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Channel Decoding Using Cyclic Elimination Algorithm for Pulse Based UWB Transceiver

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***Abstract*—Ultra-Wideband has recently become an emerging technology in internet-of-things (IoT) and wireless sensor networks (WSNs) for high-volume data transmission and sensing applications. However, channel estimation, proper signal detection, and data decoding are challenging to recover the message information in the UWB receiver successfully. A power-efficient and straightforward channel decoding receiver architecture is critically needed for low-power and resource constraints applications. This paper proposed a cyclic pulse elimination based channel decoding algorithm to recover the sending data channel. The receiving signal correlates with individual pulses and eliminates cyclically to decode the data channel. Then the decoded pulses use to recreate the pulse-sequence to find the missing data channel. The MATLAB simulation tool performs the proposed algorithm to decode the data channels from the composite signal. Simulation results indicate that the proposed channel decoding algorithm can be implemented in the micro-controller board to simplify the receiver architecture for real-time implementation. The proposed scheme will reduce the computational burden and pave the way for new platforms in high-speed wireless sensor applications.**

***Index Terms*—WSN, UWB, orthogonal pulse, composite signal, and pulse encoding/decoding, CPE.**

I. Introduction

The high-speed microprocessor and fast switching technique have made Ultra-Wideband (UWB) communication a powerful technology for short-range and low-power applications. It became a superior technology for personal area networks, sensors, consumer electronics, localization, and non-invasive medical applications. Due to short pulse duration, larger bandwidth, and lower-power requirements, the UWB system is widely used in large scale data collection, sensing, monitoring, and video imaging. Typically, a UWB transmitter transmits billions of nanosecond pulses across the wide frequency spectrum. A corresponding receiver translates the pulses into data bits according to a prior known encoding template. Literature shows that different data encoding schemes can modulate the sensor data bits symbolically by analog orthogonal pulses. Recently, novel data encoding schemes have proposed based on orthogonal pulse-sequences [1], [11], composite pulses [2], and multi-bit data encoding [3] using a power-efficient modified Hermitian pulse (MHP) generation model [4]. An adaptive spectrum scavenging technique is presented to achieve energy-efficient wireless connectivity for high-density multi-channel applications [5].

A conventional correlation receiver correlates the receiving pulse by a reference signal to recover the message data. Firstly, the received signal is multiplied by a locally available template waveform with multiple-access code synchronization algorithms. The product's output is then passed through an integrator to decode the pulse and converts to message information. The UWB system's performance can severely degrade in some harsh scenarios like as the presence of multi-user and inter-symbol interference [6]. Typically, a coherent RAKE receiver architecture can track the energy associated with multi-path replicas [7]; however, channel estimation is the critical task for the UWB receiver. A suitable channel estimation algorithm is needed through heuristic approximation to reduce the optimal detection scheme. The transmitted reference receiver decreases the channel estimation steps compared to the coherent reception; however, it possesses an inherent architectural complexity for low-cost implementations. Moreover, the template waveform is employed in the demodulation process consisting of the delayed replica in a differential UWB receiver. The correlation operation also revealed the amplitude variations pulse to pulse.

Previously, the UWB detection scheme has designed without any down-conversion, and most of them used ADC conversion with sophisticated digital signal processing computation. A pulse-based UWB demodulator has proposed to self automatic threshold recovery and time synchronize technique that involves computational complexity [8]. The down-conversion was used in the pulse-based UWB system to reduce the sampling rate in the receiver section. Recently, deep learning has gained high interest due to its ability to identify unknown nonlinear mapping functions in wireless data communications. A deep neural network-based UWB receiver has proposed considering multi-user applications for UWB pulsing, channel effect, and signal detection [9]. Moreover, a mixed-signal UWB receiver architecture has presented [10] using a non-coherent scheme for proper detection, acquisition, and synchronization. The presented method [10] integrates a sub-optimal channel selection estimator and paves a way to improve the sensitivity of the UWB receiver. However, it remains challenging to simplify the receiver architecture, including proper signal detection, time synchronization, and computation to recover the information for low-power IoT-based 5G networks.

This paper proposes a new channel decoding algorithm

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using correlation peak analysis to simplify the existing superheterodyne receiver architecture. The proposed decoding scheme eliminates individual pulses from composite pulse signal sequentially based on the higher correlation peak. The received composite signal is correlated with stored distinct order MHPs and decoded cyclically until all the pulses are eliminated from the composite signal. The eliminated pulses will be used to recreate the pulse-sequence for finding the missing data channel matched with the prior known pulse-sequence template [1]. This proposed pulse elimination algorithm simplifies the pulse decoding receiver architecture in high-speed data transmission with supporting multi-user data for IoT-based sensor networks. The rest of this paper is organized as follows: Section II describes the pulse-based UWB transceiver model. Section III and IV represents the proposed cyclic pulse elimination algorithm and simulation results, and finally concludes the paper in section V.

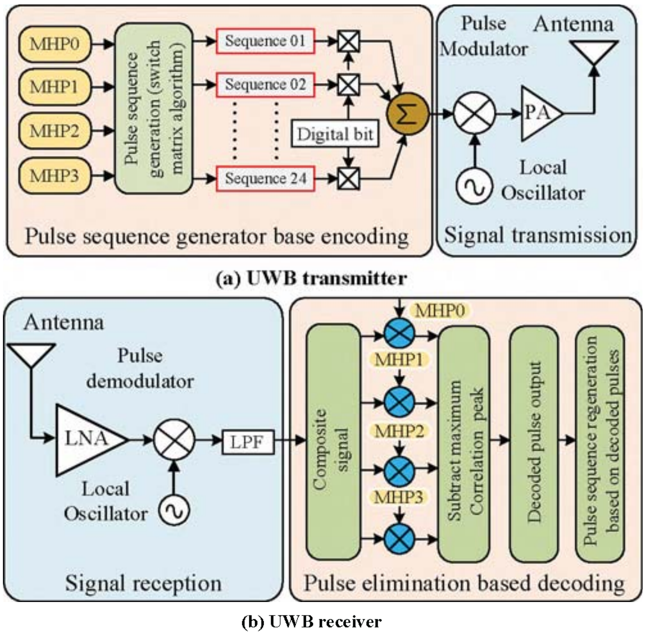


Fig. 1. Pulse-based UWB (a) transmitter and (b) receiver architecture.

II. Pulse-Based UWB Transceiver Architecture

Fig.1 shows the architecture of analog pulse-based UWB transceiver. It is the same as the conventional narrowband system, consisting of an RF transmitter (Tx), a communication channel, and an RF receiver (Rx). Typically, the UWB transmitter modulates the digital data bits by pulse-based waveforms instead of continuous carrier waves. In pulse-based UWB system, a set of MHPs uses to map the sensor data [1]–[3]. Fig. 1(a), shows the analog pulse-based UWB transmitter architecture, where the Tx modulates digital data bits by a sequence of narrow pulse instead of a single pulse. The communication channel represents the propagation media, signal transmission, reflection, diffraction, attenuation, etc. Fig. 1(b) shows the UWB receiver decodes the digital data bits using correlator peak analysis from the receiving pulse signal. A brief description of each subsection is as follows:

A. UWB Transmitter

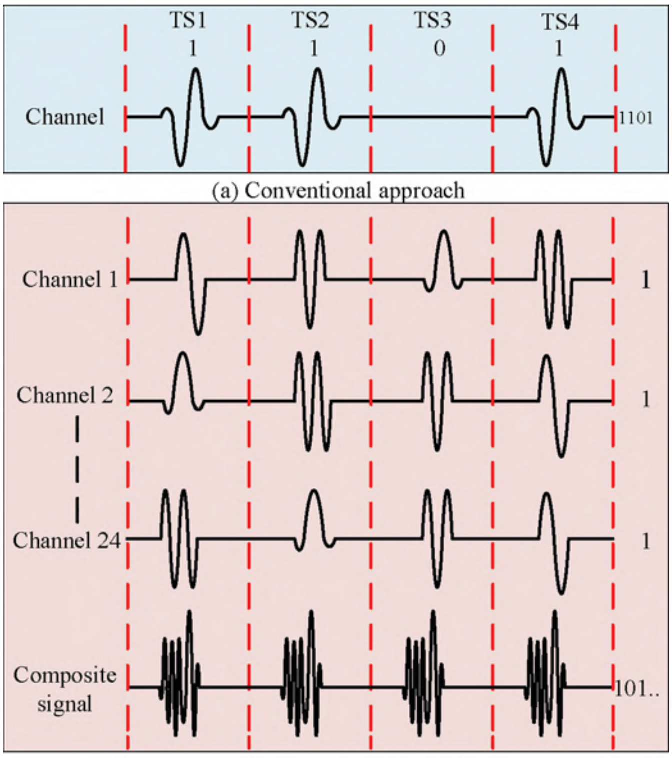
The UWB transmitter consists of MHPs generation, pulse sequence creation, data mapping, and signal transmission through RF antenna. The analog pulse-based UWB transmitter (Fig.1(a)) uses the same network protocol, communication architecture, and spectral bandwidth for transmitting the digital data bits. The power-efficient orthogonal MHPs generation, pulse-sequences creation, and novel data encoding/decoding scheme are the main difference in pulse-sequence based UWB transceiver compared to the conventional system.

1) Orthogonal Pulse Generation: In this paper, an energy-efficient orthogonal MHP generation scheme uses to generate the multi-order pulses explained in [4]. The orthogonal pulse set generator is designed for sub-GHz (500 MHz) band UWB communications. By varying 'n' to different integers, the pulse responses of two dynamic systems n^{th} and $(n-1)^{th}$ order derivatives of orthogonal pulses are obtained using the MATLAB Simulink model. The generated pulse information is then stored in flash memory for further signal processing, such as shifted pulse generation, pulse-sequence creation, composite pulse generation, etc. The advantage of the proposed MHP is the signal orthogonality, which maintains the coexistence with other pulses and indicates no loss of signal properties when multiple pulses are sent as a composite signal.

2) Pulse Sequence Based Data Encoding: Typically, in a conventional UWB system, the digital bitstream modulates by a single pulse sequence using any modulation schemes such as OOK, BPSK, PPM, etc. Recently, a novel data encoding scheme has been proposed based on the pulse-sequence generation scheme by utilizing a set of orthogonal MHPs [1]. Pulse-sequence generation was the main innovation in [1]. It was generated using the permutation of pulses order from 0 to 3 (MHP0, MHP1, MHP2, and MHP3) using a switch matrix algorithm. Authors defined each distinct pulse-sequence as a particular wireless data channel shown in Fig. 1(a). The four distinct order pulses create 24-distinct pulse-sequences that modulate the digital data bits using a suitable modulation scheme and transmits simultaneously within a specific time instant. Since all the pulses are orthogonal to each other; thus, all the 24 pulse-sequences are superimposed with their corresponding time slots (TS) to create a unified pulse sequence (UPS). The UPS occupies a 4-time slot compared to a single TS has shown in Fig. 2. Thus, the pulse sequence-based data encoding scheme can transmit multichannel data and increase the data transmission rate by sharing the same frequency bandwidth. Finally, the composite pulse signal translates to high frequency and amplifies the strength before transmitting through an RF antenna.

B. UWB Receiver

Fig. 1(b) presents the proposed correlator based channel decoding receiver architecture. Firstly, the receiving RF antenna received the electromagnetic wave that comes from the transmitting RF antenna. Then the low-noise amplifier increases the received signal strength. The baseband composite pulse is obtained from the received signal by frequency



(b) Pulse sequence approach

Fig. 2. Data encoding (a) conventional and (b) pulse-sequence approach.

down-conversation using the same carrier frequency. Then the pulse elimination algorithm is applied on the baseband composite signal to eliminate the individual pulses. In this paper, the cyclic pulse elimination (CPE) algorithm decode the individual pulses sequentially based on the highest correlation peak. Finally, the decoded pulses will apply to recreate the pulse sequence to find the missing data bits.

III. Cyclic Pulse Elimination (CPE) Algorithm

A CPE based channel decoding scheme is the main contribution in the proposed pulse-sequence based UWB receiver architecture for high-density data communications. In proposed, CPE based correlator receiver decodes the individual pulses from the received composite signal by correlation peak analysis with the time-synchronized distinct order orthogonal MHPs. Fig. 3 shows the flow chart of the proposed CPE algorithm. Firstly, in CPE algorithm, the baseband composite pulse signal correlates sequentially with the individual pulses stored in the receiver flash memory. Then check the correlation peak of each pulse with the composite signal and find the maximum correlation peak. The MHP corresponding to the highest correlation peak subtracted from the combined signal and stores the decoded pulses. This pulse elimination process will continue until the correlation peak to reach below the predefined threshold level. After eliminating all the distinct pulses from the composite signal, the correlation peaks become lower than the threshold level and end the pulse elimination loop. The CPE scheme decodes the different order MHPs cyclically by each iteration; thus, the proposed decoding scheme is defined as a cyclic pulse elimination algorithm.

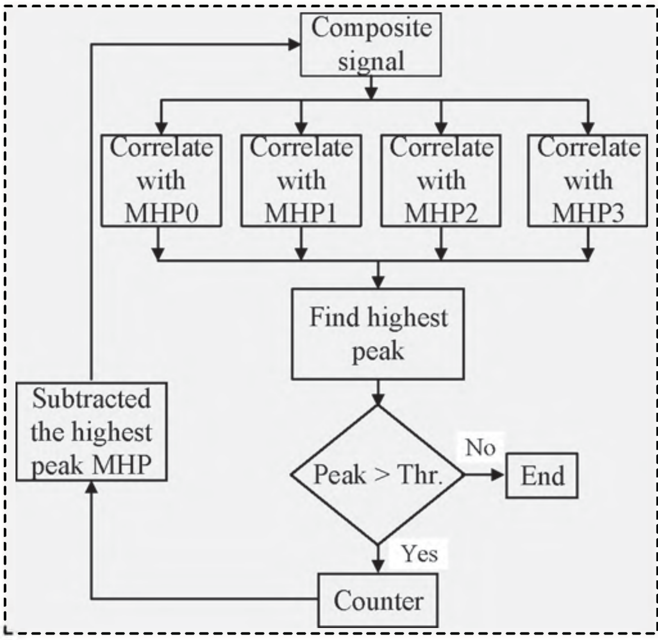


Fig. 3. The flow chart of proposed cyclic pulse elimination algorithm.

In pulse-sequence based UWB transceiver, the CPE algorithm will apply corresponding to each time slot (TS) to decode the MHPs from the received composite signal. Time synchronization is a critical issue for correlation peak analysis of MPs with composite signal. Thus, an extra pulse signal can be added in front of composite pulse at sensor nodes for time-synchronization for correlation analysis. When, receiver detect the time-synchronization pulse it starts to correlate the composite pulse with individual pulses corresponding to each TS. Finally, the eliminated individual pulses will be used in future to regenerate the pulse-sequence for finding the missing data channel with a prior known template. The decoded pulse-sequence indicates the presence or absence of a data channel in high-density sensor network applications.

IV. Simulation Results

This section presents the simulation results that demonstrate the performance of the proposed CPE based data channel decoding algorithm. The MATLAB simulation tool is used to verify the accuracy of the proposed CPE algorithm. Fig. 4(a) shows the pulse-sequence signal created from multi-order MHPs. Each pulse-sequence occupies a four-time slot and generates by changing the position of pulses sequentially without pulse redundancy. Fig. 4(b) and (c) shows the composite pulse signal consisting of multiple pulse-sequences superimpose on top of another and the composite pulse signal with adding 20 dB additive white Gaussian noise (AWGN) to verify the performance of pulse elimination by CPE.

Fig. 5 shows the simulation results corresponding to the first TS of pulse decoding from the composite signal. The correlation peak of individual pulses with the composite pulse signal is printed in MATLAB and eliminated the pulses

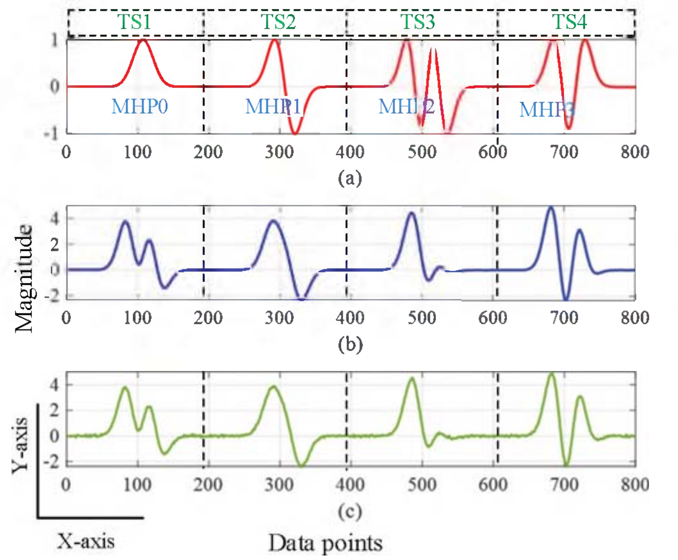


Fig. 4. Simulation results (a) pulse-sequence, composite pulse-sequence (b) without AWGN, and (c) with 20dB AWGN corresponding four TS.

TABLE I
CORRELATION BETWEEN COMPOSITE PULSES WITH MHPS

Iteration	Composite signal						Residual signal
	1st	2nd	3rd	4th	5th	6th	
MHP0	0.3958	0.5789	0.2846	0.3546	0.4785	0.9911	0.0561
MHP1	0.3768	0.4579	0.5388	0.6714	0.0056	0.10080	0.0595
MHP2	0.6210	0.3039	0.4446	0.5540	0.7476	-0.2128	0.0187
MHP3	0.4173	0.5072	0.5968	0.0120	0.0162	0.0238	0.0782

corresponding to the highest correlation peak in each iteration shown in Table I. In this paper, the CPE algorithm's accuracy is checked by the composite signal corresponding to TS1, consisting of 2MHP0, MHP1, 2MHP2, and MHP3 pulses. Fig. 5(a) shows the decoded pulses cyclically based on the highest correlation peak (Table I). Fig. 5(b) represents the remaining signal after eliminating pulses from the composite signal corresponding to the iteration number. After decoding all the pulses from the composite signal, the residual signal contains only the AWGN (Fig. 5(b)), and the correlation peak of all the pulses reach below the predefined threshold level (Table I). If any individual pulse signal is missing in the composite signal, then the corresponding pulse's correlation peak is lower than the threshold level (0.20). So, the correlation peak also an indicator to find the missing pulse in the composite signal.

V. CONCLUSION

In this paper, a cyclic pulse elimination based channel decoding scheme is presented to decode the transmitting data in high-volume wireless sensor applications. The proposed data channel decoding technique eliminates individual pulses cyclically from a composite signal using correlation analysis. The MATLAB simulation results indicate that the proposed pulse decoding algorithm can successfully decode all the pulses from the combined signal. The decoded individual pulses from the composite signal corresponding to each time slot will be used in the future

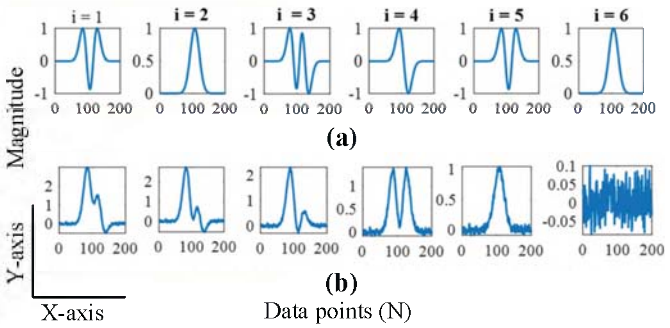


Fig. 5. Simulation results (a) decoded pulses (b) residual signal after iteration.

to regenerate the pulse-sequence to find the missing data channel. The proposed pulse elimination algorithm reduces the complexity and computational difficulties of receiver architecture. Moreover, the orthogonal pulse-sequence-based UWB transceiver increases the data transmission speed indirectly by supporting more data channels. Therefore, the pulse-sequence based UWB transceiver scheme makes a leading alternative data compression for high-density wireless data transmission in IoT-based 5G networks.

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