DS-UWB Receiver Frame Synchronization and Despreading

Paulo Pimentel, Helena Sarmento and Horácio Neto
INESSC-ID / Instituto Superior Técnico / Universidade Técnica de Lisboa
Email: pgp@ist.utl.pt, mhs@inesc.pt, hcn@inesc-id.pt

Abstract

The UWB (Ultra-Wideband) technology provides high data rate transmission with low average power consumption. It uses short range wireless networks (WPAN – Wireless Personal Area Network), using IEEE 802.15 standard.

DS-UWB technology, studied in this thesis, due to its low power consumption and speed, allows wireless solutions for many electronic devices that require a large bandwidth.

This report proposes a DS-UWB reception block that processes the received digital signal, recovering the original signal by despreading and synchronizing it. Spread spectrum technique is analyzed taking in consideration the random PN (Pseudo-Noise) sequence. Multipath scenarios are evaluated given their impact at the DS-UWB receiver, evaluating the RAKE receiver’s ability to resolve multipath interference. The tradeoff between low complexity and degradation of the received signal is evaluated in the RAKE receiver. Modulation techniques are analyzed taking into account the system’s optimization.

1. Introduction

The fast growth of technology and the success of wireless applications have a significant impact on our daily basis. With the advent of third generation mobile communications and the progressive replacement of wired communications for solutions such as WiMAX, Wi-Fi, Bluetooth, UWB, ZigBee, etc., users can access a great deal of information, virtually anywhere. With the demand for higher capacity, faster and better service and greater security, new technologies have the complex task of occupying its space in an already very saturated spectrum. UWB (Ultra Wideband) Technology for short-range wireless applications, offers a promising solution to the spectrums saturation problem, since it allows new radio services to coexist with existing ones, without interference.

The concepts concerning UWB signal definition are not new. In previous works [2], [3], [4], which led to the development of this technology, the signal with a large bandwidth (wideband), was generated by a very short duration sequence of baseband pulses (impulse radio or IR) of nanosecond-order. Current rules state that signals can be generated differently, provided they comply with the standard.

FCC (Federal Communications Commission) regulations defined a UWB signal and its different applications [1]. One application is data communication, which major focus is video streaming and cable replacement (wireless USB). A large variety of applications could also be named, but these do to evaluate UWB performance.

UWB technology is defined by the FCC as any wireless scheme that occupies a fractional bandwidth (FB = 2 (fH - fL) / (fH + fL)) greater than 0.2, or with an instantaneous bandwidth of more than 500 MHz. The FCC approved UWB devices to operate in the 3.1- 10.6GHz band.

Group IEEE802.15.3a failed to unite UWB specifications in a single standard. As a result of that working group standardization, there are two incompatible specifications, supported by two different groups of companies: DS-UWB (Direct Sequence UWB) and MB-OFDM (Multiband Orthogonal Frequency Division Multiplexing).

DS-UWB technology, discussed in this work, is based on sending short duration pulses. Pulses are sent modulated onto a radio carrier (pulse modulated RF) [5], despite the fact that original techniques to send data did not use any carrier.

The paper is organized as follows: section 2 describes DS-UWB technology. The complete structure of a DS-UWB receiver is briefly introduced. Spread Spectrum technique used in DS-UWB is studied. DS-UWB preamble and frame structure are analyzed. Section 3 shows the proposed Matlab/Simulink model for DS-UWB frame synchronization and despreading. Use of a RAKE receiver is evaluated. Simulation analysis is made in section 4 and the last section devotes to conclusion and future work.
2. DS-UWB

The UWB systems use signals that are based on repetitions and transmissions of short pulses formed by using a single basic pulse shape. The transmitted signals have extremely low power spectral density and occupy a very large bandwidth (several GHz). This technology uses a spread spectrum direct sequence (CDMA - Code Division Multiple Access), to reduce interference with other existing radio systems.

2.1 DS-UWB Receiver

The diagram block of a DS-UWB receiver is shown in Figure 1. The first block (RF Processing) processes the signal received by the antenna and generates the digital signal to the other modules. The Matched Filter and RAKE Receiver block processes signal synchronization and despreading. The remaining blocks are the DFE (Decision Feedback Equalizer) that suppresses the intersymbol interference (ISI), BPSK/4-BOK Demodulator, Deinterleaver, Viterbi Decoder and Descrambler.

2.2 Spread Spectrum

Spread Spectrum objective is to convey information in a given frequency band with a much larger bandwidth than that of the original signal. Direct sequence spreading is obtained with an independent source of information, mixing the binary signal to be transmitted with a spreading code, thus getting a much higher transmission rate.

The use of different codes to distinguish multiple communications in the same surroundings, allows users to have a physical presence on the same channel, connecting them to a common receiver as there is no radio interference between them.

Figure 2 shows a 2 bit transmitted signal, a spreading code of 24 short duration pulses (chips) and the corresponding combination of these two signals, resulting in a spread signal. When the transmitted bit stream signal equals 0, then spread signal matches the spreading code. If the transmitted bit stream signal is 1, then the spread signal is reversed from the spreading code.

The receiver uses cross-correlation to separate the appropriate signal from signals meant for other receivers, and auto-correlation to reject multipath interference.

2.3 DS-UWB Preamble and Frame Structure

The DS-UWB physical layer provides for flexible preamble lengths to allow robust and efficient operation with low overhead. The PLCP preamble has several sub-sections that are designed to allow efficient receiver acquisition and synchronization, as well as allowing efficient training of a receiver channel equalizer, if desired. The first portion of the PLCP preamble is always sent using a length 24 PAC for spreading in order to allow consistent and robust acquisition. Provision is made for a variable length training sequence in the second portion of the PLCP preamble. A short data field is included prior to this training field to indicate the code word length that is used for both the training sequence itself and the other remaining portions of the frame (the headers and payload)[1].

The preamble starts with the acquisition sequence, which is used by the receiver to set gains and achieve clock synchronization. The acquisition sequence is composed of 512 pseudo-random bits (roughly 9 microseconds in length). Each bit of the acquisition sequence is modulated by the piconet acquisition codeword (PAC), which is a predetermined 24 symbols spreading code. The acquisition sequence bits are generated using a length-17 pseudo-random bit sequence with a rotating seed (initial seed is same as last state of previous preamble transmission). Different seeds generate different pseudo-random sequences, thus increasing security in transmission due to the signals resemblance to noise. When the acquisition
sequence has been modulated by the acquisition codeword, it results in a hierarchical sequence that has flat spectral properties (critical for UWB systems) and yet still allows relatively simple synchronization in the receiver and good isolation between the different piconet channels. The acquisition sequence is used to perform coarse acquisition, timing recovery and rake training.

There are 12 piconets available for transmission and each spreading code is associated with 2 piconets, a piconet for each band of operation of the DS-UWB. The acquisition sequence, after being modulated by the spreading code, becomes the spread signal with \( 512 \times 24 = 12288 \) chips.

The SFD is a specific 32-bit sequence chosen to have large hamming distance from any 32 bit portion of acquisition PN sequence. The SFD is always the same for every packet and is used to establish timing for following payload. The SFD is modulated using the PAC and thus has a length of \( 32 \times 24 = 768 \) chips.

The training data field is an 8 bit data field (bit-wise triplicated, modulated with the PAC). The data field contains individual fields to establish the training/payload code length (i.e. \( L=24/12/6/3/2 \) or 1), the length identifier for the training sequence, and BPSK/4-BOK option. The training data field has a length of \( 32 \times 24 \times 3 = 576 \) chips.

The Proposed Matlab/Simulink model shown in Figure 4 uses the Equal Gain Combining (EGC) technique. Using EGC technique all the fingers weights are set to 1, but signals from each finger are co-phased to provide equal gain combining diversity. Using ECG gives the receiver the chance to use the signals that are simultaneously received in each finger.

In Figure 4 the number of fingers is set to 4, thus the RAKE receiver weights the received signal and 3 out-of-phased replicas, processing them separately. Combining all 4 signals, one single signal is obtained with a higher signal to noise ratio, therefore gaining robustness to fading.

Every correlator is responsible for the correlation between the PN pseudo-random replica and the delayed spread signal.

\[
y(t) = \sum_{i=1}^{4} x(t - \tau_i)
\]

4. Simulation

To simulate fading caused by intense multipath were tested by the IEEE 802.15.3a, four different propagation environments, referred to as CM1, CM2, CM3 and CM4 [6].

- CM1 was simulated in an environment in which transmitter and receiver were in line sight (LOS), and the distance between them varied between 0-4m.
- CM2 was tested in an environment where there was no line of sight (NLOS) between the devices and the distance varied between 0-4m.
CM3 was also tested in NLOS, but with a 4-10m distance between devices.
CM4 was simulated in an extreme NLOS scenario with a delay of 25ns caused by the mean square error (RMS). In each of the four environments, 100 measurements of channel conditions were tested.

BER performance is plotted in Figure 5, Figure 6 and Figure 7, considering a RAKE receiver with 4, 8, and 16 fingers respectively. Channel conditions improve when BER decreases. Increasing RAKE receiver’s number of fingers brings the advantage of achieving the same BER with lower signal to noise ratio. It is also shown that line of sight (LOS) transmissions always have the best performance as it is proven by propagation environment CM1.

5. Conclusions and Future Work

The purpose of this work was to test and simulate a Matlab/Simulink block model of a DS-UWB receiver where frame synchronization and despreading occurs.

Intense multipath influence on reception was tested, considering a RAKE receiver integration to fight it. RAKE receiver was able to resolve with success all multipath interference.

A complete Matlab/Simulink block model simulating transmission and reception of a DS-UWB signal was also studied. At the transmitter’s an acquisition sequence of 512 bit pseudo-random bits was spread by a 24 symbol spreading code and then synchronized and despread by the receiver.

BER analysis proved to be the best and most practical way to evaluate a radio communications system performance, giving a clear conclusion about the different configurations that were tested.

Future work should focus on better solving of extreme non line of sight paths, referred as CM4 environment.

A channel estimation approach should improve system performance. This hypothesis should be simulated so that it can be compared with existing data. Channel estimation can also help to develop a system that is proficient on analyzing the range of replicas received, choosing them according to their degree of energy.
6. References


