Department of Electrical and Electronic Engineering

BRAC UNIVERSITY

THESIS REPORT ON

COGNITIVE RADIO WIRELESS NETWORKS

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ABSTRACT

Standards groups and regulatory bodies around the world are increasingly seeking new ways of using, allowing access to, or allocating spectrum. In most parts of the world, cellular network bands are overloaded, but amateur radio and paging frequencies are not. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends strongly on time and place. Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used by unlicensed users, even when their transmissions would not interfere at all with the assigned service. This was the reason for allowing unlicensed users to utilize licensed bands whenever it would not cause any interference (by avoiding them whenever legitimate user presence is sensed). This paradigm for wireless communication is known as cognitive radio.

CONTENTS:

DECLARATION

We hereby declare that this thesis is based on the information found by ourselves. Resources of work found by other researcher are mentioned in the bibliography section. This thesis, neither in whole nor in part, has been previously submitted for any degree.

11/08/2011

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1. Introduction:

In the recent years, there is a spectacular increase in the access to the limited spectrum for mobile services straining the effectiveness of the traditional spectrum policies. The limited available spectrum and the inefficiency in the spectrum usage call for a new communication paradigm to exploit the existing wireless spectrum opportunistically. DSA (Dynamic spectrum access) is proposed to solve these current spectrum inefficiency problems. DARPAs approach on Dynamic Spectrum Access network, the so-called NeXt Generation (xG) program aims to implement the policy based intelligent radios known as cognitive radios. Cognitive networks can dynamically adapt their operational parameters in response to user needs or changing environmental conditions. They can learn from these adaptations and exploit knowledge to make future decisions.

Cognitive networks are the future, and they are needed simply because they enable users to focus on things other than configuring and managing networks. Without cognitive networks, the invasive computing vision calls for every consumer to be a network technician.

In 1998, the idea of cognitive radio was first officially presented by Joseph Mitola III in a seminar at KTH, The Royal Institute of Technology, and published later in 1999 in an article by Mitola and Gerald Q. Maguire, Jr. It was an original approach in wireless communications that Mitola afterward described as:

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.

The motivation for cognitive radio branches from various measurements of spectrum utilization, which generally show that spectrum is under-utilized.

Cognitive radio is an emerging technology in wireless access, aimed at vastly improving the way radio spectrum is utilized. This means that there are many "holes" in the radio spectrum that could be exploited by the secondary users. From figure 1, cognitive radio's concept is explained in the simplest way.

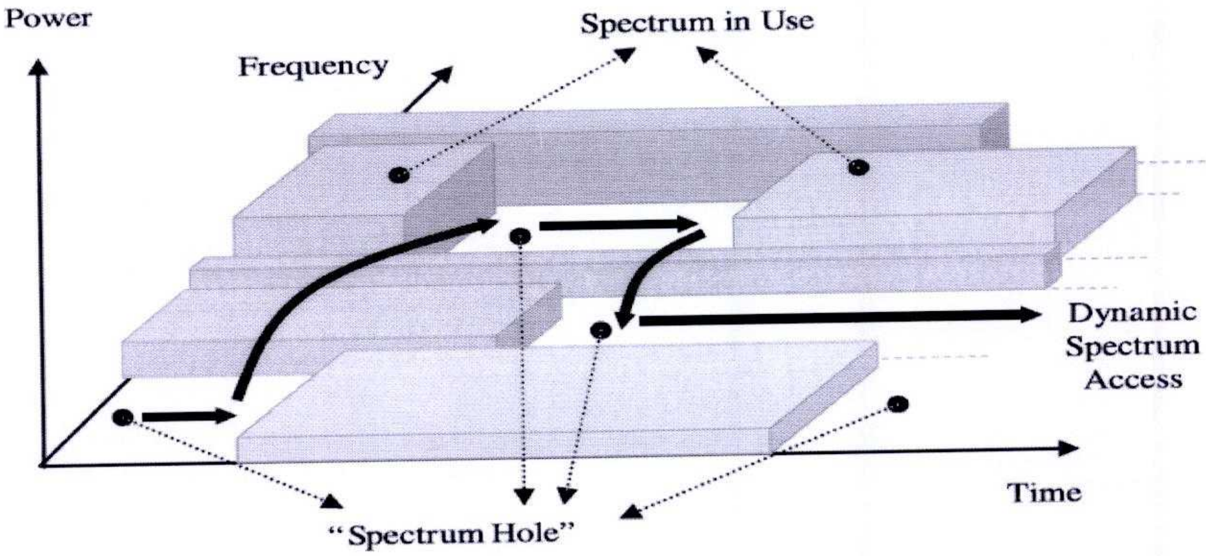

Fig. 1: Spectrum hole and Cognitive Radio

Here, most of the spectrum is already allocated, so the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users as illustrated in figure 1. The cognitive radio 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 cognitive radio moves to another spectrum hole.

To make the network adaptive to the available spectrum, this technology hence requires new functionalities in the xG network. By summarizing the main functions for cognitive radios in xG networks, we have:

- **Spectrum sensing:** Identifying unused spectrum and then sharing the spectrum without damaging intrusion with other users.
- **Spectrum management:** Capturing the best available spectrum to meet user communication requirements.

• **Spectrum mobility:** Sustaining faultless communication requirements during the transition to better spectrum.

• **Spectrum sharing:** Providing the fair spectrum scheduling method among coexisting xG users.

With the new functionalities, there come two main characteristics of the cognitive radio as follows:

• **Cognitive capability:** Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. The portions of the spectrum that are unused at a specific time or location can be identified. Therefore, the best spectrum and appropriate operating parameters can be selected.

• **Reconfigurability:** Reconfigurability enables the radio to be dynamically programmed according to the radio environment to transmit and receive on a variety of frequencies and to use different transmission access technologies.

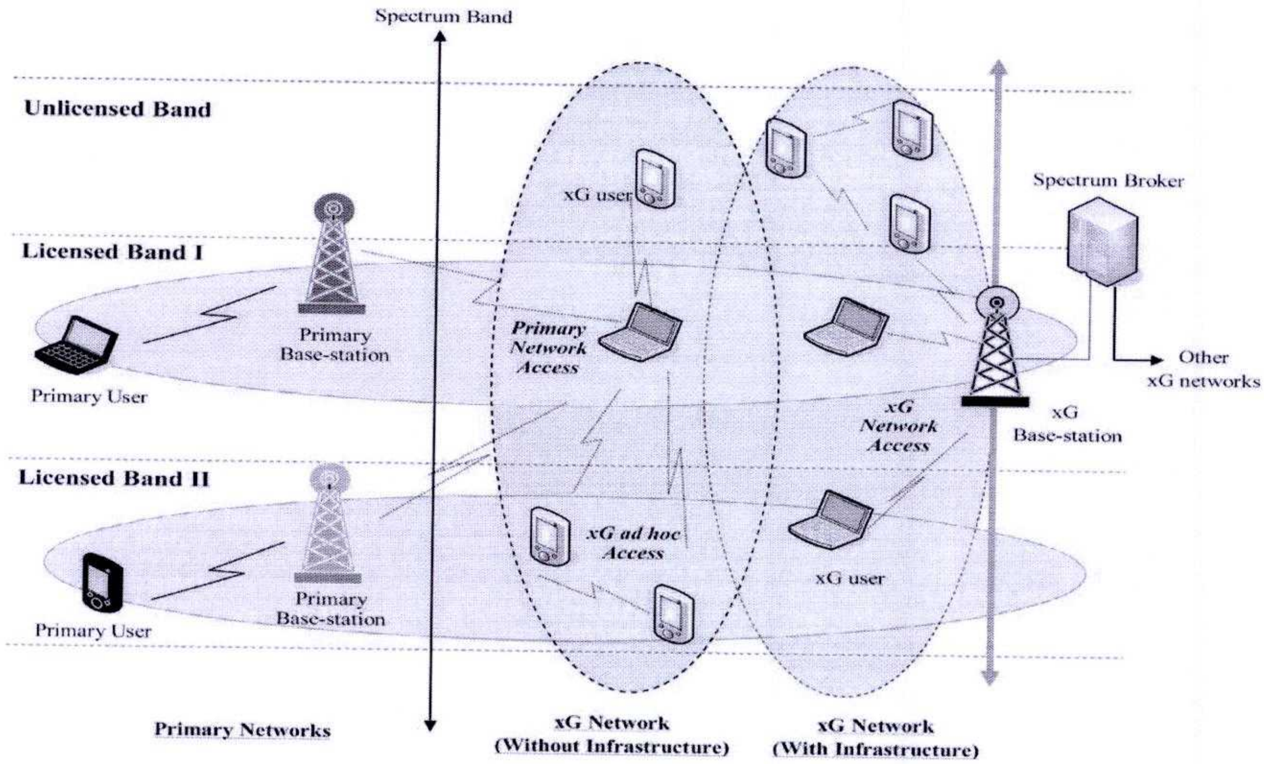

Fig. 2: xG Network architecture

The components of the xG network architecture, as shown in Fig. 2, can be classified in two groups as the primary network and the xG network. The basic elements of the primary and the xG network are defined as follows:

• **Primary network:** An existing network infrastructure is generally referred to as the primary network, which has an exclusive right to a certain spectrum band. Examples include the common Cellular and TV broadcast networks. The components of the primary network are as follows:

- **Primary user:** Primary user (or licensed user) has a license to operate in a certain spectrum band. This access can only be controlled by the primary base-station and should not be affected by the operations of any other unlicensed users. Primary users do not need any modification or additional functions for coexistence with xG base-stations and xG users.
- **Primary base-station:** Primary base-station (or licensed base-station) is a fixed infrastructure network component which has a spectrum license such as base-station transceiver system (BTS) in a cellular system. The primary base-station does not have any xG capability for sharing spectrum with xG users. However, it may be requested to have both legacy and xG protocols for the primary network access of xG users, which is explained below.

• **xG network:** xG network (or unlicensed network) does not have license to operate in a desired band. Hence, the spectrum access is allowed only in an opportunistic manner. xG networks can be deployed both as an infrastructure network and an ad hoc network as shown in Fig. 6. The components of an xG network are as follows:

- **xG user:** xG user (or unlicensed user, cognitive radio user, secondary user) has no spectrum license. That is why additional functionalities are required to share the licensed spectrum band.
- **xG base-station:** xG base-station (or unlicensed base-station, secondary base-station) is a fixed infrastructure component with xG capabilities which provides single hop

connection to xG users without spectrum access license. Through this connection, an xG user can access other networks.

- **Spectrum broker:** Spectrum broker (or scheduling server) is a central network unit that plays a role in sharing the spectrum resources among different xG networks.

The concept of Cognitive Radio is important because:

- it senses RF Environment and modifies frequency, power or modulation
- it allows Real Time Spectrum Management
- significantly it increases Spectrum Efficiency
- it acts as an enabler to improve efficiency following a step wise introduction towards a dynamic spectrum management regime.

1.1 Recent Research Areas in Cognitive Radio:

Research in Cognitive Communications, Networking, and Security by Beibei Wang, Yongle Wu, Yan Chen is provided below:

- Our research is focused on developing efficient dynamic spectrum access schemes to optimize the spectrum efficiency using game-theoretic and stochastic modeling approaches.
- Due to limited network resources in a multi-user radio environment, a particular user may try to exploit the resources for self-enrichment, which in turn may prompt other users to behave the same way. In addition, cognitive users are able to make intelligent decisions on spectrum usage and network operating parameters based on the sensed spectrum dynamics and other users' decisions. Thus, we analyze the intelligent behavior and complicated interactions of cognitive users using game-theoretic approaches.
- Moreover, the radio spectrum environment is highly dynamic, due to fading, user mobility in space and frequency domains, traffic variations, etc. Such

dynamics brings a lot of overhead when users try to optimize system performance through information exchange in real time. Hence, we perform stochastic modeling for characterizing environment variations.

- In addition, due to the intrinsic feature of dynamic spectrum access, a cognitive radio network is also very vulnerable to malicious attacks. For instance, malicious users, if also equipped with cognitive radio, can launch more complicated and unpredictable attacks with even greater damage. In our approach, we also investigate the various security issues in cognitive radio networks, and design robust spectrum access and sharing schemes.
- The advance of cognitive radio technology leads to a new challenging research direction: content-aware multimedia applications over cognitive radio networks. We study the problem of multimedia streaming over cognitive radio networks and design cheat-proof spectrum auction schemes.

The project below is divided into two main tasks which tackle on challenging issues in the cognitive radio system.

Task 1. Dynamic Spectrum Management

The key information to prevent the interference from a secondary user to a primary user is the spectrum environment at the receiver of the primary user. As shown in Figure 2, even if a secondary transmitter (ST1) does not detect the signal of a primary transmitter (PT1), the transmission of ST1 can cause interference to the primary receiver (PR1). Many solutions to this so-called hidden terminal problem have been proposed for homogeneous system where a transmitter and a possibly interfered terminal can exchange information on the interference condition. However, in cognitive radio, the primary and secondary users cannot necessarily exchange information. In this case, a secondary terminal needs to estimate the actual spectrum environment in a separate place. Such a remote sensing in a cognitive radio system is a challenging open issue. The cooperation among many secondary terminals (e.g. secondary terminals surrounding ST1 in Figure 3) at different places can be exploited to achieve this remote sensing.

Once the available spectrum is found, the secondary user must decide the transmission formats and their parameters. In cognitive radio, the primary user allows a certain level of interference from the secondary users, and this requires careful specification of the regulation, that is, the interference level and interference patterns that the secondary user is allowed to cause to the primary users. However, if we first specify the allowable interference and then develop the spectrum access algorithms, we may end up in a situation that is similar to the present regulation, where the rigid rules are severely restricting innovation in the spectrum access techniques. Therefore, in our approach, the spectrum usage rules and the spectrum usage algorithms will be addressed jointly. Only in that manner can a good trade-off be achieved between system performance and etiquette of spectrum utilization.

The above problem will be also considered for the case with different primary users requiring diverse limits on interference levels. In addition, there can be internal gradation among the secondary users, so that a secondary user from a low-priority class should give precedence to the one from a higher class. The existence and specification of such priority classes are also necessary issues to be investigated.

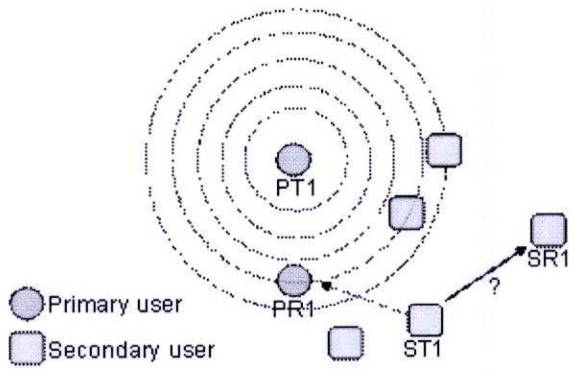

Fig. 3: Hidden terminal scenario in cognitive radio

1.2 Task Goal

The goal of this task is to develop dynamic spectrum management techniques and propose regulations for cognitive radio system. The advanced techniques for spectrum sensing, signal/power adaptation, resource allocation, and interference management must be developed together with the regulations and protocols to utilize the radio spectrum. The proposed techniques and regulations must offer a good trade-off between system capacity and etiquette of spectrum utilization. The developed rules and protocols will be proposed to European and worldwide regulation bodies and standardization organizations such as IEEE and ETSI.

In context of Bangladesh, the concept of Cognitive Radio is new. That is why research work based on Cognitive Radio has not happened yet.

1.3 Challenges of our Project:

Though there already exists a huge total of study in spectrum sharing in our project, there are still many open study issues for the understanding of efficient and flawless open spectrum action.

- The main problem is the possibility of interfering with the primary user. The xG users don't know when the primary user is busy in using the spectrum. When primary user is using their licensed spectrum at that time if secondary or xG user try to access the same spectrum then interference will occur. Therefore primary user will be interrupted. But the main target of this cognitive radio network is to use the licensed band of the primary user efficiently without interfering the primary user. If interference occurs between primary and xG user the main goal of this cognitive radio network fails.

- Many spectrum sharing techniques assume a CCC for spectrum sharing. The main functions of CCC are transmitter receiver handshake, communication with a central unit, or sensing information exchange. On the other hand, xG network users are considered as visitors to the spectrum they give out. When a primary user chooses a channel, this channel has to be vacated without interfering. This is also factual for the CCC. Therefore, implementation of a permanent CCC is infeasible in xG networks.

- Another problem with the cognitive radio network is associated with the dynamic radio range. Due to attenuation dissimilarity, radio range changes with operating frequency. In many cases, we assume a permanent range to be independent of the operating spectrum. But, in xG networks, the neighbors of a node may change as the operating frequency changes where a huge section of the wireless spectrum is considered. This affects the interference shape in addition to routing decisions. Besides, the selection of a control channel needs to be determined with awareness. It would be much efficient to select control channels in the lower portions of the spectrum where the transmission range will be higher and to select data channels in the higher portions of the spectrum where a localized operation can be utilized with minimized interference.

1.4 Proposition:

The main problem with the cognitive radio network is the interference with the primary user which affects the efficiency of the network. The reason is that the secondary or xG users don't know when the primary user is busy in using the spectrum or not. In our pre-thesis and thesis project we will work on this problem. We already contacted with some of the telecom companies of Bangladesh. They agreed to give us the data. We will collect data of average calls of the primary user at a particular period of time in a day. We will collect the data of how much time primary user is not using the licensed spectrum. Using the data we will try to find out primary user's average occupancy. We will try to find out when the spectrum is being used by primary user most. Then using the data we will do software stimulation in our thesis work to avoid the minimum interference between the primary and xG user.

2. Background:

The transfer of information between two or more points that are not physically connected is known as Wireless telecommunication. Long range communications that is unattainable or unfeasible to execute with the use of wires is now possible with the help of wireless operation. Distances can be tiny, as a few meters as in television remote control or long ranging from thousands to millions of kilometers for deep-space radio communications. Information is transferred over both short and long distances. Telecommunication systems use some form of energy (e.g. radio frequency (RF), infrared light, laser light, visible light, acoustic energy, etc.) to transmit information without the use of wires.

2.1 Populr wireless technology:

In today's world, the popular wireless technologies are:

- Cellular phone
- WiFi
- WiMax
- Bluetooth

Cellular phone:

Cellular telephone is a kind of short-wave analog or digital telecommunication in which a subscriber has a wireless connection from a mobile telephone to a comparatively close source. A cell is known as transmitter's span of coverage. Mobile phone operator uses cellular network to attain both coverage and capacity for their subscribers. Large geographic areas are split into smaller cells to avoid line-of-sight signal loss and to hold up a large number of active phones in that area. All of the cell sites are connected to telephone exchanges (or switches) which in turn connect to the public telephone network.

Usually cellular telephone service is accessible in urban areas. The telephone is efficiently passed on to the local cell transmitter as the cellular telephone user moves from one area of coverage to another.

Possibly cellular telephone is the best known example in wireless communication. It uses radio waves to permit the operator to make phone calls from different places of the world. It can be used anywhere that is in range of a cellular telephone site to address the apparatus that is necessary to transmit and receive the signal that is used to transfer both voice and data.

A mobile phone can make and receive telephone calls to and from the public telephone network which includes other mobiles and fixed-line phones across the world. It does this by linking to a cellular network provided by a mobile network operator.

A mobile phone is a portable telephone which receives or makes calls through a cell site (base station), or transmitting tower. Radio waves are used to transfer signals to and from the cell phone. Since radio frequencies are a limited, shared resource modern mobile phone networks use cells. A limited number of radio frequencies can be simultaneously used by many callers with less interference. For that cell-sites and handsets vary frequency under computer control and use low power transmitters.

Almost all mobile phones use cellular technology including GSM, CDMA, and AMPS (analog). Though satellite phones are mobile phones that do not communicate directly with a ground-based cellular tower, but they may do so indirectly by way of a satellite.

Bluetooth:

Bluetooth is a wireless technology for exchanging data over short distances. The chip can be plugged into computers, digital cameras and mobile phones. It is a technology to do away with your computer's jungle of wiring.

It creates a short range network via a special radio frequency to broadcast data. It is much protected and can connect up to eight devices like electronic equipment at the same time. Bluetooth is mostly convenient in certain situations – for example, when transferring files from one mobile phone to another without cables. Sending music and photos between a PC and a mobile phone is another useful application.

It uses short wavelength radio transmissions in the ISM band from 2400-2480 MHz from fixed and mobile devices. It creates personal area networks (PANs) with high levels of security. It was originally conceived as a wireless substitute to data cables. It can join several devices overcoming problems of synchronization. To use Bluetooth wireless technology, a device has to be able to interpret certain Bluetooth profiles, which specify general behaviors that Bluetooth enabled devices use to communicate with other Bluetooth devices.

Wi-Fi:

Wi-Fi is a popular wireless networking technology that uses radio waves to offer wireless high-speed Internet and network connections. The Wi-Fi Alliance, the organization that owns the Wi-Fi term particularly defines Wi-Fi as any "wireless local area network (WLAN) products that are based on the Institute of Electrical and Electronics Engineers' (IEEE) 802.11 standards.

Wi-Fi works with no physical wired connection between sender and receiver by using radio frequency (RF) technology, a frequency within the electromagnetic spectrum associated with radio wave propagation. When an RF current is supplied to an antenna, an electromagnetic field is created that then is able to propagate through space. The cornerstone of any wireless network is an access point (AP). The primary job of an access point is to broadcast a wireless signal that computers can detect and "tune" into. In order to connect to an access point and join a wireless network, computers and devices must be equipped with wireless network adapters.

Wi-Fi is a branded standard for wirelessly connecting electronic devices. A Wi-Fi device, such as a personal computer, video game console, Smartphone, or digital audio player can connect to the Internet via a wireless network access point. An access point has a range of about 20 meters (65 feet) indoors and a greater range outdoors. Multiple overlapping access points can cover large areas.

"Wi-Fi" is a trademark of the Wi-Fi Alliance and the brand name for products using the IEEE 802.11 family of standards. Wi-Fi is used by over 700 million people, there are over 4 million hotspots (places with Wi-Fi Internet connectivity) around the world, and about 800 million new Wi-Fi devices every year. If you've been in an airport, coffee shop, library or hotel recently, chances are you've been right in the middle of a wireless network. Many people also use wireless networking, also called Wi-Fi or 802.11 networking, to connect their computers at home, and some cities are trying to use the technology to provide free or low-cost Internet access to residents. In the near future, wireless networking may become so widespread that you can access the Internet just about anywhere at any time, without using wires. Wi-Fi allows cheaper deployment of local area networks (LANs). Also spaces where cables cannot be run, such as outdoor areas and historical buildings, can host wireless LANs. Manufacturers are building wireless network adapters into most laptops. The price of chipsets for Wi-Fi continues to drop, making it an economical networking option included in even more devices. Wi-Fi operates in more than 220,000 public hotspots and in tens of millions of homes and corporate and university campuses worldwide.

Advantages of Wi-Fi:

Flexible Working:

Access the Internet, do File Transfers, even Print from anywhere within 100 meters of the Wi-Fi Access Point.

Reduce Cable Clutter:

Reduce the clutter of wires and cables behind your Desktop/ Notebook

Reduce Setup Cost:

If you are setting up a new office, you can reduce the IT setup cost by implementing Wi-Fi - you can save the cost of cabling and the cost on Network sockets

Avoid Deterioration with Time:

Network Cables and Sockets tend to deteriorate over time, while Wi-Fi does not have this disadvantage

Eliminate Re-configuring Computers:

If you have more than one office location and your staff travel between offices, installing Wi-Fi Networks at each location makes good sense. Your staff can then access the Internet and Network at all locations, without having to re-configure their Internet settings each time

Disadvantages of Wi-Fi:

Signal Strength Sensitivity:

Wi-Fi Networks are sensitive to signal strength. To ensure good connectivity, you must ensure that all computers and gadgets receive adequate signal strength at all times

Password and Security:

It is important to secure your Wi-Fi connection at home or the office. Otherwise, anyone with a Wi-Fi-enabled computer can access your data and Internet connection! Password-protecting your Wi-Fi connection is an easy process and once you set up all your Computers and devices to access your Wi-Fi network, you do not need to type in passwords each time thereafter.

Effect of Climatic Conditions:

Wi-Fi signals are likely to be adversely affected by climatic conditions such as thunderstorms

Increased number of Network Devices:

You are increasing the number of devices on your Network, by incorporating a Wi-Fi Access point (this is a must, for Wi-Fi access). Also, you will need a power socket to plug in and power the Wi-Fi Access Point.

Wimax:

WiMAX is an IP based, wireless broadband access technology that provides performance similar to 802.11/Wi-Fi networks with the coverage and QOS (quality of service) of cellular networks. WiMAX is also a short form meaning "Worldwide Interoperability for Microwave Access (WiMAX).

WiMAX is a wireless digital communications system, also known as IEEE 802.16 that is intended for wireless "metropolitan area networks". WiMAX can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations. In contrast, the WiFi/802.11 wireless local area network standard is limited in most cases to only 100 - 300 feet (30 - 100m).

With WiMAX, WiFi-like data rates are easily supported, but the issue of interference is lessened. WiMAX operates on both licensed and non-licensed frequencies, providing a regulated environment and viable economic model for wireless carriers.

However, WiMAX is a standards initiative. Its purpose is to ensure that the broadband wireless radios manufactured for customer use interoperate from vendor to vendor. The primary advantages of the WiMAX standard are to enable the adoption of advanced radio features in a uniform fashion and reduce costs for all of the radios made by companies, who are part of the WiMAX Forum™ - a standards body formed to ensure interoperability via testing.

Advantages:

- Single station can serve hundreds of users
- Much faster deployment of new users comparing to wired networks.
- Speed of 10 Mbps at 10 kilometers within line-of-site.
- It is standardized, and the same frequency equipment should work together.

Disadvantages:

- Line of sight is needed for more distant connections.
- Bad weather conditions such as rain could interrupt the signal.
- Other wireless equipment could cause interference.
- Multiplied frequencies are used.
- High installation and operational cost
- WiMAX is a very power-consuming technology and requires significant electrical support.

3. LITERATURE REVIEW:

3.1 Spectrum sensing:

An important requirement of the xG network is to sense the spectrum holes. A cognitive radio is designed to be aware of and sensitive to the changes in its surrounding. The spectrum sensing function enables the cognitive radio to adapt to its environment by detecting spectrum holes. The most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range of an xG user. It is complex for a cognitive radio to have a direct measurement of a channel between a primary receiver and a transmitter. Generally, the spectrum sensing techniques can be classified as transmitter detection, cooperative detection, and interference-based detection, as shown in figure below:

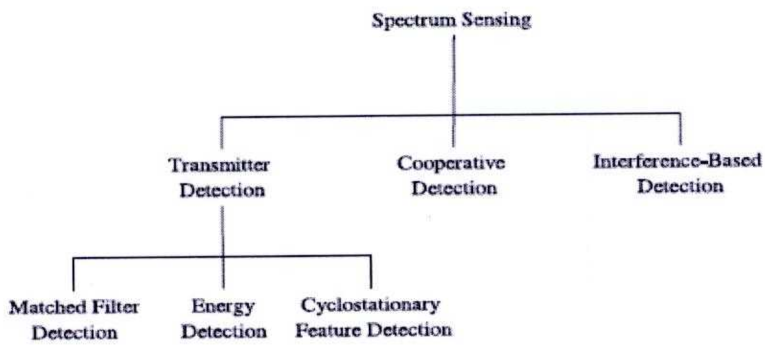

Fig. 5: Classification of spectrum sensing techniques

3.1.1 Transmitter detection:

The cognitive radio should make out between used and unused spectrum bands. As well as cognitive radio should have capability to determine if a signal from primary transmitter is locally present in a certain spectrum. Transmitter detection approach is based on the detection of the weak signal from a primary transmitter.

Three schemes are generally used for the transmitter detection according to the hypothesis mode. In the following subsections, we investigate matched filter detection, energy detection and cyclostationary feature detection techniques proposed for transmitter detection in xG networks.

i) Matched filter detection:

When the information of the primary user signal is known to the xG user, the optimal detector in stationary Gaussian noise is the matched filter because it maximizes the received SNR. While the main benefit of the matched filter is that it requires less time to achieve high processing gain due to coherency. If this information is not accurate, then the matched filter performs poorly. However, since most wireless network systems have pilot, preambles, synchronization word or dispersion codes, these can be used for the coherent detection.

ii) Energy detection:

If the receiver cannot gather sufficient information about the primary user signal, if the power of the random Gaussian noise is only known to the receiver, the optimal detector is an energy detector. The act of energy detector is susceptible to uncertainty in noise power. In order to solve this problem, a pilot tone from the primary transmitter is used to help improve the accuracy of the energy detector in. Another weakness is that the energy detector cannot differentiate signal types but can only determine the presence of the signal. The energy detector is level to the false detection triggered by the unintended signals.

iii) Cyclostationary feature detection:

Different detection method is the cyclostationary feature detection. Modulated signals are in general coupled with sine wave carriers, sequences, or cyclic prefixes, which result in built-in periodicity. These modulated signals are characterized as cyclostationarity. These features are detected by analyzing a spectral correlation function. The main advantage of the spectral correlation functions that it differentiates the noise energy from modulated signal energy. A cyclostationary feature detector can perform better than the energy detector in discriminating against noise due to its robustness to the uncertainty in noise power. It is complex and requires significantly long observation time. Distinct features of the received signal are extracted using cyclic spectral analysis and represented by both spectral coherent function and spectral correlation density function. The neural network, then, classifies signals to different modulation types.

3.1.2 Co-operative detection:

In co-operative detection we have two methods:

- Centralized method
- Decentralized method

For co-operative detection an assumption should be made. The assumption of the primary transmitter detection is that the locations of the primary receivers are unknown due to the absence of signaling between primary users and the xG users. Therefore, the cognitive radio should rely on only weak primary transmitter signals based on the local observation of the xG user. In most cases, an xG network is physically separated from the primary network so there is no interaction between them. With the transmitter detection, the xG user cannot avoid the interference due to the lack of the primary receiver's information as depicted in Fig 6. Moreover, the transmitter detection model cannot prevent the hidden terminal problem.

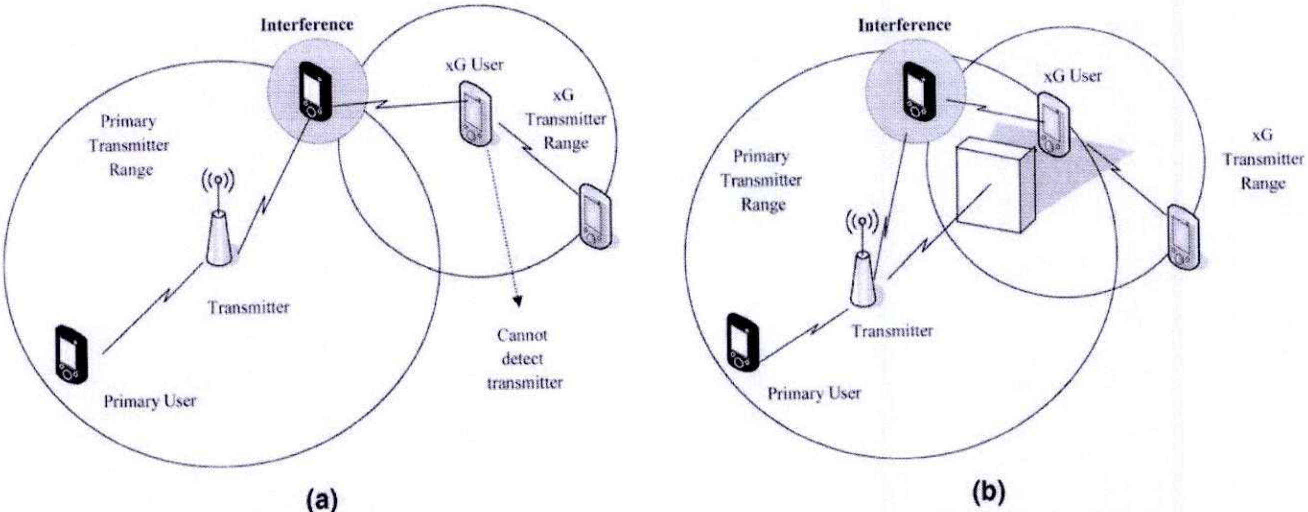

Fig. 6: Transmitter detection problem – a) Receiver uncertainty and b) Shadowing uncertainty

Cooperative detection among unlicensed users is theoretically more accurate since the uncertainty in a single user's detection can be minimized .Moreover, the multi-path fading and shadowing effect are the main factors that degrade the performance of primary user detection methods. Cooperative detection schemes allow mitigating the multi-path fading and shadowing effects, which improves the detection probability in a heavily shadowed environment. While cooperative approaches provide more accurate sensing performance, they cause adverse effects on resource-constrained networks due to the additional operations and overhead traffic. Primary receiver uncertainty problem caused by the lack of the primary receiver location knowledge is still unsolved in the cooperative sensing.

3.1.3 Interference-based detection:

Interference is typically regulated in a transmitter- centric way, which means interference can be controlled at the transmitter through the radiated power, the out-of-band emissions and location of individual transmitters. Interference actually takes place at the receivers. A new model for measuring interference, referred to as interference temperature. It has been introduced by the FCC. The model shows the signal of a radio station designed to operate in a range at which the received power approaches the level of the noise floor. As additional interfering signals appear, the noise floor increases at various points within the service area, as indicated by the peaks above the original noise floor. Not like the traditional transmitter-centric approach, the interference temperature model manages interference at the receiver through the interference temperature limit.

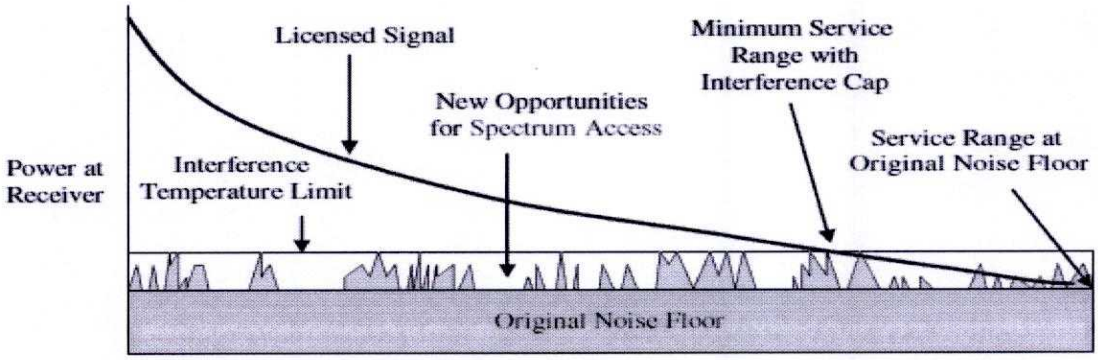

Fig. 7: Interference temperature model

There exist several open research challenges that need to be investigated for the development of the spectrum sensing function.

• **Interference temperature measurement:** The difficulty of this receiver detection model lies in effectively measuring the interference temperature. Currently, there exists no practical way for a cognitive radio to measure the interference temperature at nearby primary receivers.

• **Spectrum sensing in multi-user networks:** Usually xG networks in a multi-user environment consists of multiple xG users and primary users. The xG networks can also be co-located with other xG networks competing for the same spectrum band. Multi-user environment makes it more difficult to sense the primary users and to estimate the actual interference.

3.2 Spectrum management:

In xG networks, the unused spectrum bands will be spread over wide frequency range including both unlicensed and licensed bands. These unused spectrum bands detected through spectrum sensing show different characteristics according to not only the time varying radio environment but also the spectrum band information.

Spectrum analysis:

In xG networks, the available spectrum holes show different characteristics which vary over time. The xG users are equipped with the cognitive radio based physical layer. Spectrum analysis enables the characterization of different spectrum bands, which can be exploited to get the spectrum band appropriate to the user requirements. It is essential to define parameters such as interference level, channel error rate, path-loss, link layer delay, and holding time that can represent the quality of a particular spectrum band as follows:

- **Interference:** Some spectrum bands are more jam-packed compared to others. The spectrum band in use determines the interference characteristics of the channel.

- **Path loss:** The path loss increases as the operating frequency increases. The transmission power of an xG user remains the same, and then its transmission range decreases at higher frequencies.

- **Wireless link errors:** Depending on the modulation scheme and the interference level of the spectrum band, the error rate of the channel changes.

- **Link layer delay:** To address different path loss, wireless link error, and interference, different types of link layer protocols are required at different spectrum bands.

- **Holding time**: The activities of primary users can affect the channel quality in xG networks. Holding time refers to the expected time duration that the xG user can occupy a licensed band before getting interrupted. Obviously, the longer the holding time, the better the quality would be.

3.3 Spectrum mobility:

Present frequency allocation scheme results in poor spectrum utility. Some frequency bands, the spectrum may not be fully utilized either on geographical or at temporal level. In addition, on some hot spot business frequency bands, spectrum resources become in short supply. New spectrum management policies and the focus is dynamic spectrum access (DSA) technology based on cognitive radio. Spectrum mobility and spectrum handoff are new challenges for cognitive wireless networks. xG networks target to use the spectrum in a dynamic manner by allowing the radio terminals, known as the cognitive radio, to operate in the best available frequency band. Spectrum mobility is defined as the process when an xG user changes its frequency of operation.

Spectrum mobility challenges in xG networks:

• In a particular time, several frequency bands may be available for an xG user. Measures are required to decide the best available spectrum based on the channel characteristics of the available spectrum and the requirements of the applications that are being used by an xG user.

• Once, the best available spectrum is selected, the next challenge is to design new mobility and connection management approaches to reduce delay and loss during spectrum handoff.

• When the current operational frequency becomes busy in the middle of a communication on this node have to be transferred to another available frequency band. Appropriate algorithms are required to ensure that applications do not suffer from severe performance damage during such transitions.

3.4 Spectrum sharing

In order to provide a directory for different challenges during spectrum sharing, the spectrum sharing process consists of five major steps:

a) Spectrum sensing: An xG user can only allocate a portion of the spectrum if that portion is not used by an unlicensed user. Accordingly, when an xG node aims to transmit packets, it first needs to be aware of the spectrum usage around its vicinity.

b) Spectrum allocation: Based on the spectrum availability, the node can then allocate a channel. This allocation not only depends on spectrum availability, but it is also determined based on internal policies. The design of a spectrum allocation policy to improve the performance of a node is an important research topic.

c) Spectrum access: Another major problem of spectrum sharing comes into picture. Since there may be multiple xG nodes trying to access the spectrum, this access should also be coordinated in order to prevent multiple users.

d) Transmitter-receiver handshake: Once a portion of the spectrum is determined for communication the receiver of this communication should also be indicated about the selected spectrum.

e) Spectrum mobility: xG nodes are regarded as visitors to the spectrum they allocate. If the specific portion of the spectrum in use is required by a licensed user, the communication needs to be continued in another vacant portion.

3.4.1 Overview of spectrum sharing techniques:

Existing solutions for spectrum sharing in xG networks can be mainly classified in three aspects: The first classification for spectrum sharing techniques in xG networks is based on the architecture, which can be described as follows:
With respect to architecture two aspects can be found:

- **Centralized spectrum sharing:** A centralized entity controls the spectrum allocation and access procedures. With these procedures, generally, a distributed sensing procedure is proposed such that each entity in the xG network forwards their measurements about the spectrum allocation to the central entity and this entity constructs a spectrum allocation map.

- **Distributed spectrum sharing:** Distributed solutions are mainly proposed for cases where the construction of an infrastructure is not preferable.

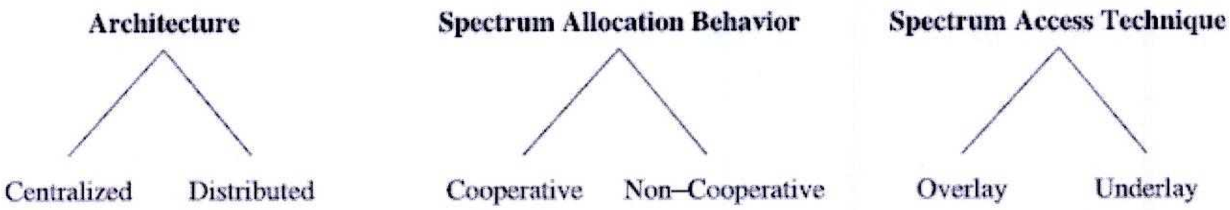

Fig. 8: Classification of spectrum sharing in xG networks based on architecture, spectrum allocation behavior, and spectrum access technique

With respect to spectrum allocation behavior two aspects can be found:

- **Cooperative spectrum sharing:** Cooperative or collaborative solutions consider the consequence of the node's communication on other nodes. The interference measurements of each node are shared among other nodes.
- **Non-cooperative spectrum sharing:** Contrary to the cooperative solutions there we find these solutions which are referred to as selfish, while non-cooperative solutions may result in reduced spectrum utilization.

With respect to spectrum access techniques we have-

- Overlay spectrum sharing
- Underlay spectrum sharing

<u>i) Overlay spectrum sharing:</u>

Overlay spectrum sharing refers to the spectrum access technique where a node accesses the network using a portion of the spectrum that has not been used by licensed users. As a result, interference to the primary system is minimized.

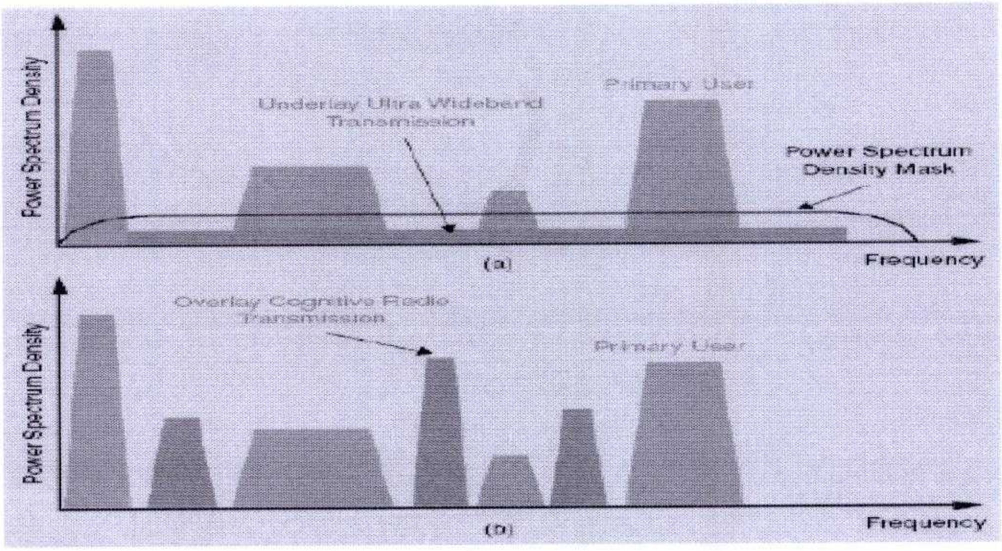

Figure 1. (a) Underlay and (b) Overlay approach for sharing spectrum with primary users.

ii) Underlay spectrum sharing:

In underlay spectrum sharing once a spectrum allocation map has been acquired, an xG node begins transmission such that its transmit power at a certain portion of the spectrum is regarded as noise by the licensed users. This technique requires complicated spread spectrum techniques and can use improved bandwidth compared to overlay techniques.

It is shown that frequency division multiplexing is most advantageous when interference among users is high. As a result, the overlay approach becomes more efficient than underlay when interference among users is high. The lack of cooperation among users, on the other hand, necessitates an overlay approach. The comparative evaluations show that the performance loss due to the lack of cooperation is small, and vanishes with increasing SNR. Another comparison is based on the control of the secondary system on the primary system in terms of outage probability.

3.4.2 Inter-network spectrum sharing:

In inter- network spectrum sharing multiple systems overlap with each other. xG networks are envisioned to make available opportunistic access to the licensed spectrum using unlicensed users. This setting enables numerous systems being deployed in overlapping locations and spectrum. Hence, spectrum sharing among these systems is a significant research subject in xG networks. Up to date, inter-network spectrum sharing has been synchronized with centralized allocations between different access points of a system in cellular networks. The inter-network spectrum sharing gives a broader observation of the spectrum sharing solution including certain operator policies for the purpose of the spectrum allotment.

There are two types of inter-network spectrum sharing. Such as-

i) Centralized
ii) Distributed

i) Centralized inter-network spectrum sharing:

In centralized inter network spectrum sharing we assume that each node is to be equipped with a cognitive radio and a low bit-rate, narrow-band control radio. Through broadcasting CSCC messages the coexistence is maintained through the management of these nodes with each other. Each user determines the channel such that interference is avoided. Channel selection is not sufficient to stay away from interference, power adjustment is also needed.

Competition for the spectrum among the users is also considered in centralized inter network spectrum sharing. In this case, there is a central spectrum policy server (SPS). SPS is projected to manage spectrum demands of multiple xG operators. Here each operator bids for the spectrum representing the cost it will give for the period of the usage. The SPS then allocates the spectrum by maximizing its profit from these bids. The operators also decide an offer for the users and users choose which operator to use for a given type of traffic. Where each operator is assigned an equal share of the spectrum, the operator bidding system achieves higher throughput leading to higher profits for the SPS, as well as a lesser cost for the users according to their necessities.

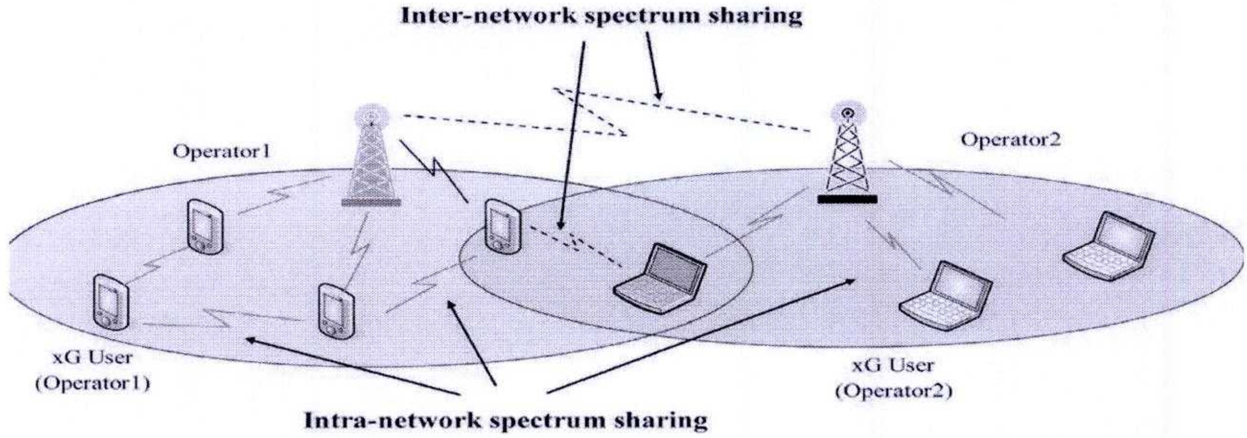

Fig. 9: Inter-network and intra-network spectrum sharing in xG networks

ii) Distributed inter-network spectrum sharing:

In distributed inter-network spectrum sharing a base station (BSs) of a WISP competes with its interferer BSs according to the QoS necessities of its users to allot a segment of the spectrum. Here the control and data channels are separated. The basic unit for channel allocation in D-QDCR is called Q-frames. When a BS assigns a Q-frame, it uses the control and data channels allocated to it for management and data communication between the users. Depending on a BSs data size and QoS prerequisite, the competition between BSs is performed according to the main concern of each BS.

3.4.3 Intra-network spectrum sharing:

In intra- network spectrum sharing, the users of an xG network try to access the available spectrum without causing interference to the primary users. An important amount of work on spectrum sharing focuses on intra-network spectrum sharing.

There are two types of intra-network spectrum sharing techniques:

i) Cooperative intra-network spectrum sharing
ii) Non-cooperative intra-network spectrum sharing

i) Cooperative intra-network spectrum sharing:

To provide both spectrum deployment and fairness, a cooperative local bargaining (LB) scheme is planned. In local bargaining scheme, local groups are formed according to a poverty line. This ensures a minimum spectrum allotment to each user and therefore focuses on fairness of users.

In this case, very limited number of common channels exists for each of the users in a network. A common control channel may not exist in xG networks or can be occupied by a primary user. A node shares many channels with its neighbors. Each group selects a common channel for communication. This channel provides distributed sensing and spectrum sharing. Besides, if this channel is engaged by a primary user at a particular time, the nodes reorganize themselves to use another control channel. Common control channel approaches particularly when the traffic load is high. When a node is using a particular data channel for communication, both the transmitter and the receiver send a busy tone signal through the connected busy tone channel.

ii) Non-cooperative intra-network spectrum sharing:

In non-cooperative intra-network spectrum sharing, users assign channels based on their observations of interference patterns and neighbors. As a result, users allot channels based on their observations instead of collaborating with other users. In case more than one node chooses the same channel in close proximity, random access techniques are used.

4. Recent research on Cognitive Radio:

4.1 Introduction and Workshop Background

Wireless technology is rapidly proliferating into all aspects of computing and communication. There are over 3 billion wireless devices in use today and that number is expected to increase to 100 billion by the year 2025. Radio technology will be at the very heart of the future computing world - one in which billions of communicators, mobile devices and sensors are connected to the global Internet and serve as the foundation for many exciting new classes of applications. These anticipated exponential growth of wireless devices and applications is contingent on our ability to design radio technologies that continue to work well with increasing deployment density – in particular, radio systems must change to cope with 2-3 orders of magnitude increase in density from ~10-100 devices/Km2 today to ~1000-10,000 devices/Km2 in 2025. Given the fact that spectrum is a finite resource, this calls for disruptive technology innovation in the radio field.

Cognitive radios offer the promise of being just this disruptive technology innovation that will enable the future wireless world. Cognitive radios are fully programmable wireless devices that can sense their environment and dynamically adapt their transmission waveform and application performance. We anticipate that cognitive radio technology will soon emerge from early stage laboratory trials and vertical applications to become a general-purpose programmable radio that will serve as a universal platform for wireless system development, much like microprocessors fulfill that role for computation. There is however a big gap between having a flexible cognitive radio, effectively a building block, and the large scale deployment of cognitive networks that dynamically optimize spectrum use. Building and deploying a network of cognitive radios is a complex task. The research community working on cognitive radio networks needs to understand a wide range of issues including smart antenna technology, spectrum sensing and measurement, radio signal processing, hardware architectures including software-defined radio (SDR), medium access control (MAC), network discovery and learning mechanisms. This is a very wide range of technologies to harness and apply, and hence understanding and properly controlling the behavior of the resulting system is a challenging research task.

The purpose of NSF sponsored workshop (held in Arlington, VA on March 9-10, 2009) was to bring together a group of technology and policy researchers who have been involved with early cognitive radio projects, and to explore how we can make the transition from cognitive radios to cognitive radio *networks*. Specific goals of the workshop were:

- Identify the cognitive radio network technology vision and research opportunity.
- Articulate some of the key research questions and challenges.
- Define the required experimental infrastructure to carry out the science agenda.
- Develop a coherent plan on how the research community could proceed and make progress with this vision and agenda.
- Define the broader impacts of cognitive radio research, both in terms of social value and educational outreach programs.

4.2 Research Agenda for Cognitive Radio Networks:

By their very nature, DSA and CRNs spans a range of disciplines. The physical layer involves high performance radio frequency circuits. We need to control and manage those circuits to gain flexibility and new capabilities. Once out of the analog domain, we need to analyze and process received communication signals. We need to limit bandwidth, be efficient in our utilization of radio frequency spectrum, deal with differences between the transmitter and receiver, handle radios in motion, adapt for the physical communications from the transmitter to the receiver.

Wireless networks are challenging systems because of the complex nature of signal propagation. DSA further exacerbates those problems since spectrum use is dynamic and unpredictable. Cognitive networking research is a multidisciplinary make an effort that must address not only traditional wireless networking challenges, but also the rational control and management of the spectrum, a distributed and dynamic resource, which raises complex policy and economic issues.

We can describe these by the following roadmap

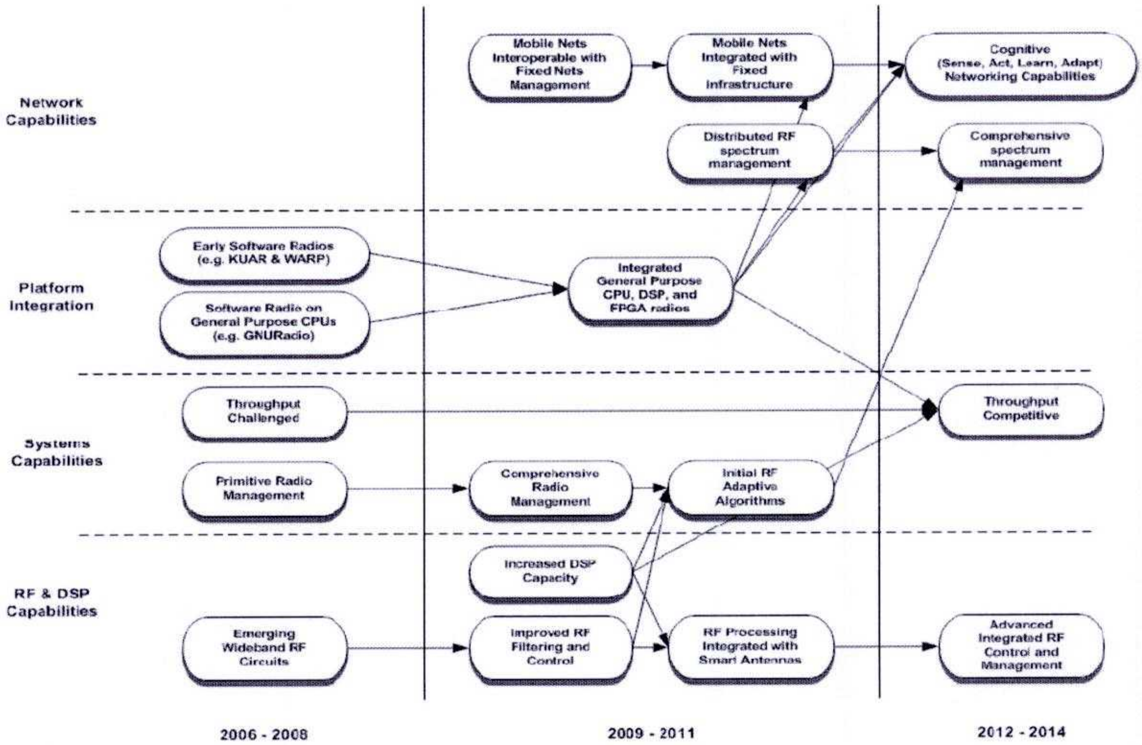

Fig. 10: Cognitive radio research roadmap

4.3 Spectrum Policy Alternatives and System Models

Advanced technology only thrive in an economic and policy regime where it returns value and does so without impeding other technologies or innovation. Research is required to support such policy reform. The CRN research community must demonstrate improved performance over other technologies and assured operation of adaptive and flexible CRNs. Advances in CRNs could make a wide variety of improved spectrum utilization and sharing approaches possible. A given spectrum sharing model may require sharing among equals, or it may give some wireless systems primary rights and others secondary status. A model may mandate cooperation among systems from different administration domains. A model may assume that systems are licensed, or unlicensed, or a mix of the two. Motivated on the above considerations, some of the spectrum policy research topics under consideration by the community include:

• High-level policy and legal frameworks, for example property rights vs. spectrum commons

• Policy parameters which help spectrum sharing in terms of primary-secondary services or new cognitive radio based unlicensed bands

• Use of dynamic auctions for spectrum allocation spectrum clearinghouse, etc.

• Distributed market mechanisms with incentives for sharing of spectrum

• Game theoretic analysis of spectrum markets in terms of scale, convergence, etc.

• How does one express regulatory and operational policies? How are policies securely updated?

• What method does one use to interpret policies? How are policies affected by different market models, e.g., property based, unlicensed, or brokered?

• Growing behavior of large-scale spectrum markets

Moving away from a simple command and control model for spectrum allocation and assignment and adopting a dynamic spectrum management model represents a tremendous change in how we use spectrum. With this change comes increased complexity, in that CR networks consist of many components, all of which can adapt in potentially extreme ways. CR networks are also not self-contained systems. Faulty behavior can have disastrous consequences poor adaptation decisions on a single wireless device can disrupt safety critical wireless communication. Such concerns have created legitimate regulatory and market resistance against the adoption of dynamic spectrum access. However, this resistance mainly stems from the uncertainty that such complex systems create. For example, it is unknown what emergent behaviors might arise as this new technology interacts with legacy radios. Core to this research is the need to explore the security, policy and operational concerns and remedies associated with DSA deployment in real-world settings. Without large-scale testbeds we will be unable to examine the technical questions surrounding this uncertainty, the consequence of which is the delay in CR networks.

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4.4 Cognitive Radio Architecture and Software Abstractions

A key challenge in the field is that of bringing radio technology into the digital age. Emerging cognitive radio platforms are essentially programmable and are expected to usher in a new era of flexible wireless networks and management of radio resources.

Modern programmers mistakenly manipulate transistors and electricity constantly, but few of them have, or need, an understanding of Kirchoff's current laws, Boolean logic reduction or band-gap materials. Currently, there is no such abstraction for the physical radio layer, and providing a understandable set of abstractions is a key challenge to better exploiting wireless communications. The rapid innovation in VLSI systems owed much to the development of the "Mead & Conway" approach, by which a generation of computer scientists and engineers learned to turn silicon into computation.

The current construction of "software defined radios" involves tools and domains spanning circuit design, hardware design languages, complex real time software and computational intensive signal processing. Current software, such as the GNU Radio software stack provides simplified abstractions that allow Simple radio architectures to be developed using a "stream computing" model; however, those tools are in their infancy and unsuitable for actual production use because of inefficiencies and excessively detailed designs. There are ongoing efforts at specifying language that use declarative methods that can be combined with compilers for developing efficient signal processing algorithms and efficient hardware-software systems to capture the physical design of radio systems. Here a block diagram of cognitive radio software giver. From this we get a good idea about the CR software.

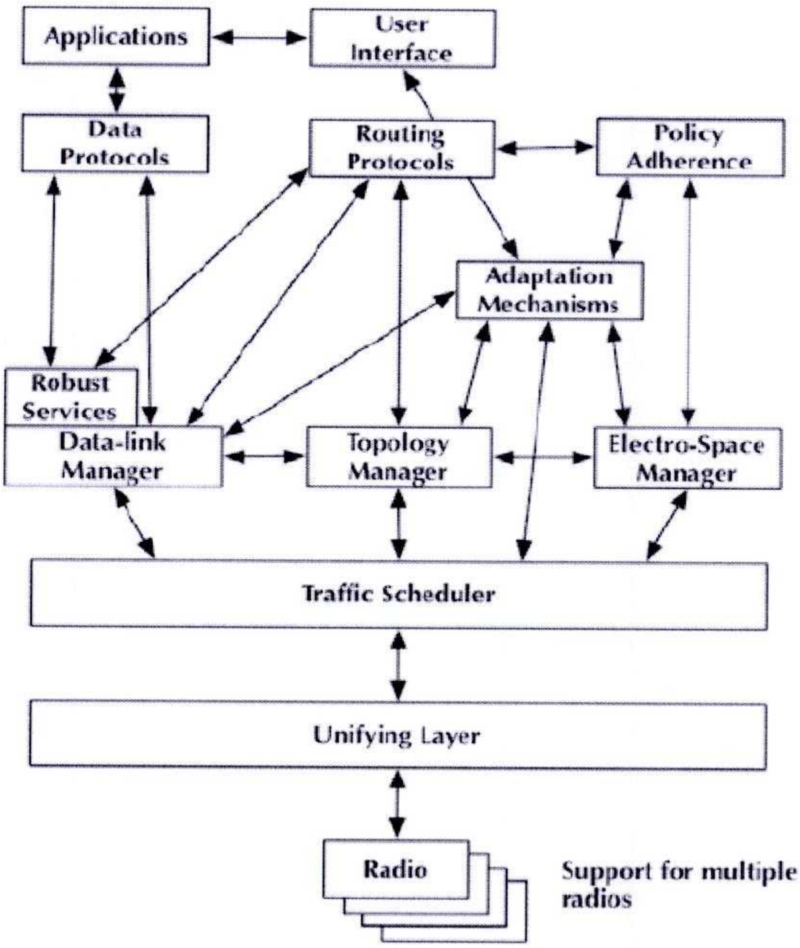


Fig. 11: Cognitive radio software block diagram

However this resistance mainly stems from the uncertainty that such complex systems create. For example, it is unknown what emergent behaviors might arise as this new technology interacts with legacy radios or with other DSA systems, and whether these behaviors may inadvertently, or through malicious manipulation, lead to communication failures in critical systems. Core to this research is the need to explore the security, policy and operational concerns and remedies associated with DSA deployment world setting is in real world. Without large scale test beds we will be unable to examine the technical matters surrounding this uncertainty, the consequence of which is the delay in adoption of CR networks.

4.5 Cooperative Wireless Communications:

Cooperative communication techniques with cognitive radios hold the promise of promoting efficient spectrum sharing by using approaches such as collaborative signal processing, cooperative coding, relaying and forwarding. Recent theoretical and experimental studies on cooperative communications have shown that significant system capacity and spectrum efficiency improvements can be achieved through cooperative methods such as Network Corporation. Taken together, these techniques have the potential of achieving ~10 bps/Hz or higher, widely used for wireless systems such as Wi-Fi and cellular.

The benefit of cooperative communications can also be expressed in terms of range extension, power savings or availability, all desirable characteristics of future wireless systems. While cooperative wireless communication is promising, there is still significant uncertainty about the practicality due to high control overhead and implementation complexity. Networks of cognitive radio platforms with full programmability and multiple operating modes offer the prospect of prototype cooperative communication methods which can then be evaluated for mass market usage scenarios. Some of the research issues which arise are:

- Fundamental cooperation mechanisms at physical, link and network layers

- Evaluation of control requirements in terms of latency and information transfer between cooperating nodes

- Practical protocol designs to support methods such as network coding, network MIMO and cooperative relay

• Introduction of incentive mechanisms to enable distributed collaboration, using methodologies such as coalitional game theory

• Prototyping and real-world experimentation with novel high-capacity wireless systems using cooperative methods

As cognitive radio platforms become available, it becomes practical to experimentally explore a wide range of innovative ideas for cooperation. Several contributors to the workshop felt that this would be an important area for NSF-funded research going forward and it is already reflected in ongoing CCF and CNS projects. It is however critical that this research can be tested and evaluated within the context of actual deployed CRNs. This is important not only to be able to evaluate different control protocols for cooperative communication and their impact on performance, but also to support research in how cooperative communication can best by integrated with higher layer protocols.

4.6 Network Security:

Cognitive radios introduce an important new dimension into the security of wireless networks. One of the advantages of conventional radio technology is the predictability of the signals emitted by wireless devices, which are typically type approved by the FCC. As programmability extends to the radio, it becomes possible to create a wide range of authorized and unauthorized waveforms with a low-cost consumer device. It would then be relatively easy to create denial of service attacks that can affect critical applications such as traffic control or healthcare. Future FCC regulations need to be aware of this potential and work with industry to develop trusted hardware architectures

At the same time, cognitive radios offer important new capabilities to defend against intrusions or denial of service attacks. The spectrum sensing and SDR capability of the radio make it feasible to employ recent developments in wireless security in which physical layer properties are used for authentication or secure communication. Also, spectrum scanning and agility associated with cognitive radios enable networks to move away from frequency channels experiencing denial of service attack. Location is another important feature of a wireless network, and information on geographic position can also be used to defend against certain types of attacks on cognitive networks.

Research questions being addressed by the community include:

• Identification of physical layer security enhancements for wireless networks, and evaluation of performance in realistic environments

• Evaluation of denial-of-service attack scenarios and methods for defense

• Use of geo-location for improved wireless network security

• Cooperative methods for detecting and isolating intruders

While initial results are promising, evaluation has been limited to lab environments, and it is not clear to what degree these techniques will be practical in real world deployments, or will scale to high density environments. Larger scale testing is needed.

4.7 Towards Large-Scale Deployment

As described a lot of progress has been made in developing the hardware, algorithms and protocols that are needed for cognitive networks. Yet, we are very far away from seeing large-scale deployments of CRNs. One of the reasons is that the research to date has focused on developing components of CRNs, rather than complete CRNs. In other words, we need to evaluate the performance of complete CRNs at reasonable scale and study emergent behavior in large-scale networks. Without this level of evaluation, it will not be possible to justify the necessary spectrum policy changes or to convince industry to make the necessary investments.

4.8 Broader Evaluation:

Cognitive networks are very complex systems that include many components that are developed by widely different communities. Both the scope and the interdisciplinary nature of cognitive networks create unique challenges for the evaluation of cognitive networking research. For example:

• **System wide**: Testing individual components is not enough – system level testing, involving all components integrated in a functional network, is essential to validate cognitive networking as a usable technology.

• **Interdisciplinary**: Researchers from different communities will want to evaluate their work both in isolation and in an integrated system context.

• **Scale**: The scalability of the solutions needs to be evaluated.

• **Safety**: Experiments, including failed experiments, should not affect/harm other wireless users.

• **Realism**: The behavior and performance of a cognitive network will depend critically on many external factors such as traffic loads, user behavior and levels of interference. The CN system needs to be evaluated in ways that reflects realistic environments.

• **Rigor**: The evaluation needs to be very rigorous so the results are convincing. This is especially the case if results are needed to drive changes in policy in the DSA domain.

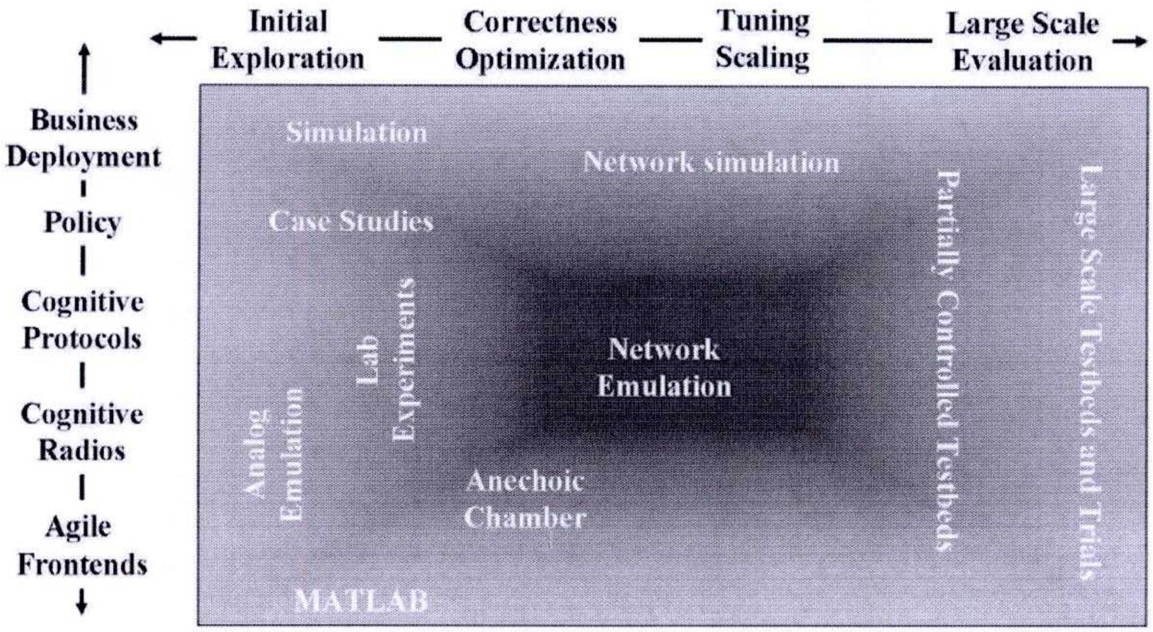


Fig. 12: Evaluation Methodologies for Cognitive Networking research

No single methodology will be able to meet all these evaluation criteria and the broader cognitive networking community has developed and used a number of different methodologies. The evaluation requirements depend both on the specific technology that is being evaluated and at the stage in the lifecycle of the project, so we placed the techniques in a two-dimensional space. In the early stages of the project, different types of simulation, modeling, formal methods, and lab experiments are used to evaluate different components. Later, in the project emulation environments that can be used to recreate realistic test environments for components prototypes and to evaluate partial integration. Finally, test beds that can be used to evaluate partially or fully integrated prototypes are needed, followed by large-scale trials.

The degree of maturity of the evaluation techniques shown in Figure is highly variable. Broadly speaking, the techniques on the left are fairly well understood and, while not perfect, there is a fairly good consensus within the various communities of the value of different evaluation techniques. Platforms for evaluation in the middle and right of the picture, for partial and full system testing, are not as advanced. Such evaluation needs to consider several system wide metrics: performance, stability, efficiency, reliability, etc. While there are analytical techniques to evaluate certain aspects of complex systems such as a cognitive network, these techniques must make many assumptions to make the analysis feasible. The behavior of cognitive radios involves considerable interaction between the radios, and their users and operating environment. This interaction is very difficult to capture in analytical models or simulations. As a result, these techniques must be complemented with experiments using actual prototypes operating under realistic conditions.

5. Proposed system:

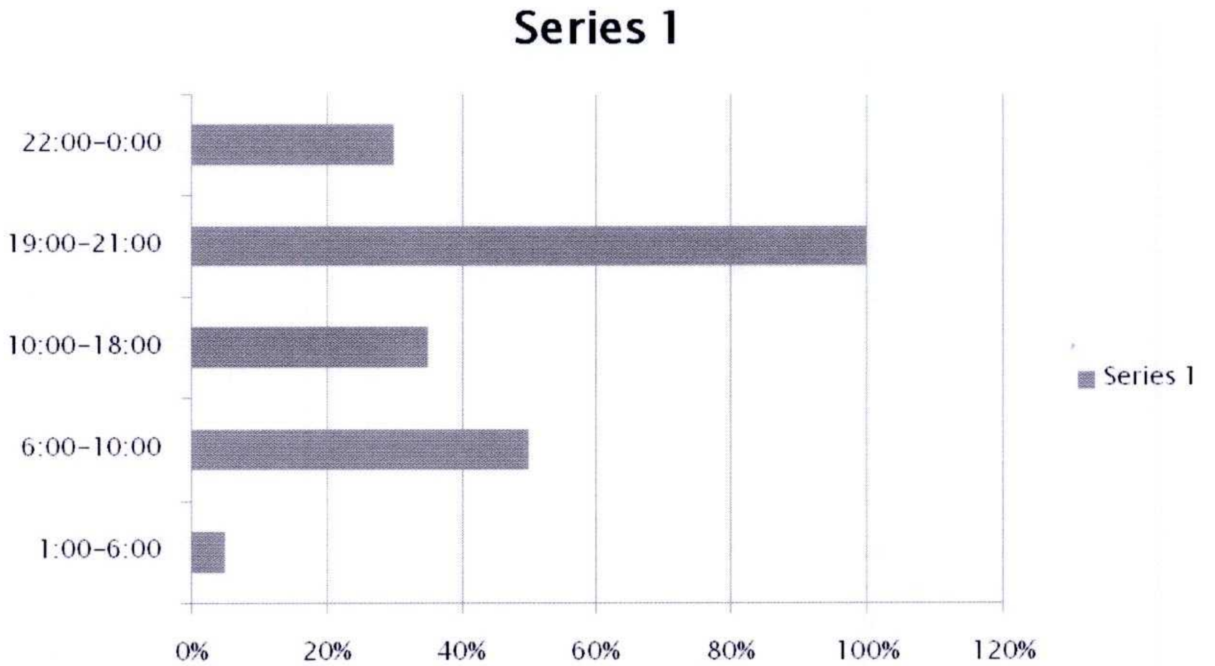
The main problem we encountered with this cognitive radio network is the interference with the primary user. Our target is to use the licensed spectrum of the primary user efficiently without causing interference with the primary user. For that we have contacted with the renowned telecom company of Bangladesh called Banglalink. We collected the data needed for our simulation work.

The data are given below:

1. Ratio of used spectrum and free spectrum in different times of the day.

On an average, utilization is as below:

1:00-6:00	5 %
6:00- 10:00	50%
10:00- 18:00	30-40%
19:00-21:00	close to 100%
22:00- 0:00	30%

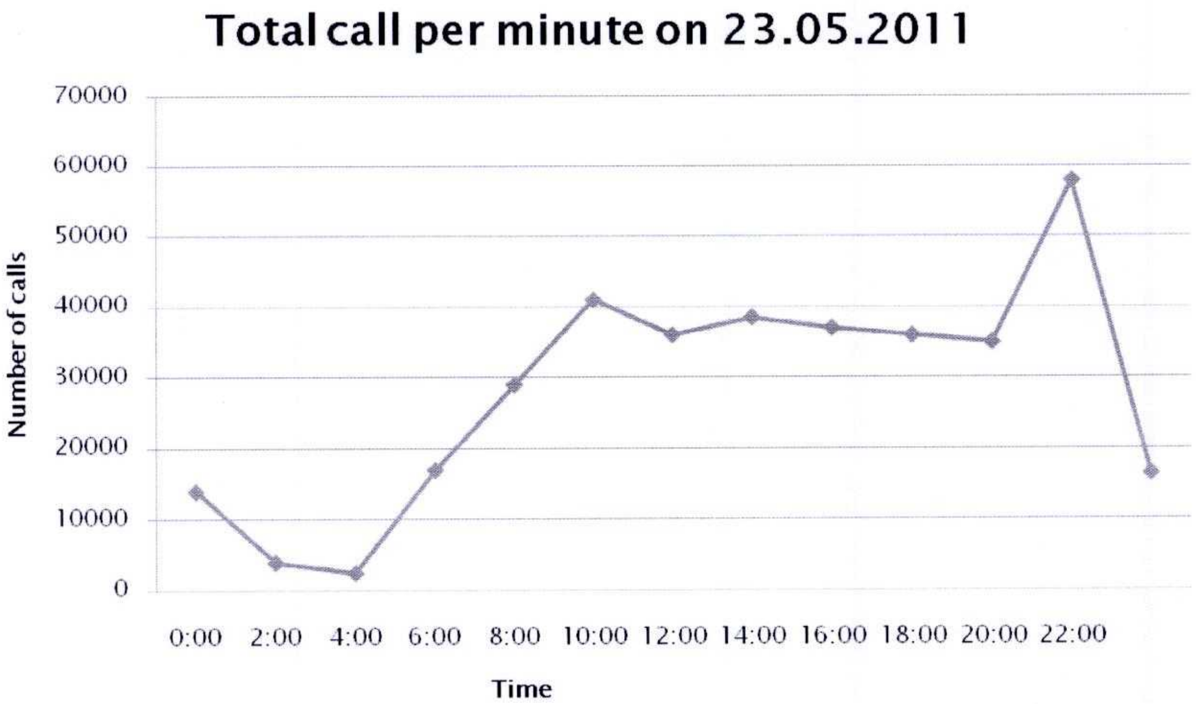


In the above bar chart, we're considering percentage of utilized spectrum along x-axis and along y-axis we're considering time period in hour.

2. Ratio of spectrum use in data and voice traffic

For data service, no additional spectrum is allocated, 1 fixed and a few dynamic TS time slots in a cell are allocated for data.

3. Average number of calls in different times of the day.



4. Average call duration.

5. Average amount of spectrum allocated to each base station, etc.

There are 3 cells in 900 band and 3 cells in 1800 band (1800 band is optional based on traffic demand). Average spectrum in a 900 cell is 2 carriers times 200 KHz and in 1800 cell it is 4 carriers times 200 KHz

6. The amount of spectrum allocation required for each call

A call is established on a TS out of 8 TS of a GSM carrier which is of 200 KHz bandwidth.

7. Total licensed spectrum allocated by the Government for uplink and downlink.

Always uplink and downlink bandwidth must be of same width. For Banglalink, 5 MHz in both UL & DL in 900 MHz and 10 MHz in both UL & DL in 1800 MHz band is allocated by government.

8. Average number of voice channels available in a cell.

On an average, 13 voice channels (TS) in 900 cell and 27 voice channels in 1800 cells are available.

6. Simulation:

Using the data received from the telecom company called Banglalink, we did our simulation work. Given a bandwidth of a telecom system, the primary or registered users are more prioritized. Though secondary users need very small portion of the allocated bandwidth, if a registered primary user requests for access then the secondary user is cut off.

If secondary user is using the channel and at the same time primary user tries to access the channel, a collision occurs.

When primary user is using the channel, secondary user can't access it. Secondary user then waits for the channel to be free and accesses it whenever finds an opening. After getting an opening, it continues to use the channel unless another primary user tries to access.

For our simulation purposes of this scenario, we used an exponential on-off method to activate both types of users. This method generates random numbers for the simulated user's time of activation, deactivation and waiting purposes. Primary user remains active for a random period of time and then it goes off. Secondary user can access the channel when the primary user is in off mode. It also uses exponential on off model by generating a random number.

After the simulation we get the output data. At first we observe how many transmissions occurred successfully and finally, we detect the collision rates.

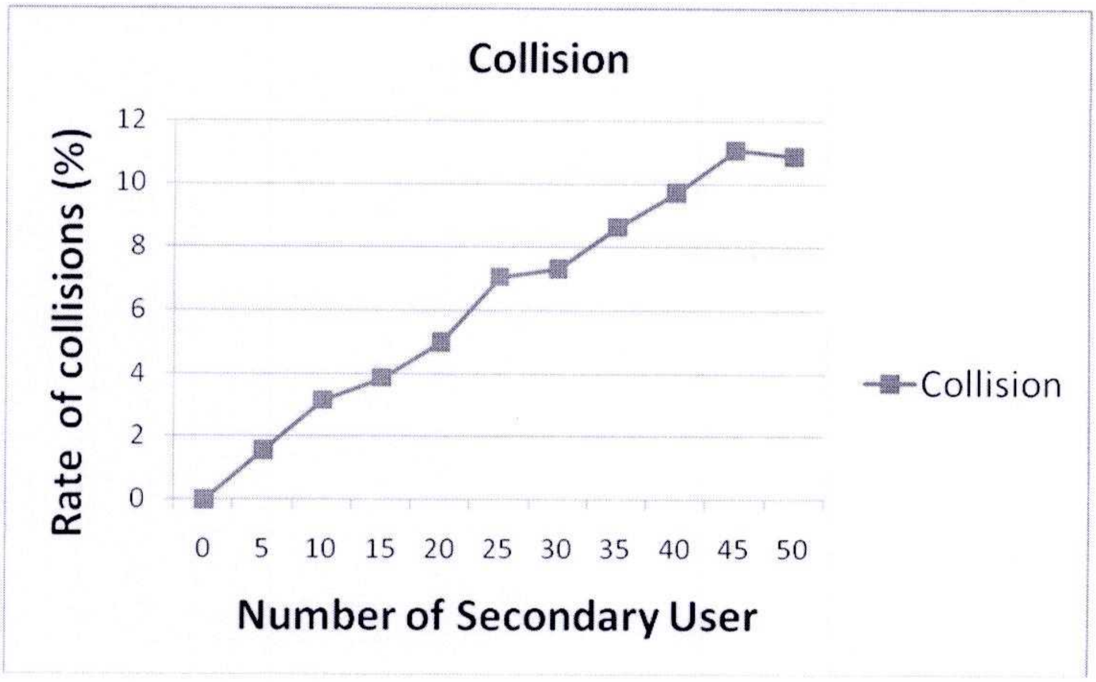
Description:

- Discrete event driven simulation using SimJava2
- 2 Types of user – Primary and Secondary
- Uses On/Off exponential model: Nodes remain On (transmitting) or off (idle) according to exponential distribution with mean lambda.
- Simulation time 1 million time units
- Primary user is not concerned about secondary user
- Secondary user uses a channel only if no primary/secondary user is accessing it.

Simulation Parameters:

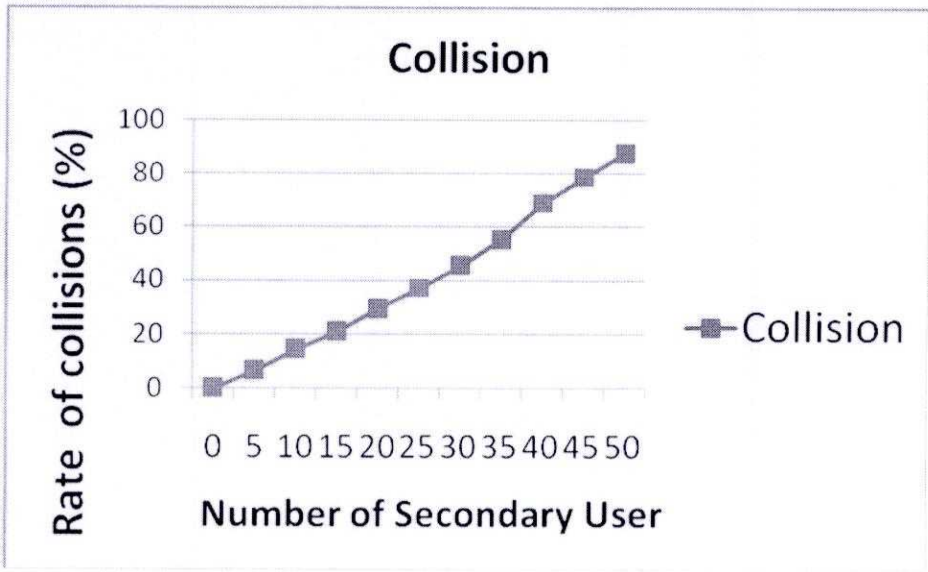
- Two sets of parameters are used
- Number of channels = 10
    - Number of Secondary User = 0, 5, 10, ... , 50
    - Set One:
        - Number of Primary User = 30
        - Mean On Time for Primary User = 200 unit time
        - Mean Off Time for Primary User = 10000 unit time
        - Mean On Time for Secondary User = 100 unit time
        - Mean Off Time for Secondary User = 10000 unit time
- Set Two:
        - Number of Primary User = 50
        - Mean On Time for Primary User = 250 unit time
        - Mean Off Time for Primary User = 5000 unit time
        - Mean On Time for Secondary User = 250 unit time
        - Mean Off Time for Secondary User = 5000 unit time
- Clearly, we can see that in set one, the medium is very much underutilized. In set two, the medium is comparatively more occupied by the primary user, as we will see in our simulation results.

Percentage of Collisions: Set One



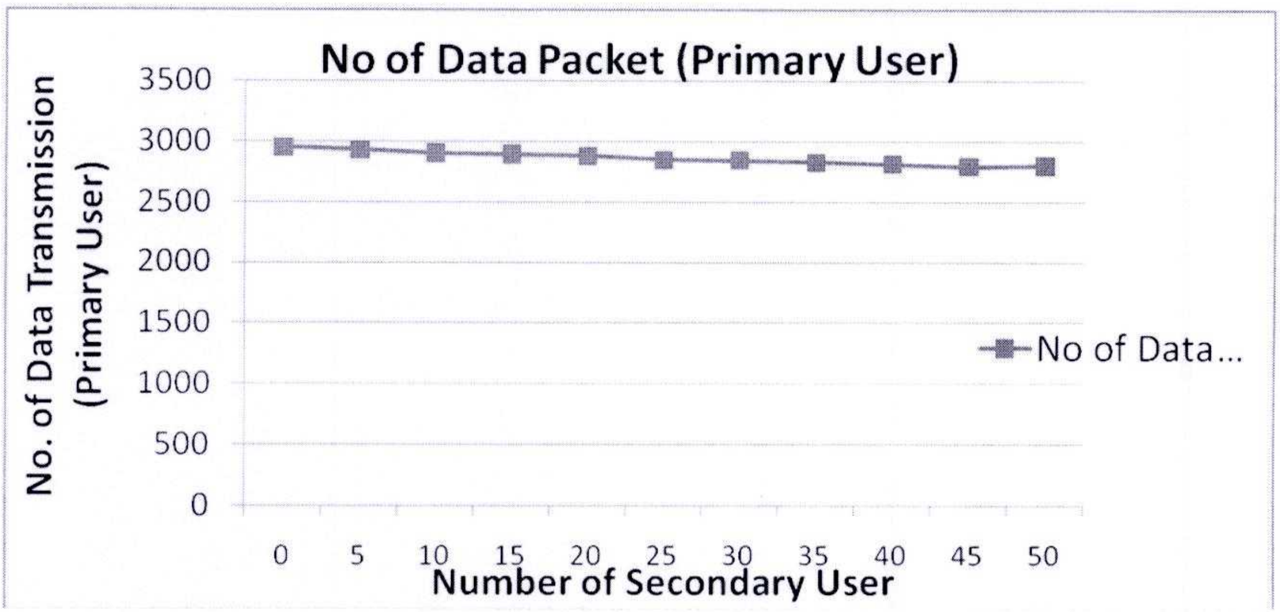
As the medium is underutilized, introducing secondary user do not increase collisions much.

Percentage of Collisions: Set Two



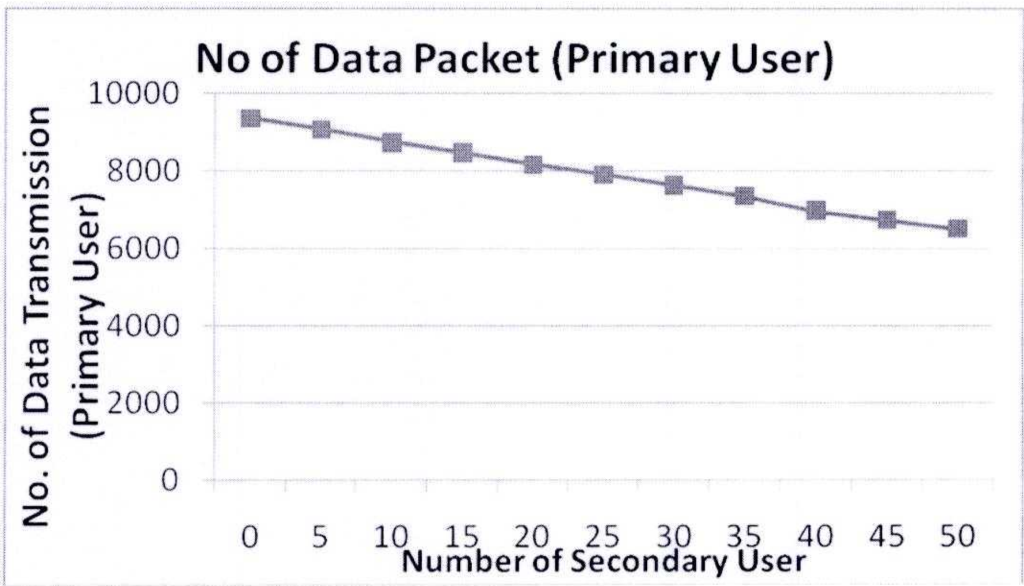
In set two, the medium is moderately busy with primary users. So introducing secondary user can increase the collisions up to 85%.

Data Transmission by Primary User: Set One



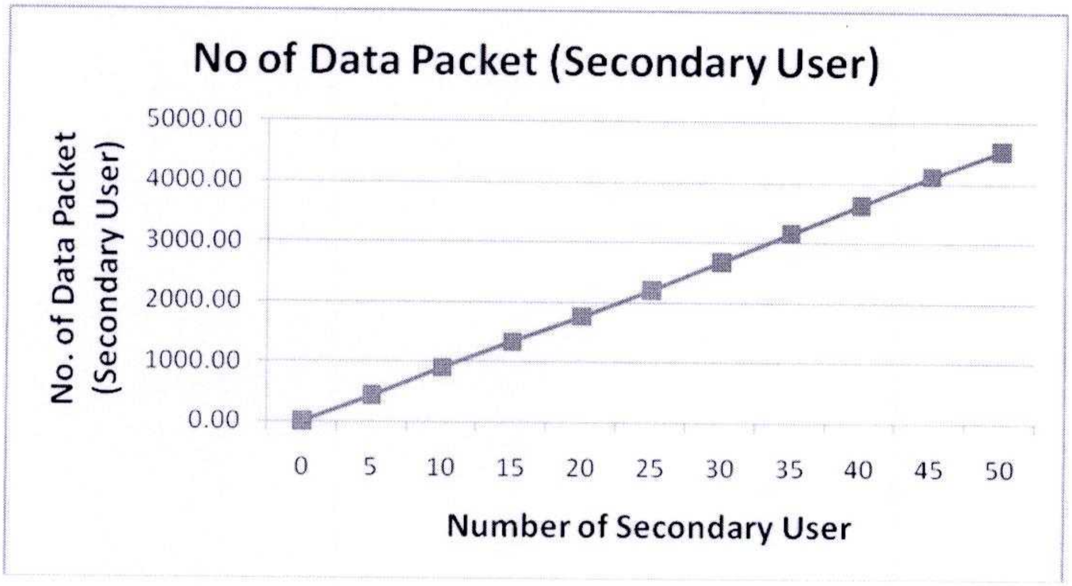
In set one, the throughput of primary users decreases very slightly as we introduce secondary users.

Data Transmission by Primary User: Set Two



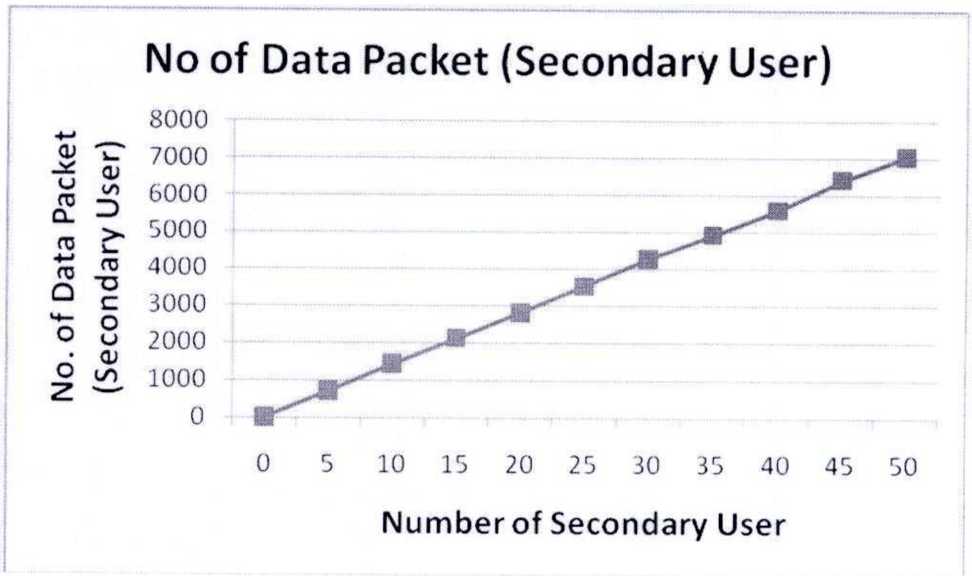
But in set two, the throughput of primary users decreases more sharply as we introduce secondary users.

Data Transmission by Secondary User: Set One



In both set one and set two, secondary user's throughput increases as we increase the number of secondary users.

Data Transmission by Secondary User: Set Two



Interpretation of Simulation Data

- So our simulation result reconfirms our idea that
  - In an underutilized network, introducing unlicensed secondary users do not interfere much with the primary users.
  - Even in a moderately busy network, secondary users can hamper the transmission quality of primary users.

In future, we can do further simulations and try to find a mathematical formulation for the decision criteria – when and how to use the network for the secondary users.

7. CONCLUSION:

xG networks are solving present wireless network problems ensuing from the inadequate accessible spectrum and the inefficiency in the spectrum usage. xG networks now are prepared with the inherent capabilities of the cognitive radio which will make available an eventual spectrum-aware communication model in wireless communications. In this paper we discussed the capabilities of cognitive radio techniques. Besides, we also emphasize on spectrum management functionalities such as spectrum sensing, spectrum analysis, spectrum decision and spectrum mobility. During analyzing the available spectrum for efficient use, we encountered few problems in xG networks as mentioned before. The main problem we encountered with this cognitive radio networks is the interference with the primary user. We contacted with one of the renowned cellular companies of Bangladesh known as Banglalink and using their information, we have completed simulation in SimJAVA.

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