the profile correspond to the arrivals, the first denoted as the time of arrival (TOA)[1]. By using ultra short pulses, TOA can be measured with a nanosecond resolution with coherent or non-coherent IR-UWB receivers. Coherent receivers use a correlation receiver with the received waveform as the template signal and choose the time shift of the template signal that produces a maximum correlation with the incoming signal[2,3]. This type of architecture usually offers better estimation precision than a non-coherent receiver. However, the received waveform has many unknown parameters to be estimated due to the multipath channel. A non-coherent receiver consists in using signal energy measurements or autocorrelation methods[4-6], and is easy to implement. However, this is suboptimal in a multipath environment.

In this paper, we present a non-coherent TOA estimation method based on the DLC receiver, whose synchronization algorithm is investigated in[7]. With the DLC receiver, the TOA estimation can be achieved quickly. The simulation results demonstrate that the TOA estimation error with the DLC receiver is within 1 meter, and is acceptable to ranging applications[1].

2. Signal model and receiver structure

In the IEEE 802.15.4a standard, the signal is transmitted in frames and each frame consisting of a SHR, PHR and a data field. The SHR, which is for synchronization and ranging purposes, includes two fields: SYN and SFD. The SYNC field consists of repetitions of the preamble symbol. The numbers of preamble symbol repetitions are 16, 64, 1024, and 4096[1]. The transmitted signals from the *k*-th user within the SYNC is given by

$$s_k(t) = \sum_{i=0}^{N_{SYNC}-1} \sum_{j=0}^{N_f-1} d_{k,i} p(t - iT_{psym} - jT_f - c_{k,j}T_c), \tag{1}$$

where N_{SYNC} is the number of preamble symbol repetitions, i is the symbol index, j is the frame index, N_f is the number of pulses per symbol, $d_{k,i}$ is the data sequence for the *k-th* user, in which symbols are all equal to 1 during the synchronization preamble, *p(t)* is the transmitted pulse waveform, T_{psym} is the preamble symbol duration, T_f is the pulse repetition time, $\{c_{k,j}\}_{j=0}^{N_f-1}$ is the TH code with code period N_f, and T_c is the chip duration.

As discussed in[7], the time offset between the *p*-th and (*p*+1*)*-th transmitted pulses from the *k*-th user is designed such that $Dk,p = Tf + (ck,[p+1]Nf - ck,p) \times Tc$, where [•] is a modular operation. Equation (1) can then be rewritten as

$$s_k(t) = \sum_{i=0}^{N_{SYNC}-1} \sum_{j=0}^{N_f-1} p(t - iT_{psym} - c_{k,0}T_c - \sum_{p=0}^{j1} D_{k,p}) \tag{2}$$

where $\sum_{p=0}^{-1} D_{k,p} = 0$ is defined for each user index k, and $d_{k,i}$=1
is given for each index k and j.

The channel is modeled as a tap delay line

with L_k +1 taps, whose amplitudes $\{a_{k,l}\}_{l=0}^{L_k}$ and delays $\{\tau_{k,l}\}_{l=0}^{L_k}$ are invariant over one symbol duration. The channe impulse response is given by

$$h_k(t) = \sum_{l0}^{k} a_{k,l}\delta(t - \tau_k - \tau_{k,l}), \tag{3}$$

where $\tau_{k,0} = 0$ and $\tau_{k,l} < \tau_{k,l+1}$ are defined; $\tau_k \in [0, T_{psym})$ is the asynchronous time between the clock of the signal received from the k-th user and the receiver clock, and $\tau_{k,Lk}$ is maximum delay spread.

The aggregated waveforms from all active users at the

receiver, which encompasses multipath effects, has the form $N-1$

$$\begin{aligned} r(t) &= \sum_{k0} s_k(t) * h_k(t) + n(t) \\ &= \sum_{k=0}^{N_u-1} \sum_{i0}^{N_{SYNC}-1} \sum_{j=0}^{N_f-1} \sum_{l=0}^{L_k} a_{k,l} w(t - iT_{psym} - c_{k,0}T_c - \sum_{p=0}^{j-1} D_{k,p} - \tau_k - \tau_{k,l}) + n(t) \\ &= \sum_{k0}^{N_u-1} \sum_{i0}^{N_{SYNC}-1} \sum_{j0}^{N_f-1} v_{k,i,j}(t) + n(t) \end{aligned} \tag{4}$$

where N_u is the total number of active users, *w(t)* is the received pulse waveform, *n(t)* is AWGN, The channel is modeled as a tap delay line line with L_k +1 taps, whose amplitudes $\{a_{k,l}\}_{l=0}^{L_k}$ and delays $\{\tau_{k,l}\}_{l=0}^{L_k}$ are invariant over one symbol duration. The channel impulse response is given by

$$h_k(t) = \Sigma_{l0}^{k} a_{k,l}\,\delta(t - \tau_k - \tau_{k,l}), \tag{3}$$

where $\tau_{k,0} = 0$ and $\tau_{k,l} < \tau_{k,l+1}$ are defined; $\tau_k \in [0, T_{psym})$ is the asynchronous time between the clock of the signal received from the *k*-th user and the receiver clock, and $\tau_{k,Lk}$ is maximum delay spread

3. Simulation results

Simulations are performed to evaluate the performance of the proposed scheme with RMS TOA estimation error. The channels are generated using the UWB channel model proposed by IEEE 802.15.3a [9]. The channel impulse response is assumed to be invariant one symbol duration. The delay of the first arrival signal, τ_k, is uniformly distributed over [0, T_{psym}) ns, with $T_{psym}= N_f \times T_f$, where N_f =32 and T_f =32 ns. For the desired user , a decimal TH code $\{c_{0,j}\}_{j=0}^{N_l-1}$ is selected from $c_{0,j} \in [0, T_f)$ that satisfies $D_{0,p} \neq D_{0,q}$, $\forall p \neq q$. The pulse duration is specified as T_p=1 ns and the receiver bandwidth specified as $B = 1/T_p$ = 1GHz. The SNR of received signals is given by $SNR\text{R}_{ec} = E_b/(N_f N_o)$.

Figs. 4 and 5 compare the normalized MSE, which is normalized with T_{psym}^2, versus various T_w on CM1 and CM4, respectively. On CM1, the better performance in normalized MSE is with T_w=17 ns in Fig.2. However, the better performance is with T_w=48 ns on CM4 (Fig. 5). Importantly, the performance is going worse while the T_w settings are either getting larger or less than the better *Tw* setting. How to get the better *Tw* setting is out of scope here[8]. We just note that the better *Tw* settings for CM1 and CM4 are 17 ns and 48 ns, respectively.

Figure 6 shows the RMS TOA estimation error in meters with N_{SYNC} =16 and 1024 symbols. The RMS TOA estimation error in meters is arrived by However, the better performance is with T_w=48 ns on CM4 **(Figure 5)**. Importantly, the performance is going worse while the T_w settings are either getting larger or less than the better T_w setting. How to get the better T_w setting is out of scope here[8]. We just note that the better T_w settings for CM1 and CM4 are 17 ns and 48 ns, respectively.

$$\varepsilon_{TOA} = c\,\frac{1}{N}\sum_{i=1}^{N}\left[\hat{t}^{k}_{signal}[i] - t^{k}_{signal}[i]\right]^2, \tag{16}$$

where t^k [*i*] is the true arrival time of the *i*-th symbol from *signal*
user *k*, *N* is the number of estimates and *c* is the speed of light. The simulation result parts have shown that the TOA estimation error in meters is in compliance with the IEEE 802.15.4a standard which specifies a ranging precision of 1 meter.

4. Conclusions

In this paper, we have proposed a solution to realize a NSYNC TOA estimation algorithm based on the preamble of the IEEE 802.15.4a standard. As the proposed scheme can achieve TOA estimation within a single symbol duration, the number of preamble symbol repetitions (NSYCN) is fully scalable, e.g. 1, 16, 64, 1024, 4096, etc. The simulation results show the effect that the CM1 and CM4 links reflect on the accuracy of TOA measurements. The TOA estimation errors (in meters) are all within 1 meter as the SNRs are large enough.

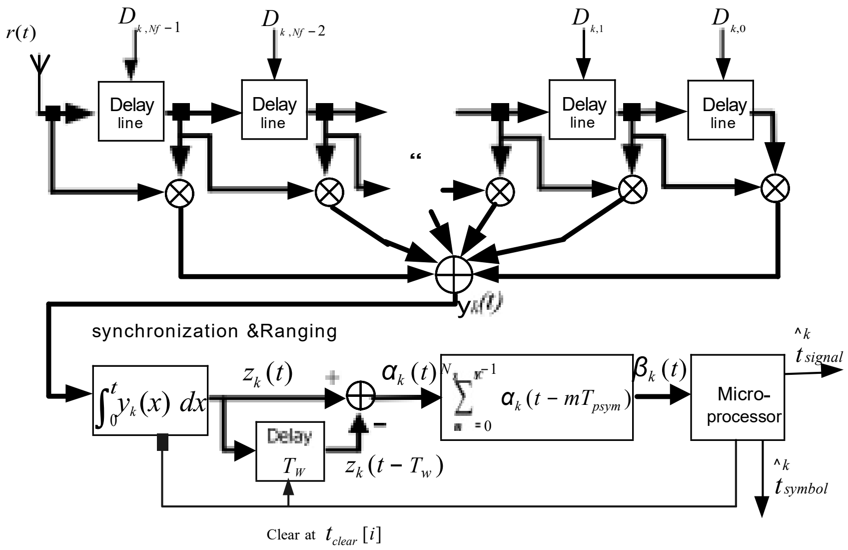

Figure 1. Receiver block diagram.

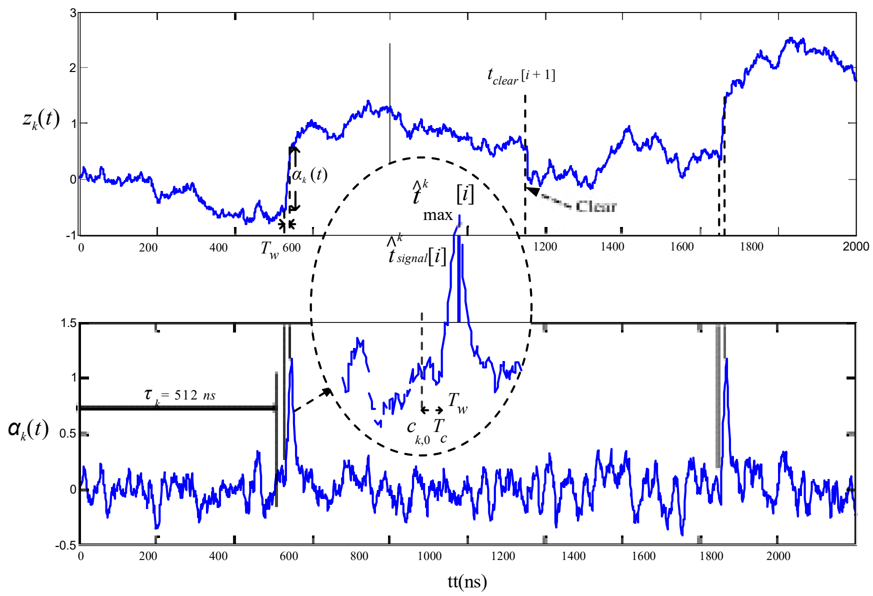

Figure 2. Simulation results $z_k(t)$ and $\alpha_k(t)$ with E_b / N_o =10 dB on for CM1 and a single user link.

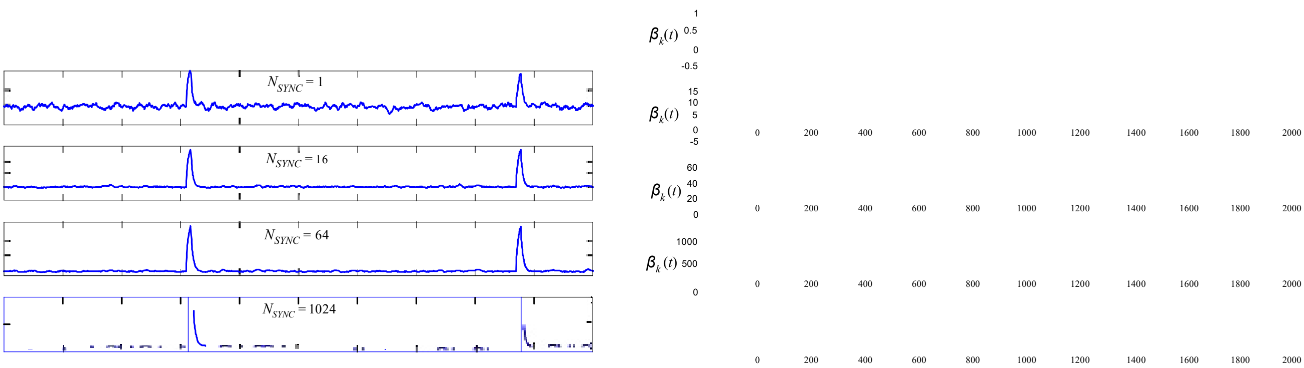

Figure 3. Simulation resu lts for $\beta_k(t)$ with E_b / N_o =10 dB on CM1 and a single user link

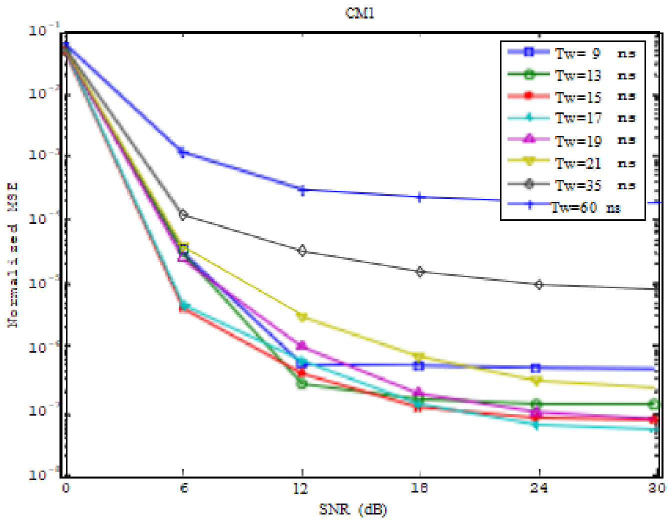

Figure 4. Normalized mean square error (MSE) versus various *Tw* with N_{SYNC} =1 symbol on CM1 and a single user link.

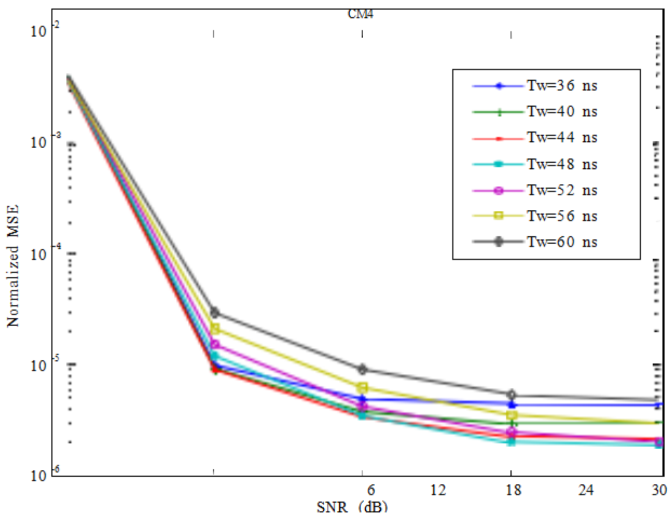

Figure 5. Normalized mean square error (MSE) versus various *Tw* **with** *NSYNC* **=1 symbol on CM4 and a single user link.**

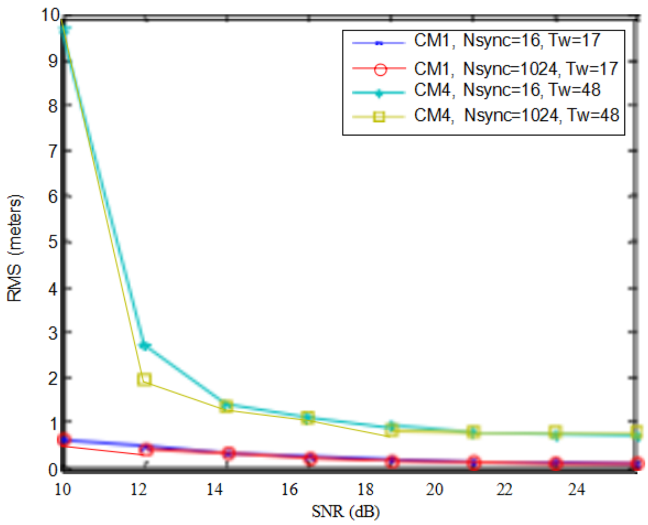

Figure 6. Root mean square (RMS) TOA estimation error in meters with *NSYNC* **=16 and 1024 symbols, and a single user link.**

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