Effective choice of parameters of IR-UWB sensor network system

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Abstract. Impulse radio ultra-wideband (IR-UWB) has been adopted in wireless sensor networks (WSN) research due to its high performance in conditions of active influence of various noises and interferences, the presence of reflections etc. In this paper, we represents a transmitter based on the controller STM32 and a receiver implemented using blocks analog and digital processing based on FPGA within the UWB WSN system. This paper focuses on experiments to determine optimal parameters of this UWB sensor network system. For this purpose, we investigate the influence of several parameters affecting the efficiency of work of WSN system which are reference value of comparator voltage, the threshold value for receiving the preamble, normalized to the length of the preamble. We present the testing algorithm and the obtained dependencies. According to the results of this investigation, it is possible to create an algorithm for the intelligent selection of receiver parameters.

1. Introduction

Wireless Sensor networks (WSNs) have become one of the most interesting areas of research in the past few years. The study of WSNs is of great interest in health and safety areas, as well as in the automotive, aviation, and shipbuilding industries [1, 2]. Such systems are often installed in complex industrial environment, which is characterized by various noises and interferences, the presence of reflections etc. It is known that narrowband systems do not provide enough performance in these conditions. Thus, there are trends of employment of UWB signal [3, 4]. An additional requirement for WSNs is the ability to minimize power consumption in order to increase the lifetime of each transmission module. For these purposes, it is possible to use thermoelectric generators [5-7] when forming the transmitter module. The mentioned development directions of UWB WSN systems may find application in various fields [8-12].

In the course of preliminary work with an industrial partner, it was found that these requirements are fulfilled by the combination of UWB signals and On-Off Keying (OOK) modulation [13, 14]. The transmitter of this system is based on the controller STM32. The received data from the 31 bits sensor is transmitted to the 8 bits checksum calculation block, then to the extension block with a code sequence of 32 elements and a block of adding a 1000 elements preamble [13]. The generated physical layer packet is sent to the UWB modulator which is using OOK modulation with a period of 1 μs. The module for receiving UWB signals is implemented using analog and digital processing units based on FPGA (figure 1) [14]. The received signal is fed to the low-noise amplifier and then to the comparator. The reference voltage is set on the comparator. If the received signal after the LNA exceeds the reference voltage level, a high voltage level corresponding to a logical 1 is recorded with the D-
trigger. A signal from an FPGA is used to reset this value. As a result, we get a stream of samples (logical 0 or logical 1) at the input of the FPGA.

![Diagram](image)

**Figure 1.** The receiving module structure.

The resulting sample stream is converted to the \{± 1\} form. The next step is to find the preamble. For this purpose, the correlation with the known preamble is calculated. The calculation result is updated after each received sample and compared with the threshold value. If this value is exceeded, it is considered that the preamble is accepted, and thus information symbols need to be processed. For these purposes, the correlation of the sample of 32 elements with a known code sequence is calculated. The result is transmitted to solving device, which compares the obtained result with the value of zero. The output information bit is formed at the output of the solving device.

To control errors in this system, a checksum and verification of the correspondence of the transmitter number to the adopted preamble number are used. However, the complexity of the application of this system is the presence of several parameters that affect the efficiency of work:

1) Reference value of voltage of comparator $U_{\text{ref}}$.

2) The threshold value for receiving the preamble $Q$, normalized to the length of the preamble.

The values of $U_{\text{ref}}$ and $Q$ will affect the statistical characteristics of the transmission (the error probability, the false alarm probability, etc.) and the range of data transmission (with a fixed probability of error). Information about the relationship of these parameters will allow you to build algorithms for the adaptive selection of the values of $U_{\text{ref}}$ and $Q$.

The goal of this work is to develop recommendations on the choice of the values of the comparator reference voltage and the threshold value for receiving the preamble.

2. Experiment description

During the experiment, the probability of bit error, the values of $U_{\text{ref}}$ and $Q$ will be recorded. Additional error control mechanisms are disabled. The testing setup is shown in figure 2.

![Diagram](image)

**Figure 2.** Testing setup.
The massages with same content is transmitted to estimate the value of bit error probability. Physical layer packet rate is 100 packets per second. The long of each record is equal 10 minutes. That corresponds to the transfer of 60000 packets (2.34\times10^6 bits). The value of the signal-to-noise ratio is controlled using a set of attenuators.

On the receiving side data is saved on PC and then processed in Matlab environment. Also the Agilent Technologies DSO9104A oscilloscope was used to monitor the experiment and record the waveform to estimate the signal-to-noise ratio. The image from the oscilloscope screen for a data packet and a single pulse from the receiver antenna is shown in figure 4 and figure 3, respectively.

Let us consider estimation of signal-to-noise ratio (SNR). The following method for estimating of SNR is proposed. Signal constitutes a UWB pulse, \( s(t) \). It is sampled at \( 1/T_s \) by oscilloscope. We define the mean value of signal power, \( P_s \), as [15]:

\[
P_s = \frac{1}{N_s} \sum_{i=0}^{N_s-1} s_i^2,
\]

where \( N_s \) is the number of samples.

The received signal represents a mixture of a useful signals \( s(t) \) and a random noise signals \( n(t) \). Thus, we recorded a waveform on the useful signal free space to estimate the mean value of noise power, \( P_n \).

\[
P_n = \frac{1}{N_s} \sum_{i=0}^{N_s-1} n_i^2.
\]

Then we define signal-to-noise ratio, SNR, as:

\[
SNR = \frac{P_s}{P_n}.
\]

The proposed technique of measurement of SNR will be used during the experiment.

3. Results and discussions

The results are obtained according to the experiment description above. Figure 5, 6, 7, depicts the dependence of the bit error rate (BER) on the signal-to-noise ratio and reference value of voltage of comparator for each threshold values for receiving preamble \( Q \). As observed in figures, the three
graphs have different fronts. For the case of a threshold of 767 elements, there are only 2 states: the probability of bit error is equal 0, or the signal cannot be detected. Therefore, this case is more selective. However, this case gives a smaller interval for the choice of reference voltages of comparator.

Figure 5. Plot for value of attenuator, reference value of voltage of comparator vs BER for case of $Q = 255$.

Figure 6. Plot for value of attenuator, reference value of voltage of comparator vs BER for case of $Q = 511$.

Figure 7. Plot for value of attenuator, reference value of voltage of comparator vs BER for case of $Q = 767$. 
Figure 8 shows the plot of BER for various threshold values for receiving preamble $Q$ and reference value of voltage of comparator $U_{ref}$. The signal-to-noise ratio value of 22, 16, 12 dB is shown on figure in blue, azure, yellow, respectively. As we can see, the maximum values of voltage of comparator is different for each SNR value. A signal cannot be detected above this maximum voltage value. It is also seen from the figure that the choice of threshold does not affect this maximum voltage value. We plot this graph on a logarithmic scale to more accurately assess this dependence. As shown in figure 9 for very small (about $10^{-5}$) or very big (about $10^{1}$) values of probability of a bit error are practically independent of the values of the signal-to-noise ratio. For mean area, this value is changed by an order of magnitude.

Thus, it is possible to give the following recommendation for optimal choice of parameters of the WSN. If it is necessary to set a small reference value of voltage in order to provide small power consumption, the value of threshold for receiving the preamble is set as low as possible. In our case this value is equal 255. On the other hand, the small value of threshold will lead to increase the probability of bit error. Therefore, the choice of reference voltage is a trade-off between a high value of bit error rate and a low power consumption.

In general, the reference value of voltage is chosen closer to the middle of the range. In this case, the maximum value of threshold is specified, because increasing the threshold reduces the probability of receiving an error (noise), in other words, the probability of receiving a correct packet increases. In addition, the choice of the middle of the range will depend on value of signal-to-noise ratio. Therefore, it is possible to automate the process of determining the reference voltage by pre-calculating the signal-to-noise ratio.

References
[1] Slottke E, Kuhn M, Wittneben A, Luecken H and Cartalemi C 2015 UWB Marine Engine Telemetry Sensor Networks: Enabling Reliable Low-Complexity Communication (IEEE 82nd Vehicular Technology Conference (VTC2015-Fall)) (Boston, MA) 1-5
[2] Kdouh H, Zaharia G, Brousseau C, Grunfelder G, Farhat H and Zein G El 2012 Wireless Sensor Network on board vessels (19th International Conference on Telecommunications (ICT)) (Jounieh) 1-6
[3] Jinghao Xu, Peric B and Vojcic B 2005 Energy-aware and link-adaptive routing metrics for ultra wideband sensor networks (2nd International Workshop Networking with Ultra Wide Band and Workshop on Ultra Wide Band for Sensor Networks) (Rome, Italy) 1-8
[4] Bhattacharya S, Senguttuvan R and Chatterjee A 2005 Production test enhancement techniques for MB-OFDM ultra-wide band (UWB) devices: EVM and CCDF (IEEE International Conference on Test) (Austin, TX) 10-245

[5] Korotkov A, Loboda V, Dzyubanenko S and Bakulin E 2018 Fabrication and Testing of MEMS Technology Based Thermoelectric Generator (7th Electronic System-Integration Technology Conference (ESTC)) (Dresden) 1-4

[6] Korotkov A S, Loboda V V, Makarov S B and Feldhoff A 2017 Modeling Thermoelectric Generators Using the ANSYS Software Platform: Methodology Practical Applications and Prospects (Russian Microelectronics) 46(2) 131-138

[7] Korotkov A, Loboda V, Feldhoff A and Groeneveld D 2017 Simulation of Thermoelectric Generators and Its Results Experimental Verification (Proc. IEEE International Symposium on Signals Circuits and Systems) (ISSCS 2017) 13–14

[8] Kvashenkina O E, Gabdullin P G and Arkhipov A V 2018 SmartFoil: a Novel Assembly Technology for Electronic Circuit Boards in Multifunctional Units (IEEE International Conference on Electrical Engineering and Photonics (EEPolytech)) (Saint Petersburg, Russia ) 202-206

[9] Pergushev A and Sorotsky V 2018 Signal Distortion Decreasing in Envelope Tracking Power Amplifiers (IEEE International Conference on Electrical Engineering and Photonics (EEPolytech)) (EEPolytech) (Saint Petersburg, Russia) 44-47

[10] Trubin P, Savchenko E and Velichko E 2018 Development of Polarimetric Sensor for Identification System (IEEE International Conference on Electrical Engineering and Photonics (EEPolytech)) (EEPolytech) (Saint Petersburg, Russia) 279-282

[11] Savchenko E A, Velichko E N, Aksenov E T and Nepomnyashchaya E K 2018 Combined method for laser selection, positioning and analysis of micron and submicron cells and particles (International Conference Laser Optics (ICLO)) (St. Petersburg) 539-539

[12] Zanina M A, Belov A A and Volvenko S V 2018 Estimation of Accuracy of Algorithm for Measuring Radiofrequency Pulse Parameters (IEEE International Conference on Electrical Engineering and Photonics (EEPolytech)) (EEPolytech) (Saint Petersburg, Russia) 98-102

[13] Volvenko S V, Zavjalov S V, Gruzdev A S and Vasiljev D S 2017 Experimental Ultra Wideband Wireless Sensor Network For Data Collection (DSPA) 1 345-351

[14] Volvenko S V, Ge D, Zavjalov S V, Gruzdev A S, Rashich A V and Svechnikov E L 2017 Experimental wireless ultra wideband sensor network for data collection (Progress In Electromagnetics Research Symposium - Spring (PIERS)) (St. Petersburg) 965-970

[15] Yajnanarayana V, Dwivedi S and Han del P 2016 IR-UWB Detection and Fusion Strategies using Multiple Detector (Types IEEE Wireless Communications and Networking Conference)