ANALYSIS OF TIMING OFFSET ESTIMATION SCHEMES FOR UWB SIGNALS

Marina Marjanovic and José Manuel Páez Borrallo

Department of Signals, Systems and Radiocommunications, Polytechnic University of Madrid
28040 Madrid, Spain
email: marina@gaps.ssr.upm.es, paez@gaps.ssr.upm.es

ABSTRACT

In this paper a joint symbol, frame and chip synchronization method for an ultra-wideband (UWB) system is presented. We assume that the channel is estimated using pilot waveform assisted modulation (PWAM), and that synchronization is achieved by maximizing the energy of the estimated multipath channel. In order to improve the time and accuracy capabilities, importance sampling was applied for designing a time-hopping system simulator. While keeping complexity low enough for real time implementation, simulation shows the good performance of this method in terms of bit error rate (BER) versus signal to noise ratio (SNR). It is also shown that this synchronization system helps to mitigate the negative effects of timing offset. The performance degradation of the downlink system at a BER=10^{-2} is only 4 dB compared to the case of perfect timing, and 5 dB in the uplink employing single user detection[1].

1. INTRODUCTION

The growing of capacity in wireless communication requires a new type of method, which does not interfere with current systems. UWB is a new technology that fulfils those requirements and in addition promises a low power, covert communication, and very high processing gain [1], [2], [3].

Channel estimation and synchronization are important tasks for the performance of UWB systems. There are many papers dealing with those topics [4]-[8].

In order to design a real UWB system, it is necessary to develop an accurate and flexible simulator. Due to extremely large sampling rate needed for processing those ultra-wide bandwidth signals, software simulator has several problems. Using a constant sampling rate, the length of the array that contains the samples of a single bit can be very large, total computing time very high, even in very fast workstations. In [9] an enhanced algorithm for designing time-hopping system simulators is developed that uses importance sampling in order to improve the time and accuracy capabilities of previous simulators based on Monte Carlo method [10].

In [4] both data-aided and non-data aided (blind) methods are considered, and due to their requirement of multi-dimensional search to maximize the log-likelihood function, those methods have high complexity. Low- complexity timing acquisition and tracking are considered in [5] based on second-order cyclostationarity without considering channel estimation.

In [6] synchronization and channel estimation are carried out via two different approaches: a least squared (LS) method that ignores channel structure and a subspace technique that exploits this structure for channel estimation. The disadvantage of the first approach is the large number of frames needed for achieving good estimation accuracy. Subspace method requires fewer frames and yields better performance at the expense of complexity.

In [8] symbol timing is obtained to a precision that is enough for symbol demodulation. This approach is based on completely blind channel estimation technique where first-order cyclostationarity is used. This method might be hardly achievable in practice due to requirement of several FFT operations. This leads that the received signal must be sampled at a much higher rate than the symbol rate.

Joint symbol, frame and chip synchronization is achieved maximizing the energy of multipath channel. It is assumed that channel is estimated using PWAM [7]. PWAM is useful for optimizing channel estimation performance and information rate. Using PWAM method for channel estimation, FFT operations used in [8] are avoided. In this study, we assume a tapped delay channel model with Rayleigh random amplitudes.

In order to gather multipath energy, RAKE receiver is applied and information is detected through the maximum ratio combining (MRC). The pseudorandom time-hopping codes are considered in order to mitigate MUI.

In this analysis, results are evaluated with a modified version of the algorithm from [9], now suited for both uplink and downlink when the asynchronism is taken into consideration and channel is estimated using PWAM.

In this work, the performance of the UWB system is presented in terms of bit error rate (BER). It is shown that those low complexity combined techniques used for synchronization and channel estimation have good performance in system uplink and downlink.

This paper is organized as follows: in section 2. a mathematical system model is presented based on the previous research found in the literature. From this model, timing recovery is described in section 3. In section 4. simulation results and concluding remarks are given.

[1] This work has been partially supported by CEDINT-UPM

2. SYSTEM MODEL

2.1 Transmitter structure

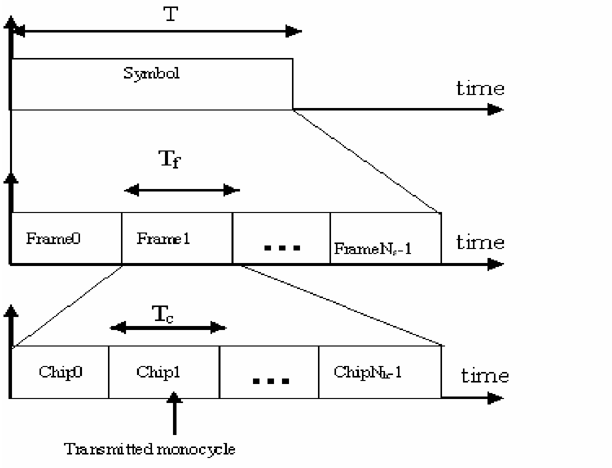

Fig.1. Frame structure for time hopping signals

If it is considered the that the UWB system is composed by N_u different links (correspond to different real users), transmitted signal through the k^{th} link can be expressed as

$$s^{(k)}(t) = \sum_{j=0}^{N_s-1} \sqrt{E_S} a_j^{(k)} w_{tr}(t - d_j^{(k)}\lambda - jT_f - c_j^{(k)} T_c - \tau_0^{(k)}) \quad (1)$$

Fig.1. illustrates the frame structure of the transmitted signal and the meaning of the terms is explained in the following points:

- $w_{tr}(t)$ is the transmitted monocycle. In this work the second derivative of the Gaussian pulse is proposed that has duration T_p<<T_f.
- N_s is the number of frames with a length T_f in one of the symbol of the duration T. Each one of the frames is subdivided in N_h chips (spreading code length) of the duration T_c. In one of them, the monocycle is transmitted.
- $\{c_j^{(k)}\}$ is the TH code, integer number, that denotes the position in the frame where the monocycle is transmitted. Integer values are taken from the range between 0 and C_{max}, where $C_{max} < N_h$. For the purposes of this paper, pseudorandom codes will be used.
- $\{a_j^{(k)}\}$ is a sequence of symbol, transmitted through the k^{th} link, usually taken from the binary alphabet.
- $\{d_j^{(k)}\}$ is a sequence of time-shifts in a PPM modulation. In order to simplify the analysis, a binary PPM modulation with a delay constant λ is used.
- $\tau_0^{(k)}$ is the asynchronism between different links, adopted as a delay respect to the beginning of the frame for the first link. For the purposes of this work, we assume that the first link is the desired signal, and the others links are interference.
- E_S presents the energy per symbol

2.2 Multipath channel model

Key to wireless receiver design is channel knowledge, which is often obtained via estimation [4], [6]-[8], and it is necessary to take accurate measurements of the channel prior to develop a complete mathematical channel model [11].

After multipath propagation, the k^{th} link of the signal propagated through a multipath channel, using tapped delay channel model may be written as:

$$y_{downlink}^{(k)}(t) = E_s \sum_{l=1}^{L} \sum_{j=0}^{N_s-1} a_j^{(k)} \beta_l^{(1)} h^{(1)}(t - iT - d_j^{(k)}\lambda - jT_f - c_j^{(k)} T_c - \tau_l^{(k)} - \tau_0^{(k)}) \quad (2)$$

$$y_{uplink}^{(k)}(t) = E_s \sum_{l=1}^{L} \sum_{j=0}^{N_s-1} a_j^{(k)} \beta_l^{(k)} h^{(k)}(t - iT - d_j^{(k)}\lambda - jT_f - c_j^{(k)} T_c - \tau_l^{(k)} - \tau_0^{(k)}) \quad (3)$$

where

$h^{(k)}(t), \forall k$ is the normalized channel response of interest

L is the total number of propagation paths, each with tap amplitude $\{\beta_l^{(k)}\}$ and delay $\{\tau_l^{(k)}\}$.

2.3 Receiver structure

The total received signal after transmitting i symbols with the period T is

$$r_{downlink}(t) = [E_S \sum_i \sum_k \sum_{l=1}^{L} \sum_{j=0}^{N_s-1} a_j^{(k)} \beta_l^{(1)} h^{(1)}(t - iT - d_j^{(k)}\lambda - jT_f - c_j^{(k)} T_c - \tau_l^{(k)} - \tau_0^{(k)})] + n_{downlink}(t) \quad (4)$$

$$r_{uplink}(t) = [E_S \sum_i \sum_k \sum_{l=1}^{L} \sum_{j=0}^{N_s-1} a_j^{(k)} \beta_l^{(k)} h^{(k)}(t - iT - d_j^{(k)}\lambda - jT_f - c_j^{(k)} T_c - \tau_l^{(k)} - \tau_0^{(k)})] + n_{uplink}(t) \quad (5)$$

where

$n_{downlink}(t)$ and $n_{uplink}(t)$ are the band-pass filtered version of AWGN noise with double-sided power spectral density $\sigma^2/2$ and a channel interference of other active users in downlink and uplink, respectively.

The arrival time of the first path of the k^{th} link is

$$\varphi_0^{(k)} = N_{frames\varphi_0}^{(k)} T_f + N_{chips\varphi_0}^{(k)} T_c + \mu_{\varphi_0}^{(k)} \tag{6}$$

where

$N_{frames\varphi_0}^{(k)} \in [0, N_s - 1], N_{chips\varphi_0}^{(k)} \in [0, N_h - 1]$

and

$\mu_{\varphi_0}^{(k)} \in [0, T_c), \forall k$

Then the signal after the multipath channel in downlink and uplink can be presented as

$$\begin{aligned} r_{downlink}(t) = [E_S \sum_i \sum_k \sum_{l=1}^{L} \sum_{j=0}^{N_s-1} a_j^{(k)} \beta_l^{(1)} h^{(1)} (t - iT \\ - d_j^{(k)} \lambda - jT_f - c_j^{(k)} T_c - \tau_0^{(k)} \\ - N_{frames\varphi_0}^{(k)} T_f - N_{chips\varphi_0}^{(k)} T_c \\ - \mu_{\varphi_0}^{(k)} - \varphi_{l,0}^{(k)})] + n_{downlink}(t) \end{aligned} \tag{7}$$

$$\begin{aligned} r_{uplink}(t) = [E_S \sum_i \sum_k \sum_{l=1}^{L} \sum_{j=0}^{N_s-1} a_j^{(k)} \beta_l^{(k)} h^{(k)} (t - iT \\ - d_j^{(k)} \lambda - jT_f - c_j^{(k)} T_c - \tau_0^{(k)} \\ - N_{frames\varphi_0}^{(k)} T_f - N_{chips\varphi_0}^{(k)} T_c \\ - \mu_{\varphi_0}^{(k)} - \varphi_{l,0}^{(k)})] + n_{uplink}(t) \end{aligned} \tag{8}$$

Accordingly, other path delays, as a delay respect to the beginning of the frame for the first path of the k^{th} link can be described by

$$\varphi_{l,0}^{(k)} := \tau_l^{(k)} - \varphi_0^{(k)}, \forall k \tag{9}$$

that represent the timing offset over the rich multipath environment.

In order to recover the information, the selective RAKE receiver correlates the received signal *r(t)* in downlink and uplink with the template signal that should be previously synchronized. It is necessary for the receiver to know the time hopping sequence of its transmitter. The statistic for the j^{th} chip is

$$\alpha_j = \int_{jT_f + \tau_0^{(1)} + c_j^{(1)} Tc}^{(j+1)T_f + \tau_0^{(1)} + c_j^{(1)} Tc} r(t) \times v(t - jT_f - c_j^{(1)} T_c - \tau_0^{(1)})\, dt \tag{10}$$

where the template signal is

$$v(t) = \sum_{m=0}^{L_{\max}} \beta_m^{(1)} \varphi(t - \tau_m^{(1)}) \tag{11}$$

The signal $\varphi(t)$ changes depending on the type of modulation employed, for PPM modulations it is

$$\varphi(t) = \hat{w}_{tr}(t) - \hat{w}_{tr}(t - \lambda) \tag{12}$$

L_{max} presents the number of RAKE fingers with amplitudes $\beta_m^{(1)}$ and finger duration $\tau_m^{(1)}$. $\hat{w}_{tr}(t)$ is the estimated waveform after the multipath propagation.

Once the chip statistics have been calculated, a bit decision should be taken. For the purposes of this work soft decision is applied as

$$\alpha = \sum_{j=1}^{N_s} \alpha_j \tag{13}$$

3. SYNCHRONIZATION

The problem will be decomposed into two steps. In the first step channel is estimated using PWAM and in the second, we estimate φ_0 from the estimated channel $\hat{h}_{\varphi_0}(t)$.

Using this method for channel estimation, simple operations at frame rate are required. According to [7], in the presence of timing offset, the estimated channel is

$$\hat{h}_{\varphi_0}(t) = \beta r_{n_p} = \beta \sum_{n_p=0}^{\bar{N}_p - 1} \sqrt{\varepsilon_p(n_p)} h_{\varphi_0}(t) + n_{n_p}(t) \tag{14}$$

where

$t \in [0, T)$ and $\beta = \left(\sum_{n_p=0}^{\bar{N}_p - 1} \sqrt{\varepsilon_p(n_p)} \right)^{-1}$

$\bar{N}_p$ is the total number of pilot waveforms and $\varepsilon_p(n_p)$ denotes the energy corresponding to the n_p^{th} pilot waveform. $n_{n_p}(t)$ is the zero mean AWGN noise in the frame containing the n_p^{th} pilot waveform.

Taking advantage of the previous estimated channel, the timing offset estimation can be achieved maximizing the energy of the estimated multipath channel as it is proposed in [8] and described with

$$\hat{\varphi}_0 = \arg\max_{0 \le \varphi_0 \le T} \int_{\varphi_0}^{\varphi_0 + T} \left[\hat{h}_{\varphi_0}(t) \right]^2 dt \tag{15}$$

where $t \in [0, T)$.

Substituting (14) in (15) the final expression for $\hat{\varphi}_0$ is obtained. The symbol synchronization requires estimation of all three components; frame synchronization requires estimation of the pair $\left(N_{chips\varphi_0}^{(k)}, \mu_{\varphi_0}^{(k)} \right)$, while estimating only the $\mu_{\varphi_0}^{(k)}$ chip synchronization can be achieved. For every user the joint synchronization can be obtained using (15). Other path delays, as a delay respect to the beginning of the frame for the first path of the k^{th} link are straightforward from (9).

4. SIMULATION RESULTS AND CONCLUSIONS

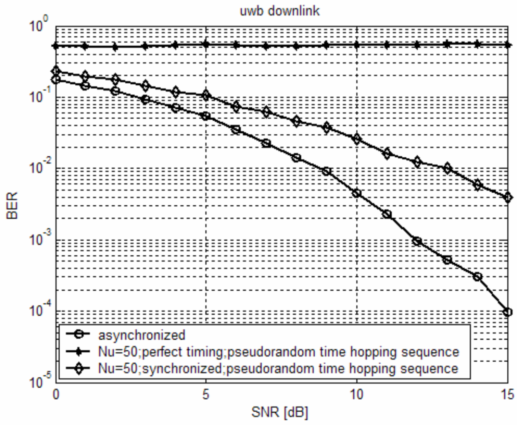

Fig.2. UWB downlink system performance

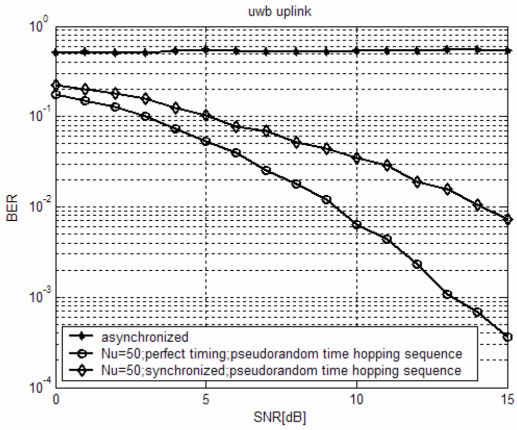

Fig.3. UWB uplink system performance

In the following section, simulation results for uplink and downlink UWB system are presented in terms of BER in order to show the effectiveness of this synchronization method. As a reference case, the curve for the case when system is perfectly synchronized is reported. During this analysis multipath channel with the Rayleigh distributed random amplitudes is considered. The multipath channel is modelled as a tap delay with L=9 taps. The channel is estimated using PWAM method, averaging 25 pilot waveforms.

We select the pulse shaper to be the second derivative of the Gaussian function, which has been normalized to have unit energy. It is assumed that this pulse is perfectly estimated.In our simulation we considered system with 50 users where chip duration is T_c=2ns, sampling frequency f_s=200/Tc, PPM time shift λ = 180 ps, number of frames N_s=8 and number of chips N_h =256. In order to gather multipath energy, the performance of the system is evaluated using RAKE correlation receivers with L_{max}=8 fingers.

In the Fig.2. the performance of the UWB downlink system is shown. It can be observed that timing offset is seriously affecting BER performance, while this synchronization system helps to mitigate its negative effects. Applying joint synchronization simultaneously when PWAM channel estimation is used, a 4dB penalty is seen at BER=10^{-2} relative to the performance of the perfect synchronized system.

In the Fig.3. the performance of the UWB uplink is presented. Using the described method for synchronization, a 5dB penalty is seen at BER=10^{-2} relative to the performance of perfect synchronized system employing single user detection. The same conclusion concerning the effect of timing offset as in UWB downlink can be drawn.

REFERENCES

[1] M. Z. Win, J. Ju, X. Quiu, V. O. K. Li and R. A. Scholtz, “ATM based Ultra-Wide Bandwidth Multiple-Access Radio Networks for Multimedia PCS,” IEEE 4th Annual Networld+Interop Conference, pp. 101–108, May 1997.

[2] M. Z. Win and R. A. Scholtz, “Ultra-Wide Bandwidth Time-Hopping Spread-Spectrum Impulse Radio for Wireless Multiple-Access Communications,” IEEE Transactions on Communications, vol. 48, no. 4, pp. 679-891, April 1997.

[3] R. A. Scholtz and M.Z Win, “Impulse Radio, How it works,” IEEE Communication Letters, vol. 2, pp. 36–38, Feb. 1998.

[4] V. Lotttici, A.D’Andrea, and U. Mengali, “Channel estimation for ultra-wideband communications,” IEEE J. Select. Areas Commun, vol.20, pp. 1638-1645, Dec. 2002.

[5] Z. Tian, L. Yang, and G. B. Gianannakis, “Non-data aided timing-offset estimation for ultra-wideband transmissions using cyclostationarity,” IEEE Trans. Commun., vol.4. pp. 121-124, Mar. 2003.

[6] C. Carobonelli, U. Mengali, and U. Mitra, “Synchronization and channel estimation for UWB signals,” GLOBECOM 2003, pp. 764-768.

[7] L. Yang, G. B. Giannakis, “Optimal Pilot Waveform Assisted Modulation for Ultra wideband Communications,” IEEE Transactions on Wireless Communications, vol.3, pp. 1236-1249, 2004.

[8] Z. Wang and X. Yang, “Ultra wide-band communications with blind channel estimation based on first-order statistics”, pp.529-532 ICASSP, 2004.

[9] G. N. Barrau, J. M. Paéz-Borrallo, “A New Time-Hopping Multiple Access Communication System Simulator. Time Hopping. Application to Ultra Wideband,”EURASIP JASP, Special Issue of UWB-State of the Art, 2005, pp. 346–358

[10] Whyless Project, “Air Interface Concept (Including Channel Model),” IST-2000-25197, Deliverable D5.1, Jan. 2002.

[11] A. Saleh and R. Valenzuela, “A Statistical Model for Indoor Multipath Propagation,” IEEE JSAC, vol. SAC-5, no. 2, Feb. 1987, pp. 128–137.