INTERFERENCE CANCELLATION USING MULTIPLE ANTENNA TECHNIQUES FOR COGNITIVE RADIO NETWORK

BY

WAN NADZLIA SHAZWANIE
BT WAN MOHD ZUFERI

A dissertation submitted in fulfilment of the requirement for the degree of Master of Science in Communication Engineering

Kulliyyah of Engineering
International Islamic University Malaysia

AUGUST 2014

ABSTRACT

The explosive growth in wireless communication services and fixed spectrum allocation policies by government agencies have led to spectrum scarcity. Besides, recent research has indicated that the actual occupancy of most licensed frequency bands is quite low leading to underutilization and waste of valuable frequency resources. Cognitive radio has emerged as a promising solution which enables the unlicensed (secondary) user to establish a communication link in licensed band under the condition that there is no or minimal interference to the licensed user. This dissertation addresses the challenge of overcoming interference effect due to coexistence of primary network and secondary network by developing several novel strategies, ranging from adaptive antenna array until the precoding technique of singular value decomposition with iterative algorithm. Two networks that communicate with their counterpart by sharing their spectrum are considered, known as spectrum sharing. In underlay spectrum sharing, the inconsistency of channel condition and simultaneous transmission by primary and secondary users occupying the same frequency band resulted interference effect still remains an issue. Joint interference cancellation and equalization for Space-Time Block Coded Orthogonal Frequency Division Multiplexing (STBC-OFDM) transmission is presented. To mitigate the interference from primary user, pre- and post-FFT adaptive antenna array is employed at secondary user receiver. Then, the optimum antenna weights that place nulls at the primary transmitters are determined. The optimum weight determination for beamformers is based on the minimum mean square error (MMSE) criterion. Simulation results demonstrate that post-FFT is optimum in terms of maximizing signal-to-noise-and-interference power ratio (SINR) and provides a lower bit error rate (BER) under existence of several primary users. Two strategies of jointly-optimized uncoordinated beamforming algorithms for cognitive radio networks are addressed in this dissertation. The optimum weights are designed to maximize the achievable rate and achievable sum rate for both primary and secondary links under the condition that the cross interference at both receivers are totally nullified. Simulation results have shown that employing gradient algorithm at the cognitive link is optimum in terms of maximizing achievable rate and provides a higher sum rate performance as compared to the discrete search. An improved strategy for jointly-optimized uncoordinated beamforming over cognitive radio network is also proposed. The proposed design is based on singular value decomposition and iterative water-filling at the primary link while employing discrete search and gradient algorithm at the secondary link. The interference cancellation is performed at the secondary user and no coordination between the primary and secondary users is required as uncoordinated beamforming is being employed in the network. The new optimum weights are designed to maximize the achievable rates for both primary and secondary links and their achievable sum rate performance of the network under the condition that the cross interference at both receivers are totally nullified. Simulation results show that the proposed design achieves more than two times increases in performance of achievable rates of both primary and secondary links and total sum rate of the network as compared to the previous reported work.

خلاصة البحث

إن النمو السريع في خدمات الاتصالات اللاسلكية وتوزيع الوكالات الحكومية لتراخيص ثابتة للطيف المغناطيسي أدى لمشكلة ندرة الطيف. من جهة آخرى، دراسة حديثة أوضحت أن الاستعمال الحقيقي لأغلب حزم الترددات ضئيل والذي يؤجي للنقص واضاعة حزم الترددات القيمة. في السنوات الحالية، ظهر (cognitive radio) كحل يتوقع منه زيادة الاستخدام للطيف و التعامل مع مشكلة ندرة الطيف. (cognitive radio) يسمح للمستخدمين غير المرخصين (مستخدم ثانوي) انشاء قناة اتصال عبر الحزمة المرخصة بشرط تقليل أو إلغاء التداخل على المستخدم المرخص.هذه الرسالة تدرس التغلب على تأثير التداخل نتيجة التواجد المشترك للشبكة الأولية والشبكة الثانوية عبر تطوير عدد من الاستراتيجيات الجديدة، بدءا من مصفوفة الهوائي المتأقلمة حتى تقنية ما قبل الترميز لتحليل القيمة المفردة (singular value decomposition) مع خورازمية التكرار (iterative algorithm). هنا، سنفترض شبكتان تتواصل مع المستخدم من خلال مشاركة طيفهما والذي يعرف بمشاركة الطيف. في التغشية التحتية لمشاركة الطيف يسمح بالارسال المتزامن للمستخدمين الاولي والثانوي بشرط ان يكون التداخل على المستخدم الاولي اقل من الحد المقبول. لكن نتيجة للتقلب بحالة القناة وارسال المستخدم الثانوي بنفس الوقت مع المستخدم الأولي وعبر نفس القناة يؤدي لاستمرار تأثير التداخل، ومعالجته هو التركيز الرئيسي لهذه الرسالة. في الجزء الأول من الرسالة، تم عرض إلغاء التداخل المشترك و التسوية لإرسال(STBC-OFDM) . لإلغاء التداخل من المستخدم الأولي تم استعمال (FFT) قبل وبعد مصفوفة الهوائي المتأقلمة عند مستقبل المستخدم الثانوي. بعد ذلك، القوى الأمثل تم تحديدها من خلال وضع أصفارا للمرسل الأولي. تحديد القوى الأمثل لتكوين الاشعاع يعتمد على معيار متوسط مربع الخطأ الأقل(MMSE). تم عرض التمثيل والتحليل للتحقق من أداء كلا من الانظمة في مستقبل -STBC) OFDM).الجزء الثاني من الرسالة يناقش استراتيجيتين للتحسين بالاشتراك لخوارزميات تشكيل الاشعاع، الغير معتمد على المكان، لشبكات . القوى الأمثل صممت لزيادة (SINR) لأقصى حد وامكانية تحقيق معدل جمع لكل من القنوات الاولية والثاتوية بشرط أن التداخل المتبادل لدى كل من المستقبلات يتم إلغائه تماما. التمثيل والتحليل استعمل على الأداء ل (SINR) ومعدل الجمع الممكن للشبكة. تم تقييم الاعتدال في أداء (SINR) للقناة الأولية والثانوية عند استعمال المستخدم الاولي لأقصى معدل تجميعي لتكوين الاشعاع بينما المستخدم الثانوي يستعمل خوارزمية البحث المنفصل.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Communication Engineering.

………………………………
Khaizuran Abdullah
Supervisor

………………………………
Nordin Ramli
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Communication Engineering.

………………………………
Wajdi Al Khateeb
Internal Examiner

………………………………
Mohd. Yusoff Alias
External Examiner

This dissertation was submitted to the Department of Electrical and Computer Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science in Communication Engineering.

………………………………
Othman O. Khalifa
Head, Department of ECE

This dissertation was submitted to the Kulliyyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science Communication Engineering.

………………………………
Md. Noor B. Salleh
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Wan Nadzlia Shazwanie bt Wan Mohd Zuferi

Signature……………………….……   Date……………………………..

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

INTERFERENCE CANCELLATION USING MULTIPLE ANTENNA TECHNIQUES FOR COGNITIVE RADIO NETWORK

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below.

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

Affirmed by Wan Nadzlia Shazwanie bt Wan Mohd Zuferi

……………………………. ……………………..
Signature Date

ACKNOWLEDGEMENT

All praise and glory to Almighty Allah (SWT) for giving me strength and ability to complete this dissertation. First and foremost, I would like to thank my supervisor, Dr Khaizuran Abdullah for his guidance and support during my Master studies. This dissertation would never have been possible without his belief in my abilities. I admire his dedication and hard work. I would like to express my deep and sincere gratitude to my field supervisor from MIMOS Berhad, Ir. Dr. Nordin Ramli, with whom I spent countless hours discussing and refining my ideas. Without Dr. Nordin's unwavering encouragement and patience, I would have never reached this point. My deepest gratitude to Dr. Hafizal Mohamad for his endless support, direction, and encouragement during this research. I also would like to thanks Bro. Muhammad Tahir and all members of Wireless Communication Cluster, MIMOS Berhad for their support in my research. Finally, I am grateful to my dearest parents for providing me with the best educational opportunities. They have been a vital source driving me to all accomplishments and success. I am also owe a million of thanks to my family and friends for their encouragement during the most important time of this work. Special thanks go to all of them listed above, which I could not done this work without supports from all of them. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BER	Bit Error Rate
CDF	Cumulative Distribution Function
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
IEEE	Institute of Electrical and Electronics Engineer
IIUM	International Islamic university Malaysia
MAC	Medium Access Control
MCMC	Malaysian Communication and Multimedia Commission
MIMO	Multiple-Input-Multiple-Output
ML	Maximum likelihood
MMSE	Minimum Mean Square Error
MRC	Maximal Ratio Combining
NBI	Narrowband Interference
NTIA	National Telecommunications and Information Administration
Ofcom	Office of Communications
OFDM	Orthogonal Frequency Division Mutiplexing
OIC	Opportunistic Interference Cancellation
QPSK	Quadrature Phase Shift Keying
SINR	Signal-to-interference-plus-noise ratio
SIR	Signal-to-interference ratio
SMI	Sample Matrix Inversion
SNR	Signal-to-noise ration
STBC	Space-Time Block Coding
SVD	Singular Value Decomposition

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

Wireless communication is considered as one of the fastest growing segments of the communications industry that have significantly changed the lives of human beings. A new era was born since 1901 when Guglielmo Marconi convincingly demonstrated the practicality of wireless communication by sending the first radio signal across the Atlantic. After evolving over a century, wireless communication can find its applications in various aspects of our lives nowadays, ranging from highly commercialized cellular and satellite communication systems to personally used computer notebook, Bluetooth devices, home appliances, and many more. The explosive growth of the wireless communication market is expected to continue in the future as the demand for all types of wireless services is increasing.

Current wireless networks are characterized by a static spectrum assignment policy, where government agencies assign wireless spectrum to license holders on a long-term basis for large geographical regions. However, as the spectrum demand increases, this policy has been faced with spectrum scarcity at particular spectrum bands. While static allocation has many advantages and has generally served well in the past, it can lead to very inefficient usage of spectrum. Recent studies have shown that many allocated frequency bands are significantly underutilized. According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85% (FCC, 2003) for spectrum below 3 GHz. In Malaysia, it is shown that the similar scenario happen based on the measurement study on spectrum occupancy (Omar, Hassan, & Shabli, 2010). The available spectrum is becoming increasingly scarce over certain bands, yet it is found to be significantly underutilized.

This has necessitated a new communication standard that allows unlicensed (secondary) users to utilize the vacant bands which are allocated to licensed (primary) users. However, this opportunistic access should be in a manner that does not cause harmful interference to the primary users who have higher priority or legacy rights on the usage of the spectrum. Therefore, the secondary users, which have lower priority, must be aware of the activity of the primary user in the target band. They should spot the spectrum holes and the idle state of the primary users in order to exploit the free bands and also promptly vacate the band as soon as the primary user becomes active. Cognitive radio, which was originally proposed by Joseph Mitola encompasses this awareness by dynamically interacting with the environment and altering the operating parameters with the mission of exploiting the unused spectrum without interfering with the primary users (Mitola, 1999). Showing support for the cognitive radio idea, the FCC has recently approved the usage of unused television spectrum by unlicensed users wherever the spectrum is free.

1.2 MOTIVATION

Interference is one of the key factors affecting the wireless network performance and has been a long-lasting problem coupling wireless communication system. In the context of cognitive radio networks, the interference cancellation issue is extremely important. Cognitive radio holds the fundamental basis of not causing any harmful interference to the primary system. Besides, both primary and cognitive radio performance may be limited by interference coming from either the secondary transmitter towards the primary receiver or from primary transmitter towards the secondary receiver, respectively. Therefore, the interference cancellation issue in cognitive radio networks deserves a careful and comprehensive study, which is the main focus of this dissertation.

1.3 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Interference is a fundamental nature of wireless communication systems, in which multiple transmissions often take place simultaneously over a common communication medium. In the context of coexistence between primary and secondary users, interference cancellation is one of the key issues to be considered.

Due to coexistence between the two networks, a cognitive radio network inevitably operates in interference intensive environments. One of the most challenging problems of cognitive radio is the interference which occurs when a cognitive radio accesses a licensed band but fails to notice the presence of the licensed user. To address this problem, the cognitive radio should be designed to co-exist with the licensed user without creating harmful interference to primary user.

Therefore, effective interference cancellation is essential to the coexistence of primary and cognitive radio networks as the secondary user can reuse the spectrum of the primary user only under the condition that the primary services are not harmfully interrupted. This has driven research toward interference cancellation issues which is a significant concern when many users are sharing the spectrum.

1.4 RESEARCH OBJECTIVES

The aim of this dissertation is to develop a novel interference cancellation technique for cognitive radio networks. More specifically, the study has the following objectives:

i. To assess the impact of coexistence between primary and secondary users in the environment of sharing the radio resources.
ii. To design the optimum beamforming weight for interference cancellation in cognitive radio networks.
iii. To maximize the achievable rate of primary and secondary links and their achievable sum rate in cognitive radio networks.

1.5 RESEARCH SCOPE

This research focus on physical layer signal processing scheme, particularly on interference mitigation techniques in cognitive radio network. In this research, an underlay network where concurrent transmissions of primary and secondary users are permitted provided that the interference to the primary user is below a certain threshold level is considered. This dissertation also covers the research area in Space-Time Block Coded Orthogonal Frequency Division Multiplexing (STCB-OFDM), Multiple-Input Multiple-Output (MIMO), adaptive antenna arrays, equalization technique, and uncoordinated beamforming.

1.6 RESEARCH METHODOLOGY

Research activities of this work are centred on interference cancellation for cognitive radio network. In order to solve issues in the problem statements and achieve the objectives stated above, the methods taken in this dissertation may be listed as below and simplified in Figure 1.1. The research methodology consist of the followings:

i. Literature review on cognitive radio particularly on interference issues is studied thoroughly.
ii. Based on earlier study, research works are conducted on the interference issues in cognitive radio networks.
iii. Simulation models are developed.
iv. Computer simulations are performed using Matlab coding to determine the performance of each methods.
v. The results are analyzed and discussed.

It is noted that, the output of research methodology (i) is presented in Chapter 1 and Chapter 2, while research methodology (ii)-(v) is done for each case study presented in Chapter 3 and Chapter 4, respectively.

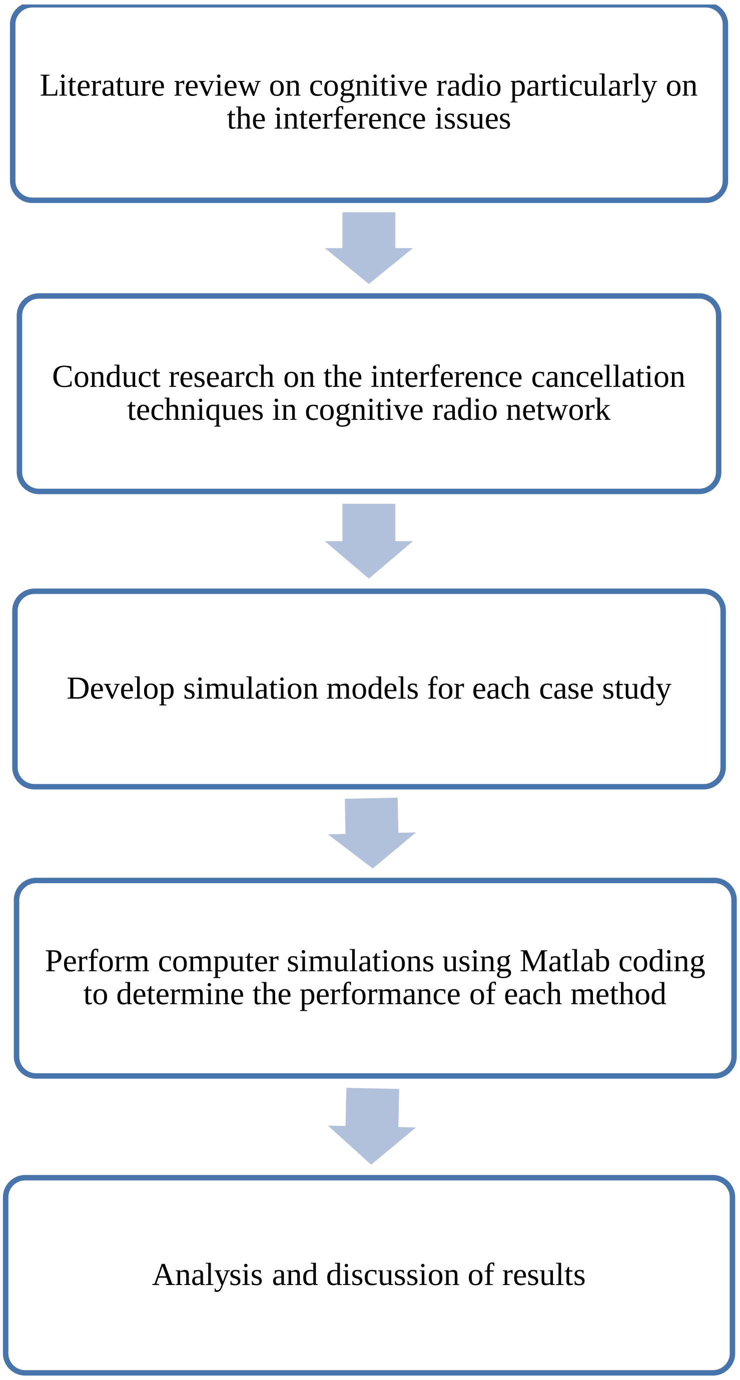

Figure 1.1: Research methodology flow chart.

1.7 DISSERTATION OUTLINE

This dissertation is organized into six chapters.

Chapter 1 gives the overview of this dissertation including the introduction of cognitive radio, problem statement and its significance, research objectives, scope of work and research methodology.

Chapter 2 provides the necessary background information for cognitive radio technology that will be further used in this dissertation, and presents some interference cancellation techniques that have been proposed by others. The chapter also gives the brief description on MIMO, STBC-OFDM and adaptive antenna array.

Chapter 3 presents the joint interference cancellation and equalization for STBC-OFDM transmission over underlay cognitive radio network. In this chapter, pre- and post-FFT adaptive antenna array is employed at secondary user receiver to find optimum antenna weights that place nulls at the primary transmitters. The chapter discusses the performance of using both systems in STBC-OFDM receiver and presents the optimum weight determination for beamformers based on the minimum mean square error (MMSE) criterion.

Chapter 4 is divided into two main problem formulations considering the same network model. In the first part, the chapter presents two strategies of jointly optimized uncoordinated beamforming algorithms for cognitive radio networks. Here, simulation and analysis is conducted to determine the performance of achievable rate of both primary and secondary links and achievable sum rate of the network when both primary and secondary users transmit concurrently over the same spectrum. The optimum weights are designed to maximize the achievable rate and achievable sum rate for both primary and secondary links under the condition that the cross interference at both receivers are totally nullified. The fairness of the achievable rate performance in primary and secondary links is discussed using different number of transmit and receive antennas. In the second part of this chapter, an enhanced strategy for jointly-optimized uncoordinated beamforming over cognitive radio network has been proposed. A transmission of a single information stream in both primary and secondary links where both primary and secondary users are equipped with multiple antennas and transmit concurrently over the same spectrum is considered. Here, the optimum weights are designed to maximize the achievable rates for both primary and secondary links and achievable sum rate performance of the network under the condition that the cross interference at both receivers are totally nullified.

In Chapter 5, conclusion of this dissertation is drawn and a summary of the contributions is presented and some remarks are made for possible future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The goal of this chapter is to give some overview on the background and revolution of the cognitive radio technology, and describes its basic functionalities. The existing work in spectrum sharing, particularly on the interference cancellation in cognitive radio network and descriptions of MIMO Systems, STBC-OFDM, and adaptive antenna arrays are also presented.

2.2 BACKGROUND OF COGNITIVE RADIO

Radio spectrum refers to the part of electromagnetic spectrum corresponding to radio frequencies which is lower than 300 GHz. Radio spectrum, which is the transmission media enabling wireless communication is a scarce and precious natural resource. For wireless systems operating in low frequencies, the effective antenna size need to be very large, therefore it is not practical for portable wireless devices. On the contrary, for spectrum with high frequencies, the wireless channel becomes too hostile for the propagation of electromagnetic waves. Therefore, only a limited range of spectrum is usable for wireless communications.

At present, wireless networks are characterized by a static spectrum assignment policy in a manner that government agencies assign wireless spectrum to the license holders exclusively. The spectrum allocations in Malaysia as assigned by Malaysian Communications and Multimedia Communication (MCMC) have shown that most of the spectrums are fully allocated, as can be seen in Figure 2.1.

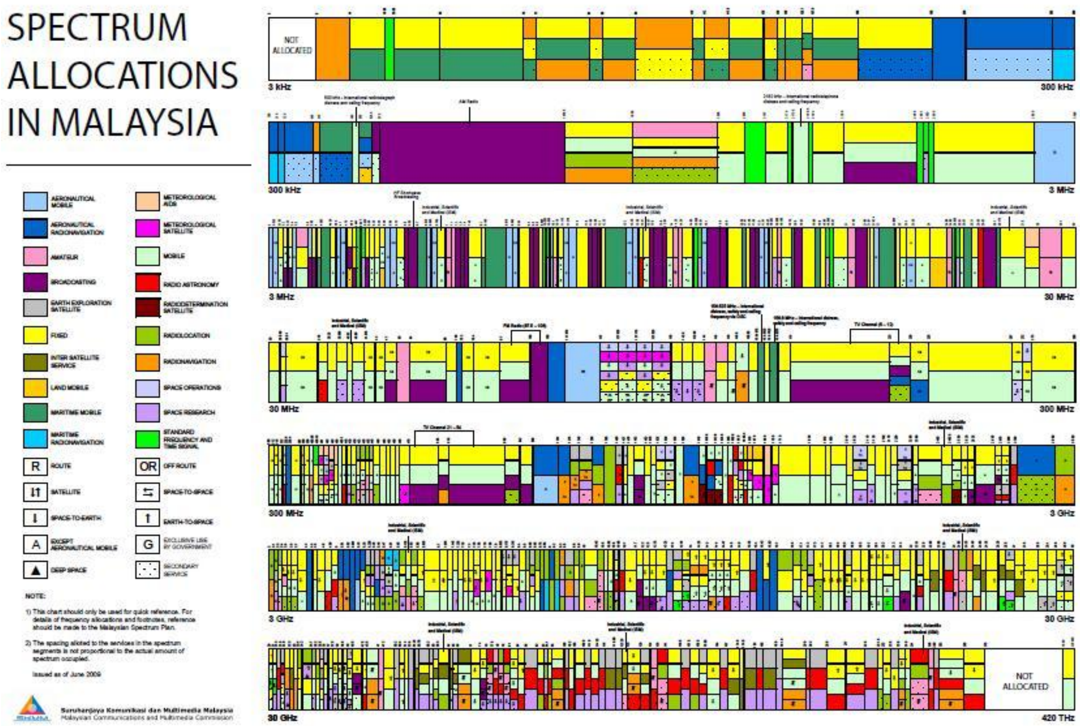

Figure 2.1: Spectrum allocation in Malaysia (MCMC, 2012).

While static allocation has many advantages and has generally served well in the past, it can lead to very inefficient usage of spectrum. Recently, because of the increase in spectrum demand, this policy has been faced with spectrum scarcity at particular spectrum bands. Study has shown that most of the licensed radio spectral bands are underutilized in time and space domain resulting in unused white spaces (Cabric, D., Mishra, S. M. & Brodersen, R.W., 2004). The spectrum utilization is mainly around certain parts of the spectrum whereas a considerable amount of the spectrum is unutilized as depicted in Figure 2.2. As can be observed, spectrum utilization is more intense and competitive at frequencies below 3 GHz whereas the spectrum is underutilized in the 3-6 GHz bands (Cabric et al., 2004). Recent studies conducted by the Federal Communications Commission (FCC) in the United States (FCC, 2005) and Office of Communications (Ofcom) in the United Kingdom (Ofcom,