**This document is downloaded from DR-NTU (https://dr.ntu.edu.sg)**
**Nanyang Technological University, Singapore.**

# A fast sensing algorithm for spectrum detection in cognitive radios

Prashob Ramachandran Nair

2012

Prashob, R. N. (2012). A fast sensing algorithm for spectrum detection in cognitive radios. Master’ s thesis, Nanyang Technological University, Singapore.

https://hdl.handle.net/10356/48179

https://doi.org/10.32657/10356/48179

*Downloaded on 02 Dec 2021 17:53:36 SGT*

# Acknowledgement

Research is like starting a long journey on an unknown road with no clear signs. The journey is shaped by the road you take. The road to the destination is long and arduous and tests the mental strength of the research student. I have been no exception to the same stresses and anxiety. The people who help you during those times are the ones whom you are ever indebted to in your life and I take this opportunity to thank them from the bottom of my heart.

My supervisor at the university Dr. Vinod A Prasad has been a shining example of how to motivate students and get the best out of them. He has been soft when pointing out the areas where I could do better yet firm enough to keep me focused and motivated to solve the problem at hand. No amount of words can express the gratitude I have towards him for believing in me and giving me an opportunity to do quality research.

Dr. Anoop Kumar Krishna at EADS IW, Singapore who made me think hard on the problems and gave precise insights which helped me in identifying and narrowing down on the problem to solve. His questions always made me think deep and it is no doubt that it were these questions that prodded me to investigate further and come out with interesting results.

My friends in the research group, Dr. Mahesh, Dr. Smitha, Navin, Narendar, Sumit, Neethu and Rakesh with whom I had innumerous discussions which in their own subtle ways have helped me in framing up this thesis. Also special thanks to my flat mates for their kind heartedness in keeping a nice dinner saved for me so that I can work late in the lab and not worry about a hungry stomach upon reaching back.

Last but by no means least, my parents and teachers who have shaped my thinking and molded my persona into making me the person that I am.

*To my parents and teachers*

# Abstract

Cognitive Radio (CR) has emerged as a very promising solution to mitigate the scarcity in electromagnetic spectrum for wireless communication. CR promises to maximize the efficiency of spectrum utilization by seeking out spectral vacancies (holes) in the licensed band and using it for communication purposes. Thus sensing of the spectrum to detect the vacant holes forms an integral part of a CR system.

The performance of a cognitive radio system depends on how well it can maximize the usage of a vacant frequency band without causing any interference to the licensed user, also called the primary user. Thus the ability to detect a primary user as well as to avoid any false alarm is of paramount importance for such a system. There are various techniques to examine the presence of a communication signal in a given frequency band. The easiest and most widespread of these is the energy based detection. In this technique, the energy of the received samples is computed and compared with a predetermined threshold. If the total energy of the received samples is more than the computed threshold, the frequency band is assumed to be occupied by the licensed user.

The selection of the threshold to discriminate between the binary hypothesis of presence and absence of primary user signal plays a very vital role in determining the accuracy of the spectrum sensing algorithms. Conventionally, for an energy detector (ED) based CR, the threshold is set based on estimated noise power and this is not changed even though the CR may have more information available about the channel. It has been observed that for a conventional energy detector based CR at low signal-to-noise ratio (SNR), when the time to sense the spectrum is short, the ability to detect the presence of the primary user deteriorates significantly. However, if the threshold is chosen based on the target probability of detection, then there is a significant improvement in the ability of the CR to detect the presence of the primary user. Also the energy detector based CR suffers from the fundamental limitation in that the threshold is a function of the estimate of the noise variance. Any error in the estimation of the noise variance can lead the ED to hit a lower bound for the signal to noise ratio below which the ED cannot detect the signal.

The first contribution of this thesis is an investigation into an adaptive setting of the threshold which takes into account the ever changing channel condition. A study on the effect of low SNR and short sensing time on the probability of detection and probability of false alarm is presented in this thesis. The required number of samples and the desired SNR for meeting the target

performance has been simulated and validated. Also the effect of uncertainties in the estimation of noise power on the performance of an ED and the minimum SNR required guaranteeing the intended performance metrics has been studied in this thesis.

Though the ED has known limitation in the presence of uncertain noise power, it is the simplest detector to design and implement. Also the probability of false alarm of the ED remains low even at low SNRs. To mitigate the disadvantage in the detection probability of the ED, this thesis investigates a two-stage detector for spectrum sensing. Not only can this approach be used to mitigate the disadvantages of a single stage detection technique, but it can also be used to synergize the advantages offered by the individual methods. However, a two-stage analysis increases the time taken to sense the spectrum and arrive at a conclusive result.

As a second contribution of this thesis, an algorithm which can be used to minimize the time taken by a two-stage detector has been proposed. The second stage uses a pilot assisted cyclostationary feature detection technique because of its robustness to noise and better performance at low SNRs. The usage of known pilot in the PU signal has been done to aid in faster detection of the cyclic frequencies. Simulation results have been used to show that the proposed algorithm leads to a larger savings in time as compared to an existing two-stage detection algorithm. The time saved increases as spectrum utilization of the band under consideration becomes sparser. A hardware implementation of the two-stage algorithm has also been presented to quantify the area and power consumption values.

Further the thesis presents a study on the real world signals captured using an universal software radio peripheral 2 (USRP2) board. A GNU radio framework was used to interface with the USRP2 board. This setup was used to sense GSM Mobile signals and signals generated from a signal generator. The spectrum of the captured signals showed the difficulties in estimation of the noise floor and how an error in estimation of the noise variance can make an ED based CR non functional in a practical scenario when the signal power is low.

# Contents

# List of Figures

# List of Tables

# List of Abbreviations

| | |
|---|---|
| **AIC** | Akaike Information Criterion |
| **ADC** | Analog to Digital Converter |
| **ATSC** | Advanced Television Systems Committee |
| **AWGN** | Additive White Gaussian Noise |
| **CAF** | Cyclic Autocorrelation Function |
| **CDMA** | Code Division Multiple Access |
| **CDR** | Constant Detection Rate |
| **CFAR** | Constant False Alarm Rate |
| **CFD** | Cyclostationary Feature Detector |
| **CPM** | Central Processing Module |
| **CR** | Cognitive Radio |
| **CSD** | Cyclic Spectral Density |
| **DAC** | Digital to Analog Converter |
| **DAD** | Distribution Analysis Detector |
| **DAM** | Data Acquisition Module |
| **DSSS** | Direct Sequence Spread Spectrum |
| **DDC** | Digital Down Converter |
| **ED** | Energy Detector |
| **EEPROM** | Electrically Erasable Programmable Read Only Memory |
| **EME** | Energy with Minimum Eigen value |
| **EVD** | Eigen Value Detector |
| **FAM** | Fast Fourier Transform based Accumulation Method |
| **FCC** | Federal Communications Commission |
| **FFT** | Fast Fourier Transform |

| | |
|---|---|
| **FPGA** | Field Programmable Gate Array |
| **GRC** | GNU Radio Companion |
| **GSM** | Global System for Mobile communication |
| **I & Q** | In-phase and Quadrature |
| **IF** | Intermediate Frequency |
| **ISM** | Industrial Scientific and Medical |
| **MED** | Maximum Eigen value Detector |
| **MF** | Matched Filter |
| **MIMO** | Multiple Input Multiple Output |
| **MME** | Maximum-Minimum Eigen value |
| **MMI** | Man Machine Interface |
| **NTIA** | National Telecommunication and Information Administration |
| **NTSC** | National Television and Systems Committee |
| **OFDM** | Orthogonal Frequency Division Multiplexing |
| **PACD** | Pilot Assisted Cyclostationary feature Detection |
| **PC** | Personal Computer |
| **PSD** | Power Spectral Density |
| **PU** | Primary User |
| **QAM** | Quadrature Amplitude Modulation |
| **QPSK** | Quadrature Phase Shift Keying |
| **RF** | Radio Frequency |
| **RMT** | Random Matrix Theory |
| **ROC** | Receiver Operating Characteristics |
| **SD** | Secure Digital |
| **SDR** | Software Defined Radio |
| **SNR** | Signal to Noise Ratio |

| | |
|---|---|
| **SSCA** | Strip Spectral Correlation Method |
| **SU** | Secondary User |
| **SWIG** | Simple Wrapper and Interface Generator |
| **TETRA** | Terrestrial Trunked Radio |
| **UHD** | Universal Hardware Driver |
| **USB** | Universal Serial Bus |
| **USRP2** | Universal Serial Radio Peripheral2 |
| **UWB** | Ultra Wide Band |
| **VHF** | Very High Frequency |
| **WLAN** | Wireless Local Area Network |

# Publications

**International Journal**

[1] **Prashob Nair**, A. P. Vinod, Smitha K.G., and Anoop Kumar Krishna, "Fast two-stage spectrum detector for cognitive radios in uncertain noise channels," *IET Communications,* Accepted in February 2012.

**International Conferences**

[1] **Prashob Nair**, A. P. Vinod, and Anoop Kumar Krishna, "A fast two stage detector for spectrum sensing in cognitive radios," *IEEE International Conference on Vehicular Technology*, September 2011, San Francisco, USA.

[2] **Prashob Nair**, A. P. Vinod, and Anoop Kumar Krishna , "An energy detector for cognitive radios in channels at low SNR using adaptive threshold," *IEEE International Conference on Information, Communications and Signal Processing,* December 2011, Singapore .

[3] **Prashob Nair**, A. P. Vinod, and Anoop Kumar Krishna, "An adaptive threshold based energy detector for spectrum sensing in cognitive radios at low SNR," *IEEE International Conference on Communication Systems (ICCS),* pp. 574-578, November 2010, Singapore.

[4] Smitha K.G., A. P. Vinod, and **Prashob Nair**, "Low power DFT filter bank based two-stage spectrum sensing," *8th International Conference on Innovations in Information Technology*, Al Ain, United Arab Emirates, March 2012 (Accepted).