Analog Pulse-Based Channel Sensing for Spectrum Efficient Wireless Data Transmission

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***Abstract*—Spectrum sharing techniques overcome spectrum scarcity and inefficient management by allowing unoccupied channels with other users without interfering with primary users. Therefore, channel sensing plays a vital role in finding the vacant data channel available for secondary users in signal transmission. However, the existing channel sensing techniques suffer from uncertainty because of random measurement, fast sampling, signal recovery and immediate signal reconstruction algorithm, reliability measurement, implementation complexity, etc. This paper proposes an analog pulse based innovative channel sensing technique for spectrum-efficient data transmission. The pulse-sequence based channel encoding scheme identifies the individual data channel and the correlator-based channel decoding algorithm decodes the distinct data channel from the received composite pulse-sequence signal. A MATLAB® simulation is performed to verify the proposed channel sensing concept for spectrum-efficient applications. The encoding scheme implements a BPSK modulation under different SNR ranging from -5.0 dB to 20.0 dB for an AWGN channel. The results show that the proposed channel sensing technique simplifies the implementation complexity for spectrum sharing in high-density pulse-based wireless data transmission in future 5G networks.**

***Index Terms*—Orthogonal pulse, pulse sequence, channel encoding/decoding, spectrum sensing and sharing.**

I. Introduction

The technical innovation in mobile communication and the proliferation of intelligent sensor devices has started many new applications with an increasingly aggressive data volume in the sensor networks. This escalation in demand for smart devices increases the requirements of wireless frequency band. It burdens the unlicensed frequency spectrum, whereas the licensed spectrum remains underutilized. The present spectrum allocation technique provides each service with its limited frequency band. It already assigned most of the primary frequency bands among the existing communication technologies. As a result, it is very difficult to find a vacant spectrum for new services or expand the current services to support high-density data channels. Moreover, the radio channel spectrum needs proper utilization for minimizing cost for all users. Thus, the next-generation networks seek to provide the users' demands, including the improved data rate, increased channel capacity, effective spectrum utilization, and Quality of service that enabled telecommunication services [1].

Recent studies reported that in the United States the current spectrum utilization ranges from 15% to 85% under the fixed spectrum allocation policy. The Federal Communications Commission (FCC) measurements also show that some channels are barely used, and most of the time remain unused, while others are heavily used. This sparse unused spectrum creates a problem to assign new users for the scarcity of spectrum. The radio frequency band is inefficiently exploited in the current spectrum management policy. To manage the spectrum band usage effectively and efficiently, the FCC organization introduces the Cognitive Radio (CR). CR network has a unique potential to co-exist with the primary users (PUs), which imposes several challenges and constraints, including spectrum sharing, power, sub-carrier allocation, etc. [2]. Thus, the scarcity and inefficiency of the spectrum management require an urgent intervention to enhance the spectrum access, and increases network performance.

Spectrum sharing is a way to overcome the scarcity issue by dynamically managing the unoccupied channels and reused for data transmission, called secondary users (SUs). Channel sensing is the core part of sharing with others, and it is critical due to the multipath fading or channel uncertainty, etc. There are several channel sensing including energy detection, wavelet-based, matched filter detector, and autocorrelation technologies have been proposed for spectrum management and resource utilization applications [3]. The energy detection technique requires FFT computation to compare the received signal power with a threshold that depends on the noise power level [4]. The wavelet-based sensing can identify the number of occupied bands over a frequency spectrum by continuous wavelet transform through the power spectral density. In matched filter-based detection scheme, the process involves with determining the types of signals occupying the spectrum, including the modulation technique, bandwidth, and carrier frequency [5]. Among all the schemes, the autocorrelation based sensing is an optimal one that can differentiate the signal and noise, and makes it less sensitive to noise uncertainty.

Recently, the analog pulse-based data transmission scheme has been proposed by using a set of distinct order orthogonal pulses for high-density sensor applications [6]. It is an innovative data modulation scheme that indirectly increases the data transmission rate by supporting a large data volume. The orthogonal pulse set has been used to create the distinct order pulse-sequences for encoding the digital bit-stream, where the distinct pulse sequences indicates the channels. This paper proposes an analog pulse-sequence (APS) based channel sensing scheme using a set of orthogonal Modified Hermitian Pulses (MHPs) to detect the individual data channel. In the proposed method, all the distinct data channels are modulated by orthogonal pulse-sequences (PSs) instead of a single pulse, and then decoded at the receiver with a correlator-based approach by matching with the orthogonal PS templates. The orthogonality property of PSs simplifies the encoding/decoding implementation, and reduces computational complexity for spectrum-efficient transmission. Our proposed channel sensing scheme detects the unused channels and supports a large number of data channels based on the number of pulses in a single sequence [6].

The rest of this paper is organized as follows. Section II presents the proposed APS-based channel sensing technique. Sections III and IV describe the methodology and simulation results, respectively. Finally, we conclude the paper in section V.

II. Proposed Channel Sensing Techniques

Fig. 1 shows architecture of the proposed data channel sensing scheme for spectrum efficient applications. It consists of three sections (A) primary signal transmitter, (B) signal transmissions and receptions, and (C) primary signal detection.

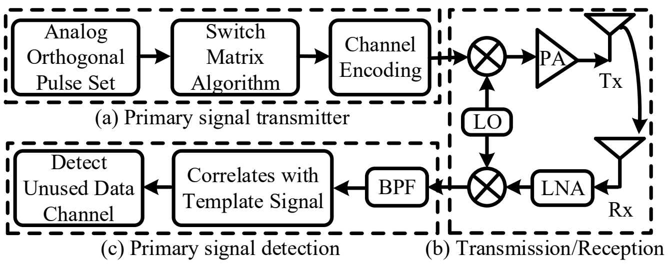

Fig. 1. Analog pulse-based channel sensing scheme.

A. Primary Signal Transmitter

In proposed channel sensing, the primary user signal needs to be generated in the transmitter section with different parameters, including the operating frequency and the modulation scheme. Therefore, the PS generation is the core part of the APS-based channel sensing techniques. A set of orthogonal MHPs uses to create the distinct PSs for encoding the data channels. Then, it passes through the communication channel, which also has some characteristics, i.e., fading propagation, reflection, channel obstruction, noise, etc. Therefore, we have set the parameters for the proposed transmitter model as the operating frequency at which the primary signal is transmitted. The BPSK modulation techniques modulate the sensor data by analog PSs. For the channel modeling, additive white Gaussian noise (AWGN) is added to the receiver's transmitted signal.

B. Signal Transmission and Reception

Fig. 1(b) shows the signal transmission and reception of the APS-based channel sensing scheme. In signal transmission, the original frequency of the channel encoded PSs translates to higher frequency using local Oscillator (LO) signal either 500 MHz, or 2.4 GHz, 5.0 GHz, or any specified frequency band. Power amplifier then increases the signal strength to drive the RF antenna before transmits. At the signal reception, the modulated PSs receives by an RF antenna and increases the power level by a low noise amplifier (LNA). The frequency mixer circuit then down-converts the received frequency by the same carrier to recover the based frequency of PSs.

C. Primary Signal Detection

The proposed primary signal detection scheme detects the distinct data channel encoded PS signal for sensing the specific frequency band. In this work, the correlator-based decoding architecture uses to decode the individual data channel. The PS decoding algorithm eliminates the distinct order transmitted PSs from the composite signal using correlation peak analysis. The decoded PSs then use for decoding the digital bit-stream by using the previously known data encoded template. At the receiver, the presence or absence of a specific PS indicates the status of that data channel, either transmitting data bits or not.

III. Methodology

The orthogonal distinct PS generation is crucial to decode the individual data channel for spectrum-efficient and spectrum sharing in high-density wireless sensor applications. Therefore, orthogonal pulse generation is the prior condition to create the PS for channel modulation schemes.

A. Orthogonal Pulse Set Generation

Fig. 2 shows the multi-order orthogonal MHPs generated by an orthogonal pulse set generator based on a modified Hermitian polynomial, which consists of two first-order differential equations. It is easy to implement in MATLAB Simulink and capable of generating multi-order orthogonal MHPs. Unlike the existing orthogonal pulse generation, the developed mathematical model described in [7] offered less computational power, time, and reduced system complexity. We generate narrow-band (NB) signal of pulse width of 20 μs using τ = 1.0×10^{-6} and setting the Sawtooth wave function at -5.0 μV to 5.0 μV with a time period of 2.0 μs ranging from -1.0 μs to 1.0 μs. The constant value of 'n' defines the pulse order and the factor 'τ' decides the pulse duration. By varying 'n' to different integers, the pulse responses of two dynamic systems n^{th} and $(n-1)^{th}$ order derivatives are obtained that represent MHP orders, respectively.

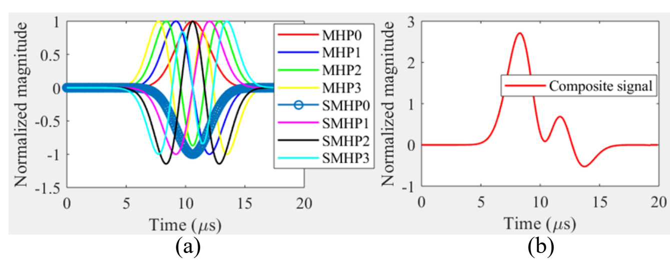

Fig. 2. Different order orthogonal pulse signal with 20.0 μs pulse width.

B. Orthogonal Pulse Sequence Generation

In this work, we create distinct orthogonal PSs using the switch matrix algorithm. The generated orthogonal MHPs described in subsection III-A are stored in a micro-controller flash memory. The permutation techniques-based switch matrix algorithm then applies to create the distinct PSs from the stored multi-order pulses [6]. Typically, the permutation technique rearranges a set of numbers by changing their positions without repetition of any number in a permutation series. In the PS generation scheme, the pulse position modulation (PPM) concept applies to rearrange all the distinct order MHPs to create the possible numbers of PSs by changing the pulse order. The length of PS depends on the number of MHPs. For instance, in a 3-pulse system, the total 3! or 6-distinct PSs generates by rearranging distinct order MHPs sequentially. Since each MHP has 20 μs pulse width; therefore, the total length of a PS is 60 μs that contains '3' time slots (TS) compared to a single pulse period of 20 μs.

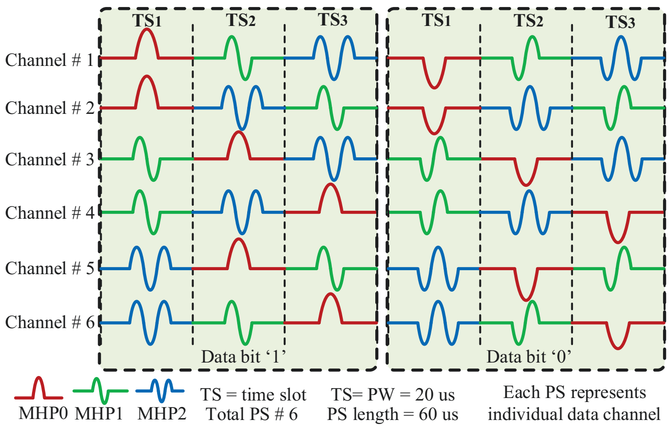

Fig. 3. Pulse sequence based data channel encoding scheme.

C. Pulse Sequence Based Channel Encoding

Fig. 3 shows the APS-based data channel encoding scheme. The individual PS indicates the distinct data channel in the proposed scheme where data comes from different sensor nodes. Therefore, the distinct PS carries the channel identity of the respective sensor node and encodes as per the template. In a 3-pulse system, the 6-distinct PS indicates 6-distinct data channels and modulates the digital bit-stream using BPSK modulation techniques. The original PS shows data bit '1,' and out-of-phase PS represents data bit '0' in the data modulation schemes. Therefore, the proposed APS-based encoding scheme increases the channel capability compared to the conventional single pulse system. At the end of the encoding scheme, it superimposed all the PSs to create the composite PS signal containing the compressed data volume. Since in the proposed technique, each PS comprises 3-distinct order MHPs; therefore, it requires more TS than a single pulse system. Though the proposed scheme initially scarifies time; however, it will support more data by allowing more channels.

D. Data Channel Decoding

The received down-converted composite signal passes through a band-pass filter to recover the specific frequency band signal. The PS elimination techniques then applies after synchronizing the composite signal with the template signal for correlation analysis [8]. A sync pulse of width 20 μs can be added at the front of the composite signal at the transmitter for time synchronization with the template signal at the receiver. The correlation cycle runs parallel to decode

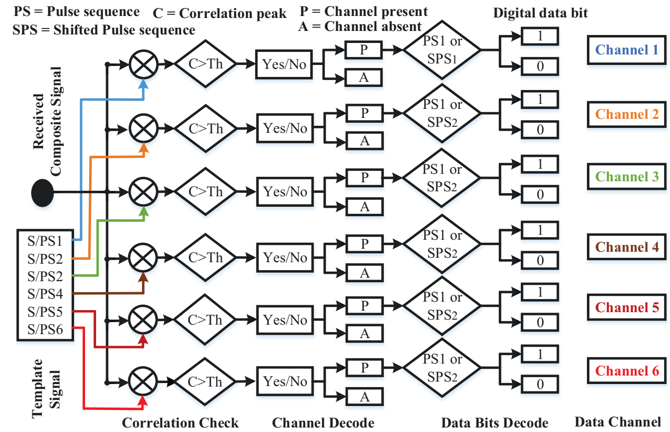

Fig. 4. Correlator based Channel decoding scheme.

the distinct orthogonal PSs from the composite signal based on the correlation peak. Each correlator block correlated the incoming composite signal with a specific PS and compared the correlation peak with a pre-defined threshold value. If a particular PS is presence in the composite signal, then the correlation peak should be much higher than the threshold level and set index '1' otherwise set '0'. Therefore, the correlation peak indicates either the presence or not of a PS in the composite signal. The presence of a PS indicates that the corresponding data channel transmits data bits and vice versa.

To find the missing data channel, a threshold time period will set and check the status of the data channel based on the received PS. Since each PS length is 60 μs; therefore, we can select the threshold time at 10 ms. If any specific PS continuously absent until 10 ms in the received composite signal, then the corresponding data channel will be out of service. The decoding scheme finds either the corresponding data channel transmits bit '1' or '0'. After decoding the distinct PS, the decoded PS information will match the previously known template to find the digital bit-stream. The presence of a PS indicates data bit '1', and shifted PS represents '0'.

IV. Simulation Results and Analyses

The proposed channel sensing technique has been verified using MATLAB Simulation with a BPSK modulation-based data encoding scheme. AWGN assumed the channel model with zero mean and different variance according to a range of SNR varies from -5.0 dB to 20.0 dB as shown in Table I. These test results helps to select the optimal threshold level for decoding all the distinct orthogonal PSs successfully.

TABLE I
Thresholds level with SNR at different test experiments.

	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6
SNR (dB)	- 5.000	0.0000	5.0000	10.000	15.000	20.000
Threshold	0.1500	0.2500	0.3500	0.3500	0.3500	0.3500

Fig. 5 shows the data channel encoding using distinct orthogonal PSs generated from orthogonal distinct order analog MHPs using PPM techniques. The 6-distinct orthogonal MHPs show 6-different data channels. Table II represents the correlation coefficient of each PS with others and their composite signal. The correlation table shows that the auto-correlation peak of each PS with itself is '1.0', and the cross-correlation peak with other PSs ranges between '0' to '1'.0. The cross-correlation coefficient '0' between two PSs indicates that those are perfectly orthogonal to each other. However, the coefficient between '0' and '1.0' shows that the PSs are partially orthogonal and coexist with other PS in their composite signal. It can make it possible to decode all the PS successfully using correlation peak analysis.

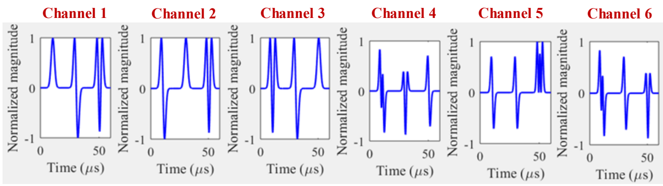

Fig. 5. Pulse sequence based Channel encoding results.

TABLE II
AUTO AND CROSS-CORRELATION COEFFICIENT OF DISTINCT PS.

	Seq. 1	Seq. 2	Seq. 3	Seq. 4	Seq. 5	Seq. 6	Comp.
Seq. 1	1.0000	0.3431	0.2964	0.0000	0.5169	0.5820	0.7383
Seq. 2	0.3431	1.0000	0.0816	0.1745	0.5169	0.5419	0.6488
Seq. 3	0.2969	0.0816	1.0000	0.0000	0.4549	0.2145	0.5198
Seq. 4	0.0000	0.1746	0.0000	1.0000	0.1226	0.4202	0.3665
Seq. 5	0.5169	0.5169	0.4549	0.1226	1.0000	0.4379	0.7962
Seq. 6	0.5820	0.5419	0.2145	0.4202	0.4379	1.0000	0.7960
Comp.	0.7383	0.6488	0.5198	0.3665	0.7962	0.7960	1.0000

Fig. 5 shows the channel sensing results using APS based scheme. In this experiment, we assume the sensor data at distinct data channels are encoded by the orthogonal PS following the template described in subsection III-C, where channels 1, 2, and 4 transmit data bit '1', Channel 3 and 5 transmit bit '0', and channel 6 doesn't transmit any data. Fig. 5(b) and (c) show the corresponding composite signals without and with 20 dB AWGN signal, respectively. Fig. 5(d) presents the decoding results at the receiver, where channel 6 is out-of-service, and the rest of the channels are in-service. Table III presents the test results at different conditions, where the composite signal composed of both original PS and 180° shifted PS, generates positive and negative correlation outputs. The correlation value 'Nan' indicates the absence of the corresponding PS in the composite signal.

TABLE III
CORRELATION PEAK AT DIFFERENT TEST EXPERIMENTS.

	Seq. 1	Seq. 2	Seq. 3	Seq. 4	Seq. 5	Seq. 6
Exp. 1	0.3584	0.6223	-0.5989	0.3950	-0.2101	Nan
Exp. 2	0.2291	-0.6386	0.5431	-0.4756	0.1848	Nan
Exp. 3	-0.3071	0.2571	Nan	0.6978	0.7930	-0.4673

V. CONCLUSION

In this paper, a novel analog pulse-sequence based channel sensing technique has been implemented in MATLAB under an AWGN channel with varying SNRs. Simulation results show that all the distinct data channels can be decoded from the composite signal at different test conditions using a fixed threshold level of 0.10. The composite signal indicates the compressed data version and forms a single PS signal that contains all the information of the data channels. Simulation

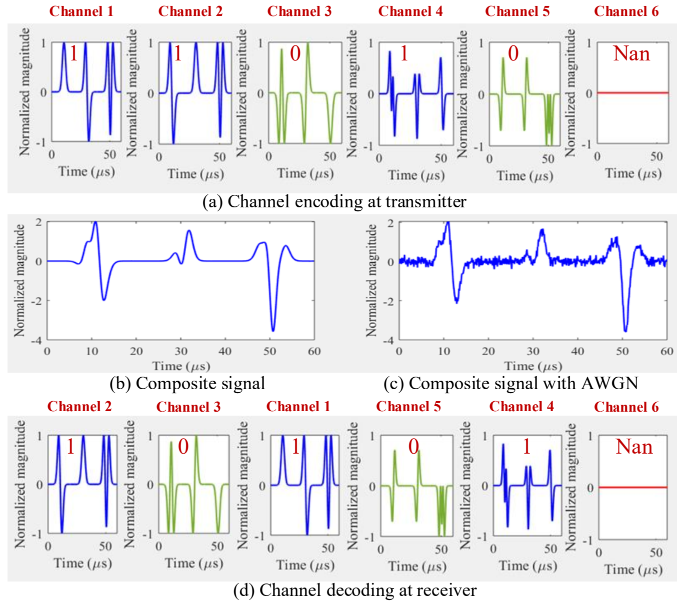

Fig. 6. Simulation results (a) PS based data encoding and (b) data decoding.

results also show that the PS decoding scheme can successfully detect all the unused data channels for increasing spectrum efficiency and effective utilization. The proposed APS-based data channel sensing technique shows great potential for an alternative and simple way to detect the data channels in spectrum-efficient high-density wireless sensor networks.

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