# A Resilient Cognitive Detection with Automated Channel Selection for Enhanced Channel Management in Wireless Local Area Network

by


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## TABLE OF CONTENTS


| | PAGE |
|---|---|
| **DECLARATION OF THESIS** | **ii** |
| **ACKNOWLEDGEMENT** | **iii** |
| **TABLE OF CONTENTS** | **iv** |
| **LIST OF TABLES** | **viii** |
| **LIST OF FIGURES** | **ix** |
| **LIST OF ABBREVIATIONS** | **xii** |
| **ABSTRAK** | **xv** |
| **ABSTRACT** | **xvii** |
| **CHAPTER 1 INTRODUCTION** | **1** |
| 1.1 Overview | 1 |
| 1.2 Spectrum Detection | 3 |
| 1.3 Research motivation and problem statement | 7 |
| 1.4 Aim and objectives of the research | 9 |
| 1.7 Organization of the thesis | 10 |
| **CHAPTER 2 LITERATURE REVIEW** | **11** |
| 2.1 Overview | 11 |
| 2.2 Study module | 12 |
| 2.3 Frequency spectrum | 14 |
| 2.4 Cognitive radio | 16 |

2.5 Cognitive radio detection 17
2.5.1 Interference based detection 18
2.5.1.1 Primary receiver detection (PRD) 19
2.5.1.2 Interference temperature model (ITM) 21
2.5.2 Cooperative spectrum detection 22
2.5.2.1 Cooperation architecture 22
2.5.2.2 Fusion scheme 24
2.5.2.3 Cooperative user selection 26
2.5.2.4 Detection errors 28
2.5.3 Non-cooperative spectrum detection 29
2.5.3.1 Matched filter detection 30
2.5.3.2 Cyclostationary feature detection 31
2.5.4 Energy detection 33
2.5.4.1 Threshold determination 36
2.5.4.2 Energy detection in licensed and unlicensed spectrum 38
2.5.5 Other detection techniques 39
2.6 Research apparatus overview 40
2.6.1 Wireless LAN 40
2.6.2 Wi-Fi Direct 42
2.6.3 Android OS 43
2.6.4 Android applications 44
2.6.5 Eclipse with ADT 45
2.6.6 IxChariot WLAN interferer 46
2.6.7 Wi-Spy spectrum analyser 47

2.7 WLAN channel adaptation in CR environment 48

2.8 Chapter summary 50

**CHAPTER 3 RESEARCH METHODOLOGY 52**

3.1 Overview 52

3.2 Research methodology workflow 52

3.3 System model 55

3.4 Energy detection technique 58

3.5 Threshold determination 60

3.6 Automatic Channel selection algorithm 63

3.7 Real-time channel customization 64

3.8 Performance analysis 65

3.8.1 Real-time detection performance 65

3.8.2 Throughput measurement 66

3.8.3 Bit error rate analysis 67

3.8.4 Noise floor measurement 68

3.5 Chapter Summary 70

**CHAPTER 4 RESULTS AND DISCUSSIONS 72**

4.1 Overview 72

4.2 Experiments and results 72

4.2.1 Real-time detection performance 73

4.2.2 Channel utilization 77

4.2.3 Throughput 81

4.2.4 Average packet transfer time 83

4.2.5 Bit error rate 84

4.2.6 Noise floor 85

4.3 Neighbor node experience 87

4.4 Channel utilization and noise floor inconsistencies 89

4.5 Chapter summary 91

**CHAPTER 5 CONCLUSION AND FUTURE WORKS 93**

5.1 Summary of the research 93

5.2 Research achievements 95

5.3 Limitations of the research 96

5.4 Future Recommendation 97

**REFERENCES 98**

**APPENDIX A 108**

**APPENDIX B 109**

**LIST OF PUBLICATIONS 130**

## LIST OF TABLES


| NO. | | PAGE |
|---|---|---|
| 2.1 | Available ISM frequency bands and type | 14 |
| 2.2 | WLAN channels in 2.4 GHz | 41 |
| 2.3 | Android versions and API level until October, 2016 | 44 |
| 3.1 | Smartphones/Tablets configuration | 57 |
| 3.2 | Real-time experimented and analytical RSS for various distances | 66 |

## LIST OF FIGURES


| NO. | | PAGE |
|---|---|---|
| 1.1 | Frequency utilization for 2.4 GHz WLAN | 1 |
| 1.2 | Basic CR spectrum detection technique | 5 |
| 2.1 | Study Module of the Research | 13 |
| 2.2 | Spectrum hole illustration for different frequency and time | 17 |
| 2.3 | Spectrum sensing classifications | 18 |
| 2.4 | Sensor node receiver architecture | 21 |
| 2.5 | Centralized fusion architecture | 23 |
| 2.6 | Decentralized fusion architecture | 24 |
| 2.7 | Pilot signal and matched filter based detection | 31 |
| 2.8 | Cyclostationary based detection | 32 |
| 2.9 | WLAN channel structure for 2.4 GHz | 41 |
| 2.10 | Non-overlapped channel combination | 42 |
| 2.11 | IxChariot and streaming load variable interface | 46 |
| 2.12 | Chnalyzer Pro viewing panels | 48 |
| 3.1 | Research methodology workflow | 54 |
| 3.2 | Real-time experimental setup | 56 |
| 3.3 | Threshold determination for WLAN 2.4 GHz FSPL model | 61 |
| 3.4 | RSS for 2.4GHz WLAN channels (analytical & experimented) with Threshold | 62 |
| 3.5 | Automatic Channel Selection coding snippet | 63 |

| | | |
|---|---|---|
| 3.6 | Threshold determination coding snippet | 65 |
| 3.7 | Block diagram of the experimental setup for real-time interference measurement | 67 |
| 3.8 | Channel information panel viewed in Chanalyzer Pro software | 69 |
| 4.1 | Developed application and log file | 73 |
| 4.2 | Real-time channel detection performance vs. RSS | 74 |
| 4.3 | Successful packet delivery ratio (PDR) vs. RSS | 75 |
| 4.4 | Average channel detection throughput for different algorithm | 76 |
| 4.5 | Frequency amplitude for overlapped, mutual overlapped and non-overlapped channels | 77 |
| 4.6 | Instantaneous channel utilization without and with Wi-Fi Direct activity | 78 |
| 4.7 | Non-overlapping channel utilization for PU and SU | 79 |
| 4.8 | Average channel utilization of overlapped and usual non-overlapped channels for single SU pair activities | 80 |
| 4.9 | Average channel utilization of overlapped and usual non-overlapped channels for multiple SU pair activities | 81 |
| 4.10 (a) | Instantaneous throughput during SU activity | 82 |
| 4.10 (b) | Average throughput difference for customized channel | 83 |
| 4.11 | Average packet transfer time for overlapped and customized non-overlapped channel | 84 |
| 4.12 | BER for overlapped and customized non-overlapped channel | 85 |
| 4.13 | Channel noise of overlapped and customized non-overlapped channels for single pair of SU activities | 86 |
| 4.14 | Channel noise of overlapped and customized non-overlapped channels for multiple SU activities | 87 |
| 4.15 | Average channel utilization experienced by PU-3A/4A for interfering channels | 88 |

| | | |
|---|---|---|
| 4.16 | Noise Floor experienced by PU-3A/4A for interfering channels | 89 |
| 4.17 | Channel utilization for standalone and non-overlapped channels | 90 |
| 4.18 | Noise floor for standalone and non-overlapped channels | 91 |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ACS | Automatic Channel Selection |
| ADC | Analog to Digital Converter |
| ADT | Android Development Tools |
| AP | Access Point |
| API | Application Program Interface |
| ASDCS | Active Scanning Dynamic Channel Switching |
| AWGN | Additive White Gaussian Noise |
| BER | Bit Error Rate |
| CACAO | Client-assisted Channel Assignment Optimization |
| CR | Cognitive Radio |
| CSD | Cooperative Spectrum Detection |
| CSI | Channel State Information |
| CUSUM | Cumulative Sum |
| dBm | Decibel in milliwatt |
| DC | Direct Current |
| DOMP | Distributed Orthogonal Matching Pursuit |
| DSA | Dynamic Spectrum Access |
| ED | Energy Detector |
| EGC | Equal Gain Combining |
| FCC | Federal Communications Commission |
| FFT | Fast Fourier Transform |
| FM | Frequency Modulation |
| FSPL | Free Space Path Loss |
| GHz | Gigahertz |
| GRL | Generalized Likelihood Ratio |
| GSM | Global System for Mobile |

| | |
|---|---|
| IDE | Integrated Development Environment |
| IF | Intermediate Frequency |
| IPv4 | Internet Protocol version 4 |
| IPv6 | Internet Protocol version 6 |
| ISM | Industrial, Scientific, and Medical Radio Band |
| ITM | Interference Temperature Model |
| ITU | International Telecommunication Union |
| KHz | Kilohertz |
| LCCS | Least Congested Channel Selection |
| LO | Local Oscillator |
| LTE | Long Term Evolution |
| Mbps | Megabits per Second |
| MHz | Megahertz |
| MMV | Multiple Measurement Vector |
| MRC | Maximal Ratio Combining |
| MTU | Maximum Transfer Unit |
| MUSIC | Multiple Signal Classification |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OHA | Open Handset Alliance |
| OMP | Orthogonal Matching Pursuit |
| OS | Operating System |
| P2P | Peer to Peer |
| PRD | Primary Receiver Detection |
| PSD | Power Spectral Density |
| PU | Primary User |
| QPSK | Quadrature Phase Shift Keying |
| RF | Radio Frequency |
| RSS | Received Signal Strength |
| RSSI | Received Signal Strength Indicator |

| | |
|---|---|
| SDK | Software Development Kit |
| SDR | Software Defined Radio |
| SNR | Signal to Noise Ratio |
| SOMP | Simultaneous Orthogonal Matching Pursuit |
| SU | Secondary User |
| TV | Television |
| UDP | User Datagram Protocol |
| UHF | Ultra High Frequency |
| USB | Universal Serial Bus |
| UWB | Ultra-wide Band |
| WCDMA | Wideband Code Division Multiple Access |
| Wi-Fi | Wireless Fidelity |
| WLAN | Wireless Local Area Network |

**Pengesanan Kognitif Berdaya Tahan Dengan Pemilihan Saluran Automatik Untuk Meningkatkan Pengurusan Sumber Dalam Rangkaian Kawasan Tempatan Tanpa Wayar**

## ABSTRAK

Masalah spektrum tepu adalah isu kritikal pada masa sekarang kerana bilangan pengguna peranti tanpa wayar menyertai rangkaian setiap hari adalah tinggi, tetapi sumber-sumber spektrum adalah terhad. Untuk mengatasi masalah ini, teknologi radio kognitif (RK) adalah dicadangkan pada kali pertama tahun 1999. Objektif utama RK adalah untuk menggunakan spektrum pengguna utama (PUs') yang berlesen oleh pengguna-pengguna sekunder (SUs') tanpa mengganggu pengunaan pengguna utama. Untuk mengesan saluran PU, teknik pengesanan spektrum memainkan peranan utama untuk mencari kehadiran atau ketiadaan pengguna utama untuk mengelakkan gangguan. Untuk melindungi pengguna utama daripada gangguan yang tidak diingini, skim pengesanan saluran diperlukan untuk digunakan di dalam persekitaran nisbah isyarat yang rendah kepada bunyi (SNR) . Kebanyakan kerja dalam kesusasteraan dilakukan berdasarkan simulasi berasaskan komputer dan sangat sedikit dengan aliran kerja eksperimen, tetapi mereka telah menggunakan peralatan makmal yang susah untuk mengesan saluran. Memandangkan isu ini, tesis ini memberi satu kaedah eksperimen untuk mengesan saluran penguna utama yang sedia ada untuk Wi-Fi Direct pada lokasi tertentu dalam rangkaian kawasan tempatan tanpa wayar (WLAN) berdasarkan rangkaian RK dengan menggunakan telefon pintar Android / tablet PC . Dicadangkan juga, kaedah pemilihan saluran secara automatik (ACS), yang telah dieksperimenkan dengan teknik ambang penentuan penyesuaian dalam 2.4 GHz WLAN. Algoritma ini telah direka untuk bekerja terutamanya dengan Android berasaskan telefon pintar dan tablet. Kaedah pengesanan tenaga dengan kehilangan lintasan persekitaran ruangan bebas (FSPL) dititik berat sepanjang eksperimen ini untuk pengesanan saluran PU yang sedia ada. Aras ambang ditentukan memandang kepada keadaan aras kebiasaan bunyi bagi cuaca yang cerah, manakala, algoritma ACS digunakan untuk memilih saluran yang terbaik untuk komunikasi SU merujuk kepada nilai ambang. Fail log juga telah dijana untuk mengesan semua maklumat mengenai PU, termasuk tarikh dan masa, nombor saluran, frekuensi,penunjuk kekuatan isyarat diterima (RSSI), alamat fizikal Pus' dan lokasi maklumat bagi pengurusan sumber. Dalam kajian ini, telefon pintar bertindak sebagai SUS, manakala 2.4 GHz WLAN saluran berstruktur yang sedia ada bertindak sebagai PU. Untuk menyemak keteguhan model yang dicadangkan, rangkaian ditetapkan dalam makmal persekitaran yang bising / luaran yang biasa dan diuji dengan kehadiran dan ketiadaan PU. Keputusan menunjukkan bahawa daya pemprosesan sistem keseluruhan telah meningkat kepada 12.5% manakala bunyi bising dikurangkan kepada 6% daripada sistem bertindih yang biasa. Julat ambang boleh digunakan didapati dari -3,13 ke 3,0

dB untuk meningkatkan prestasi pengesanan saluran. Prestasi pengesanan saluran juga dieksperimen dengan setiap perubahan ambang dan didapati pengesanan saluran adalah 100% berjaya untuk +3,0 dB SNR dan 0% -4.0 dB SNR dan ke bawah. Cadangan kaedah ini dapat mengurangkan paket masa pemindahan dengan meminimumkan bit error rate (BER) untuk saluran pengguna PU dan meningkatkan kecekapan saluran PU tersebut dengan mengurangkan paras lantai bunyi yang disebabkan oleh aktiviti SUs.

**A Resilient Cognitive Detection with Automated Channel Selection for Enhanced Channel Management in Wireless Local Area Network**

**ABSTRACT**

Spectrum saturation problem is a critical issue now a day due to huge number of users with wireless capable devices joined the network every day, but the spectrum resources are limited. To overcome this issue, cognitive radio (CR) technology was first proposed in year of 1999. The main objective of CR is to use licensed primary users' (PUs') spectrum by secondary users (SUs) without interfering the PUs. To detect PU channels, spectrum detection technique plays a major role to find the presence or absence of PUs to avoid interference. To protect licensed PUs' from unwanted interference, the channel detection scheme is required to perform well in low signal to noise ratio (SNR) environments. Most of the work in the literature were performed based on computer based simulations and very few with experimental workflow, but they have used heavy laboratory instruments or stationary sensors for channel detection. Considering this issue, this thesis presents a method for real-time channel detection technique in a wireless local area network (WLAN) based CR network using Android based smartphones/tablet PCs. Also, designed an automatic channel selection (ACS) algorithm, which is practically experimented with an adaptive threshold determination technique with the 2.4 GHz WLAN. The algorithm is designed to work especially with Android based smartphones and tablets. Energy detection method with free space path loss (FSPL) environment is considered throughout the experiment for available PU channel detection. The threshold level is determined considering the usual noise floor conditions for clear sunny weather, whereas, the ACS algorithm selects the best channel for SU communication based on the threshold. A log file is also generated to keep track of all information regarding PU, including date and time, channel number, frequency, received signal strength indicator (RSSI), PUs' physical address and location information for further resource management. In this study, smartphones act as SUs, whereas the existing 2.4 GHz WLAN structured channels act as the PUs. To check the robustness of the developed model, the network is set up in a usual noisy lab/outdoor environment and tested with presence and absence of PU conditions. The results show that the throughput of the overall system has increased to 12.5% while the noise reduced to 6% than the usual overlapped system. The desired range of usable threshold is found from -3.13 to +3.0 dB for improved channel detection performance. Channel detection performance is also experimented with each change of threshold and found channel detection is 100% successful for +3.0 dB of SNR and reduced to 0% for -4.0 dB SNR and below. The enhanced method reduced packet transfer time by minimizing bit error rate (BER) for PU channel users and increased the PU channel efficiency by reducing noise floor level caused by SUs activity.

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

In cognitive radio systems, radio devices may access a potentially large number of frequency bands or channels. Examples of such systems are those “white space” spectrums, the unused part of the TV/UHF spectrum (unallocated or not used locally). Spectrum saturation problem is a major issue in wireless communication systems all over the world. Every day huge numbers of users are joining to the existing fixed band frequency but the bandwidth is not increasing. Figure 1.1 shows one hour of peak time frequency utilization for unlicensed 2.4 GHz wireless local area network (WLAN) channels for an average busy area.



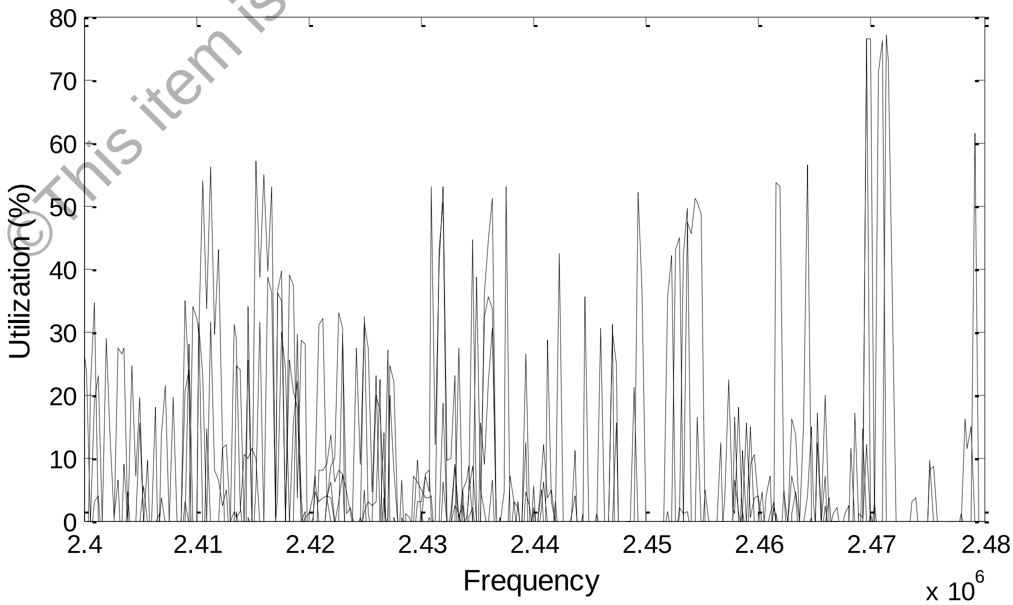


Figure 1.1: Frequency utilization for 2.4 GHz WLAN

The Federal Communications Commission (FCC) 2008 ruling allowed unlicensed devices to use parts of this spectrum, provided that devices can detect primary users (TV transmitters and wireless microphones). As a part of the 2010 ruling (Commission & others, 2010), FCC mandates the use of a geolocation database to identify which frequencies are free from PUs. Spectrum detection of a wireless heterogeneous network is a fundamental issue to detect the presence of PUs signals in CR networks (Akyildiz, Lee, Vuran, & Mohanty, 2006; A. Ghasemi & Sousa, 2008). In order to protect PUs from harmful interference, the spectrum detection scheme is required to perform well even in extremely low signal-to-noise ratio (SNR) environments (Luo, Wang, Li, & Li, 2012). The detection period is usually required to be short enough so that secondary (unlicensed) users (SUs) can fully utilize the available spectrum. CR networks can be designed to manage the radio spectrum more efficiently by utilizing the spectrum holes in PU's licensed frequency bands. The present available unlicensed spectrum is very limited. Demands for various applications and their respective data rates in wireless communications requires additional spectrum which imposes limits on spectrum access (Kim, Kim, Park, & Kim, 2009). These requirements lead forwards to the efficient and intelligent use of spectrum. According to the FCC, CRs are defined as radio systems that continuously perform spectrum detection, dynamically identify unused spectrum, and then operate in those spectrum holes where the licensed/unlicensed (primary) radio systems are idle (Quan, Cui, Sayed, & Poor, 2009a). In this way, spectrum detection and utilization efficiency is dramatically enhanced.



In this thesis, focus is given to develop a simple method for detecting unused channels and propose an algorithm to select the best channel automatically for SUs without interfering the PU users' using smartphones. The smartphones support heterogeneous spectrum with applications such as global system for mobile (GSM), wideband code division multiple access (WCDMA), long term evolution (LTE), Bluetooth, WLAN etc. The detection log files can be stored to the cloud storage through wireless network. As the GSM, WCDMA, LTE and other licensed band is allocated for different mobile service provider according to Malaysian Communication and Multimedia Commission (Communications & Commission, 2015), SU's are not able to use those spectrums for secondary use. So, an unlicensed 2.4 GHz WLAN system is considered throughout the study. Peer to peer (P2P) communication using Wi-Fi Direct also getting popular to minimize the traffic load to existing licensed spectrum (Lu & Hui, 2015). Wi-Fi Direct allows device to device communication without help of any fixed network infrastructure.

However, the structured WLAN routers and access points (APs) are considered as PUs and Android based smartphones are used as SUs. Smartphones detect available PU channels and find the best channels for smartphone to smartphone communication using Wi-Fi Direct without interfering the AP channel users. The following few paragraphs describe some spectrum detection techniques for CR network.



## 1.2 Spectrum detection

As cognitive radio is an advanced software-defined radio that automatically detects its' surrounding spectrum and intelligently adapts its operating parameters to network infrastructure while meeting user demands. Since cognitive radios are considered SUs for using the licensed spectrum, a crucial requirement of cognitive radio networks is that they must efficiently exploit without causing harmful interference to the PUs (Hongjian Sun, Nallanathan, Cheng-Xiang Wang, & Yunfei Chen, 2013).

In order to maintain the PUs' right to interference-free operation, the SUs need to regularly detect the allocated band and reliably detect the presence of the PUs' signals with little delay. Therefore, spectrum detection plays a crucial role in the CR technology to prevent damaging interference to the PUs and to reliably and quickly spot the white spaces in the spectrum and utilize the opportunity.

Figure 1.2 shows the basic CR spectrum detection work flow, where 'n' denotes the total number of channel under considerations and 'i' is the counter variable. Various spectrum detection methods are used in literature depending on how much information about the primary signal is available to the SUs'. Cooperative and non-cooperative methods are mostly the common methods so far and among them non-cooperative methods are only usable for real scenario. The classifications of non-cooperative methods are discussed in the following paragraphs.

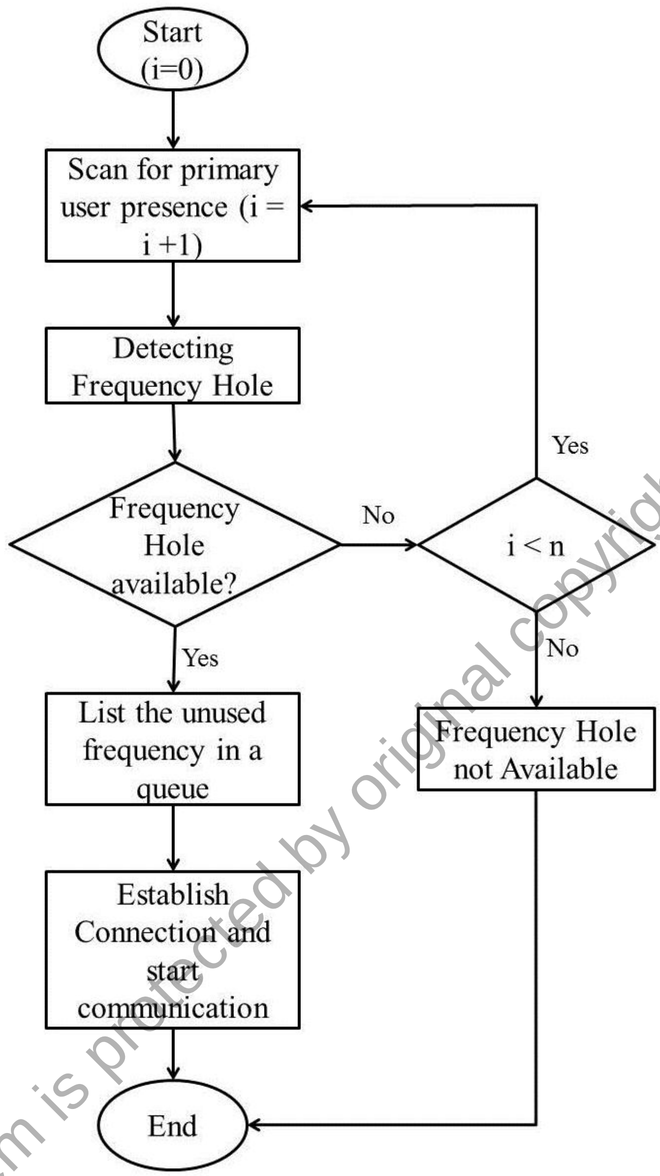




Figure 1.2: Basic CR spectrum detection technique

Matched filtering-based methods are optimal for stationary Gaussian noise scenarios as they maximize the received SNR (Y. Zeng, Liang, Hoang, & Zhang, 2010). For this optimal performance, they require perfect knowledge of the channel responses from the PU to the SU and the structure and waveforms of the primary signal (including modulation type, frame format and pulse shape) as well as accurate synchronization at the SU (Yücek & Arslan, 2009; Y. Zeng et al., 2010). In CRs, however, such knowledge is not readily available to SUs and implementation cost and complexity of this detector is high especially as the number of primary bands increases. Therefore, this method is not practically applicable to CR technology (Zarrin, 2011).

Another detection method can be applied for spectrum detection is the cyclostationary detector. Cyclostationary feature detectors can distinguish between modulated signals and noise (Y. Zeng et al., 2010). This detector exploits the fact that the primary modulated signals are cyclostationary with spectral correlation due to the built-in redundancy of signal periodicity (e.g., sine wave carriers, pulse trains, and cyclic prefixes), while the noise is a wide-sense stationary signal with no correlation (Zarrin, 2011). This task can be performed by analyzing a spectral correlation function. Therefore, cyclostationary feature detectors are robust to the uncertainty in noise power. Moreover, it requires the knowledge of the cyclic frequencies of the PUs, which may not be available to the SUs.

For a Gaussian model, when the noise power is known to the SU energy detection can be applied to detect the existence of the primary signal. This simple scheme accumulates the energy of the received signal during the sensing interval and declares the band to be occupied if the energy surpasses a certain threshold (Yücek & Arslan, 2009). Energy detection, unlike the other schemes, does not require any information about the primary signal and channel gains and is robust to unknown fading channel. Compared to other methods it has simpler implementation and hence is less expensive. Therefore, in literature energy detection is mainly adopted for spectrum detection (Zarrin, 2011; Y. Zeng et al., 2010).

As 2.4 GHz WLAN system uses 13 different mutual overlapped channels (14 channels in Japan) both for WLAN APs and Wi-Fi Direct technology, the structured

AP users may cause interference for the use of Wi-Fi Direct communications at the same location. Spectrum detection is the task of obtaining awareness about the spectrum usage and existence of PUs in a geographical area. This awareness can be obtained by using geo-locations and the channel using by the WLAN APs in that locations, by using beacons, or by local spectrum detection at CRs (Marcus, 2005; Y. Zhao et al., 2007). For this thesis, energy detection based technique was applied for PU channel availability for SU activity i.e., smartphone to smartphone communications using Wi-Fi Direct.

## 1.3 Research motivation and problem statement

CRs need to keep track of variations in spectrum availability and should make predictions to minimize interference (Qing & Sadler, 2007). Stemming from the fact that a CR senses the spectrum steadily and has the ability of learning, the history of the spectrum usage information can be used for predicting the future profile of the spectrum. Towards this goal, knowledge about currently active devices or prediction algorithms based on statistical analysis can be used.

An analytical work focused the energy detection technique on data fusion and decision fusion (Atapattu, Tellambura, & Jiang, 2011). Under data fusion, upper bounds for average detection probabilities were derived for different scenarios. The analysis was authenticated by numerical and simulation results. The analytical results focused on Rayleigh multipath fading and lognormal shadowing channels only. An experimental channel power detection comparisons between embedded software defined radio (SDR) chips to a spectrum analyzer experimented in (Palaios et al., 2013). The authors considered four different frequency bandwidths (1 kHz, 30 kHz,