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# COGRADNET: UBIQUITOUS HETEROGENEOUS WIRELESS NETWORKS

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**Abstract**

Mobile radio systems have shown rapid growth and hence increase the awareness for more efficient use of spectrum. With the advancements of technology, the development of radio systems that is dynamic and efficient in terms of spectrum usage can be realized. Cognitive radio system is one of the advancement that enhanced the adaptive capabilities of the systems that make the usage of spectrum more efficient, versatile and flexible. It also able to adapt their operations based on its internal and external factors by sensing its environment. The cognitive radio systems may be a solution for the spectrum scarcity faced by developer to tackle the issue of signal propagation and bigger coverage for broadband internet access. This paper will addressed the cognitive radio technology for ubiquitous broadband wireless internet access.

Keywords: Cognitive Radio Networks, Wireless Networks, Ubiquitous, Heterogeneous

## 1. Introduction

The advancement of wireless communication has brought up the idea of getting connection to the internet seamlessly regardless of where we are. People are increasingly dependant on information available on the internet. Therefore, telecommunication operators are investing and bidding for spectrums band to provide services such as 3G and WiMAX to deliver broadband internet access for the users.

Although spectrum is control and governed by regulator of the country, however the resources in some frequency bands have come to its limit. For example the usage of spectrum in the Very High Frequencies (VHF) and Ultra High Frequencies (UHF) are nearly fully occupied. Hence some mechanisms need

**Abbreviations**

| | |
|---|---|
| 3G | Third Generation Mobile System |
| AODV | Ad Hoc On Demand Distance Vector |
| AP | Access Point |
| BS | Base Station |
| CogRadNet | Cognitive Radio Networks |
| CPE | Customer Premises Equipment |
| CR | Cognitive Radio |
| DSDV | Destination Sequenced Distance Vector |
| DSR | Dynamic Source Routing |
| FCC | Federal Communications Commission |
| IEEE | Institute of Electrical and Electronics Engineering |
| ITU | International Telecommunication Union |
| MAC | Medium Access Control |
| MS | Mobile Station |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OLSR | Optimized Link State Routing |
| P2MP | Point To Multipoint |
| PHY | Physical Network Layer |
| QAM | Quadrature Amplitude Modulation |
| SDR | Software Defined Radio |
| UHF | Ultra High Frequency |
| UWB | Ultra Wide Band |
| VHF | Very High Frequency |
| WiMAX | Worldwide Interoperability for Microwave Access |
| WRAN | Wireless Regional Area Network |
| WRC | World Radiocommunication Conference |

to be formed so that the VHF and UHF can be used by other applications. The VHF and UHF are popular for their propagation and their long-range coverage.

Researchers at the moment are looking into two broadband concept called cognitive radio and ultra-wide band (UWB). Among the two, cognitive radio is the concept being considered by most of the researchers. The term “Cognitive Radio” was coined by Joseph Mitola III [1] and has been a topic of interest since it evolved from the Software Defined Radio (SDR) concept. Many definitions have been introduced to describe the cognitive radio concept. The standards for cognitive radio were also being developed to make the concept realized and relevant. This paper will highlight on the terminology of the Cognitive Radio Networks (CogRadNet), specifications, architectures and related protocols in enabling the CogRadNet for ubiquitous heterogeneous wireless networks.

## 2. The Terminology

The terminology being discussed for cognitive radio is very extensive since there is no finite definition to the term. Several researchers have outlined their definitions according to the field they are tackling. However, the keywords for cognitive radio networks can be deduced as it share the common criteria in terms of it operations.

Cognitive radio are said to be adaptive enough to selects communication methods, modulation methods, frequency and other parameters according to the recognized radio environment. It has the possibility to intermittently change or hop from one frequency to another in order to provide service to the user. This will drastically change the conventional frequency assignment policy made by regulators.

In the conventional frequency assignment policy, the frequency band is fixedly assigned to the operator. On the other hand, in the cognitive radio, the frequency band that is not used by the other communication systems can be used for any users, so the fixed frequency assignment may not be required.

According to [2], the cognitive radio is defined as a radio that can change its transmitter parameters based on interaction with the environment in which it operates. Hence, the concept should include the cognitive capabilities which include capturing or sensing the propagation parameters i.e. transmission power, centre frequency etc., from its radio environment. While in [3], cognitive radio is defined as network of radios that co-exists with higher priority primary users, by sensing their presence and modifying its own transmission characteristics in such a way that they do not yield any harmful interference. FCC [4] defines cognitive radio as technologies that can make possible more intensive and efficient spectrum use by licensees within their own networks, and by spectrum users sharing spectrum access on a negotiated or an opportunistic basis.

## 3. Related Works

Several works have been done by the international bodies to define the cognitive radio terminology and standardized it. The well-known international bodies such as the Federal Communications Commission (FCC), the International Telecommunication Union (ITU) and the Institute of Electrical and Electronics Engineers (IEEE) have been working on the concept of cognitive radio. The organizations were looking at different angle of standardization which is described in the following.

### 3.1. Federal communications commission (FCC)

In December 2003, FCC has release a notice of proposed rule making and order number FCC 03-322 to study the cognitive radio technology. According to FCC [4], cognitive radio systems can be deployed in network-centric, distributed, ad hoc, and mesh architectures, and serve the needs of both licensed and unlicensed applications. For example, cognitive radios can function either by employing cognitive capabilities within a network base station that in turn controls multiple individual handsets or by incorporating capabilities within individual devices.

A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. The FCC [4] refers to a Software Defined Radio (SDR) as a transmitter in which the operating parameters can be altered by making a change in software that controls the operation of the device without changes in the hardware components that affect the radio frequency emissions. The majority of cognitive radios will probably be SDRs, but neither having software nor being field reprogrammable are requirements of a cognitive radio [4].

### 3.2. Institute of electrical and electronics engineering (IEEE)

In November 2004, the IEEE 802.22 Working Group was established to define wireless air interface standard based on cognitive radio. The Working Group is chartered with the development of a cognitive radio based Wireless Regional Area Networks (WRAN) Physical (PHY) and Medium Access Control (MAC) layers for used by license-exempt devices in spectrum that is currently allocated to the Television (TV) service [5]. The IEEE 802.22 specifies that the network should operate in a point to multipoint basis (P2MP). The system will be formed by base stations (BS) and customer-premises equipments (CPE and also Access Points).

In April 2007, the IEEE Standards Board has approved the reorganization of the IEEE 1900 effort as Standards Coordinating Committee 41 (SCC41), Dynamic Spectrum Access Networks (DySPAN). The IEEE Communications Society and EMC Society are sponsoring societies for this effort, as they were for the IEEE 1900 effort [6].The IEEE SCC41 initially divided into four working groups (WGs) and added two more WGs later. Each of the WG will be responsible to form standards in different aspects of cognitive radio and denoted as IEEE 1900.x. The six WGs and their responsibility are listed in Table 1.

**Tab. 1. IEEE SCC41 Working Groups.**

| Working Group | Responsibility |
|---|---|
| IEEE 1900.1 | Standard definitions and concepts for spectrum management and advanced radio system technologies. |
| IEEE 1900.2 | Recommended practice for interference and coexistence analysis. |
| IEEE 1900.3 | Recommended practice for conformance evaluation of software defined radio software modules. |
| IEEE 1900.4 | Coexistence support for reconfigurable, heterogeneous air interfaces. |
| IEEE 1900.5 | Policy language and policy architectures for managing cognitive radio for dynamic spectrum access. |
| IEEE 1900.6 | Spectrum sensing interfaces and data structures for dynamic spectrum access and other advanced radio communication systems. |

### 3.3. International telecommunication union (ITU)

International Telecommunication Union (ITU) is still working to come up with proper definition for cognitive radio. Currently the cognitive radio and its issues are being discussed in the Working Party 5A under the title of Cognitive Radio Systems in the Land Mobile Service.

The working party has not finalized the definition but has provided the idea of the cognitive radio which is [7]:

> *A radio system that has the capability to sense and be aware of its operational environment, to be trained to dynamically and autonomously adjust its radio operating parameters accordingly and to learn from the results of its actions and environmental usage patterns.*

The definition of the cognitive radio will be finalized in the World Radiocommunication Conference 2011 (WRC11).

## 4. Cognitive Radio Specifications

Although the cognitive radio concept is still under development, some of the characteristics and specifications can be outline as there have been a lot of undergoing experiments to facilitate the standardization of cognitive radios. The characteristics and specifications of cognitive radio are described below.

### 4.1. Operating frequencies

The cognitive radio is a solution to accommodate lack of frequency resource in Very High Frequency (VHF) band and Ultra High Frequency (UHF) spectrum. The VHF band is the radio frequency band ranging from 30 MHz to 300 MHz. The UHF band is the electromagnetic waves raging between 300 MHz and 3 GHz. The VHF and UHF are commonly used for the transmission of television signals. Besides that, UHF is widely used for mobile phones, two-way radio communication, radio broadcasting and global positioning system (GPS).

In the UHF bands, there is the industry, scientific and medical (ISM) band between 2.4 GHz and 2.5 GHz. The popular use of this band is the 2.45 GHz band which consists of WiFi, Bluetooth and US cordless phones. Other than that the UHF also commonly is used by the amateur radio operators which operate in several UHF bands.

### 4.2. Cognitive techniques

According to [2], the key enabling technologies of CogRadNet are the cognitive radio techniques that provide the capability to share the spectrum in an opportunistic manner. Based on the definition of CR, the two main characteristics of cognitive radio techniques are [8]:

- ***Cognitive capability***: using real-time sensing of the radio environment, spectrum holes or white spaces that were unused at a specific time or location can be determined. Therefore, the best spectrum can be selected, shared and exploited without interference with the licensed user.

- ***Re-configurability***: taking advantages of cognitive radio evolved from the software defined radio, it should be able to be programmed to transmit and receive various frequencies and use different access technologies available. Therefore, the best spectrum band and its operating parameters can be selected and reconfigured.

In order to have a workable cognitive radio network, the cognitive radio system should accommodate spectrum sensing, spectrum management activities, support spectrum mobility and spectrum sharing. These functions must be incorporated in the design of any cognitive radio system. The details of the function are described below [9]:

- ***Spectrum Sensing***: detects the unused spectrum and used it without causing harmful interference with other users. The CogRadNet device should sense the spectrum holes by detecting whether the primary user is using the specific spectrum. This technique can be classified into three categories: transmitter detection, cooperative detection and interference based detection
- ***Spectrum Management/Decision***: this function deals with capturing the best available spectrum to meet the secondary user communication needs. The cognitive radios should decide on which spectrum bands is the best to meet the quality of service (QoS) requirements from all available spectrum bands. Therefore the function should assist the cognitive radios to do spectrum analysis and spectrum decision.
- ***Spectrum Mobility***: this is a process where cognitive radio users change its operating frequency. The CogRadNets target is to use the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band while maintaining seamless connection during the transition to better spectrum band.
- ***Spectrum Sharing***: the function provides fair spectrum scheduling method. A major challenge in the open spectrum usage is the spectrum sharing where issues of interference would probably triggers the primary users. It is similar to the generic medium access control (MAC) problems in the existing networking system.

The cognitive techniques are the most crucial part of the cognitive radio system. The techniques determined the functionality of each step to be implemented.

### 4.3. Overlay spectrum

As mentioned earlier, the cognitive radio utilized the spectrum holes or the white spaces available at the specific time and location. In CR techniques, frequency agile transmitters target unused spectrum “holes” and transmit power within these unused regions. By doing so, CR interference to existing wireless systems is minimized. The cognitive radio transmission employs an overlay waveform which operates only in vacant spectral bands. Hence, it is clear that current cognitive radio transmission is a soft decision cognitive radio when no underused frequency components are exploited [10]. Figure 1 shows the spectrum band usage of the primary and the CogRadNet in term of power density and frequency.

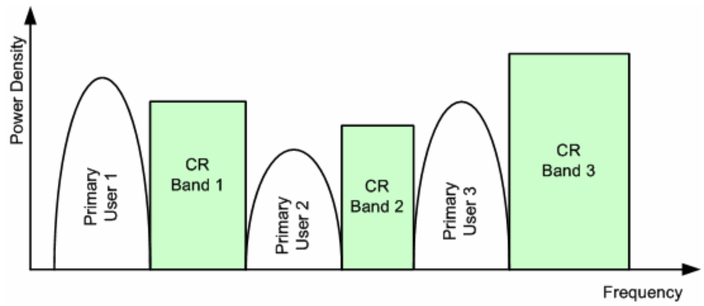


**Fig. 1. Cognitive Radio Overlay Waveform.**

Referring to the graph, the cognitive radio user or the secondary user will be sensing for the spectrum "holes" within the spectrum range. In this case, the secondary user will utilized the frequencies between 30 MHz to 3 GHz. Any spectrum "hole" will be accommodated by the secondary user subject to its availability. However, the frequency allocation for the cognitive radio network need to be defined before it can operate.

### 4.4. Orthogonal frequency-division multiplexing (OFDM)

The Orthogonal Frequency-Division Multiplexing (OFDM) is a scheme utilized as a digital multi-carrier modulation method. In a large number of closely-spaced orthogonal sub-carriers, the data are divided into several parallel data streams or channel which is one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (QAM or PSK) at low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

The OFDM has been a popular scheme for wideband digital communication, whether wireless or over copper wires. Examples of the applications using OFDM are the digital television and audio broadcasting, wireless networking and broadband internet access.

The advantage of OFDM over the single-carrier schemes is its ability to cope with severe channel conditions i.e. attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath fading. Channel equalization is simplified in OFDM since it may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. Low symbol rate make the use of guard interval between symbols reasonable, making it possible to handle time-spreading and eliminate intersymbol interference (ISI). The mechanism also facilitates the design of single-frequency networks, where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively rather than interfering as it would typically occur in a single-carrier system.

## 5. CogRadNet Architectures

According to [11] the cognitive radio networks can be deployed in network-centric, ad hoc and mesh architecture. CogRadNet can be divided into three types of architectures which are infrastructure, ad hoc and mesh architectures. Four basic components involve are mobile stations (MS), base stations (BS) or access points (AP), CogRadNet terminal (CRNT) and backbone/core networks. The architectures are described as follows.

### 5.1. Backbone/infrastructure architecture

The infrastructure architecture facilitates the communication between CRNT, MS and BS/AP only in one-hop. All MSs and CRNT using the same BS/AP will communicate with each other via the BS/AP. In this case the BS/AP will act as the switch between the MSs and CRNT. Communication with other MSs with different BS/AP will be done via the backbone/core network. A CRNT can access the network via the dedicated BS/AP using any standards or protocols to connect with each other. The architecture is depicted in Fig. 2.

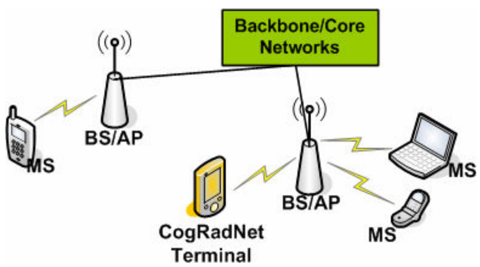


**Fig. 2. Infrastructure Architecture.**

### 5.2. Ad hoc architecture

The ad hoc infrastructure consists of at least two MSs or CRNTs. There are no infrastructure support or defined in the ad hoc architecture (see Fig. 3). The MS and CRNT will have to initiate the connection or define its own network before making connection among the neighbouring MS or CRNT. Two CRNTs can be connected via existing communication protocol such as the WiFi, Bluetooth or by utilizing any spectrum holes that exist.

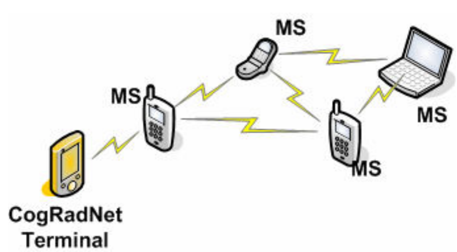


**Fig. 3. Ad hoc Architecture.**

### 5.3. Mesh architecture

The mesh architecture, Fig. 4, takes the advantage of the infrastructure architecture and ad hoc architecture by enabling all the wireless connection that available on the MS and CRNT. The MS and CRNT might have the WiFi, Bluetooth or any WRAN related equipment yet to be developed. The BSs/APs will work as wireless routers to form the wireless backbone. MSs and CRNTs can access the BSs/APs directly or by using other MSs and CRNTs as multi-hop relay nodes. Some BSs/APs will be connected to the wired backbone/core networks and may act as a gateway to the internet. While the BSs/APs are not necessarily connected to the backbone, it can also function as a repeater to form a wireless mesh. In this architecture, both CRNTs and BSs/APs have to be smart enough to sense and use the spectrum holes to facilitate the communications between them.

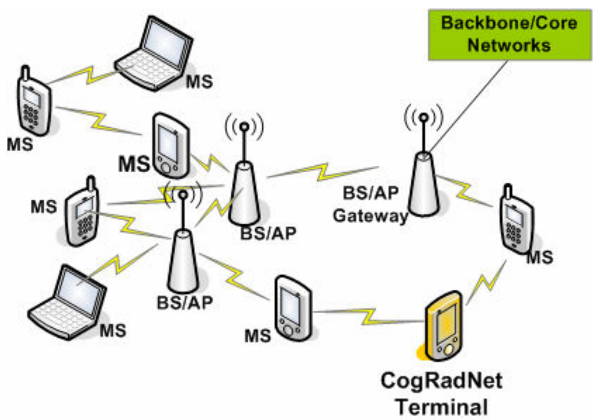


**Fig. 4. Mesh Architecture.**

From the highlighted architectures described above, overall architecture of the CogRadNet can be realized. The overall architecture for the cognitive radio network should consist of all available mobile technology that falls into the frequency range from 30 MHz to 3 GHz. The available mobile services falls into the range of frequency are the second/third generation (2G/3G) mobile, wireless technology (WiFi), Worldwide Interoperability for Microwave Access (WiMAX) and etc. The overall architecture that consists of all highlighted architectures can be visualized in Fig. 5.

## 6. Cognitive Radio Protocols

Cognitive radio protocols are still under development by research communities and industrial players. According to [12], the cognitive radio networks are more specific in the physical (PHY) and the link layer of the OSI/ISO network layer. Details of the about the communication stacks can be found in [12].

Since the architecture of the CogRadNet is the combination of ad hoc and mesh architecture, the numbers of routing protocols can be pick-up to suit it, combined

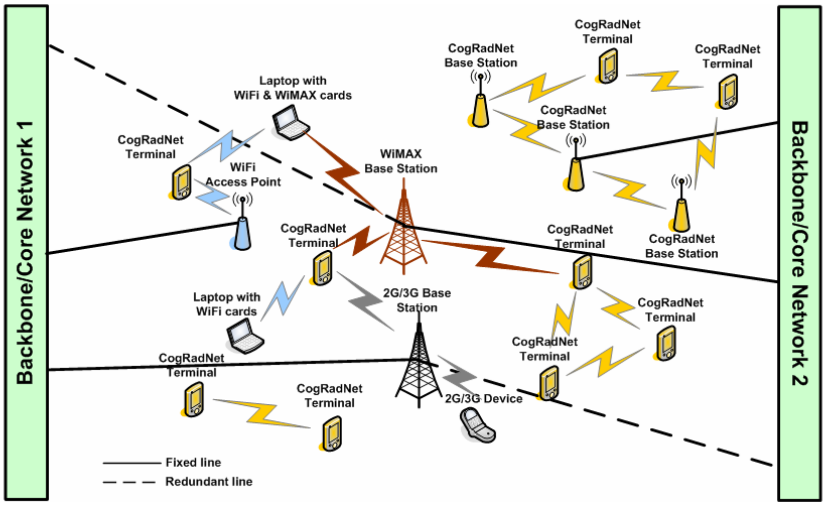


**Fig. 5. Ubiquitous Heterogeneous CogRadNet Architecture.**

with the infrastructure routing protocols. Some of routing protocols available for the cognitive radio network include the Destination-Sequenced Distance-Vector (DSDV) [13], Optimized Link-State Routing (OLSR) [14], Ad Hoc On-Demand Distance Vector (AODV) [15], AODV-OLSR [16] and Dynamic Source Routing (DSR) [17]. For the time being, specific routing protocols for the CogRadNet have not been developed yet. This has opened a research opportunity to further investigate and deduce the suitable routing protocol for the CogRadNets.

## 7. Potential Applications

According to [18], future applications for development of cognitive radio include: collaborative networks; maintenance and fault detection networks; self-organized networks; and cognitive multiple input multiple output.

In addition, while countries are promoting the digital broadcasting, there would be other opportunity for the existing broadcaster to utilize their existing band by introducing more services. The cognitive radio approach can be useful in other applications such as home environment, messaging devices and other non-real time communication systems [19]. The cognitive radio would also improve the communications in emergency situations when the traditional network becomes congested due to the limited availability of spectrum bands.

## 8. Conclusion

Cognitive Radio has been a very interesting technology since it was coined by Mitola. Although the technology promotes the efficient usage of spectrum in VHF and UHF bands, however the technology itself must guarantee the licensed user does not affected by introducing this technology. Therefore, a regulatory measure must be taken into account in enhancing the cognitive radio technology. Therefore, from the perspective of the internet service provider (ISP), there is an opportunity to rationalize the implementation of ubiquitous heterogeneous wireless network. The service could be extended to every home whether they are living in the urban, sub-urban, or rural areas without relying on the cable connections to each house. Hence this technology could bridge the gap of the digital divide.

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