UNIVERSITI PUTRA MALAYSIA

A NEW DISCRETE COSINE TRANSFORM-BASED ENERGY DETECTION SCHEME INVESTIGATION USING BARTLETT PERIODOGRAM METHOD IN COGNITIVE RADIO SPECTRUM SENSING

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By

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A NEW DISCRETE COSINE TRANSFORM-BASED ENERGY DETECTION SCHEME INVESTIGATION USING BARTLETT PERIODOGRAM METHOD IN COGNITIVE RADIO SPECTRUM SENSING

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December 2016

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Cognitive Radio (CR) is a promising technique through which the efficiency of utilization of the electromagnetic spectrum can be increased in various ways. CR lets unlicensed secondary users (SUs) utilize the licensed spectrum during the period of no transmission where the primary users (PUs) are in an idle state; this will improve the spectrum utilization to deal with spectrum scarcity. By using spectrum sensing in cognitive radio, the unused spectrum can be sensed, exploited and used to fill the lack of bands in the new applications. The current energy detectors which are used to reduce the scarcity of the spectrum suffer from weak performance due to high noise variance, low signal resolution and low signal-to-noise ratio, especially when it is working in the frequency domain.

This thesis focuses on the Bartlett periodogram method using the discrete cosine transform (DCT) instead of previous methods which used the discrete Fourier transform (DFT) to get the power spectrum density that is used to detect the primary user by comparing with the predefined threshold. Digital Video Broadcast-Terrestrial (DVB-T) signals are used as an application example to analyze and assess the proposed spectrum sensing algorithm in the frequency domain in the AWGN channel. The accuracy of the proposed analysis is confirmed by using Monte Carlo trials.

The results show an accurate performance analysis of the Bartlett periodogram based on DCT, reducing the noise variance without decreasing the signal resolution compared with the Bartlett periodogram based on FFT. In this proposed method the average noise variance in the DCT Bartlett's periodogram in all the scenarios is 0.35385 for the QPSK and 0.3478 for 16-QAM, while the average noise variance in the FFT Bartlett's periodogram in all the scenarios is 11686.5 for the QPSK and 5841.37 for 16-QAM. This is because using the DCT transform yields better results compared to the FFT transform as shown in the simulation results. This is mainly due to DCT being a real

transform possessing an energy compaction property. The leakage effect is not there for DCT as compared to DFT. The better spectrum sensing algorithm would require some trade-off between probability of detection (P_D) and the probability of false alarm (P_{FA}) to obtain good accuracy with low noise variance.

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SUATU SKIM BARU MENGESAN TENAGA-BERDASARKAN JELMAAN KOSINUS DISKRET MENGGUNAKAN KAEDAH PERIODOGRAM BARTLETT DI BIDANG PENDERIAAN SPEKTRUM RADIO KOGNITIF

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Radio Kognitif (CR) adalah satu teknik yang cerah masa depannya di mana kecekapan penggunaan spektrum elektromagnet boleh ditingkatkan melalui pelbagai cara. CR membolehkan pengguna sekunder tidak berlesen (SU) menggunakan spektrum berlesen dalam tempoh tiada penghantaran apabila pengguna utama (PU) berada di dalam keadaan melahu; ini akan meningkatkan penggunaan spektrum untuk menangani kekurangan spektrum. Dengan menggunakan penderiaan spektrum di dalam radio kognitif, spektrum yang tidak digunakan boleh dideriai, dieksploitasi dan digunakan untuk mengisi kekurangan jalur bagi aplikasi baru. Pengesan tenaga semasa yang digunakan untuk mengurangkan kekurangan spektrum mengalami prestasi lemah kerana varians hingar yang tinggi, resolusi isyarat yang rendah dan nisbah isyarat-ke-hingar rendah, terutamanya apabila ia beroperasi di dalam domain frekuensi.

Tesis ini memberi tumpuan kepada kaedah periodogram Bartlett menggunakan penjelmaan kosinus diskret (DCT) dan bukannya kaedah sebelumnya yang menggunakan penjelmaan Fourier diskret (DFT) untuk mendapatkan ketumpatan kuasa spektrum yang digunakan untuk mengesan pengguna utama secara membandingkan dengan suatu ambang yang telah ditetapkan sebelumnya. Isyarat Penyiaran Video Digital-Terestrial (DVB-T) digunakan sebagai contoh aplikasi untuk menganalisis dan menilai cadangan algoritma penderiaan spektrum di dalam domain frekuensi di saluran AWGN. Kejituan analisis yang dicadangkan disahkan dengan menggunakan ujian-ujian Monte Carlo.

Keputusan menunjukkan analisis prestasi yang tepat oleh periodogram Bartlett berdasarkan DCT, mengurangkan varians hingar tanpa mengurangkan resolusi isyarat berbanding dengan periodogram Bartlett berdasarkan FFT. Di dalam kaedah yang dicadangkan ini purata varians hingar di dalam periodogram DCT Bartlett bagi semua senario adalah 0.35385 untuk QPSK dan 0.3478 untuk 16-QAM, manakala

varians hingar purata di periodogram FFT Bartlett bagi semua senario adalah 11686.5 untuk QPSK dan 5841.37 untuk 16-QAM.

Ini adalah kerana penggunaan penjelmaan DCT memberi hasil yang lebih baik berbanding dengan penjelmaan FFT sepertimana yang ditunjukkan oleh keputusan simulasi. Ini kebanyakannya disebabkan DCT ialah penjelmaan yang sebenar yang mempunyai ciri pemadatan tenaga. Kesan kebocoran tidak ada bagi DCT berbanding dengan DFT. Algoritma penderiaan spektrum yang lebih baik tersebut memerlukan sedikit keseimbangan antara kebarangkalian pengesanan (P_D) dan kebarangkalian tanda amaran palsu (P_{FA}) untuk mendapatkan ketepatan yang baik dengan varians hingar yang rendah.

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I certify that a Thesis Examination Committee has met on 28 December 2016 to conduct the final examination of Hussein Mohammed Barakat on his thesis entitled "A New Discrete Cosine Transform-Based Energy Detection Scheme Investigation using Bartlett Periodogram Method in Cognitive Radio Spectrum Sensing" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

ADC	Analog-to-Digital Converter
AWGN	Additive White Gaussian Noise
BPF	Band-Pass Filter
EPG	Electronic Program Guide
BPSK	Binary Phase Shift Keying
BS	Base Station
BW	Bandwidth
CC	Cognitive Cycle
CDF	Cumulative Distribution Function
CFD	Cyclostationary Feature Detection
CP	Cyclic Prefix
CPE	Customer Premise Equipment
CM	Cognitive Manager
CR	Cognitive Radio
CRN	Cognitive Radio Network
COFDM	Channel coding with Orthogonal Frequency Division Multiplexing
DAB	Digital Audio Broadcast
DCT	Discrete cosine transform
DFT	Discrete Fourier Transform
DVB	Digital Video Broadcasting
DVB-H	DVB-Handheld
DVB-T	DVB-Terrestrial
ED	Energy Detection
ETSI	European Telecommunication Standard Institute
FCC	Federal Communications Commission (of United States)
FD	Frequency domain
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
i.i.d	Independent and Identically Distributed
IFFT	Inverse Fast Fourier Transform

ISI	Inter Symbol Interference
ITU	International Telecommunication Union
IPB	Improved Periodogram-Based
GLRT	General Likelihood Ratio Test
LRT	Likelihood Ratio Test
LTE	Long Term Evolution systems
MAC	Media Access Control
MCM	Multi-Carrier Modulation
MFD	Matched Filter Detection
MPEG	Moving Picture Experts Group
MTM	Multitaper Method
OFDM	Orthogonal Frequency Division Multiplexing
Pd	Probability of detection
Pfa	Probability of False alarm
Pmd	Probability of missed detection
PHY	Wireless Radio System Physical Layer
PSD	Power Spectrum Density
PSDE	Power Spectrum Density Estimation
PU	Primary User
PUs	Primary Users
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
Rx	Receiver
ROC	Receiver Operating Characteristics
SFN	Single Frequency Network
SSA	Spectrum Sensing Automation
SSF	Spectrum Sensing Function
SM	Spectrum Manager
SNR	Signal to Noise Ratio
SU	Secondary User
SUs	Secondary Users
TD	Time domain

TDD	Time Division Duplexing
TPS	Transmission parameter signaling
TV	Television
Tx	Transmitter
UHF	Ultra-High Frequency
VHF	Very-High Frequency
WRAN	Wireless Regional Area Network

LIST OF SYMBOLS

H0	Primary user is absent
H1	Primary user is present
N	Number of samples during detection period
Fs	Sampling frequency
Fc	Carrier frequency
Ts	Total OFDM symbol period
Tu	Sampling Time
Q (.)	Complementary cumulative distribution
$s(n)$	The PU signal
$y(n)$	The Received signal
$w(n)$	The additive white Gaussian noise
σ_s^2	The noise variance for signal
σ_w^2	The noise variance for the noise
$a[n]$	The original M-point sequence
$A[k]$	The DCT M-point of $a[n]$
λ	Threshold
Δ	Guard band duration

CHAPTER 1

INTRODUCTION

1.1 Background

The requirements for modern communications systems which need higher data rates is growing rapidly due to evolution from voice applications to multimedia transmission. Since the spectrum is limited and static frequency allocation schemes in a particular area, therefore, it cannot fulfill the demand for increasing number devices used high data rate. There are many innovative concepts which can offer new ways to utilize the available spectrum [1]. The technique defined Cognitive Radio (CR) devices it considered the best solution for this problem which lets secondary users utilize the spectrum licensed to the primary users when they are not active or idle [2]. The development of cognitive radio (CR) platform for opportunistic spectrum sharing is a potential solution for this arising problem [3].

The proper implementation cognitive radio technique without interference with authorized users is a result of the ability for detection presence authorized user under very low signal-to-noise ratio (SNR) conditions [4]. Currently, cognitive radio technology it became an important method to solve the lack of spectrum resources and improve the efficiency of using the spectrum. Cognitive radio technology based on unlicensed use is firstly prepared to work in the TV whitespaces in range 54-862 MHz, without interfering basis with the primary users (licensed) working in lower population density areas. IEEE 802.22, is a measure for wireless regional area network (WRAN) utilizing white spaces in TV frequency spectrum. In IEEE 802.22 standard, secondary user can detect a primary user for DVB-T signals with a probability of detection (PD) at least 90% and the probability of false alarm (PFA) no more than 10%, under very low SNR conditions.

A working group, defined wireless regional area network (WRAN), it used to improve standard cognitive radio tocoverage area extended to as far as 30 miles [5]. Therefore, it will increase the efficiency of utilization of that spectrum, and provide enormous economic and societal benefits [6]. Spectrum detection can help new applications to find other available frequencies to reuse as a secondary user. Also, spectrum detection is the one of the key technology in cognitive radio [7]. Many factors are making the spectrum sensing more practically challenging. First, time dispersion and multipath fading of the wireless channels make the detection problem more difficult. Second, the signal-to-noise ratio (SNR) of the primary users may be subtle [2].

The primary detection methods are including the likelihood ratio test (LRT), ED method, matched filtering (MF)-based method, cycle stationary detection method, the covariance based detection and periodogram-based methods each of which has different requirements and advantages/disadvantages [8].

Energy detector differs from the rest of the other detectors, where it does not need any information of the transmitted signal and is robust to unknown dispersed channel and fading, but it still needs information of noise power. In the frequency domain, the energy detector based approach known as periodogram is the most traditional method of spectrum sensing because of its low computational and implementation complexities [9]-[18].The signal detected by comparing the output of the energy detector with a threshold which depends on the noise floor [19],[20]. There are many methods for Periodogram based spectrum sensing for improving the simple Periodogram, like Welch method, Bartlett method, and Blackman-Tukey method [21],[22]. When the energy detector implemented in the frequency domain, it requires the use of a power spectral density (PSD) estimator. But the conventional energy detector is applied in the time-domain using a bandpass filter (BPF), a squaring module and an integrator [23].The power spectral density (PSD) of a stationary stochastic process is a Fourier transformation of its autocorrelation sequence. Consequently, the Periodogram method [24],[10] estimates PSD with high signal resolution as well as high noise variance[4].

In this thesis, the research focused on a new application in the frequency domain to analyze the performance of the detector when the statistic decision taken from Bartlett periodogram based on DCT. The major application of the DCT is in signal compression, where it is an essential part of many standardized algorithms[25]. Bartlett's Method [26] reduces the noise variance of the periodogram, by dividing the data sequence into segments, and averages the periodograms obtained from the segmentation [4]. Now existing studies in the literature on the performance of such a technique it focused on the conventional time-domain implementation.

1.2 Motivation

Spectrum scarcity and the inefficient use of the electromagnetic spectrum motivated the development of CR, which aims to extend the spectral efficiency, with borrowing the available frequency bands. Therefore, the need of more spectrum due to the under utilization of the available spectrum is the primary motivation behind the cognitive radio and implementing it leads to a lessening of spectrum scarcity and hence the optimal use of spectrum resources. Spectrum sensing which checks for the empty or unused spectrum band forms the central part of the cognitive radio.

There are many designs are using based on spectrum sensing like Cyclo-stationary detector, matched filter detector, an energy detector, Eigen value based sensing. Each one of them has various requirements from the other such as the need information about the transmitted signal (prior information) or well work the detector in high-value SNR environments only or the high complexity of the designing the detector. These constraints led to research for an optimal detector which performs well under low SNR conditions as well and with a complexity not so high. ED is considered the best choice for the spectrum sensing in the cognitive radio applications due to its simplicity and not need any prior information of the signal with low computational cost [27].

This thesis focused on energy detection working in frequency domain because of providing the flexibility to process large bandwidths and detects dual channels together by appropriate selecting the frequency bins in the separate representation of the PSD [28], [24]. Therefore, it used the DCT transform in the Bartlett periodogram instead of using the DFT transform to improve the probabilities of detection and false alarm (Pd and Pf) for the energy detector. The spectrum of the licensed primary users of the

DVB-T is considered the best solution to verify the proposed detection because it had many holes in the spectrum and adopted the OFDM modulation.

1.3 Problem Statement

The development of modern wireless communications systems has caused weakness in the efficient performance of using these systems. Therefore, as a result for these reasons;

1- Insufficiency the current available spectrum to deal with the growing demand for wireless communication systems [28],[29].
2- Undesirable energy detection performance when it is working in the frequency domain due to high noise variance, low signal resolution for the sigmal to be detected and low SNR [30], [15].
3- Insufficiency and more complexity in implementation for some currently available spectrum detectors because of needed complete information of the signal to be detected [31],[30].

1.4 Objectives and Scope of the Work

In studying the properties and characteristics of the spectrum for certain periods of time, it is noted that none of all bands is busy all times, where there are several bands are idle sometimes, such as Digital Video Broadcast (DVB-T). This research proposes a new method to sense the signals that clearly contribute to the gap in the literature. Therefore the primary objective of this work is to address the problem of spectrum sensing under noise variance. The following objectives can be include:

1- To develop the detection method to enhance the performance of the detector in the spectrum scarcity.
2- To improve the performance of the energy detector by decreasing the noise variance without decreasing the signal resolution in low SNR.
3- To design the detection system without adding much complexity by using DCT transform in power spectrum estimate.

1.5 **Contribution**

This thesis is dedicated to find the best spectrum sensing technique for better targets representation of the spectrum sensing in cognitive radio and to get the most possible benefit from the signal detection. Therefore, in this thesis, the main contributions to attain these objectives are:

1. Develop the energy spectrum sensing in cognitive radio network by using the Bartlett periodogram based on the DCT capable to detect the signals in low SNR at-20dB.
2. Design the system to sense the DVB-T signals using (QPSK, 16-QAM) modulation with (2k, 8k) mods and with all the values of the cyclic prefix (CP).
3. Clarification the effect of selecting a suitable value for the coefficient vector in DCT Bartlett periodogram in increasing the efficiency of the performance for the proposed detector.

1.6 Thesis Outline and Organization

The thesis is split into five chapters;

Chapter 1 demonstrates the background of the research, the motivation behind this investigation, problem statement, the research objectives and Contribution.

Chapter 2 reviews the literature on cognitive radio and energy detection. This chapter mainly discusses the general principles and methodology of energy detection in time domain and frequency domain, also including reviews the concept of cognitive radio, spectrum sensing, DVB-T signals, wireless regional area network (WRAN) – IEEE802.22.

Chapter 3 presents the methodology and framework of the thesis. This section presents and discusses the DCT transformer used in the Bartlett method. The section includes the following: design and implementation of the algorithm and system model, characteristics and implementation of a new proposed periodogram, characteristics of the DVB-T signals and the summary.

Chapter 4 presents the collected information and the results of the performance the energy detector in thefrequency domain according to evaluation the Pd and Pfa in cases of the using the DCT and DFT and evaluation of the proposed method’s performance.

Chapter 5 summarizes the research finding, limitations and suggests directions for future work.

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