SPECTRUM MANAGEMENT TECHNIQUES IN COGNITIVE RADIO NETWORK

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JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

May 2011

Submitted in partial fulfillment of the degree of

Bachelor of Technology

B.Tech

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT

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CERTIFICATE

This is to certify that the work titled "**Spectrum management techniques in cognitive radio network** ", submitted by "**Prashant Navin Gupta, Kanika Tiwari, Aakash Srivastava**" in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

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ACKNOWLEDGEMENT

We take this opportunity to express our profound sense of gratitude and respect to all those who helped us throughout the duration of six months of our project.

This report acknowledges to the intense driving and technical competence of the entire individual that have contributed to it. It would have been almost impossible to produce fruitful results during the six months of the project without the support of those people. We extend thanks and gratitude to our Project Guide Dr. Ghanshyam Singh and Mr. S.V.R.K.Rao who have helped us at every step. They spent their valuable time from their busy schedule to train us and provided their active and sincere support for our daily activities.

This report has been compiled by the sincere and active support from our guides who provided us proper guidance and direction regarding various problems. We have tried our best to summarize this report.

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SUMMARY

Cognitive Radios have been proposed as the solution for the problem of underutilization of spectrum by licensed users. This leads to developing new methods to manage spectrum in efficient manner to overrule the current mechanism of fixed assignment of a frequency to one purpose across a vast geographic area. This paper presents an overview of Game theory using the techniques of cognitive radio network. The ability of Game Theory to model individual, independent decision makers, whose actions potentially affect all other decision makers, renders it partially attractive to analyze the performance of the networks. Game theory offers a suite of tools that can be used effectively in modeling the interaction among independent users (nodes) and can help predict the outcome of complex interactions among rational entities.

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CHAPTER 1 - INTRODUCTION

1.1 THE GENERAL SPECTRUM SCENARIO

It is commonly believed that there is a crisis of spectrum availability at frequencies that can be economically used for wireless communications. This misconception has arisen from the intense competition for use of spectra at frequencies below 3 GHz. At higher frequencies, there is actually very little usage of the spectrum.

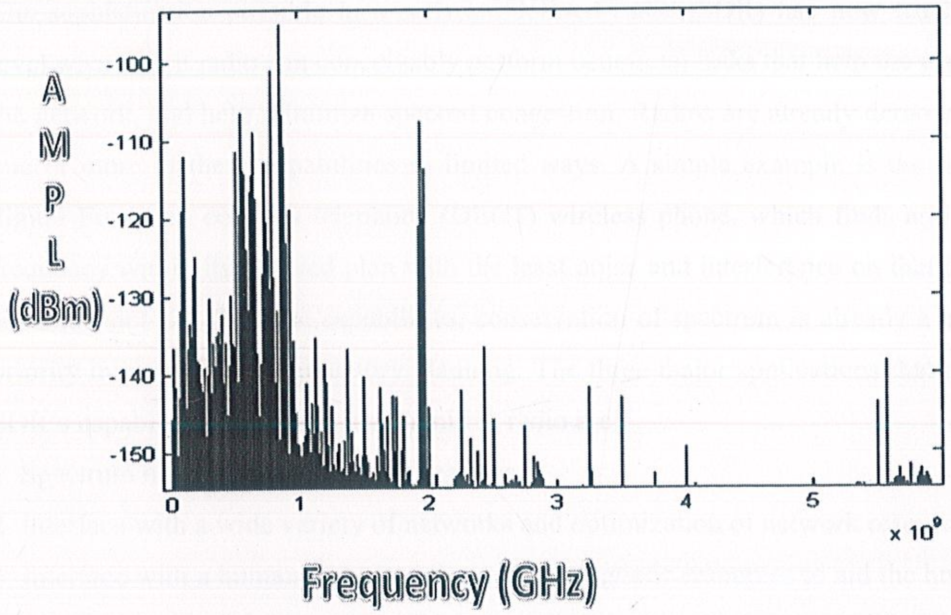

Figure. 1.1 Snapshot of spectrum utilization below 6 GHz in an urban area. [1]

We observe in Figure. 1.1, that Actual utilization in the 3-4 GHz frequency band is 0.5% and drops to 0.3% in the 4-5 GHz band [1]. This implies that we have spectrum abundance, and the spectrum shortage is in part an artificial result of the regulatory and licensing process. We also observe that there is considerable usage in the upper 5 GHz band in this location. This corresponds to the unlicensed UNII spectra, which has only minimal constraints from the regulatory standpoint. What is clearly needed is an extension of the unlicensed usage to other spectral bands, while accommodating the present users who have legacy rights and also to insure that future requirements can be met.

An approach to avoid these problems is to develop a radio that is able to sense the spectral environment over a wide available band and use the spectrum only if communication does not interfere with licensed user. These un-licensed low priorities **Secondary Users (SU)** would thus be using **Software Defined Radios** or **Cognitive Radio (CR)** technique, to ensure non-interfering coexistence.

1.2 INTRODUCTION TO COGNITIVE RADIO

The sophistication possible in a software-defined radio (SDR) has now reached the level where each radio can conceivably perform beneficial tasks that help the user, help the network, and help minimize spectral congestion. Radios are already demonstrating one or more of these capabilities in limited ways. A simple example is the adaptive digital European cordless telephone (DECT) wireless phone, which finds and uses a frequency within its allowed plan with the least noise and interference on that channel and time slot [2]. Of these capabilities, conservation of spectrum is already a national priority in international regulatory planning. The three major applications that raise an SDR's capabilities and make it a cognitive radio are:

1. Spectrum management and optimizations.
2. Interface with a wide variety of networks and optimization of network resources.
3. Interface with a human and providing electromagnetic resources to aid the human in his or her activities.

Many technologies have come together to result in the spectrum efficiency and cognitive radio technologies. These technologies represent a wide swath of contributions upon which cognitive technologies may be considered as an application on top of a basic SDR platform.

CHAPTER 2 – SDR AND CR

2.1 THE SOFTWARE DEFINED RADIO

With a rapid growth of wireless and mobile communication as well as wide acceptance of the third generation mobile communication and beyond, integration and intercommunication of existing and future networks is not a far-sighted envision. In recent years, different types of networks, like self-organizing ad hoc networks, wireless mesh networks, etc. have rapidly evolved and exhibited much prospects in the wireless networking arena [3]. The ubiquitous, seamless access between second and third generation mobile communication, broadband wireless access schemes, as well as inter-operation among the self organizing networks encouraged the market to have a common terminal for different network entities. To support universal access along with user satisfaction in terms of content, quality of service (QoS), and cost, reconfigurable software radio (SR), or its practical form, software defined radio (SDR) terminals are indispensable[4]. The need for additional bandwidth for different wireless technologies has further increased the search for new spectrum and SDR is expected to provide a reasonable solution without any need to search for additional spectrum. The gradual transition from the first generation cellular communication to the advent of re-configurable terminals and base stations is depicted in Fig 2.1.

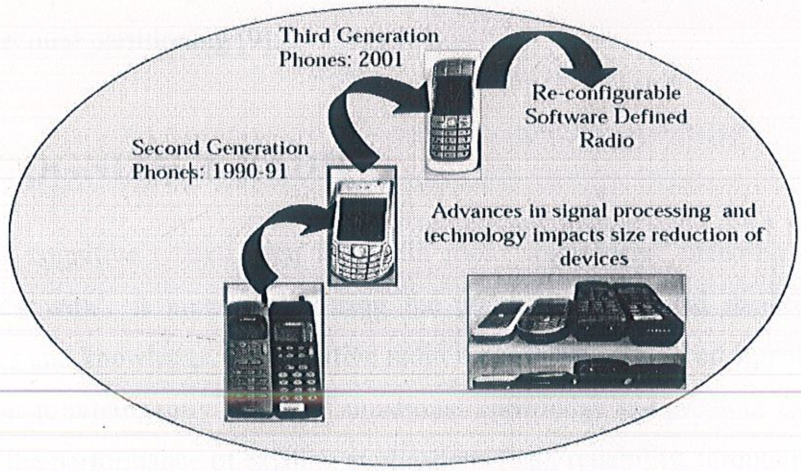

Figure.2.1 Advancement of technology and signal processing leading towards re-configurable SDR's.[5]

Software Defined Radios: It is defined as a radio where the digitization is performed at the baseband stage, downstream from the receive antenna. This digitization is performed after the wideband filtering at the radio frequency (RF) section, low noise amplification and passband filtering at the intermediate frequency (IF) stage and down conversion of the signal to baseband frequency. The reverse operations are valid for the transmit digitization [6].

Software signal processing is performed by a SDR since their operating frequencies and waveforms are controlled by using various software. Switching between modulations and protocols simply requires running different code by a special architecture called Cognitive Radio. Hence, a CR adds intelligence into an SDR [7],[8].

The ideal SDR will cover all frequencies from 9 KHz to 300GHz. It will receive/transmit and modulate/demodulate all modulation modes and bandwidths.

2.1.1 LIMITATIONS OF SDR

1) There are technology limits on achievable RF performances.
2) The choice of architecture depends on the available technology e.g ADC performance, semiconductor technology.
3) Even medium performance SDR tends to require more power for a given function than equipment designed specifically for purpose with optimum analogue/digital architectural partitioning [9].

2.2 THE COGNITIVE RADIO

The term cognitive comes from the Latin root "cognoscere" meaning 'to become acquainted with'. It means possessing the power to think and meditate towards awareness and knowledge. A cognitive radio incorporates advanced signal processing techniques to intelligently leverage situational knowledge and previous experience to improve the performance of existing applications (e.g., reliability, throughput, latency) and to enable new applications (e.g., dynamic spectrum access, spectrum trading, automated network management) [10].

Cognitive radio is a paradigm for **wireless communication** in which either a network or a wireless node changes its transmission or reception parameters to communicate efficiently **avoiding interference** with **licensed or unlicensed users**. This alteration of parameters is based on the active monitoring of several factors in the external and internal radio environment, such as **radio frequency spectrum**, user behaviour and network state [11].

One of the simplest scenarios of cognition is depicted in Fig 2.2

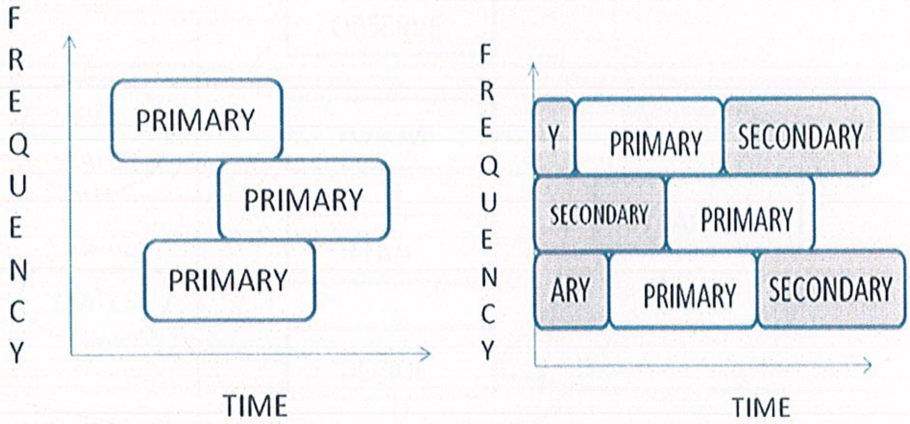

Figure. 2.2 Detecting white spaces in time/frequency coordinates.

The first diagram shows the real time scenario while the second half is efficient sharing of frequency of primary users with secondary users.

The demand for wireless access in voice and high rate data multi-media applications are increasing. New generation wireless communication systems are aimed at accommodating this demand through better

1) **RESOURCE MANAGEMENT** and
2) improved **TRANSMISSION TECHNOLOGIES**

2.3 WORKING OF A COGNITIVE RADIO

The basic steps taken by Cognitive Radio to perform its major functionalities are depicted in Fig 2.3.

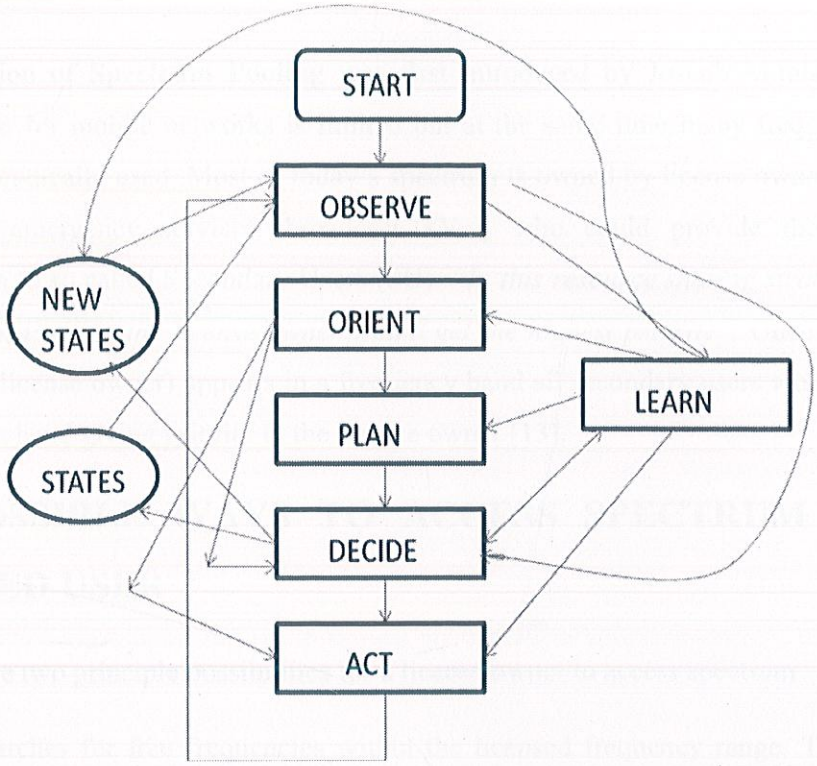

Figure. 2.3. The basic steps performed by cognitive Radio.

In the cognition cycle, a radio receives information about its operating environment (**Outside world**) through direct observation or through signalling.The Cognitive Radio **observes** from the outside world. It **orients** i.e. establishes priority by inferring from context and radio model. It then **plans** or decides its alternatives i.e. generates and select its alternate goals and then **decides** and determines "Best plan" and "Best Waveform". It then **acts** to allocate resources by performing proper signaling, initiate processes and negotiate protocols. From the **orient** phase, it may immediately **act** as well as in certain circumstances, it directly **decides** instead of planning. These changes are then reflected in the interference profile presented by the cognitive radio in the outside world. It follows a continuous cycle of these steps and re-observes after completion of one cycle [12].

2.4 SPECTRUM POOLING

The notion of **Spectrum Pooling** was first introduced by Joseph Mitola in 1999. Spectrum for mobile networks is limited but at the same time many frequencies are only sporadically used. Most of today's spectrum is owned by license owners (GPRS, UMTS, emergency services, broadcast TV...) who could provide their unused spectrum to so called Secondary Users (SU). *"In this resource sharing strategy called Spectrum Pooling the license owner would get the highest priority"*. Once a Primary User (= license owner) appears in a frequency band all secondary users would have to clear this band giving priority to the license owner [13].

2.4.1 POSSIBLE WAYS TO ACCESS SPECTRUM BY A LICENSED USER

There are two principle possibilities for a license owner to access spectrum

1) It searches for free frequencies within the licensed frequency range. The license owner has the right to reclaim frequencies from secondary users who are operating within that band. This approach requires the license owner to be able to detect secondary users and probably even to communicate with them. There is an underlying assumption that the license owner does not necessarily need the use of the entire controlled spectrum and is willing to share it under certain constraints.

2) In the second approach the license owner has no knowledge about secondary users. Consequently it just claims some frequency within its frequency band forcing a secondary user to change to other unoccupied frequencies.

In both approaches Secondary Users have to sense the spectrum in order to detect unused frequencies before they acquire spectral resources. They also have to continuously sense the frequencies they use in order to detect (re)appearing Primary

Users. For the first approach the primary user might possibly inform the secondary user about his intended reappearance before acquiring its spectrum thus eliminating the need for continuous sensing [13], [14].

2.4.2 COGNITIVE RADIO IMPLEMENTATION

The differences in the definitions for cognitive radio can be largely attributed to differences in the expectations of the functionality that a cognitive radio will exhibit. In his dissertation, Joseph Mitola III[15] considers the nine levels of increasing cognitive radio functionality shown in Table 2.1, ranging from a software radio to a complex self-aware radio.

Level	Capability	Comments
0	Pre-programmed	A software radio
1	Goal Driven	Chooses Waveform According to Goal. Requires Environment Awareness.
2	Context Awareness	Knowledge of What the User is Trying to Do
3	Radio Aware	Knowledge of Radio and Network Components, Environment Models
4	Capable of Planning	Analyze Situation (Level 2& 3) to Determine Goals (QoS, power), Follows Prescribed Plans
5	Conducts Negotiations	Settle on a Plan with Another Radio
6	Learns Environment	Autonomously Determines Structure of Environment
7	Adapts Plans	Generates New Goals
8	Adapts Protocols	Proposes and Negotiates New Protocols

Table 2.1 Levels of cognitive radio functionality

2.5 FUNCTIONS OF COGNITIVE RADIO

The main functions of Cognitive Radios are:

1) **Spectrum Sensing**
2) **Spectrum Management**
3) **Spectrum Mobility**
4) **Spectrum Sharing**

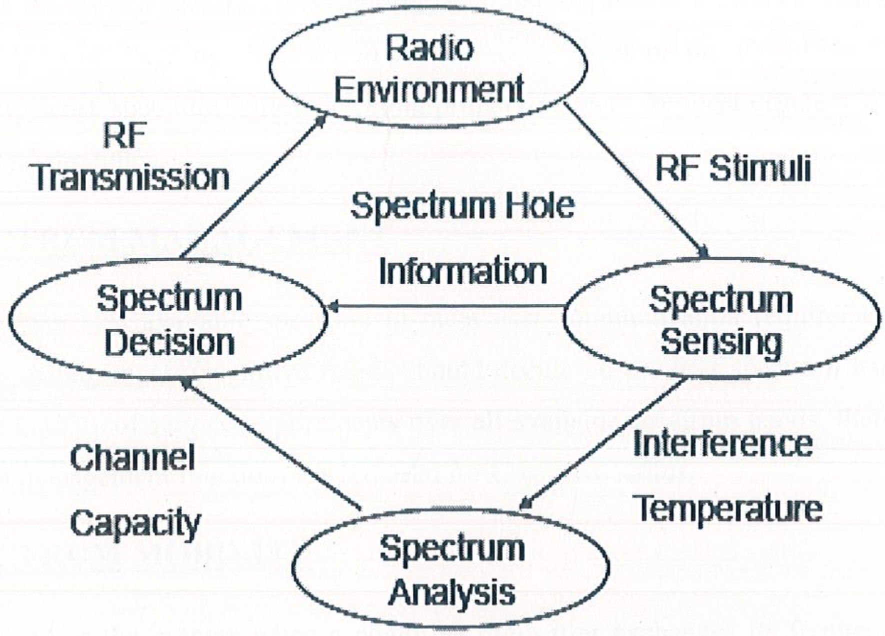

Figure. 2.5. Basic Cognitive Cycle.

INTERFERENCE TEMPERATURE:

It has been argued that soft decision combining of sensing results yields gains that are much better than hard decision combining [16]. This is true when radios are tightly synchronized in which case they can collectively overcome the *SNRwall*. Also it is known that the physical noise uncertainty gives a lower bound on signal strength that a user can reliably detect. This lower bound is increased further to keep the probability of false alarm tolerable [16].

The central role of spectrum management is interference management. The design and operation of RF equipment including communications and emitting non-communications devices are predicated upon preventing and/or mitigating electromagnetic interference.

2.5.1 SPECTRUM SENSING

Detecting the unused spectrum and sharing it without harmful interference with other users is spectrum sensing. It is an important requirement of the Cognitive Radio network to sense spectrum holes. Detecting primary users is the most efficient way to detect spectrum holes.

2.5.2 SPECTRUM MANAGEMENT

Capturing the best available spectrum to meet user communication requirements is spectrum management. Cognitive radios should decide on the best spectrum band to meet the Quality of service requirements over all available spectrum bands, therefore spectrum management functions are required for Cognitive radios.

2.5.3 SPECTRUM MOBILITY

It is defined as the process when a cognitive radio user exchanges its frequency of operation. Cognitive radio networks target to use the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during the transition to better spectrum.

2.5.4 SPECTRUM SHARING

It is providing the fair spectrum scheduling method, one of the major challenges in open spectrum usage is the spectrum sharing.

Another function of Cognitive Radio is Spectrum decision. The decision as to which secondary user should be given the unused spectrum is very difficult and important too. There are many ways to decide this. It could be on the basis of:

a) Who senses the spectrum first
b) The purpose or the requirement of the secondary users
c) The power management, etc.

2.6 REASONS FOR SPECTRUM MANAGEMENT

With the advent of high bandwidth multimedia applications and the growing demand for ubiquitous information network access for mobile wireless devices, enhancing the efficiency of wireless spectrum utilization is essential for addressing the scarcity of available transmission bandwidth. Results from spectrum occupancy measurement studies show that wireless spectrum is generally under-utilized in both the frequency and temporal domains [17], [18]. The vital role of CR comes into play in the detection of such white spaces and in the opportunistic allocation among requesting users in varying time and space.

Cognitive radio technology has the potential of affecting the marketplace for radio devices and services as well as changing the means by which wireless communications policy is developed and implemented. One of the key parameters that must be addressed to enter the radio market is access to radio spectrum. Once access is obtained, the capacity to manage interference becomes a key attribute in order to increase the number of users. Throughput is critical in order to maximize benefit (for the device) or maximize revenue (for the service). Radio frequency (RF) spectrum access and interference management are thus the primary roles of spectrum management.

2.7 SPECTRUM SHARING TECHNOLOGIES

Spectrum sharing can mitigate the apparent spectrum scarcity problem and improve spectrum efficiency. The Spectrum sensing techniques can be divided on the basis of Network architecture or on the basis of Spectrum allocation Behaviour[19] based on [20]

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1. Network Architecture

(a) Centralized Approach

(b) Distributed Approach

2. Spectrum Allocation Behavior

(a) Cooperative Approach

(b) Non-cooperative Approach

3. Spectrum Access Technique

(a) Underlay Approach

(b) Overlay Approach

2.7.1 Network Architecture

2.7.1.1 Centralised Architecture

In a *centralized spectrum sharing* approach, a centralized entity coordinates with arbitrary wireless technologies and manages access to arbitrary radio spectra by issuing clients temporary leases for parts of the radio spectrum [21]. In this model, a centralized server collects information from a collaborating group of secondary users, which learn about the primary user transmission characteristics, along with primary user cooperation, if possible, and manages a database for the spectrum access and availability information. The users communicate with the centralized server using a pre-assigned dedicated radio control channel (RCC). A basic framework for a centralized spectrum sharing model is shown in Figure 2.7.1. In the figure, the dashed RCC link between the primary user and the centralized server implies that the primary user may or may not choose to cooperate, whereas the solid RCC link between the secondary user and the centralized server implies that they must cooperate with each other. This form of spectrum management offers simpler and coordinated spectrum access, which enables efficient spectrum sharing and utilization in wireless environments.

PROBLEM:

a) BW gets limited as the network grows in size

b) complexity is high

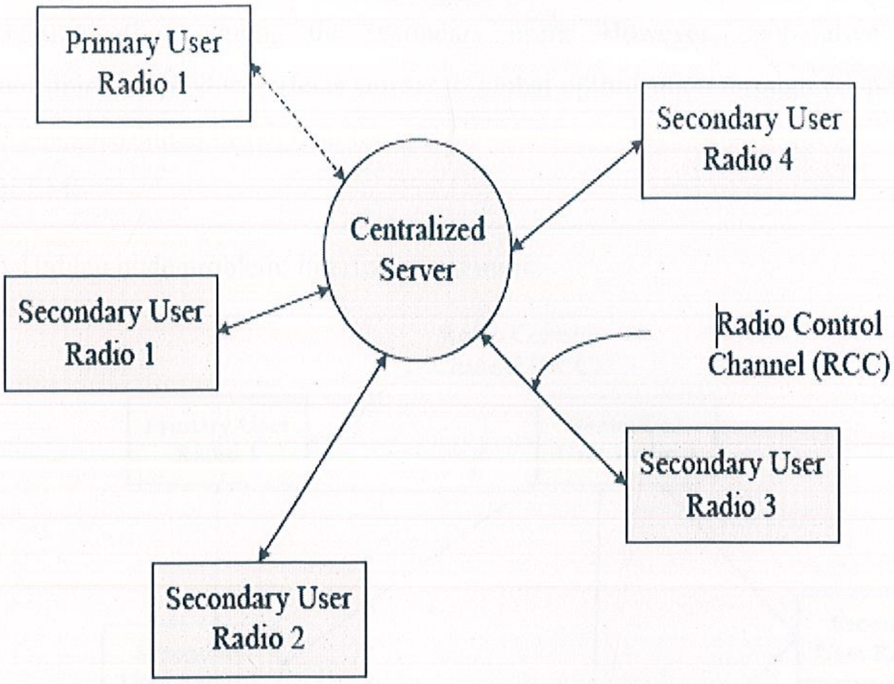


Figure. 2.7.1. Centralized Network Architecture.

2.7.1.2 Distributed Architecture

In a *distributed spectrum sharing* approach, each node is responsible for its own spectrum allocation and access based on primary user transmissions in its vicinity and policies [22,23]. In this model, since secondary users can sense and share the local spectrum access information among themselves, primary user contributions need not be enforced. Therefore, this model poses an advantage for the primary license holders, since there would be no overhead involved with the incumbent users. A basic framework for a distributed spectrum sharing model is shown in Figure 2.7.2. In the figure, the dashed RCC link between the primary user and other secondary users implies that the primary user may or may not choose to cooperate, whereas the solid RCC link among the secondary users implies that they must cooperate with each other.

Since individual nodes are responsible for maintaining the correct information about current spectrum usage, distributed spectrum sharing results in increased overhead communications among the secondary users. However, cooperative distributed algorithm can produce effects similar to global optimization through cooperative local actions distributed throughout the system

PROBLEMS :

a) Hidden node problem, interference is more.

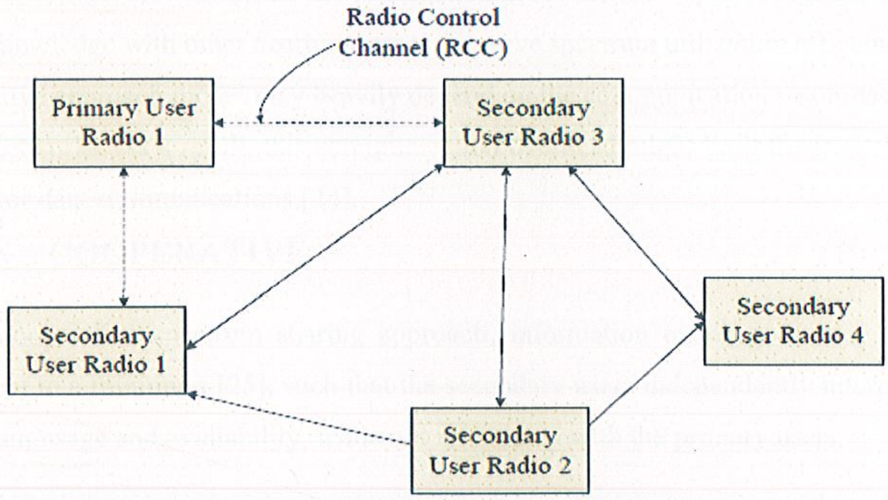


Figure. 2.7.2(a). Distributed Network Architecture.

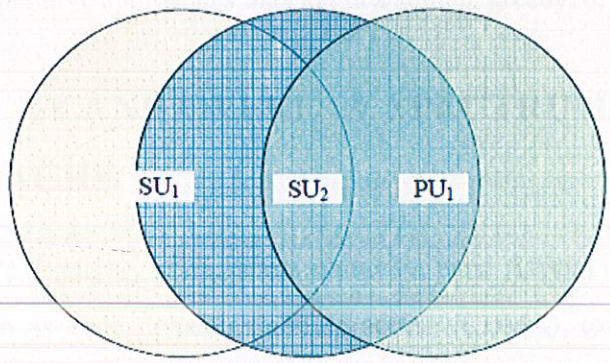


Figure. 2.7.2 (b) An example illustrating a hidden node problem, where the primary user *PU*1 is hidden from the secondary user *SU*1

2.7.2 Spectrum Allocation Behaviour

2.7.2.1 Co-operative

In cooperative spectrum sharing, the primary and secondary users can cooperate and share spectrum occupancy information with each other to improve the spectral usage. It may be the case that a centralized entity maintains the database of the spectrum usage and coordinates the spectrum access information among the users, or distributed sharing, where each user maintains the information about the local spectrum usage and share its knowledge with other nearby users to improve spectrum utilization efficiency. A cooperative approach model may heavily depend on the communication resources of the DSA networks. As a result, this communication overhead might limit the available spectrum for data communications [24].

2.7.2.2 NON – COOPERATIVE

In a non-cooperative spectrum sharing approach, information exchange among the users is kept to a minimum [25], such that the secondary users independently interpret the spectrum usage and availability, while not interacting with the primary users.

PROBLEMS:

(a) The non-cooperative approaches result in minimal communication requirements among the nodes at the expense of poor spectrum utilization efficiency.

(b) The non-cooperative approaches may act in a selfish, greedy, or rational way.

2.7.3 UNDERLAY AND OVERLAY SPECTRUM SHARING APPROACHES

UNDERLAY: Underlay systems use ultrawide band (UWB) or spread spectrum techniques, such as code division multiple access (CDMA), to transmit the signal below the noise floor of the spectrum. An example of the time and frequency domain information of an underlay spectrum sharing system is shown in Figure 2.7.3(a). In this figure, we see that the underlay systems use wide band low power signals for transmissions. However, this technique can increase the overall noise temperature and thereby worsen error robustness of the primary users as compared to the case without underlay systems. To avoid any interference to the primary users, underlay system can use interference avoidance techniques, such as *notching* and *waveform adaptation* [26].

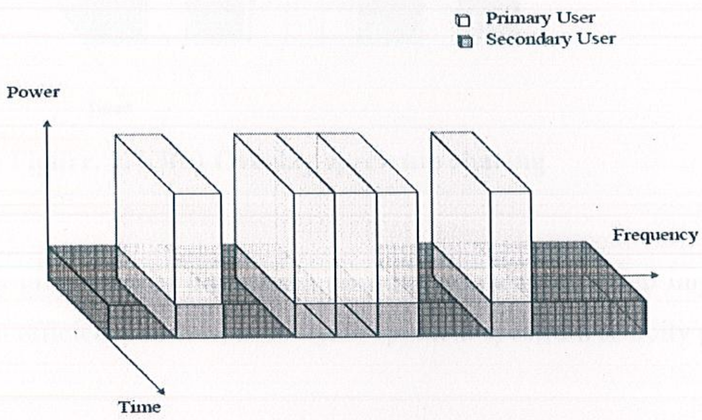


Figure. 2.7.3(a) Underlay

OVERLAY: To improve the spectral efficiency, overlay systems utilize the unused portions of the spectrum. The spectrum holes filled in by secondary transmissions in an overlay system is shown in Figure 2.7(b). As shown in this figure, the overlay systems use the unoccupied portions of the spectrum with a reasonable amount of guard intervals for secondary transmissions keeping the interference to the primary users to a minimum. Since the licensed system has privileged access to the spectrum, it must not be disturbed by any secondary transmissions.

This results in two main design goals for an overlay system[27]:

1) Minimum interference to licensed transmissions
2) Maximum exploitation of the gaps in the time-frequency domain.

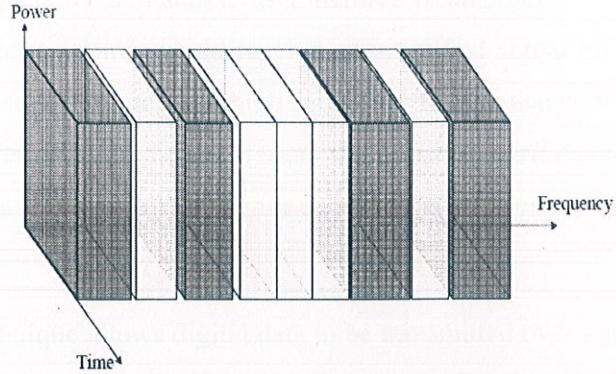


Figure. 2.7.3(b) Overlay spectrum sharing

2.7.4 Problem

Enabling secondary utilization of the unused portions of the spectrum to improve the spectrum utilization efficiency as well as mitigate apparent spectrum scarcity problem

Solution :

A cognitive radio / spectrum pooling architecture has been developed at the University of Karlsruhe. Weiss and Jondral have defined a centralized spectrum pooling architecture based on OFDM [28].

Orthogonal frequency division multiplexing (OFDM)-based transmission is a promising candidate for a flexible spectrum pooling system in DSA (dynamic spectrum allocation) environment, where the implementation achieves high data rates via collective usage of a large number of subcarrier bands. Subcarrier bands are separated analog or digital signal carried on a main radio transmission which carries extra information such as voice or data.

In this solution in order to detect primary users the base station periodically broadcasts so called *detection frames which are frames containing no data at all. During that period all* mobile users perform sensing of the spectrum. All the sensing data has to be gathered at the base station, which would take considerable time using traditional medium access techniques.

All mobile terminals (but the base station) modulate a complex symbol at maximum power in those sub-carriers where a licensed user appeared, i.e. only those sub-carriers that were not occupied by a licensed user before. If all mobile terminals do this simultaneously the base station would receive an amplified signal on all sub-carriers with new licensed users resulting in a high reliability for the detection. Although this causes extra interference to the licensed users the *boosting period is short enough to neglect it.* Additionally this is only done for sub-carriers with newly detected licensed users.

This modulation technique allows digital data to be transmitted over a radio channel by using a large number of narrow bandwidth subcarriers. Usually, these subcarriers are regularly spaced in frequency, forming a contiguous block of spectrum. OFDM offers several advantages over other transmission technologies such as high spectral efficiency, robustness to fading channel, immunity to impulse interference, and capability of handling very strong multi-path fading and frequency selective fading without having to provide powerful channel equalization.

One of the major drawbacks of an OFDM signal is that it may exhibit large PAPR (peak to average power ratio) values. But, OFDM spectrum access is scalable while keeping users orthogonal and non-interfering provided the users are synchronized. OFDM is a proven technique which supports high data rates that are robust to channel impairments due to frequency selective channels. In order to keep the cognitive receiver demodulator fairly simple, it has been proposed to restrict a single user transmission to a single frequency band. In this dissertation, we proposed an NC-OFDM framework which allows the single user to utilize multiple frequency bands collectively for high data rate transmissions.

CHAPTER 3: COOPERATIVE SPECTRUM SENSING

3.1 INTRODUCTION

The greatest advantage of CR is that it can be operated in licensed bands without a license. Since the cognitive (unlicensed) users are utilizing the licensed band, they must detect the presence of licensed (primary) users in a very short time and must vacate the band for the primary users. Thus one of the major challenges that confront this technology is: how do the cognitive (unlicensed) radios sense the presence of the primary (licensed) user? One may expect this to be trivial but there are fundamental limits to the detection capabilities of CR networks. Improvement in spectrum sensing capabilities can be obtained through cooperation between individual cognitive users [29]. Cooperative schemes with orthogonal transmission in a TDMA system have been recently proposed.

Two user single hop networks in which one of the user acts as a relay for the other, result in lower outage probabilities. In particular, it is shown that the *amplify-and-forward* (AF) protocol, in which the relay transmits the signal obtained from the transmitter without any processing, achieves full diversity.

3.2 OBJECTIVES OF COOPERATIVE SCHEME

Use of cooperation in wireless has been studied extensively especially in respect to achieving **diversity gains** and **lowering outage probabilities** via cooperation of mobile users. In the Cognitive Radio context, exploitation of this cooperative effect in a different way is required. Rather than improving confidence by increasing cooperation, maintaining confidence while reducing competence is required. Hence the chosen metric is the reduction in sensitivity requirements once cooperation is employed. Sensitivity of a radio is inherently limited by cost and delay requirements. Thus the device designer can figure out the implications of cooperation on the device specification through the well understood metric of detection sensitivity, thereby isolating the issue from unrelated concerns like the access regime, etc.

1) Cooperation allows independently faded radios to collectively achieve robustness to severe fades while keeping individual sensitivity levels close to the nominal path loss. Furthermore, a small number of radios (»10-20) are enough to achieve practical sensitivity levels.
2) Practical "link budgets" for dealing with fading depend strongly on the target probability of detection which in turn depends on the tolerable probability for harmful interference at the Primary receiver and the number of non-cooperating Cognitive networks.

3) Communicating tentative hard decisions can achieve cooperative gains nearly identical to sharing soft decisions.

4) In a correlated fading environment, we cannot necessarily operate robustly with the sensitivity levels predicted by the analysis of independent users. In this case, polling a few independent users is better than polling many correlated users.

5) Radios that fail in unknown ways or may be malicious, introduce a bound on achievable sensitivity reductions. As a rule of thumb, if we believe that a fraction 1 / *N* of users can fail in an unknown way, then the cooperation gains are limited to what is possible with *N* trusted users.

3.2.1 COOPERATIVE REGIMES

The level of cooperation is determined by the bandwidth of the control channel and the quality of the detector. Using these two metrics we can define three regimes of interest:

1) *Low bandwidth control channel, Energy detector Radios:* In this regime, we expect a low bandwidth control channel which is especially true of initial setup stages. Under such a scenario, it is realistic to assume that the radios exchange decisions or summary statistics rather than long vectors of raw data. Furthermore, we assume radios that have no *a priori* information about the correlation structure of the signal and hence must integrate the received energy. It has been proved that with noise uncertainty, energy detectors suffer from a lower bound on the SNR (called *SNRwall*) below which detection is not reliable.

2) *Low bandwidth control channel, Detectors utilizing signal statistics:* An example of such detectors is cyclo-stationary detectors which utilize the correlation in the signal and hence perform better than energy detectors. However, given the presence of a low bandwidth control channel, only summary statistics can be exchanged.

3) *High Bandwidth Control channel, all possible detectors:* In this regime, Cognitive Radios can exchange entire raw data and hence sophisticated detection can be performed. In this scenario, we can show that cooperation can enable tightly synchronized radios to collectively overcome the *SNRwall*.

The first regime is the best of all since it gives us the lower bound on cooperative performance.

3.2.2 THE RADIO CHANNEL

The Radio channel has three different elements which are important for analysis:

1) **Distance dependent Path Loss:** Path loss forms the most significant portion of the energy loss. A realistic model of cooperative Cognitive usage is a group of users localized in a small area (» 1*km*2). In such a situation, differences due to path loss are negligible (.1-.5dB)^4. If we consider a group of Cognitive Radios situated at a distance of 60km from a TV transmitter of 100kW power. The distance of 60km is well beyond the grade B service contour of TV reception.

2) **Multipath:** Small scale fading is flat and exhibits a Rayleigh distribution. For Primary user detection, flat fading yields the worst case performance since frequency selectivity provides multiple 'looks' at the same signal. Similarly, Rayleigh fading is considered, since the case of interest is when we cannot count on line of sight between the Cognitive Radio and the Primary transmitter. It is important to note that multipath cannot be relied upon to yield gains (our aim is only to avoid severe multipath losses) since we could easily end up in a deployed scenario where there is Ricean fading.

3) **Shadowing:** Shadowing on the log scale has been assumed to be normally distributed based on the application of Central Limit Theorem to a large number of small absorptive losses. The standard mechanism to derive the shadowing environment is to take measurements at various locations for a fixed transmitter-receiver separation and attribute the variance in the measurements to shadowing. A naive interpretation would indicate that shadowing can lead to a gain – however it must be realized that the mean received power level in this case has no physical significance. To relate the shadowing to the distance dependent path loss, we used a different model of shadowing where shadowing is viewed as losses via a series of obstacles. For each obstacle, there is a small probability that the obstacle will be missed. Using this model, shadowing is viewed as *extra* loss beyond the distance dependent path loss.

3.2.3 GAINS FROM COOPERATION

1) Impact of number of users

There is a reduction in sensitivity of individual radios as the number of users is increased. This simulation assumes path loss predictions by the NTIA model at a confidence level of 15% as the nominal distance dependent path loss. This model accounts for losses due to frequency, distance, antenna heights, polarization, surface refractivity, electrical ground constants and climate and hence yields realistic loss levels. There is also a change in threshold with increasing number of users under three different effects: multipath only, shadowing only and multipath together with shadowing. Gains beyond the nominal path loss as artificial and these should be ignored. When multipath is considered together with shadowing, the threshold asymptotically approaches the nominal path loss. With shadowing alone, the approach is slower due the absence of multipath gains. Half the gain is achieved by using »10-20 users, beyond which the gains exhibit a 'law of diminishing returns' as the number of users is increased.

4) Soft versus Hard cooperation

It has been argued that soft decision combining of sensing results yields gains that are much better than hard decision combining. This is true when radios are tightly synchronized in which case they can collectively overcome the *SNRwall*. It is also known that the physical noise uncertainty gives a lower bound on signal strength that a user can reliably detect. This lower bound is increased further to keep the probability of false alarm tolerable[29].

CHAPTER 4: GAME THEORY

Game theory describes and analyses interactive decision situations. It adheres to a strategy to predict the outcome. It aims at the attainment of Nash equilibria. Game theory is basically a mathematical tool that is based on intelligent and interactive decision making that considers a set of 'n' primary users and 'm' secondary users, where m>n, and it focuses on intelligent spectrum sharing and management between primary and secondary users in order to avoid interference and make the full utilization of the spectrum that is currently not being used by any user.

Game theory is an appropriate tool because it deals primarily with distributed optimization- every user makes their own decisions [30 - 33]. They become computationally infeasible as network size increases. It has basically 3 components – a set of players that play the game, the set of various actions that they can take, commonly known as the "action tuple", and a set of utility functions that map their action profiles into real numbers. Every player tries to follow a strategy that would maximize their efficiency. They judge what strategy their opponent may follow, and thereby takes an intelligent step so as to win the game [34-35].

4.1 PROBLEM FORMULATION IN COGNITIVE RADIO AND GAME THEORY

The major issue of CR is to cope with the problem of Interference. Hence instead of Signal to Noise Ratio (SNR) we use Signal to Interference plus Noise Ratio (SINR) for measuring the signal strength of Cognitive Radio .It is necessary to study the SINR pattern of Cognitive Radio because-

a) SINR is an important metric of wireless communication link quality.

b) Interference with primary users should be within a acceptable range.

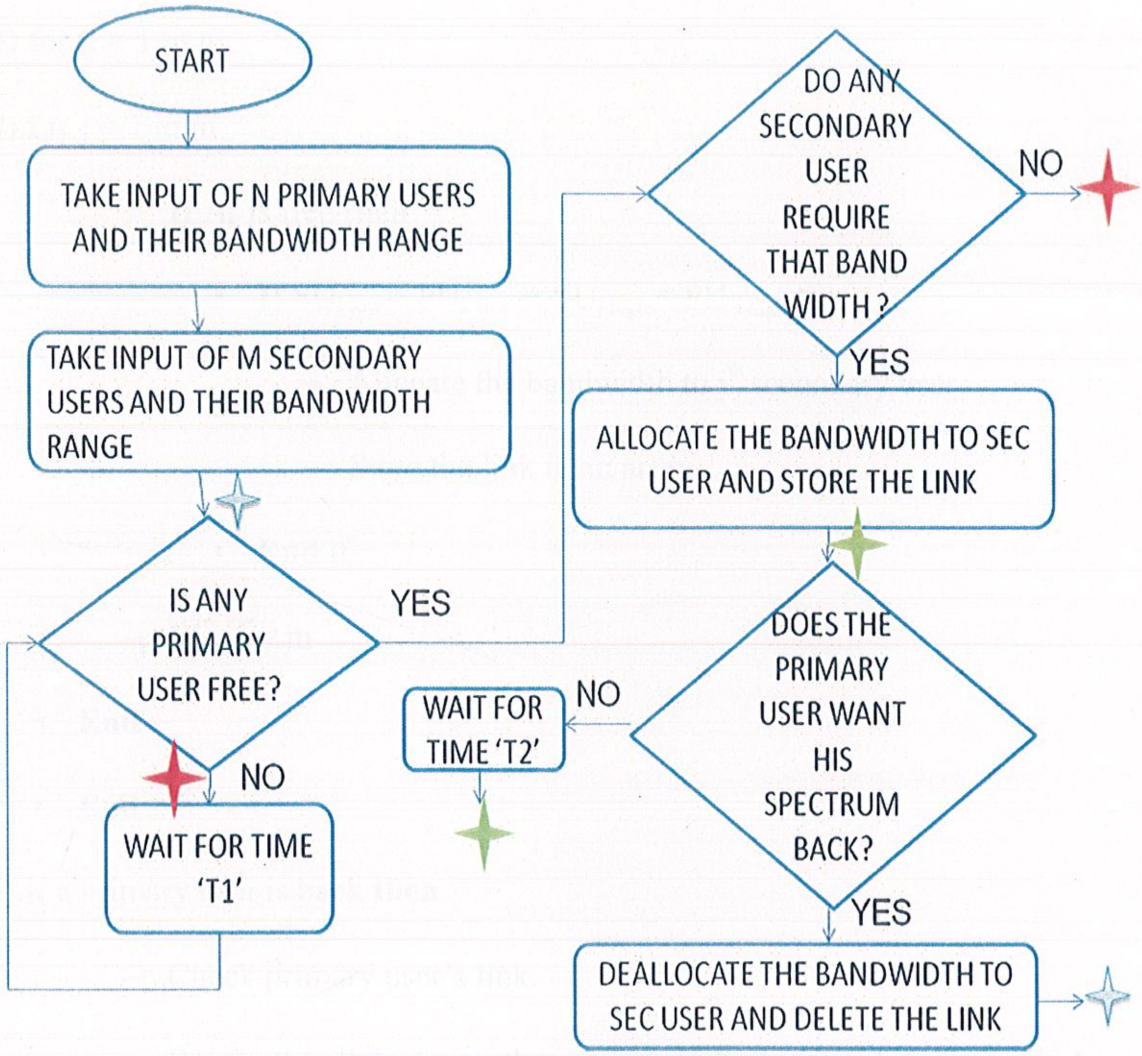
c) Evaluating the network performance.

Signal to Interference plus Noise Ratio (SINR) is the ratio of the received strength of the desired signal to the received strength of undesired signals (noise and interference). SINR estimates have several important applications. These include optimizing the transmit power level for a target quality of service, assisting with handoff decisions and dynamically adapting the data rate for wireless Internet applications. Accurate SINR estimation provides for both a more efficient system and a higher user-perceived quality of service [36].

Another most important problem comes into account when a primary user wants his spectrum back, and the secondary user takes time to return back the spectrum to the primary user as he may be currently sending large chunk of packets and cannot terminate his transmission/ reception immediately. Also, all users must have strong sensing techniques in order to immediately detect as to which spectrum is free and can be utilized for one's own usage.

FLOWCHART AND CODE

FLOWCHART:



ALGORITHM:

1) A = {primary user}$_{1-n}$ = BW(PU_{low} , PU_{upper})

2) B = (secondary user} $_{1-m}$ = BW(SU_{low} , SU_{upper})

3) for k = 1 to n

4) for j = 1 to m

- **If** A_k is free **then**
  - **If** $SU_{j\ low} > PU_{k\ low}$ & $SU_{j\ high} < PU_{i\ high}$ **then**
    - Allocate the bandwidth to jth secondary user
    - Store the link in an array
  - **End if**
- **Else** j = m

- **End**
- **End**

5) if a primary user is back **then**

- Check primary user's link.
- Break the link from the corresponding secondary user and provide it back to the primary user

- **else**

Wait for time t and repeat steps 3 and 4

CODE:

- ***Step 1: definition of classes of primary and secondary users***
- ***Step 2: declaration of array of busy secondary users (busy_s) and initialization of all its values as -1***
- ***Step 3: taking inputs of all primary and secondary users and their corresponding bandwidth requirements***
- ***Step 4: for every single primary user, checking all secondary users with whom it can share its bandwidth and storing it in an array (p[i].share)***
- ***Step 5: creating an array for free primary users (free_p) for storing as to which primary user is currently sharing its bandwidth***
- ***Step 6: checking which primary user is free***
- ***Step 7: checking the corresponding users 'share' array***
- ***Step 8: catching the first secondary user of the share array and checking in busy_s array, that the secondary user is not listed in that array***
- ***Step 9: if his name is listed then catching the next element, else allocating him the bandwidth and entering his name in the busy_s array and the corresponding primary user's name in free_p array.***
- ***Step 10: store the link***
- ***Step 11: repeating the process desired number of times***
- ***Step 12: checking if a primary user wants to return***
- ***Step 13: accessing the link array, deleting the entry, reallocation of the bandwidth to primary user***
- ***Step 14: repeat the process***

RESULTS

```
enter the data for three secondary users
Welcome new user... Enter your name sec1

Enter your lower bandwidth requirement 700

Enter your upper bandwidth requirement1000

Welcome new user... Enter your namesec2

Enter your lower bandwidth requirement200

Enter your upper bandwidth requirement400

Welcome new user... Enter your namesec3

Enter your lower bandwidth requirement750
```

```
How many primary user do u want???
100

Welcome new user... Enter your name user1

Enter your lower bandwidth requirement 100

Enter your upper bandwidth requirement 1000

Welcome new user... Enter your name user2

Enter your lower bandwidth requirement 500

Enter your upper bandwidth requirement 700

Welcome new user... Enter your name user3

Enter your lower bandwidth requirement 650

Enter your upper bandwidth requirement 1200

Welcome new user... Enter your name user 4
```

```
the primary user 3 is free !!! the seconday user 1 has been alloted the bandwi
th !! the secondary user is busy using the bandwidth
```

```
the primary user 3 is free !!! the seconday user 1 has been alloted the bandw
th !! the secondary user is busy using the bandwidth the primary user 0 is fre
!! Primary User 1is back...
bandwidth deallocated from secondary user1
```

FUTURE WORK

We plan to include database connectivity in our program that would include the primary and secondary users and their bandwidth requirements. We also plan to incorporate the concept of partial sharing.

Ability of the software to learn from its past actions can be incorporated into the programme which would smoothen the functioning of the radio and make it more effective.

CONCLUSION

Next-generation wireless networks are expected to use flexible spectrum sharing techniques for achieving more efficient and fair spectrum usage. Game models can provide insight into the design and implementation of cognitive radios. By studying the intelligent behaviours of cognitive users, game theoretical dynamic spectrum sharing is important for developing efficient distributed spectrum sharing schemes and ensuring the optimality of spectrum sharing in various scenarios. However, to ensure efficient and fair spectrum sharing in next-generation networks, more research is needed along the lines of game theoretical study.

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