CHANNEL SELECTION STRATEGIES FOR CO-EXISTENCE BETWEEN WIMAX AND WIFI

JONG SIAT LING

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Electronic & Telecommunication)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

MAY 2009

ABSTRACT

Cognitive radio (CR) is a paradigm for wireless communication in which a wireless node changes its transmission or reception parameters to communicate efficiently avoiding interference with licensed or unlicensed users. The utilization of spectrum is one of the critical issues in development of cognitive radio. Therefore, channel selection algorithm is developed to select the best operating band which can maximize the total system performances. This project study the spectrum co-existence between IEEE 802.16a and 802.11b network in the same un-licensed band using cognitive radio technique. A channel selection algorithm is proposed to improve the secondary user's throughput and avoid interference with primary user. NS2 simulation model is presented to evaluate the channel selection in scenarios with co-existing IEEE 802.16a and 802.11b networks.

ABSTRAK

Radio kognitif ialah suatu paradigma untuk komunikasi radio dimana nod radio menukar penyiaran and penerimaan parameter untuk berkomunikasi secara berkesannya dengan menjauhkannya dari gangguan pengguna lesen atau tanpa lesen. Penggunaan spektrum adalah salah satu isu-isu yang kritikal dalam pembangunan radio kognitif. Oleh sebab itu, prosedur pemilihan saluran diuruskan untuk memilih jaluran operasi dimana ia boleh mengoptimumkan prestasi sistem dengan lengkapnya. Projek ini adalah mengkaji spekrum wujud bersama antara jaringan IEEE 802.16a and 802.11b dalam satu jaluran yang tidak berlesen dengan menggunakan teknik radio kognitif. Prosedur pemilihan saluran dikemukakan supaya boleh mempertingkatkan pemprosesan pengguna kedua dan mengelakkan gangguan dengan pengguna pertama. Model simulasi NS2 digunakan untuk menilai pemilihan saluran dalam senario yang wujud bersama antara jaringan IEEE 802.16a dan 802.11b.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACK	-	Acknowledgements
AES	-	Advanced Encryption Standard
AP	-	Access Point
BS	-	Base Station
BW	-	Bandwidth
CBR	-	Constant Bit Rate
CR	-	Cognitive Radio
CSMA/CA	-	Carrie Sense Multiple Access/ Collision Avoidance
DARPA	-	Defense Advanced Research Project Agency
DCF	-	Distributed Coordination Function
DFS	-	Dynamic frequency selection
DIFS	-	DCF Inter Frame Space
DSS	-	Dynamic Spectrum Sharing
DSDV	-	Destination Sequence Distance Vector
DSSS	-	Direct Sequence Spread Spectrum
FC4	-	Fedora Code 4
FCC	-	Federal Communications Commission
FHSS	-	Frequency Hopping Spread Spectrum
GUI	-	Graphic User Interface
IEEE	-	Institute of Electrical and Electronic Engineering
IF	-	InfaRed
ISM	-	Industry Scientific and Medical
Kbps	-	Kilobits per Second

WLAN	-	Wireless Local Area Network
WPAN	-	Wireless Personal Area Network

CHAPTER 1

INTRODUCTION

1.1 Background

The idea of cognitive radio (CR) was first presented officially in an article by Joseph Mitola III and Gerald Q. Maguire in 1999. It was a novel approach in wireless communications that Mitola later described as [1]: The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs.

In wireless communication, the most valuable resource is the available radio frequencies. The dramatic increase in wireless services today aggravates the scarcity of the spectrum resource. However, regulatory bodies such as Federal Communications Commission in US and Ofcom in UK found that most of the radio frequency spectrum was inefficiently utilized [2]. The utilization of the spectrum range is from 15% to 85%. This is because of the spectrum access problem at which spectrum resource is available but its use is compartmented by traditional policies based on traditional technologies. On the other hand, several spectrums such as ISM/unlicensed spectrum are densely occupied with high interference conditions. This situation creates an imbalance in spectrum utilization and led to researching new technologies providing better utilization of the spectrum usage.

Spectrum scarcity problem can be overcome by proposing an opportunistic spectrum usage approach in which frequency bands that are not being used by licensed users utilized by CR users and their transmission must not interfere at all with the assigned service. This paradigm for wireless communication is known as CR.

Cognitive radios, usually based on software defined radio (SDR) techniques to detect the current spectrum, sense the spectrum holes and adjust the parameters such as frequency power and transmission rate in order to use the spectrum more efficiently and economically. According to [3], spectrum utilization depends strongly on time and place.

CR schemes enable spectrum coexistence between short-range WiFi and long-range WiMAX radios. Co-existence of these wireless services in the same unlicensed ISM band is motivated by the need for more efficient use of spectrum.

1.2 Channel Selection Strategy

Channel selection strategy governs how secondary users decide its operating band and what triggers a change of the operating band. These secondary users follow CSMA/CA to access the operating band and assume secondary users have the capability of sensing the spectrum and willingness of terminating the current transmission whenever the primary user returns. Each secondary user initially decides its operating band randomly. Over an operating band, each network tries to transmit and received packet within a network. If the corresponding primary user who owns the selected channel does not return within the time slot, the transmission is successful. On the contrary, if primary user returns, the secondary have to select another available primary band.

1.3 Problem Statement

Due to its global availability, Industry Scientific and Medical (ISM) unlicensed band nowadays is very congested as more and more companies produce products that uses the 2.4GHz portion of the radio spectrum. For example, Bluetooth, microwave oven, WiFi and Zigbee. A lot of spectra have been assigned for licensed use, but actually spectrum is more congested in urban area and hardly used in rural areas. Some licensed services only operate in a few locations and cause wastage of spectrum. High interference and throughput performance degradation experienced by primary user due to secondary user's access of its primary band. Retransmission probability is high when secondary users are required to terminate the current transmission immediately after the corresponding primary user return. However, if the secondary user chooses to wait the primary users become inactive again, it will cause the long transmission period. Thus, channel selection algorithm is developed to select the best operating band which can maximize the total system performances in the co-existence of WiMax and WiFi.

1.4 Objectives

The main objectives of this project are:

- To investigate the dynamic spectrum sharing between WiMax and WiFi. Dynamic spectrum sharing increase the efficiency of spectrum usage, which allows unlicensed secondary users to dynamically access the licensed bands from legacy spectrum holders on an opportunistic basis.
- To determine the best channel selection for CR using Network Simulator version 2 (NS2).

1.5 Scopes

This project is entirely simulation project using operating system Fedora Core-4 (FC-4). There are two approaches will be used in this project which is simulation using NS-2 and it follow by the trace file analysis.

There will be few steps to develop the co-existence of WiMax and WiFi scenario. Firstly, develop a suitable WiMax model follow by WiFi model. The parameters of both the model must be classified before the model is developed. Next is co-exist both model to create the co-existence of WiMax and WiFi scenarios. The final step is applies the channel selection algorithm in the co-existence model to enable dynamic spectrum sharing.

1.6 Project Report Outline

Chapter 2 covers an overview of CR technology and elaborated WiMax and WiFi device in detail. It also included some previous study regarding to dynamic channel selection and spectrum sharing.

Chapter 3 explains the process of the whole project from installing the Linux operating system until testing work in NS-2.

Chapter 4 shows the result of simulation in NS-2 and network simulation (NAM). The environment animation captured using NAM and the results are analyzed from trace files using trace graph.

The final chapter, chapter 5 summarized the work that has been done and proposals of future works that can be developed to enrich the testbed environment.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction To CR

CR technology is introduced to overcome the spectrum scarcity problem and enables a network to use a spectrum in a dynamic manner. The definition of CR as state in [2] is as follow:

"A CR is a radio that can change its transmitter parameters based on interaction with the environment in which it operates (Akyildiz *et al,* 2006)".

According to [4], the prime objectives of CR network are:

- Highly reliable communications whenever and wherever needed,
- Efficient utilization of radio spectrum

CR techniques try to utilize the spectrum holes that exist in the spectra in time. The CR enables the usage of temporally unused spectrum, which is referred to as spectrum hole or white space. If this band is further used by a licensed user, the CR moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference as shown in Figure 2.1.

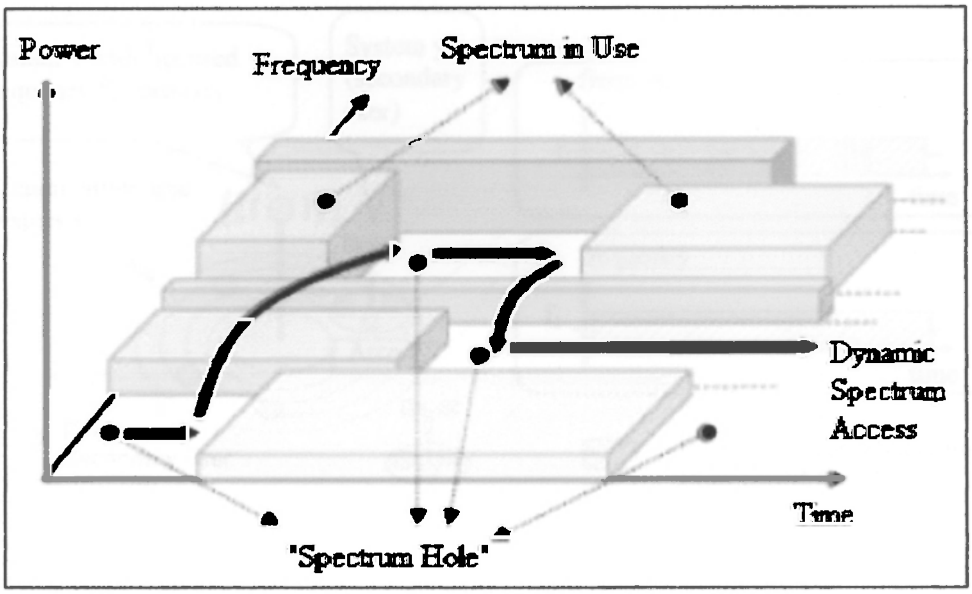


Figure 2.1: Spectrum hole concept [2].

Figure 2.2 shows an example of the spectrum utilization with ideal operation of CR. In the area 1 which is a region within communication range of primary users, the secondary users build communication links with frequency f1 while the primary users are not active on the communication links. On the other hand, in the area 2 which is out of communication range of primary users, the secondary users can continuously utilize this frequency band without the interference from/to the primary users. In the conventional system without CR, the frequency band f1 cannot be utilized by any user at any location. Thus, CR allows users to utilize a frequency band more densely in time and space, thereby leading to a drastic increase of the total spectrum efficiency.

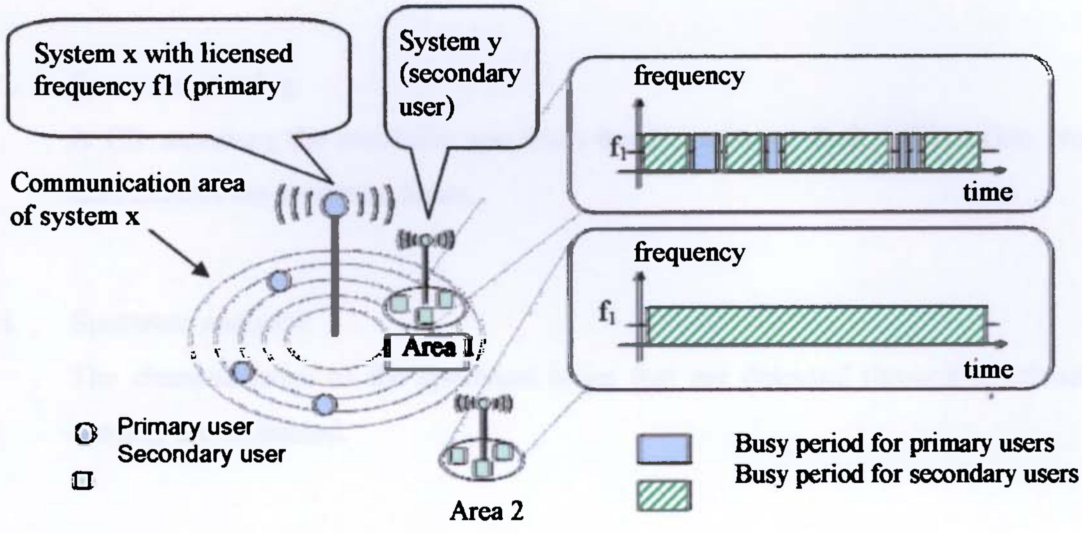


Figure 2.2: Frequency utilization of primary and secondary users in CR environment.

2.1.1 Key CR Terms

Several terms related to CR technique should be defined beforehand. There are:

- Primary user: Primary user has a license to operate in a certain spectrum band.
- Primary band: It is a licensed band which can access by a CR network.
- Secondary user: User operating in unlicensed band and uses CR technology to access licensed band.

2.1.2 Cognitive Capability

Cognitive capability is the ability of a communicating node sense the information from its radio environment and adapts itself to the changes in the environment [5]. These tasks are carried through a process termed as the cognitive cycle. The steps of cognitive cycle are spectrum sensing, spectrum analysis and spectrum decision as shown in Figure 2.3.

i. Spectrum sensing:
A CR monitors the available spectrum bands, captures their information and then detects the spectrum holes.

ii. Spectrum analysis:
The characteristics of the spectrum holes that are detected through spectrum sensing are estimated.

iii. Spectrum decision:
A CR determines the data rate, the transmission mode, and the bandwidth of the transmission. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements.

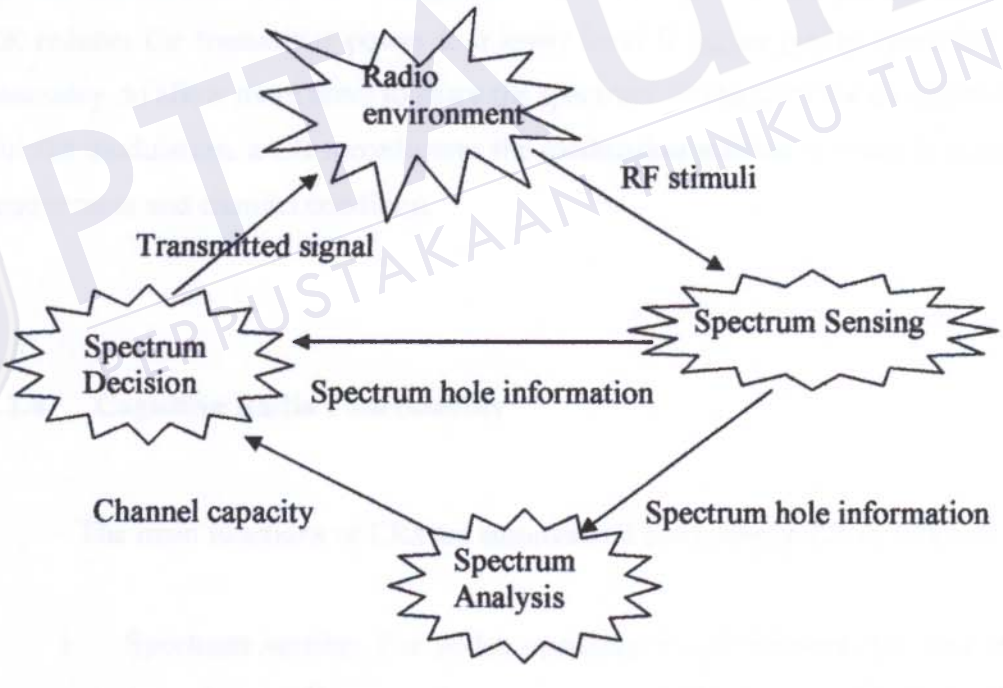


Figure 2.3: Cognitive cycle

The communication can be performed over the spectrum band once the operating spectrum band is determined. Since the radio environment changes over time and space, the CR should keep track of the changes of the radio environment. If the current spectrum band in use becomes unavailable, the spectrum mobility is performed to provide a seamless transmission.

2.1.3 Reconfigurability

Reconfigurability is the ability to change operating parameters, such as operating frequency, transmission power and modulation without changing the node hardware [2]. This capability enables the CR to adapt easily to the dynamic radio environment. For the operating frequency, a CR is able to change it operating frequency based on the information about the radio environment. Transmission power can be reconfigured with the power constraints. Power control enables dynamic transmission power configuration within the permissible power limit. The CR reduces the transmitter power to a lower level if higher power operation is not necessary ,to allow more users to share the spectrum and to decrease the interference. For the modulation, a CR reconfigures the modulation scheme in order to adapt user requirement and channel condition.

2.1.4 Cognitive Radio Functionality

The main functions of CRs are summarized according to [2] as follows:

i. Spectrum sensing: For nodes operating in CR network, the first step of operation is discovering spectrum opportunities. Spectrum sensing is the technique used by secondary users to detect an unused primary spectrum for its use, such that it will not interfere the primary user. Spectrum sensing technique should be able to detect unused primary spectrum not only in secondary transmitter but also in secondary receiver so that collision and minimum interference can be achieved. Several algorithms varies from simple techniques such as transmitter detection, to scheme that requires signalling exchange between user in cooperative detection, and more complex techniques such as interference-based detection.

Spectrum management: It is the technique used by secondary user to decide the best spectrum for the communication requirements. After identifying several unused primary spectrum, decision on which primary spectrum should be used is done. Primary spectrum can be categorized on several parameters such as interference level, allowable interference threshold, channel error rate, spectrum utilization including mean holding time and power constraint (data rate limitation).

Spectrum mobility: When a primary user becomes active, or the performance in a primary band becomes too poor (due to reasons such as interference or too many users), secondary users operating in its primary band has to vacate the band and move to a new one. Spectrum mobility is the technique used by secondary user to change spectrum in order to get a free or better spectrum without foiling ongoing communication. The nature of dynamic channel allocation is there within the CR technique, so that seamless spectrum handoff could be achieved.

Spectrum sharing is the technique used to accommodate secondary users with fairness on spectrum occupancy. This can be viewed as analogous to Medium Access control (MAC) problem in existing system. However difficulties here differ to a great extent in that a CR enabled network has a wide number of primary bands available to choose from sharing along with primary users.

2.2 Worldwide Interoperability for Microwave Access (WiMax)

Cognitive radios have been advanced as a technology for the opportunistic use of under-utilized spectrum wherein secondary devices sense the presence of the primary user and use the spectrum only if it is deemed empty. The distinguishing aspect of cognitive radios is the ability to sense the primary user and modify their transmission parameters to avoid interference to the primary. In CR schemes, we explore spectrum co-existence between short-range of WiFi and long range of WiMax radios.

2.2.1 WiMax (IEEE 802.16)

WiMax is one of the hottest broadband wireless technologies around today. It is a metropolitan area network technology whose goal is to provide last mile broadband wireless access to the general population [6]. It expected to deliver broadband access services to customers in an economic way. WiMax provide broadband wireless connectivity to fixed, portable and nomadic devices, and it is designed for outdoor, long-range and carrier-class application, with high throughput in NLOS propagation environments. One base station can connect to several towns as it has a wide coverage area, it can also connect to multiple subscriber station and provide a connection to remote area. The link from 802.16 base stations (BS) to subscriber station (SS) is called the downlink (DL) and the link from SS to BS is called the uplink (UL). WiFi hotspots can get a connection to internet via a connection to the subscriber station.

2.2.2 How the WiMax Works

A WiMax tower station can connect directly to the internet using a high bandwidth or wired connection. It also can connect to another WiMax tower using a line-of-sight (LOS) microwave link. The connection to second tower is referred to backhaul. The ability of a single tower can cover up to 3000 square miles which enable to provide wide coverage to remote rural areas.

WiMax provide two forms of wireless services which is NLOS and LOS [7]. WiFi is NLOS type of service, where a small antenna on the computer connects to the WiMax tower as shown in Figure 2.4. It operates in the lower frequency range of about 2 GHz to 11 GHz. For the LOS service, a fixed dish antenna point straight at the WiMax tower from the rooftop. The LOS connection is very strong and stable, so it is able to send a lot of data with fewer errors. LOS transmissions use higher frequencies with ranges reaching a possible 66 GHz. At higher frequencies, there are less interference and lots of more bandwidth.

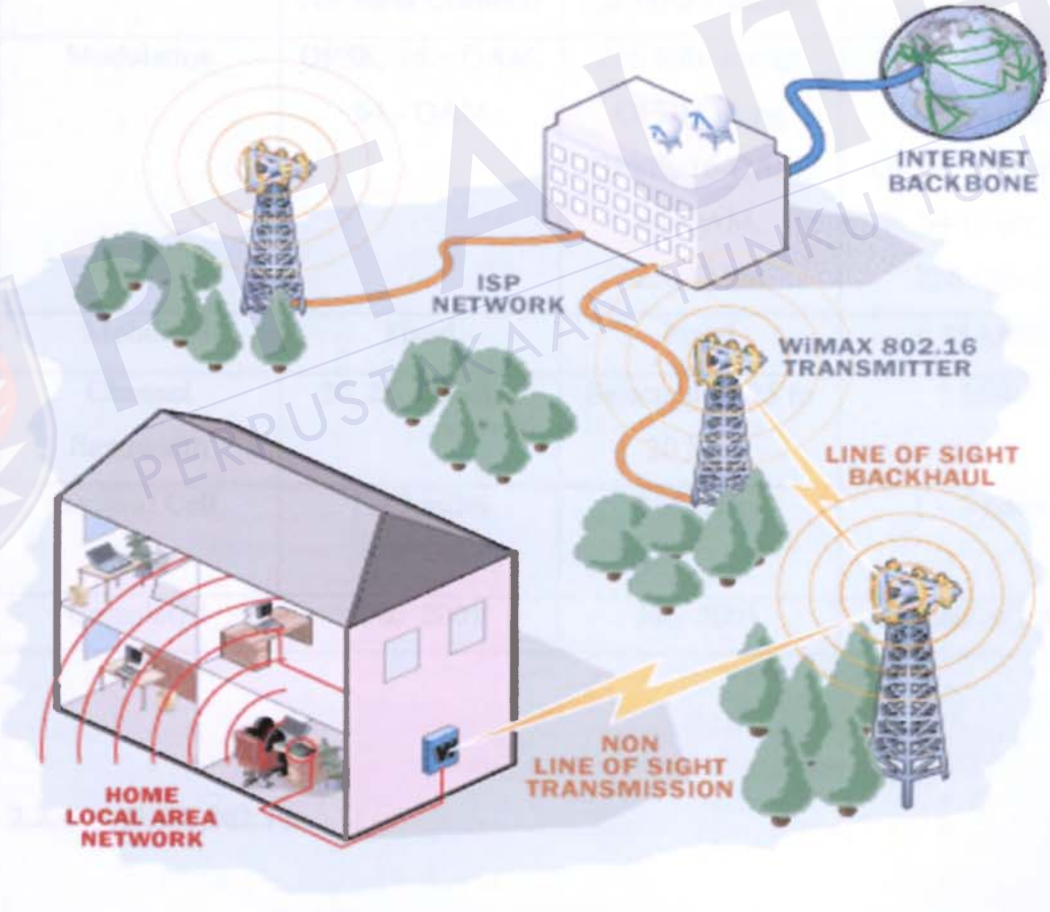


Figure 2.4: The process of WiMax [6]

2.2.3 IEEE 802.16 Standard

Generally WiMax refers to the IEEE 802.16 series of communication standards. The following is the chart of various IEEE 802.16 standard related to WiMax.

Table 2.1: IEEE 802.16 Standards [8].

Parameter	802.16	802.16a	802.16e
Spectrum	10 – 66 GHz	2 – 11 GHz	< 6GHz
Configuration	Line of Sight	None Line of Sight	None Line of Sight
Bit Rate	32 to 134 Mbps (28 MHz Channel)	≤ 70 or 100 Mbps (20 MHz Channel)	Up to 15 Mbps
Modulation	QPSK, 16 – QAM, 64 - QAM	256 Sub- carrier OFDM using QPSK, 16-QAM, 64-QAM, 256-QAM	256 Sub- carrier OFDM using QPSK, 16-QAM, 64-QAM, 256-QAM
Mobility	Fixed	Fixed	< 75 MPH
Channel Bandwidth	20, 25, 28 MHz	Selectable 1.25 to 20 MHz	5 MHz
Typical Cell Radius	1 – 3 miles	3 -5 miles	1 – 3 miles
Completed	Dec. 2001	Jan, 2003	2nd half of 2005

2.2.4 IEEE 802.16a

802.16a is a wireless networking standard that offers greater range and bandwidth than the WiFi family of standards, which includes 802.11a, 802.11b and 802.11g. While WiFi is intended to provide coverage over relatively small areas, such as in offices or hotspots, WiMax can transfer around 72 Mbps over a distance of 3Km to thousands of users from a single base station.

The 802.16a provides wireless, last-mile broadband access over the frequency bands below 11 GHz to connect homes, businesses and wireless LAN hot spots. 802.16a greatly improves non-line-of-sight performance, and it is the most appropriate technology available when obstacles such as trees and buildings are present. Stations can be mounted on homes or buildings rather than towers on mountains.

802.16a provides flexibility not possible with wired services, such as high-speed backhaul for events such as trade shows, with hundreds or even thousands of 802.11 hot-spot users. On-demand connectivity also could benefit businesses such as construction companies that have sporadic or nomadic connectivity needs.

A laptop and desktop computers are connected via wired Ethernet or 802.11 WiFi access points located throughout the campus. An 802.16a directional antenna provides the connection from the business to a service provider's cell tower. Even there is no LOS between the antenna and the tower, signal still can be received after it reflects off buildings or other obstructions and reaches the tower indirectly. At the base station, 802.16a technology correctly interprets the information even though reflections distort the radio frequency signal.

Technical aspects of 802.16a that are instrumental in powering robust performance include it support for licensed and license-exempt band operation below 11 GHz. It has a high spectral efficiency, which reduce carriers costs and improves users' experience. 802.16a also support for advanced antenna techniques to improve range and capacity. For more reliable transmission, forward error correction and space/time coding to enhance performance in fading environments is used. 802.16a technology also provides low latency for delay-sensitive services such as circuit-switched voice traffic or voice over IP, optimized transport for video, and prioritization of data traffic.

2.3 WiFi (IEEE 802.11)

WiFi is the popular wireless technology used in home network, mobile phones, video phones, video games and other electronic devices that require some form of wireless networking capability. In particular, it covers the various IEEE 802.11 technologies including 802.11a, 802.11b, 802.11g, and 802.11n.

2.3.1 802.11 Standard

The IEEE 802.11 specifications are wireless standards that define an "over-the-air" interface between a wireless client and a base station or access point, as well as among wireless clients.

The 802.11 family has grown and contain many standards with very specific objectives. The most popular of those defined by the 802.11b and 802.11g protocols, and are amendments to original standard [9]. Table 2.2 shows the existing norms and their characteristics.

Table 2.2: 802.11 standards [10]

Norm	Characteristic
802.11a	Debit rate up to 54 Mbits/s in the 5 GHz frequency in band.
802.11b	Debit rate up to 11 Mbits/s in the 2.4 GHz frequency in band.
802.11d	The 802.11d norm is an add-on to the norm 802.11 that provide an international use of 802.11 networks by using the appropriate frequency band and the allowed power of the country where you are.

802.11e	The 802.11e norm is focusing on Quality of Services. It operates on the link layer to improve the results of packet transmissions and bandwidth, especially for movie and voice.
802.11f	The 802.11f norm uses the Inter-Access Point Roaming Protocol that allows the user to use handover in a transparent way for him.
802.11g	Debit rate up to 54 Mbits/s in the 2.4 GHz frequency band, full compatibility with the 802.11b norm.
802.11h	The 802.11h norm tends to make converge the 802.11 norm to the European standard HyperLAN 2 to be conformity with European regulation about the used frequencies and energy saving.
802.11i	The 802.11i is focusing on data transmission security by using encryption keys, and authentication techniques. This norm is based on Advanced Encryption Standard (AES) and is used for 802.11a, 802.11b and 802.11g.
802.11j	The 802.11j norm is the equivalent of the 802.11h, in Japan.

The 802.11 works on two lower layer of the OSI model which is a physical and a data link layer as shown in Figure 2.5. Network applications, network operating system or a protocol will work perfectly in the 802.11 network as in the Ethernet. The basic architecture and services of the 802.11b are defined in the initial standard 802.11.

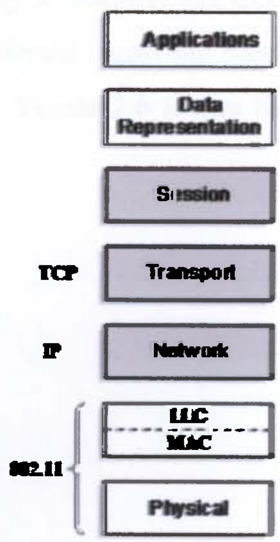


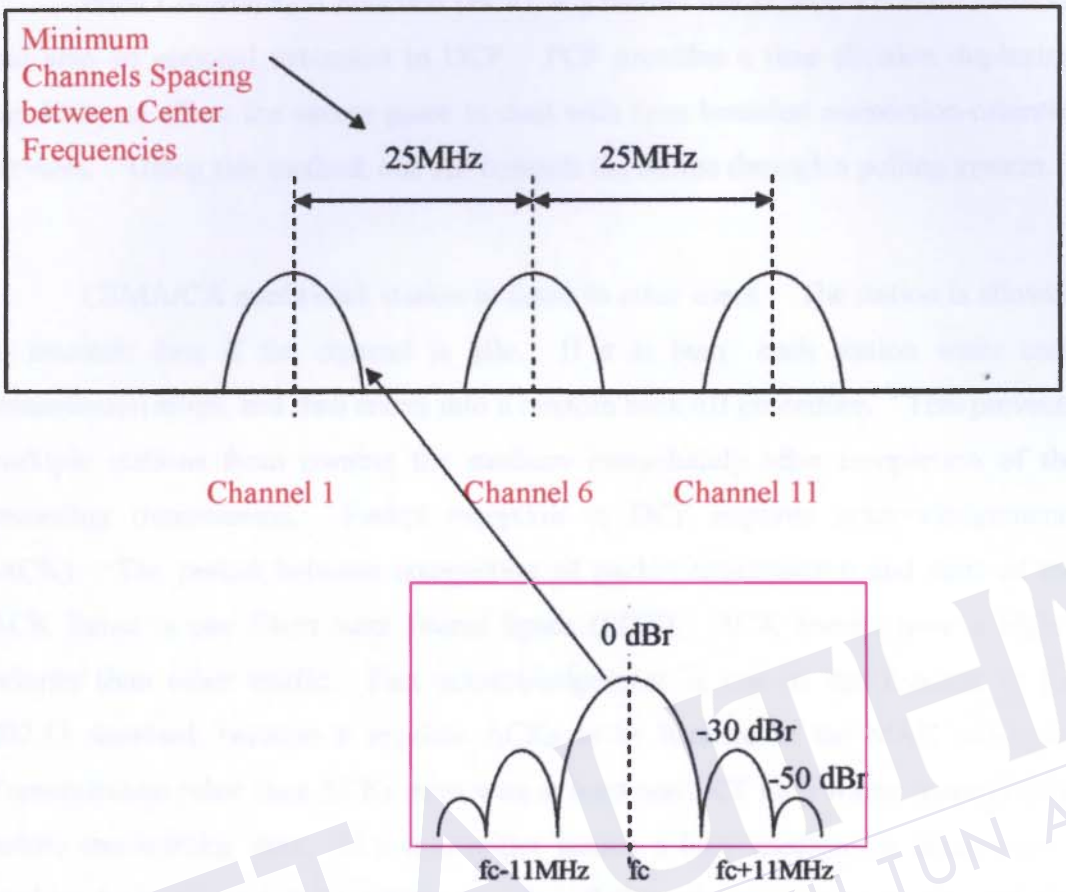
Figure 2.5: OSI model [11]

2.3.2 The 802.11 Physical Layer

The main technologies are used for wireless communications which is Radio Frequency (RF) and InfraRed (IR). RF is located in the 2.4GHz ISM-band and capable of being used for NLOS and longer distance situations. IR is not a useful technology for use in a WLAN system since it is used for short distance communications.

There are two methods of spread spectrum modulation used within the unlicensed 2.4 GHz frequency band: frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). Spread spectrum is ideal for data communications because it is less susceptible to radio noise and creates little interference and it is used to comply with the regulations for use in the ISM band.

By using frequency hopping, the 2.4 GHz band is divided into 75 1-MHz-channels. FHSS allows for a less complex radio design than DSSS but FHSS is limited to a 2-Mbps data transfer rate, the reason for this are the FCC regulations that restrict sub-channel bandwidth to 1 MHz, causing many hops which means a high amount of hopping overhead. For wireless LAN applications, DSSS is a better choice. DSSS divides the 2.4 GHz band into 11 channels. Channels used at the same location should be separated 25 MHz from each other to avoid interference. This means that only 3 channels can exist at the same location. FHSS and DSSS are fundamentally different signalling mechanisms and are not capable of interoperating with each other. Figure 2.6 shows the three non-overlapping DSSS channel.



Channel Spectrum Mask

Figure 2.6: Three non-overlapping DSSS channel

2.3.3 The 802.11 Data Link Layer

The data link layer for 802.11 is divided in two sub-layers which are Logical Link Control (LLC) and Media Access Control (MAC) [11]. The 802.11 characterise the same in LLC sub-layer but defines a different MAC protocol.

The 802.11 standard defines the protocol and compatible interconnection of data communication equipment via the air, radio or infrared, in a local area network (LAN) using the Carrie Sense Multiple Access/ Collision Avoidance (CSMA/CA) medium sharing mechanism. This access method for 802.11 is called Distributed Coordination Function (DCF) and it's mandatory for all stations. In a WLAN, collision detection is not possible as the protocol regulates the access of the stations.

Point Coordination Function (PCF), is a second media access control method, and also an optional extension to DCF. PCF provides a time division duplexing capability to allow the access point to deal with time bounded connection-oriented services. Using this method, one AP controls the access through a polling system.

CSMA/CA needs each station to listen to other users. The station is allowed to transmit data if the channel is idle. If it is busy, each station waits until transmission stops, and then enters into a random back off procedure. This prevents multiple stations from owning the medium immediately after completion of the preceding transmission. Packet reception in DCF requires acknowledgements (ACK). The period between completion of packet transmission and start of the ACK frame is one Short Inter Frame Space (SIFS). ACK frames have a higher priority than other traffic. Fast acknowledgement is one of the features of the 802.11 standard, because it requires ACKs to be handled at the MAC sub-layer. Transmissions other than ACKs must wait at least one DCF inter frame space (DIFS) before transmitting data. If a transmitter senses a busy medium, it determines a random back-off period by setting an internal timer to an integer number of slot times. Upon expiration of a DIFS, the timer begins to decrement. If the timer reaches zero, the station may begin transmission. If the channel is seized by another station before the timer reaches zero, the timer setting is retained at the decremented value for subsequent transmission. The CSMA/CA algorithm is shown in Figure 2.7.

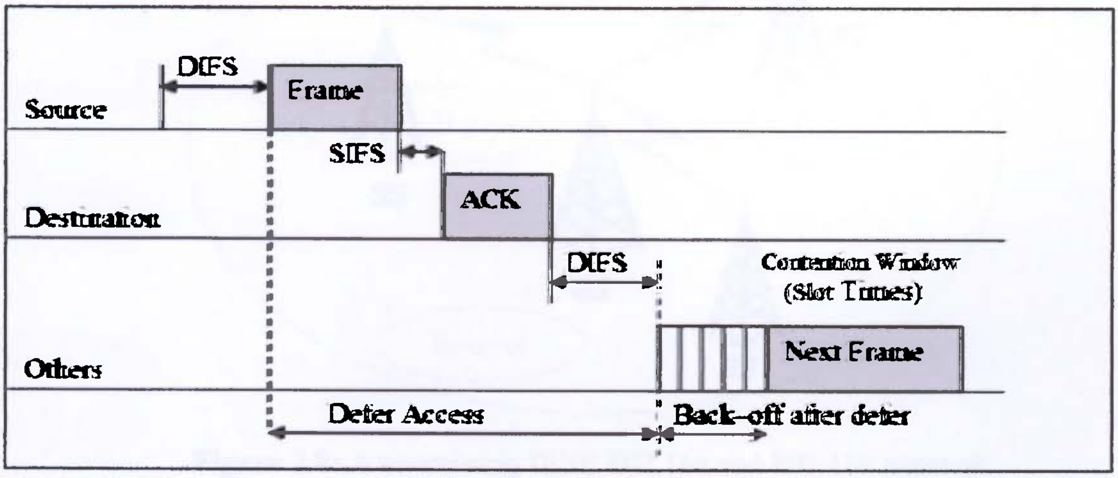


Figure 2.7: CSMA/CA back-off algorithm [11]

2.3.4 IEEE 802.11b

802.11b can support for a maximum data rate of 11 Mbps. It typically provides local network access for around a five hundred meter with speeds of up to 54 Mbps. 802.11b transmits their signal in a narrow radio frequency range of 2.4 GHz. Variety types of electronic devices such as cordless phones, garage door openers, microwave ovens may use this same frequency range. These devices can interfere with a WiFi home network, slowing down its performance and potentially breaking down network connections.

The 2.4 GHz signal range is divided into a number of smaller bands or channels. Any of the channels 1 - 11 can be chosen when setting up a WLAN in order to avoid sources of wireless interference as mention in section 3.4.

2.4 Co-existence of IEEE 802.16a and 802.11b

IEEE 802.16a and 802.11b cells co-exist in overlapping channels is proposed in [12] as shown in Figure 2.8.

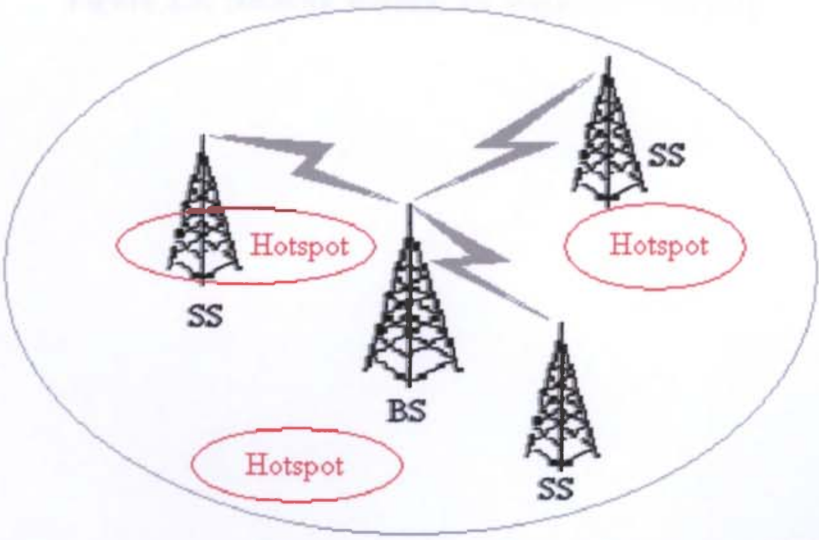


Figure 2.8: A co-existing IEEE 802.16a and 802.11b network

The figure above shows a co-existing network which consist of 802.16a cell with one base station (BS) and several subscriber stations (SS) per cell, and 802.11b hotspots with one access point (AP) and multiple clients in each hotspot. The two systems are deployed in one large geographical area and 802.11b hotspot is inside the coverage of 802.16a as the coverage of the 802.16a cell is larger than the hotspot. The CR scenario is where the 802.16a SS clustered with 802.11b hotspot and they overlap in space.

Another single 802.16a cell and a single 802.11b hotspot, and multiple 802.11b hotspots with varying 802.16a SS are proposed in [13]. Simple network scenario with one 802.16a cell (one BS and one SS) and one 802.11b hotspot (1 AP in the center and 1-4 clients placed 100m away from AP), as shown in Figure 2.9. Figure 2.10 shows the 802.11b nodes are randomly placed inside the hotspot with the distance to AP less than Rmax 11 meters.

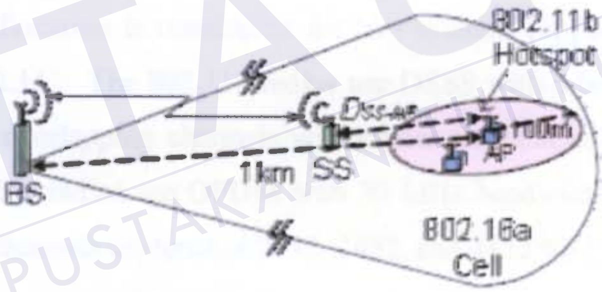


Figure 2.9: Network scenario for single cell case [13]

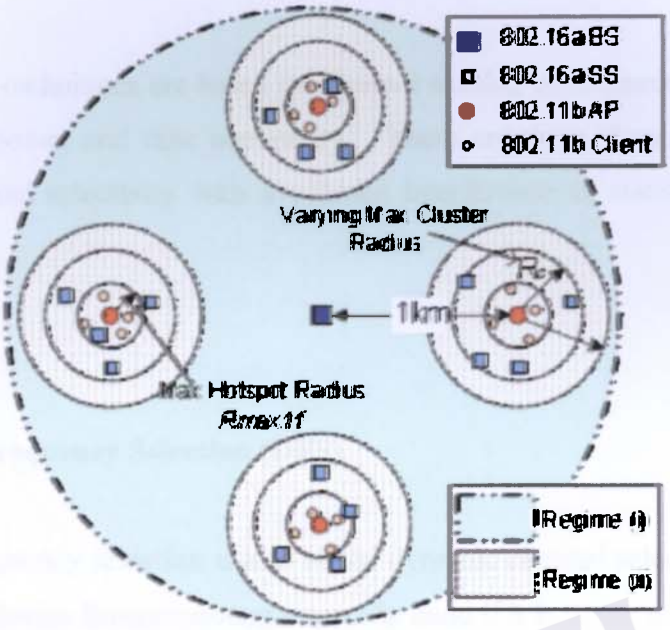


Figure 2.10: Clustered hotspots and 802.16a SS (overlap in space) [13]

Channel allocation is considered for two systems proposed by [14] [12], as shown in Figure 2.11. The 802.11b radios use DSSS with a bandwidth of 22 MHz and there are 11 overlapping channels with center frequencies from 2412 to 2462 MHz. The 802.16a radios use OFDM with 20 MHz bandwidth and there are three non-overlapping channels centered at 2412, 2432, and 2452 MHz.

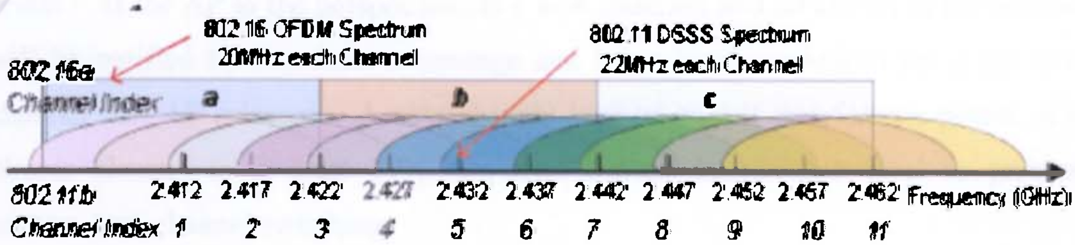


Figure 2.11: Channel allocation for IEEE 802.11b and 802.16a [14]

2.5 Reactive Channel Selection Techniques

Reactive CR techniques are based on channel sensing of transmit parameters such as frequency, power and time occupancy. There are three channel selection techniques for channel selectivity with avoidance interference as stated in section below.

2.5.1 Dynamic Frequency Selection (DFS)

Dynamic frequency selection is also called dynamic channel selection. DFS is used to prevent a device from accessing a specific band if it is in use and to present co-channel interference of the primary user from a secondary user. DFS detects other devices using the same radio channel and it switches operation to another channel if necessary. DFS is responsible for avoiding interference with other devices, and must be able to detect a primary user above a detection threshold of -62dBm [15]. For 802.11b devices, it can dynamically switch channels based on interference level in available sub-bands. Radio nodes scan all the channels in the service band and select the channel with lowest received signal strength indicator for data transmission. In an 802.11b network, channel selection is done by the AP [12], which periodically scans the spectrum band for channels with lower interference levels. If the AP in the hotspot selects a new channels and all clients in the hotspot will be notified by broadcast a message and immediately switch to the same new channel that AP selected. A new channel is used only if interference power of a clearer channel is at least 10% less than current interference level to prevent unnecessary channel switching.

In [5], channel selection is based on primary user activities and throughput threshold. The secondary user changes its operating band when it detects the primary user activity over the operating band. When primary user become active in a primary band occupied by secondary users, the secondary user can either become silent or sense the band until primary user become inactive again or change to another available band, as shows in Figure 3.12.

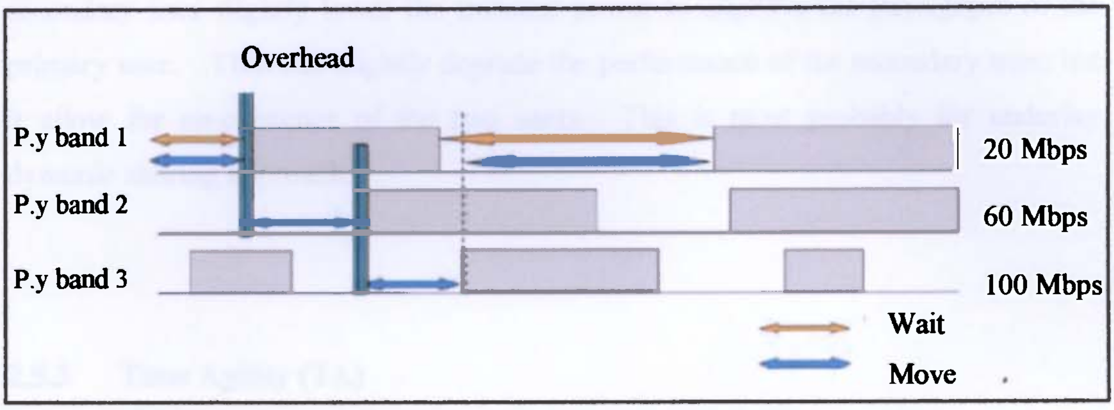


Figure 2.12: Wait or move strategy with three primary bands

Another strategy to select another primary band can be based on preferential channel selection (PCS) or random channel selection (RCS). In the case of preferential channel selection, band with higher maximum data rate are given higher priority. While random channel selection is select the next primary channel in Random Channel Sequence, as show in Figure 2.13.

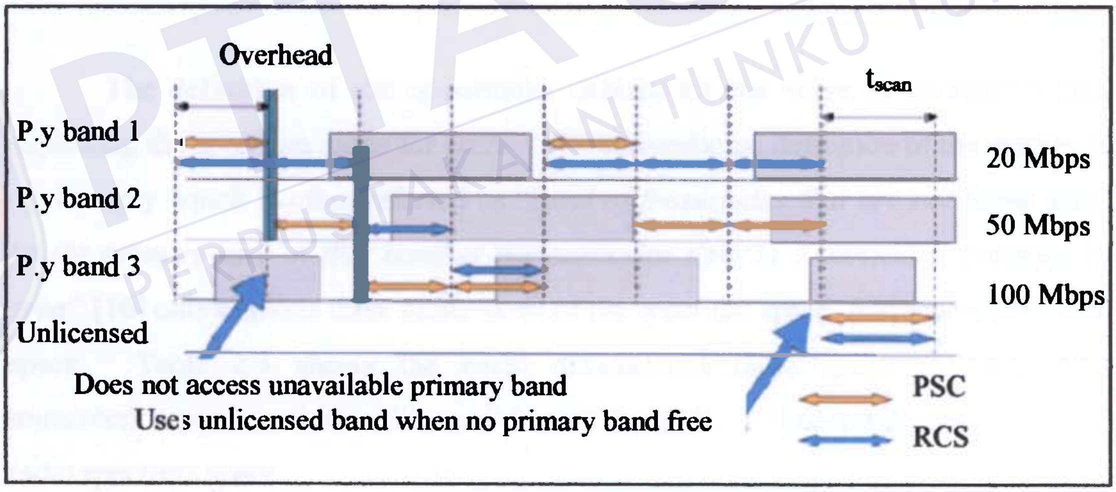


Figure 2.13: RCS and PCS operation with three primary bands

2.5.2 Power Control (PC)

According to [14], this algorithm allow transmitters to use the minimum transmit power for data transfer. In order to allow greater sharing of spectrum,

REFERENCES

[1] Mitola, J. and Maguire, G. (1999). Cognitive radio: Making software radios more personal. *IEEE Wireless Communication,* 6,13-18.

[2] Akyildiz, I. F., Lee, W. Y., Vuran, M. C., and Mohanty, S. (2006). Next Generation/ Dynamic Spectrum Access/ Cognitive Radio Wireless Networks: A Survey. *Computer Network Journal (Elsevier),* 50, 2127-2159.

[3] Cabric, D., Mishra, S. and Brodersen, R. W. (2004). Implementation Issues in Spectrum Sensing for Cognitive Radios. *Signal, System and Computer,* 1, 772 - 776.

[4] Haykin, S. (2005). Cognitive Radio: Brain-Empowered Wireless Communications. *IEEE Journal on Selected Areas in Communications,* 23, 201 -220.

[5] Puri, N. A., Nurul, H. M., Josselin, B., Nicolas, C., Laurent, M. and Hiroyuki, Y. (2008). Dynamic Channel Selection for Cognitive Radios with Heterogenous Primary Bands. *Wireless Personal Communication,* 45, 369-384.

[6] Justin, B. and Ken. L. (2005). WiMax-Ieee 802.16. WiMax Forum. http://nislab.bu.edu/nislab/education/sc441 /JustinKen/JustinKen/Networking%20Webpage/index.htm

[7] Rappaport, T. S. (2002). *Wireless Communication - Principle and Practice.* (2nd ed.). Unites Stated of America: Prentice Hall.

[8] WiMax Standard, http://www.tutorialspoint.com/wimax/wimax_standards.htm

[9] IEEE.802.11. http://en.wikipedia.org/wiki/IEEE_802.11

[10] Puri, N. A., Nurul, H. M., Josselin, B., Nicolas, C., Laurent, M. and Hiroyuki, Y. (2007). *Dynamic Channel Selection for Cognitive Radios with Heterogenous Primary Bands.* Master Thesis. Aalborg University.

[11] William, S. (2007). *Data and Computer Communications.* (8th ed.) Malaysia: Prentice Hall.

[12] Jing, X. P, Mau, S. C. and Matyas, R. (2003). Reactive Cognitive Radio Algorithms for Co-Existence between IEEE 802.11b and 802.16a Networks. Research supported in part by a grant from Nortel, Ottawa, Canada.

[13] Aynur, A., Julie, B., Eddie, B. *et al.* (2007). Cognitive Radio Technology. *QINETIQ, 1.*

[14] Jing, X. P. and Raychaudhuri, D. (2006). Spectrum Co-existence of IEEE 802.1 lb and 802.16a Networks Using Reactive and Proactive Etiquette Policies. *Mobile Network Application,* 11, 539-554.

[15] Bruce, F. (Ed.) (2006). *Cognitive Radio Technology.* (1st ed.). United Stated of America: Elsevier Inc.

[16] Arslan, H. (2007). *Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems.* Netherlands: Springer.

[17] Cristian, I. and Andy, M. (2005). Cognitive Radio and Dynamic Spectrum Sharing. *Proceeding of the SDR 05 Technical conference and Product Exposition.*

[18] The Network Simulator-2 website, http://www.isi.edu/nsnam/ns/

[19] Marc, G. Tutorial for Network Simulator.

[20] E. Altman and T. Jimenez (2003). NS Simulator for Beginners

[21] F. Kelvin and V. Kannan (2008). The NS Manual.

[22] Fedora web. http://fedoraproject.org/

[23] Tao, Y. (2006). The Design and WiMax Module for NS-2 Simulator. Chang Gung University, Taiwan.