



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

by

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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

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**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 penggunaan 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 pengguna 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 . Dicapangkan 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 memandangkan 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.

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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.

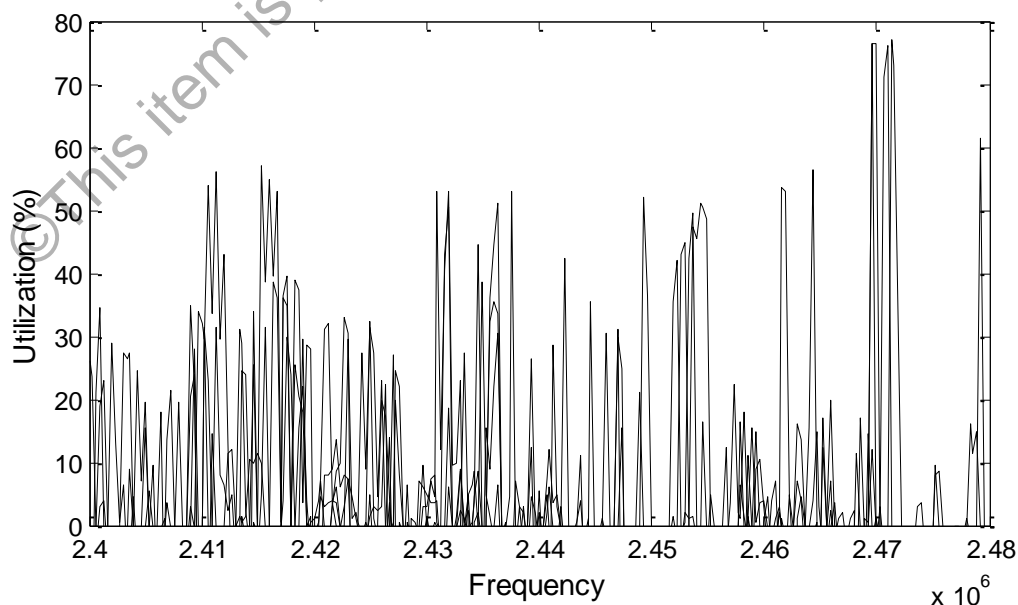


Figure 1.1: Frequency utilization for 2.4 GHz WLAN

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.

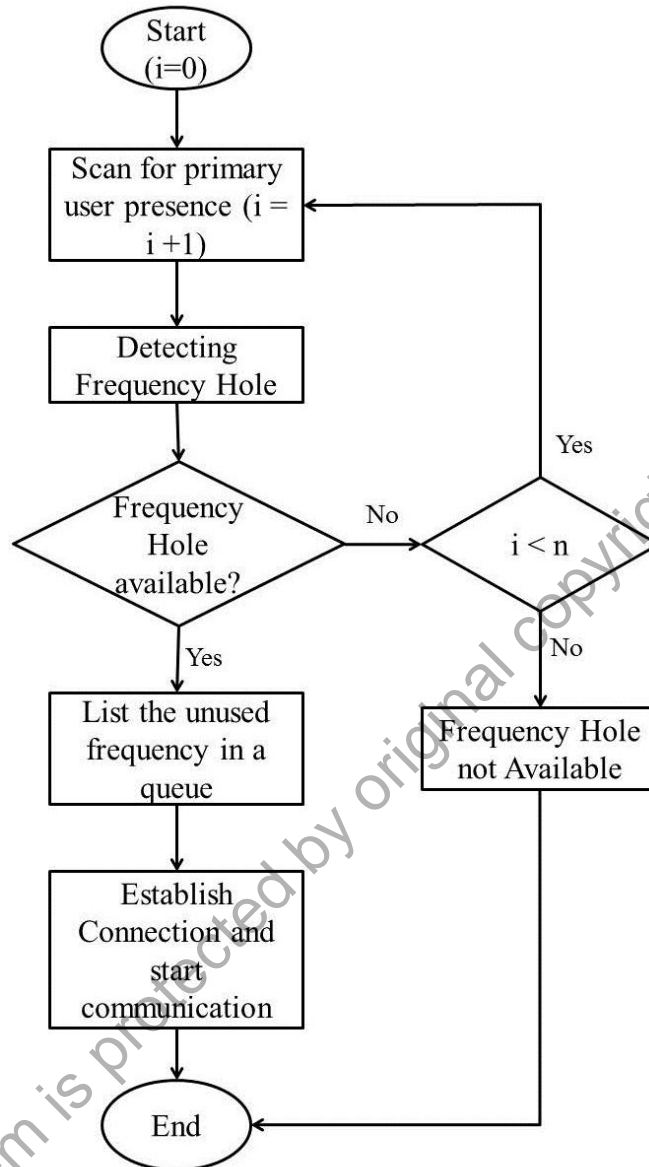


Figure 1.2: Basic CR spectrum detection technique

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,

150 kHz, and 300 kHz) to measure in both indoor (lab) and outdoor environments. The work concluded with the decision that the portable alternatives do suffer from limited frequency resolution when measuring wide band signals.

To detect the least congested channel for PUs are another primary objective for channel selection for any type of wireless network like WLAN or other ISM bands. Some works already have done based on WLAN channel adaptation techniques including distributed channel selection scheme (Kwon, Choi, Kim, & Chung, 2016), which is able to find the least congested channel considering both downstream and upstream transmission. The authors performed a system level simulation and also experimented forming a test bed. The work concluded that the developed the enhanced scheme performed better and increased the throughput by 11% and 20% compared to least congested channel selection (LCCS) and the client-assisted channel assignment optimization (CACAO) schemes respectively. They also claimed the scheme can enhance data rate of an AP up to three times than LCCS scheme. The major limitation of the work is, the authors considered only channel capacity for a WLAN AP, not an unstructured peer to peer (P2P) network or Wi-Fi Direct channels.

Most previously proposed CR detection and WLAN channel adaptation methods are based on computer simulations. Simulation environments are complex computer programming which provides optimum results for an optimum environment, but there may a huge gap in simulated results and real-time scenario. So, complexity is an issue needs to be considered. A few real-time experimental detection methods also been studied, but most of them are bulky and need a laboratory environment for implementation, or using stationary sensors. Also there's not an initiative to develop a database containing free channel information for a radio resource management. So, mobility and a database prior to location should be under consideration. Also,