OPTIMAL SPECTRUM SENSING FOR COGNITIVE RADIO NETWORK UTILIZING SOFTWARE DEFINED RADIO PLATFORM

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To my beloved family and friends

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ABSTRACT

The static spectrum allocation policy in Malaysia and the rapid growth of wireless communication services have led to spectrum scarcity problem. Consequently, the Quality of Service (QoS) for new wireless services might be compromised as most of the radio bands are already assigned to licensed users. But, the spectrum occupancy's measurement shows that the allocated spectrum is underutilized. Therefore, in this project, Opportunistic Spectrum Access (OSA) scheme is used to overcome the spectrum scarcity problem. The concept of OSA in cognitive radio technology is used to exploit the spectrum by permitting the secondary user to temporally use the licensed spectrum band when it is free. Hence, spectrum sensing is very important for the secondary user to avoid harmful interference to other wireless services. This project specifically will develop an optimal spectrum sensing mechanism using Particle Swarm Optimization (PSO) algorithm on Software Defined Radio (SDR) using platform called Universal Software Radio Peripheral (USRP). The data has been analysed to validate the performance of the spectrum sensing mechanism referring to the Probability of Detection (P_d) and Probability of False Alarm (P_f). The result shows that the optimal throughput is 93% for P_d 90%, SNR of 1.5dB and P_f 5% which is an improvement of 14% compared with non-optimal method.

ABSTRAK

Polisi pembahagian spektrum di Malaysia yang statik dan pertumbuhan pesat servis komunikasi wayarles telah menyumbang kepada masalah kekurangan spektrum. Akibatnya, kualiti servis untuk khidmat wayarles yang mungkin terjejas kerana hampir semua jalur radio telah diperuntukkan kepada pengguna-pengguna berlesen. Walaubagaimanapun, pengukuran penggunaan spektrum menunjukkan spektrum yang telah diperuntukkan ini sebenarnya tidak digunakan sepenuhnya. Oleh itu, skim penderiaan berasaskan Capaian Spektrum Opurtunistik (OSA) dicadangkan untuk mengatasi masalah spektrum ini. Konsep OSA dalam radio kognitif digunakan untuk mengeksploitasi spektrum dengan membenarkan pengguna sekunder menggunakan jalur spektrum berlesen dalam masa ia tidak digunakan. Oleh yang demikian, spekturm sangat penting untuk pengguna sekunder mengelakkan penderiaan gangguan berbahaya kepada khidmat wayarles yang lain. Projek ini secara spesifik akan membangunkan mekanisme penderiaan spektrum optimum menggunakan algoritma *Particle Swarm Optimization* (PSO) di atas platform *Software Define Radio* (SDR). Data telah dianalisis untuk menilai perkembangan mekanisma penderiaan spekturm dari segi kebarangkalian pengesanan (P_d) dan kebarangkalian amaran palsu (P_f). Keputusan menunjukkan optimum penghantaran untuk penderiaan spektrum adalah 93% untuk P_d 90%, SNR 1.5dB dan P_f 5% iaitu penambahbaikan sebanyak 14% jika dibandingkan dengan penderiaan spektrum normal.

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LIST OF ABBREVIATIONS

ADC	-	Analog to Digital Converter
AWGN	-	Additive White Gaussian Noise
CR	-	Cognitive Radio
CSS	-	Cooperative Spectrum Sensing
DTRS	-	Digital Trunked Radio System
ED	-	Energy Detection
FCC	-	Federal Communication Commission
GA	-	Genetic Algorithm
GPS	-	Global Positioning System
GRC	-	GNU Radio Companion
GSM	-	Global System for Mobile
HF	-	High Frequency
ICA	-	Imperialistic Competitive Algorithm
LTE	-	Long Term Evolution
MATLAB	-	Matrix Laboratory
MCMC	-	Malaysian Communication and Multimedia Commission
NPRM	-	Notice of Proposed Rule Making
OFDM	-	Orthogonal Frequency Division Multiplexing
PC	-	Personal Computer
PU	-	Primary User
PSO	-	Particle Swarm Optimization
QoS	-	Quality of System
RAM	-	Random Access Memory

RF	-	Radio Frequency
RSSI	-	Received Signal Strength Indicator
SDR	-	Software Defined Radio
SNR	-	Signal to Noise Ratio
SU	-	Secondary User
UHD	-	Universal Hardware Driver
USB	-	Universal Serial Bus
USRP	-	Universal Software Radio Peripheral
VHF	-	Very High Frequency
WiMAX	-	Worldwide Interoperability for Microwave Access
WRAN	-	Wireless Regional Area Network

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CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless communication nowadays is widely used for the internet access. Internet access eases connectivity to the internet without having to plug in any cable. Moreover, single wireless internet access point can support a large number of users simultaneously. Besides that, wireless communication supports the community with wide range of applications such as radio and television broadcasting, high frequency (HF) radio and satellite communication, home accessories, global positioning services (GPS) service and others.

Each of this wireless communication service is operated at a predetermined band in the spectrum and this band is basically determined and licensed by the regulator in the country. In Malaysia, the Malaysian Communications and Multimedia Commission (MCMC) is the regulator. However, different country may have a different spectrum allocation, for example, MCMC allocates 2.3GHz band for WiMAX, 900MHz and 1800MHz band for GSM and 2000MHz band for IMT2000 in Malaysia. The complete list of spectrum allocation in Malaysia is shown in Figure 1.1 [1].

Referring to Figure 1.1, the static spectrum allocation causes the spectrum to be fully assigned especially from 3 kHz until 420 THz. Consequently, it is almost impossible to assign a frequency band in the spectrum to a new wireless communication technology such as LTE and LTE-Advanced. Over time, this scenario will lead to scenario so called spectrum scarcity where there is not enough spectrum or bandwidth to offer for new communication services.

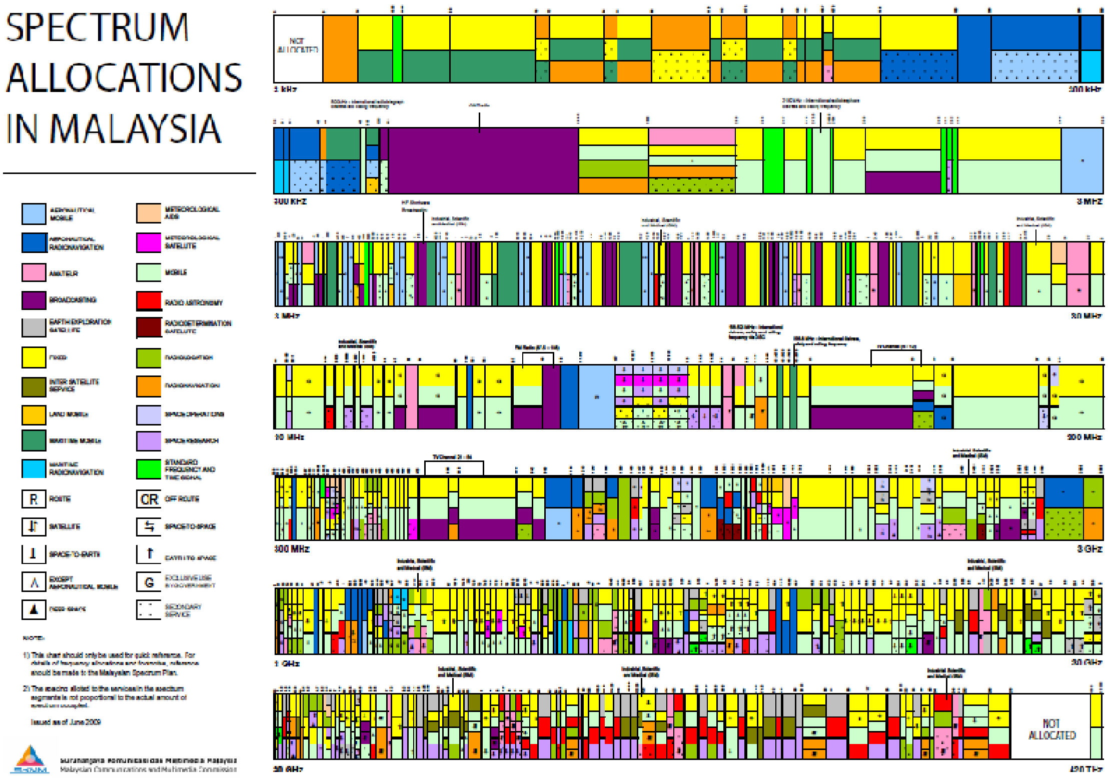

Figure 1.1 Spectrum Allocations in Malaysia [1]

But, the big questions to answer are ‘Is there really spectrum scarcity problem?’ and ‘Where to find spectrum for new wireless communication services? On the other hand, recent research shows that most of this allocated spectrum is underutilized. For instance, study shown by [2] reveals that most spectrum bands are underutilized or having a lot spectrum holes.

Figure 1.2 shows the spectrum occupancy for frequency band 30 to 3000 MHz in Malaysia. The red colour represents power, black for time per hour and blue for the duty cycle. It is shown clearly that most of the spectrums are underutilized, only certain portion of frequency band are utilized. The most underutilized spectrums are at the frequency higher than 1000 MHz.

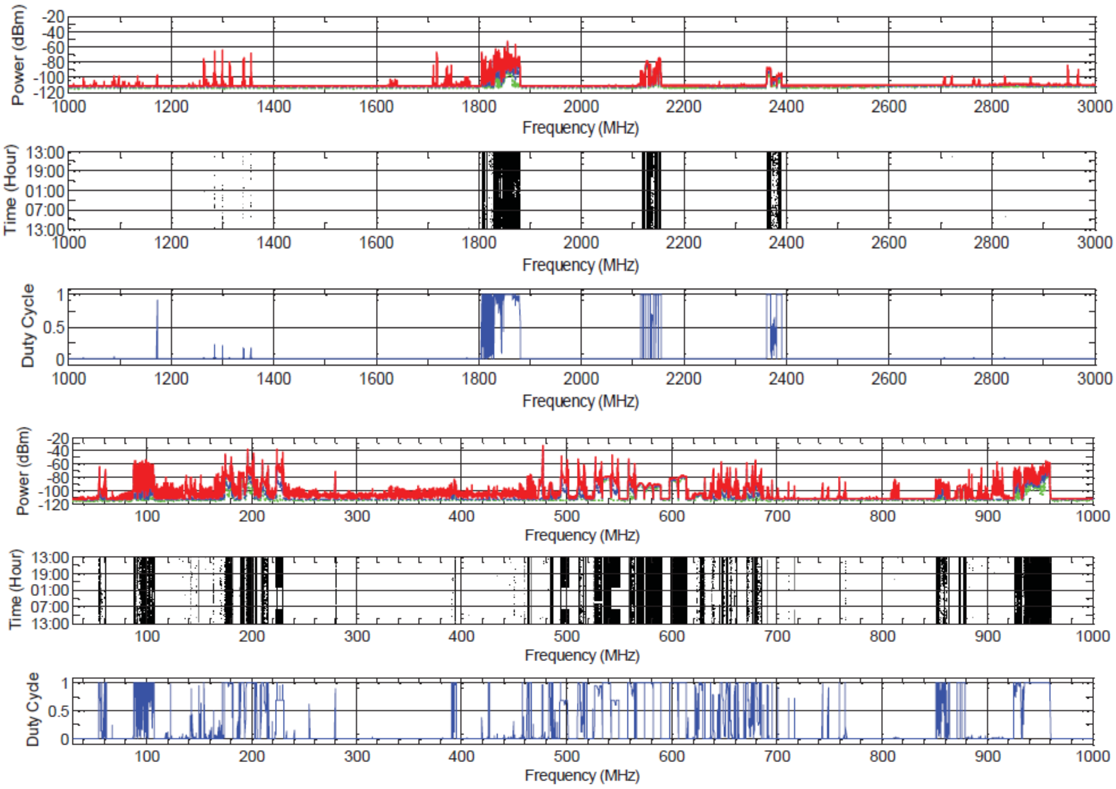

Figure 1.2 Spectrum Occupancy for Frequency Band 30-3000 MHz in Malaysia

Study shown by [2] also summarized the average spectrum occupancy percentage in Malaysia is considered very low as shown in Figure 1.3. The highest occupancy is FM radio broadcasting at 71.17%, followed by TV broadcasting 59.81% and GSM 900 with 41.55%. Some of the spectrum occupancy is below than 10% such as for Fixed Mobile, Radiolocation, Very High Frequency (VHF) Mobile Radio and Digital Trunked Radio Systems (DTRS).

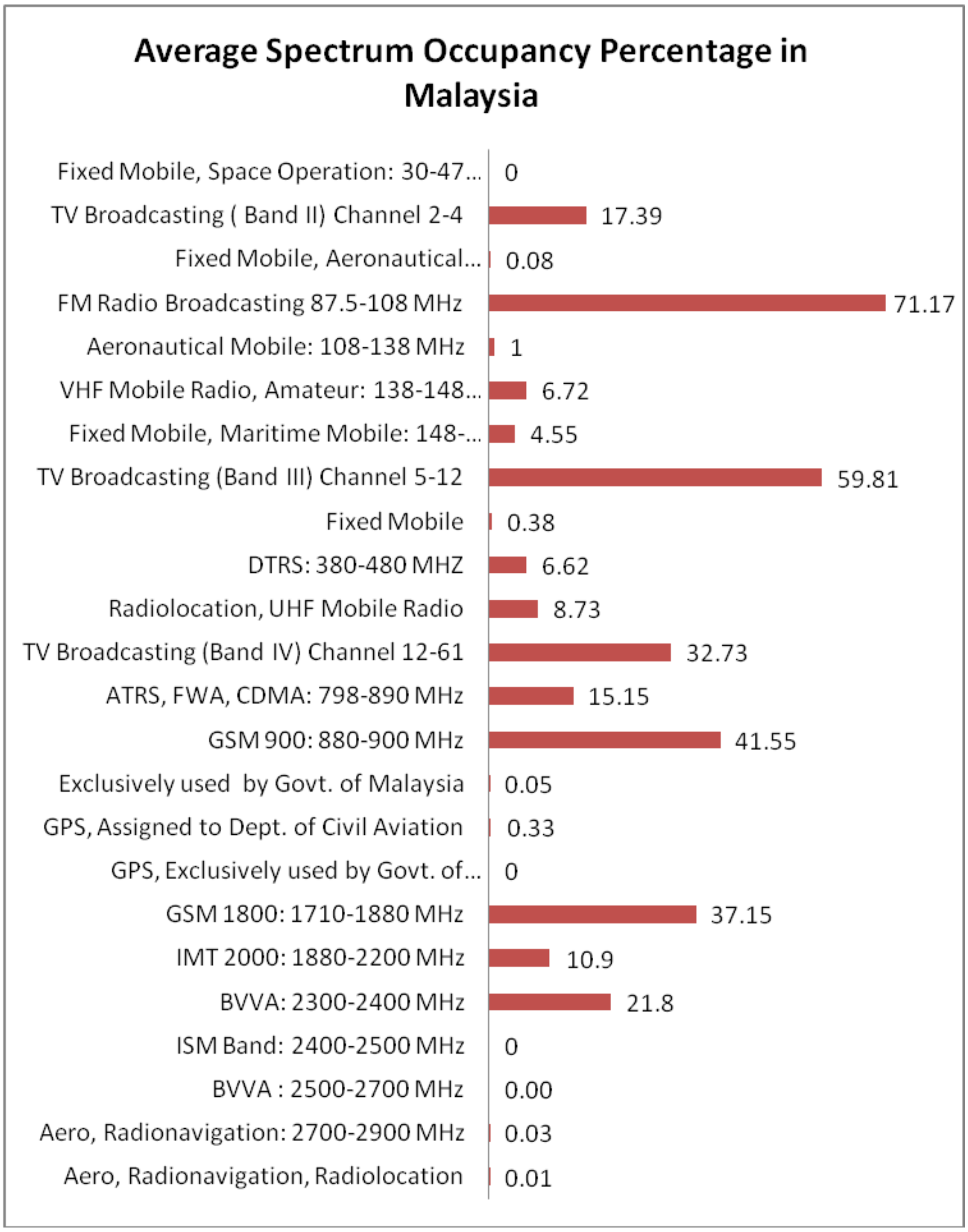

Figure 1.3 Average spectrum occupance percentage in Malaysia [2]

The craving for spectrum is very demanding specifically due to the explosion of new wireless technologies and services nowadays. The current static spectrum allocation policy cannot bear the need of this demand and it needs to be revised. In order to overcome this underutilized spectrum and solve the spectrum scarcity problem, a cognitive radio (CR) technology can be used where CR utilizes the spectrum more efficiently without interfering with the primary users of the spectrum [3].

1.2 Problem statement

Spectrum sensing mechanism enables cognitive radio network to detect Primary User (PU) and utilize spectrum holes for Secondary User (SU) transmission. However, precise PU detection leads to longer sensing time and lower achievable throughput in one frame cycle. The optimal spectrum sensing mechanism is proposed to reduce sensing time so that the maximized throughput can be achieved. In this research, PU is defined as a licensed user which is the owner of the spectrum or unlicensed user but has more priority than SU. The PU can use the spectrum whenever desired. Meanwhile, SU also recognized as cognitive user which opportunistically uses the spectrum only when the spectrum is unused.

1.3 Research objectives

The objectives for this project are:

1) To implement the optimal spectrum sensing mechanism using Software Define Radio (SDR) platform

2) To obtain the optimal throughput subject to Probability of Detection (P_d) 90% under various Signal-to-Noise (SNR) conditions

3) To measure the performance of optimal and non-optimal spectrum sensing mechanism for sensing time for various Probability False Alarm (P_f)

1.4 Scope of project

This project specifically follows the IEEE802.22 standard radio system for sensing time and P_d. By referring to this standard, sensing time for spectrum sensing must not exceed 2s and P_d is 90%. The SDR platform used is GNU Radio and Universal Software Radio Peripheral (USRP) B200 with addresses F4CC60 and

F4F586 for experimental measurement. The spectrum sensing method used is Energy Detector (ED) while Ubuntu 15.10 is designated as the operating system (OS).

The optimal spectrum sensing module deploys P_d of 90% to satisfy IEEE802.22 Standard Radio System requirement. The algorithm used is Particle Swarm Optimization (PSO). P_f is varied in order to determine the minimal sensing time for the spectrum sensing.

1.5 Significant contributions

This report describes the development and implementation of optimizer for spectrum sensing in CR system using SDR platform consists of GNU Radio and USRP. The contributions of the report are listed below:

- Development of an optimizer spectrum sensing mechanism using SDR platform called GNU Radio and USRP. The P_d of the CR system is set based on IEEE802.22 requirement.
- Optimal sensing time using Particle Swarm Optimization (PSO) by experimental measurement with the objective function of maximized throughput (R_n) at minimized sensing time.
- Performance investigation of optimal sensing time under various SNR conditions.

1.6 Organization of thesis

This report consists of six chapters starting with chapter 1 as an introduction to the thesis. Chapter 1 will cover topics such as objectives of the research, problem statement, and scope of the work.

Chapter 2 provides the background theory for understanding the CR system including the spectrum sensing, spectrum management and spectrum decision and also the SDR platform. Lastly, this chapter discusses on the existing works related to the CR with optimal mechanism.

Chapter 3 discuss the methodology used to gather and present the results of the project. The design concept of the work is discussed including the complete experimental set up. Then, this chapter elaborates on the optimal sensing algorithm used which is PSO and the implementation of the optimal algorithm on GNU Radio and USRP.

Chapter 4 elaborates the experimental results using SDR platform for optimal and non-optimal spectrum sensing. The performance of the sensing time and R_n with P_d of 90% and under various SNR conditions are discussed.

Chapter 5 concludes this research work and provides recommendations for work in the future related to the topic under optimal spectrum sensing area.

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