2020 11th International Conference on Electrical and Computer Engineering (ICECE)

Analog Pulse Based Data Transmission for Internet-of-Things Applications

Md. Kamal Hossain* and Mohammad R. Haider*
*School of Engineering, University of Alabama at Birmingham, Birmingham, AL, USA

2020 11th International Conference on Electrical and Computer Engineering (ICECE) | 978-1-6654-2254-3/20/$31.00 ©2020 IEEE | DOI: 10.1109/ICECE51571.2020.9393146

***Abstract*—The development of sensor devices and wireless technologies are a continuing impact on our society by connecting everything under the same network. However, reliable data transmission is becoming instability with the proliferation of wireless sensors in the IoT system. So, data compression is one of the possible keys to support more data within the existing capacity in high-density wireless sensor networks. This paper presents a novel data encoding scheme with the critical aim of indirectly increasing the transmission rate by supporting many data channels using both original and 25% time-shifted pulses. In the proposed data encoding scheme, a sequence of the multi-orders orthogonal pulse represents a single data bit with no pulse redundancy. The proposed method increases the transmission capacity and supports many data channels. This work performs the MATLAB simulation package to generate the pulse sequences and verify the FCC's transmission power requirements. The proposed data encoding scheme supports 2n!-numbers of data channels with n!*(2n+1)/n(n+1)-times data rate improvement, where n is the number of distinct pulse order.**

***Index Terms*—Orthogonal pulse, time shifted pulse, sequence of pulse, composite signal, and power spectral density.**

I. Introduction

The Internet-of-Things (IoT) technology involves many interconnecting "Things" under the same network. It has developed for large-scale data gathering, continuous monitoring, location tracking, sending video-imaging, and measurement devices. However, the exponential growth of IoT devices in sensor networks increases the cumulative data volume, data congestion, and data collisions that make the instability for reliable data transmission. The 5G technology's challenge is to ensure higher channel capacity, lower data latency, and support large numbers of data channels to meet IoT networks' demand. Therefore, a high data rate is a demanding application to support a large volume of sensor nodes for spectral efficiency and data reliability. These requirements attracted the researchers' concern to overcome the challenges of IoT-based 5G networks. In recent work, both Narrow Band (NB) and Ultra-Wideband (UWB) schemes have been investigated with energy-efficient approaches for wireless data transmission in IoT networks. The existing digital signal transmission (DST) techniques have suffered from resource constraints such as a few channels, lower throughput, computation power, memory allocation, etc.

The most common DST techniques are Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiplexing (OFDM). The well known Bluetooth low energy (BLE) and the standard Bluetooth technologies use the FSSS technique for short-range communications. However, they suffer from a lower data rate of up to 1 Mbps with a few data channels. The Zigbee and the IEEE 802.15.4 communication protocols use the DSSS technique to spread the bandwidth by spreading code. Typically, Zigbee based wireless personal area networks work in radio frequency at 868 MHz and 2.4 GHz with a data rate of 250 kbps. In recent work, an orthogonal Walsh code data encoding scheme has developed to overcome spectral efficiency and sensitivity for frequency dispersion in the IS95 or CDMA2000 system [1]. However, the IFFT based Walsh-Hadamard orthogonal code generation CDMA technique suffers from the degradation of performance with increasing the number of channels and system complexity.

The analog pulsed-based UWB technology has a relatively high data rate, lower power consumption, and widely used video streaming, monitoring, and localization applications. In the UWB system, the weak transmitted power shows a lower probability of interception, resistance to jamming, and multipath interference. However, the multi-band (MB) OFDMA UWB radio technology is not amenable to energy-constrained applications. Therefore, the pulse-based UWB technique widely studied for transceiver architecture's simplicity, lower power consumption, and broader frequency spectrum. The commercially available DWM1001 UWB transceiver communicates wireless data within 300 m with a data rate of 6.8 Mbps for location detection [3], [4]. Recently, a pulse-based UWB transceiver has developed to reduce the peak transmission power for short-range communications by improving the time synchronization at the receiver [5]. Moreover, the waveform based rectangular lattice and superimposed technique improve data rate up to n-times and (n+1) times, respectively, for n-pulse system [9], [10].

In pulse-based UWB technology, each data bit modulates by a single short orthogonal pulse using either pulse position coding or binary phase-shift keying technique. Recently, a multi-order orthogonal pulse set-based data encoding scheme is proposed using single-order pulses and composite pulses [7], [8], [11]. However, this paper proposed a novel data encoding scheme using a sequence of analog orthogonal

978-1-6654-2254-3/20/$31.00 ©2020 IEEE

pulses to represents a single data bit instead of a single pulse. The Modified Hermite pulse (MHP) and their 25% time-shifted pulses are used for generating the pulse sequence to encode data bits. The proposed scheme supports a total of 2n!-numbers of data with data rate improvements by 2n!/(n+0.25)-times using n^{th} orders of orthogonal MHPs. The proposed scheme also offers high volume data compression for monitoring, assessment, and control to expand the high-speed IoT applications. The rest of this paper is organized as follows: Section II, III, and IV describes the system architecture of the proposed transceiver, pulse sequence-based data encoding scheme, and simulation results, respectively. Finally, we summarize and conclude the paper in section V.

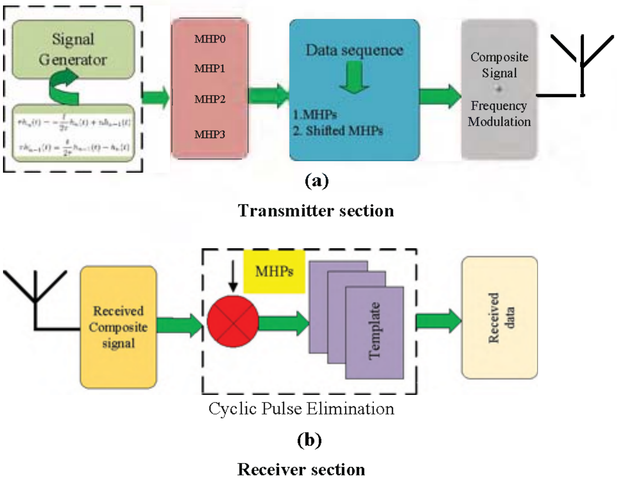

Fig. 1. Architecture of the pulse-sequence based sensor data transmission.

II. System Architecture of Proposed Transceiver

Fig.1 shows the architecture of the proposed analog pulse sequence-based data encoding technique. It comprises a transmitter, communication channel, and the receiver section, same as the existing pulse-based UWB system. The transmitter section has three components: the orthogonal Hermite pulse set generator [6], the pulse sequence generation, and the data encoding scheme. The baseband pulse sequence translates to a higher frequency using a carrier signal before transmitting via RF antenna. The communication channel represents the effects of distortion, reflection, scattering, and attenuation when traveling through air media [12]. The cross correlation-based cyclic pulse elimination (CPE) algorithm is the leading architecture of the receiver section. Each pulse decodes from the baseband composite signal using CPE. To find the missing data regenerates the pulse sequence from the decoded pulse for matching with known prior templates.

A. MHP and SMHP set Generation

The energy-efficient multi-order orthogonal pulse set generator comprises two first-order Hermite polynomials. The pulse set generator architecture is implemented in MATLAB Simulink [6], which reduces the computational complexity and power dissipation. Changing the value of n from zero to any finite number generates the orthogonal pulses and higher-order derivatives. This power-efficient and straightforward orthogonal pulse set generator is designed for sub-GHz (500 MHz) band pulse-based UWB communications with a pulse width of 20 ns. Fig. 2 shows, the four different MHP set and their 25% time-shifted pulses. The four distinct zeroth, first, second, and third orders MHPs and SMHPs represent by MHP0, MHP1, MHP2, MHP3, and SMHP0, SMHP1, SMHP2, and SMHP3, respectively.

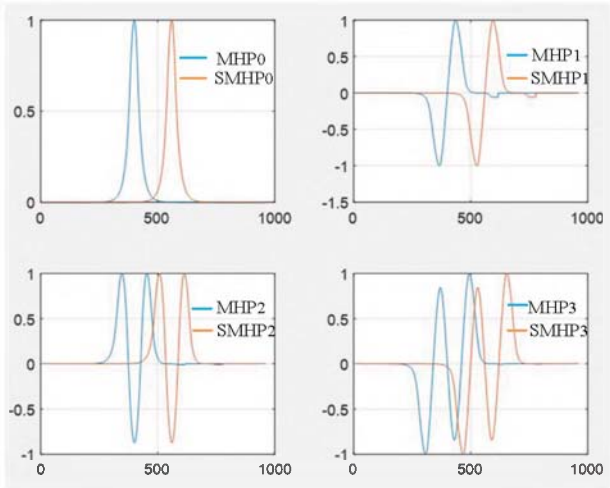

Fig. 2. Different order MHP pulses with 25% time-shifted pulses.

B. Signal Orthogonality Analysis

The four different order MHP and their time-shifted pulses are orthogonal to each other. In this paper, the cross-correlation analysis is investigated to check the signal orthogonality. We use two types of MHPs set for correlation analysis: (i) the original MHPs set and (ii) the time-shifted MHP set. The value of correlation coefficient r ranges from '-1' to '1'. The correlation coefficient '1' shows the perfect match between the signal. The coefficient' -1' depicts the pulses opposite each other, and 0 implies no correlation.

TABLE I
Correlation between different MHPs and 0.25 shifted MHPs

	MHP0	MHP1	MHP2	MHP3	SMHP0	SMHP1	SMHP2	SMHP3
MHP0	1.000	0.000	-0.206	0.000	-0.311	-0.009	-0.183	-0.044
MHP1	0.000	1.000	0.000	0.000	0.009	-0.025	0.059	-0.101
MHP2	-0.206	0.000	1.000	0.000	-0.183	-0.059	-0.007	-0.194
MHP3	0.000	0.000	0.000	1.000	0.044	-0.101	0.194	-0.256
SMHP0	-0.311	0.009	-0.183	0.044	1.000	0.000	-0.206	0.000
SMHP1	-0.009	-0.025	-0.059	-0.101	0.000	1.000	0.000	0.000
SMHP2	-0.183	0.059	-0.007	0.194	-0.206	0.000	1.000	0.000
SMHP3	-0.044	-0.101	-0.194	-0.256	0.000	0.000	0.000	1.000

*1) **Auto/cross-correlation study among individual pulses:*** The correlation factor between different MHPs defines how closer a signal to other signals. When two pulses matched perfectly is called auto-correlation. The cross-correlation factor between one signal to any other signals is always less than 1. In this paper, the cross-correlation is performed at various time-shift factors 0.25, 0.3, 0.4, 0.5, etc. The correlation peak analysis results depict that a 0.25 time-shift factor is the threshold level of time-shifted pulses to maintain the signal orthogonality. The results of autocorrelation and cross-correlation study among individual MHPs and their time-shifted pulses, SMHPs are shown in Table: I.

*2) **Cross-correlation study among individual pulse with composite pulses:*** Table: II shows the cross-correlation results between individual MHPs with the composite of MHPs and shifted MHPs. The composite of shifted MHPs is correlated highly with the individual SMHPs while having lower relationships with the original MHPs. A higher correlation peak depicts the presence of individual pulses in the composite signal. It also helps to select the threshold level for decoding the individual pulses from the composite signal using pulse elimination and finding the missing data bits.

TABLE II
CORRELATION BETWEEN COMPOSITE MHPS AND SMHPS WITH MHPS

	Sum MHPs	Sum SMHPs		Sum MHPs	Sum SMHPs
MHP0	0.293	-0.293	MHP1	0.494	-0.184
MHP1	0.539	-0.038	MHP2	0.430	0.217
MHP2	0.452	-0.225	MHP3	0.542	-0.445
MHP3	0.591	-0.084	MHP4	0.473	0.420
SMHP0	-0.193	0.293	SMHP1	0.050	0.494
SMHP1	-0.108	0.539	SMHP2	-0.053	0.430
SMHP2	0.069	0.452	SMHP3	0.068	0.542
SMHP3	-0.328	0.591	SMHP4	-0.073	0.473

III. PULSE SEQUENCE BASED DATA ENCODING

A pulse sequence-based data encoding scheme is a significant contribution to this proposed high-density data encoding technique. In this paper, the digital data is encoded in time domain analogy by a sequence of analog pulses considering the time-shifting property of orthogonal MHPs. The permutation of n-distinct order MHPs and SMHPS are applied to generate the pulse sequences. In this proposed scheme, the serial to parallel data communication technique is used for multi-user applications. The switch matrix algorithm

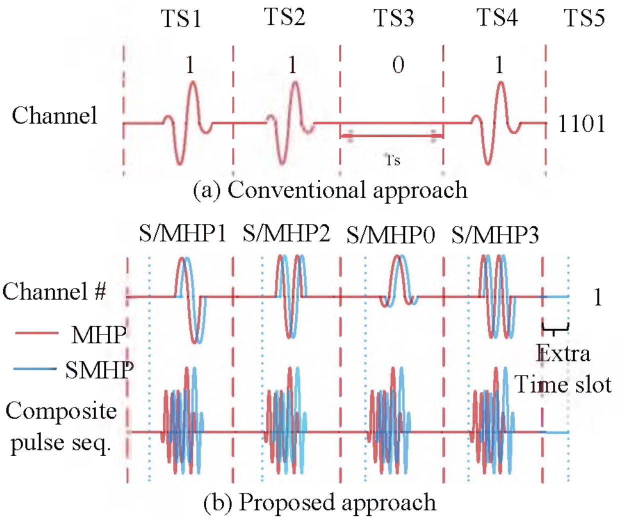

Fig. 3. Data compression in proposed scheme using both MHPs and SMHPs.

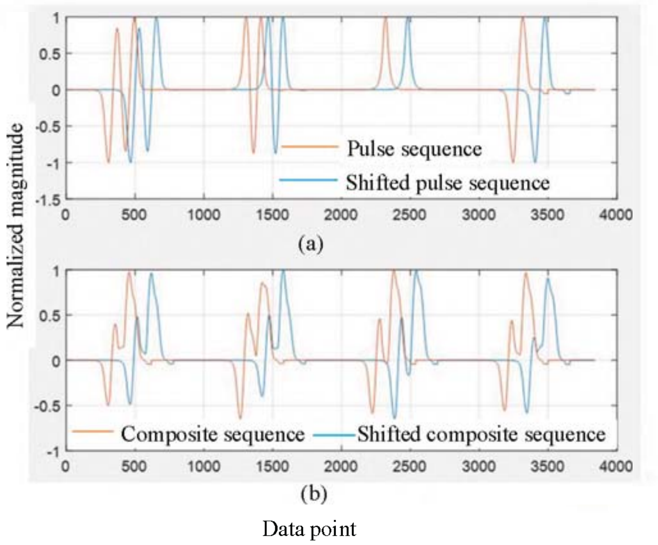

Fig. 4. The pulse sequences and their composite signals.

generates the pulse sequences using the four MHPs by reordering the pulses with no redundancy. The permutation of four different order pulse creates a total of 24 distinct pulse sequences. Similarly, the time-shifted pulse also creates another 24 pulse sequences. In this proposed scheme, each pulse sequence indicates a particular data channel to represent the digital bit-stream. Typically, the presence of a pulse sequence indicates data bits and vice versa. Fig. 3 shows the concept of the proposed data encoding scheme symbolically.

In the conventional approach, a single pulse is used to present a single data bit either using an on-off keying modulation scheme (Fig. 3(a)). Compared to the conventional approach, the proposed method represents a single data bit by a pulse sequence instead of single pulse. Our proposed scheme initially uses extra pulses to present a single data bit; but, the ultimate benefit is higher than the initial scarification of pulses and time slot. Moreover, time-shifted MHPs also occupied an extra 25% time slot of the original pulse period; however, it also supports an extra data volume by increasing the number of data channels. In the conventional approach, only (4+4)-bit data can modulate by the four MHPS and their shifted pulses, while our scheme transmits a total of 48-bit (24+24) data by 48-distinct pulse sequences using the same number of MHPs and SMHPs. Since all the individual pluses and time-shifted pulses are orthogonal to each other; therefore, all the pulse sequences are superimposed on top of another corresponding to each time slot to create a unified composite signal. Fig. 3(b) shows the composite signal that compressed the data volume with no digital signal processing. Therefore, our proposed scheme creates a total of 2n!-pulse sequences using n-distinct order MHPs with considering time-shifted pulses and increases the data transmission rate indirectly by supporting more data.

IV. SIMULATION RESULTS

In this work, the MATLAB simulation tool is performed to implement the theoretical concept of a pulse sequence-based data encoding scheme to support many data channels. Fig. 2 shows, all the pulses are normalized in between magnitude +1 to -1. In this work, 48 pulse sequences are created to encode the data by implementing the pulse sequence generation algorithm. The permutation technique uses to create the pulse sequence changing the position of four-distinct MHPs and SMHPs sequentially. Fig. 4 shows the pulse sequence generated by both MHPs and SMHPs, respectively, and their composite sequence. All the orthogonal MHPs coexist with other pulses without losing signal property.

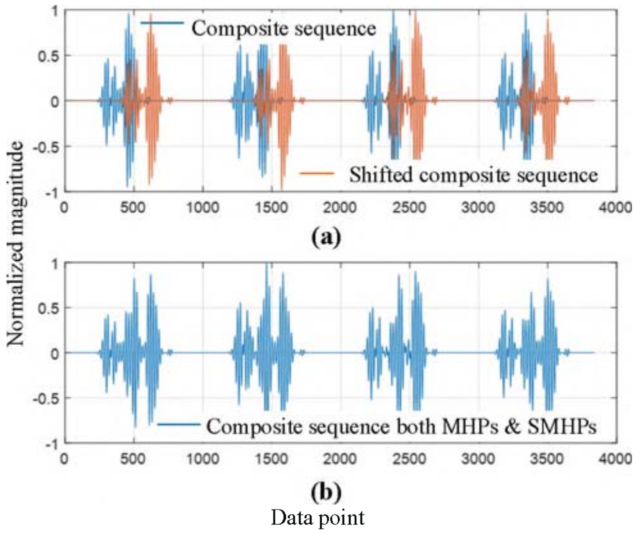

Fig. 5. The modulated signal of composite signal with 500 MHz carrier.

The low-frequency base band composite pulse sequence translated to a high-frequency with a 500 MHz carrier signal. Fig. 5 shows the modulated signal of both composite pulse sequence signals. In Fig. 5(a), the orange and blue trace indicates the modulated composite pulse sequences for MHPs and SMHPs, respectively and Fig. 5(b) shows the composite signal of 48-distinct pulse sequences.

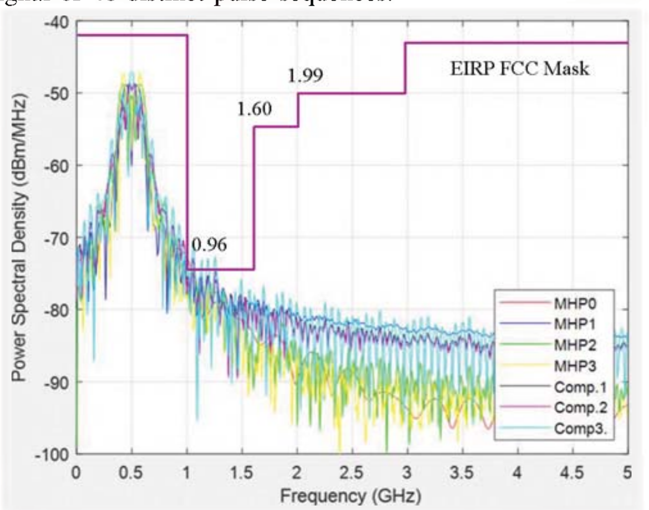

Fig. 6. The power spectral density of various pulses and composite signals.

Fig. 6 shows the simulated PSD curves of both individual and composite pulses. In 2002, FCC defined the power requirements for indoor communication is -41 dBm/MHz allocated the frequency ranges from 3.1 GHz to 10.0 GHz. All the individual pulses and the composite pulse sequences meet the FCC power requirements for UWB indoor communication.

V. Conclusion

In this paper, a new data encoding scheme is presented to support high-volume wireless data transmission using the existing channel capacity in sensor network applications. The proposed data encoding scheme compressed the sensor data volume indirectly using pulse sequence generation based on (i) orthogonal pulses and (ii) time-shifted pulses. This novel encoding scheme is efficient, simple, and particularly suitable for energy-constrained wireless sensor nodes. The simulation results show that the proposed system supports 2n!-several distinct data channels simultaneously transmitting multiple sensor data with no additional spectral capacity. It also improves data rate by $n!*(2n+1)/n(n+1)$-times more by supporting a large volume of data using both shifted and original pulses in the n-order pulse system. The simulation results show that our proposed scheme competent in enhancing the number of data channels for high-speed data transmission simultaneously in sub-GHz (500 MHz) band UWB communication. It makes a leading alternative data compression technique for high-density wireless sensing applications in the IoT-based 5G networks.

Acknowledgment

This work was supported by the NSF under the Award no. ECCS-1813949 and CNS-1645863.

References

[1] P. Patil et al., "A Review on MIMO OFDM Technology Basics and More," *2017 International Conference on Current Trends in Computer, Electrical, Electronics and Communication*, Mysore, 2017, pp. 119-124.

[2] W. Zhang et al., "STC-GFDM systems with Walsh-Hadamard transform," *IEEE International Conference on Electronic Information and Communication Technology*, Harbin, 2016, pp. 162-165.

[3] DWM1001 Module: UWB and BLE-ready module offering RTLS systems configurable anchor or tag options; https://www.decawave.com/products/dwm1001-module, accessed May 2018.

[4] PulsON 440 The worlds most capable UWB smart sensor; https://timedomain.com/products/pulson-440/, accessed May 2018.

[5] F. Chen et al., "A 1mW 1Mb/s 7.75-to-8.25GHz chirp-UWB transceiver with low peak-power transmission and fast synchronization capability," *IEEE International Solid-State Circuits Conference Digest of Technical Papers*, San Francisco, CA, 2014, pp. 162-163.

[6] Y. Li, M.R. Haider and Y. Massoud,"An efficient orthogonal pulse set generator for high speed sub-GHz UWB communications," *IEEE International Symposium on Circuits and Systems*, 2014, pp. 1913-1916.

[7] M. K. Hossain, Y. Massoud and M. R. Haider, "A Spectrum-Efficient Data Modulation Scheme for Internet-of-Things Applications," *IEEE 63rd International Midwest Symposium on Circuits and Systems*, Springfield, MA, USA, 2020, pp. 770-773.

[8] M. K. Hossain et al., "Randomized Pulse-Based Encoding for Secure Wireless Data Communications," *IEEE 63rd International Midwest Symposium on Circuits and Systems*, MA, USA, 2020, pp. 289-292.

[9] E. atak and L. Durak-Ata, "An efficient transceiver design for superimposed waveforms with orthogonal polynomials," *IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)*, Istanbul, 2017, pp. 1-5.

[10] S. Aldirmaz, A. Aserbes and L. Durak-Ata,"Spectrally Efficient OFDMA Lattice Structure via Toroidal Waveforms on the Time-Frequency Plane," *EURASIP J. Adv. Signal Process*, 2010: 684097.

[11] K.P. Pradhan, et al.," Modified Hermite Pulse-Based Wideband Communication for High-Speed Data Transfer in Wireless Sensor Applications", *Journal of Low Power Electronics*, vol. 7(30), 2017.

[12] M. K. Hossain and M. R. Haider, "S Parameters Based Channel Characterization Using Ultra Wideband Pulse Signal, *in International Conference on Electrical and Computer Engineering*, December, 2020.