Spectrum Allocation in Cognitive Radio Networks based on Shapley value

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DECLARATION

We declare that, this thesis work is our own and has not been submitted for any other degree or professional qualifications. All sections of the paper that use quotes or describe an argument or concept developed by another author, have been referenced in the reference section.

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ABSTRACT

In the era of spectrum allocation Cognitive Radio (CR) is a favorable solution to the lack of spectrum which is static for each type of communication device and operator causes the waste of a lot of idle spectrum. So that, Significant amount of research are focused on the application of game theory in effective spectrum allocation problem in cognitive radio. Proper utilization of spectrum is needed where the demand of the wireless communication rate is increasing. For fairly distributing those spectrum to unlicensed user by CR without creating interference to authorized users here we will provide a large content or scope to give a better allocation model based on Shapley Value of cooperative Game theory, which will contribute a detail inspection of flexible and logical spectrum allocation in wireless networks through general infrastructure. In this paper**,** shapely value algorithm has been applied for dynamic network where both authorized and unauthorized users can utilize the radio frequency at the same time with maximum throughput without interfering the authorized users. The allocation process is allowed only when a spectrum has been requested and idle spectrum is present in the network. Fair policy in the spectrum for the unauthorized users has been ensured with a universal price function. Here, results of the proposed method has been compared with other game theory's (VCG model, Cournot , Bertrand) which have been applied for spectrum allocation in cognitive radio.

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CHAPTER 1

INTRODUCTION

In this chapter we are discussing about our background of that thesis and why we are motivated to do that work. As there are a number of research is being done about that topic and still now research is continuing. We focused on some areas of improvement which have been overlooked by most of the researchers. We also discuss about how the main allocation process happens and what our hypothesis about our research was.

1.1 Motivation

Much research interest has been focused on spectrum allocation in recent years because of the increasing demand of wireless communication with limited wireless spectrum resources. For a very long time period, authorized users have been allocated spectrum in Cognitive Radio Network (CRN) which resulted in excessive unused spectral band in the network. Although allocated spectrums are more often used by Primary Users (PU) or authorized users, a significant share of available spectrum remain unused [2]. In order to utilize these unused spectrums, often known as spectrum holes, PUs offers their idle spectrum to Secondary Users (SU) or unauthorized users. CRN have mainly six theory in terms of spectrum allocation. Those are graph theory, the interference temperature, price auction, game theory and Partially Observable Markov decision Process (POMDP). Most of the allocation process occur based on game theory. Some popular spectrum allocation algorithms based on Non-cooperative game theory are VCG (Vickrey-Clarke-Groves) mechanism [3], Cournot Game model [4], and Bertrand Game model [5].

VCG mechanism is known as Vickrey–Clarke–Groves and is widely used around the world [5]. Even so, possibilities of unused spectrum in the network still remain certain. Here, each non-cooperative game player has to play the game by oneself without forming a group in order to maximize his/her profit for finding the best strategy [5]. Each player selfishly plays to avail the limited resources. Resources are only offered to one particular user who will offer the highest charge for using spectrum. In terms of sharing and allocating resources through VCG model, only one SU who gets the whole spectrum offered by PU although all the offered spectrums are being unused by that particular SU. The selection of an SU among all unauthorized users is done by auction. The individual SU offering the highest bid in the auction wins and allowed to use the spectrum from PU by placing the second highest bid in the auction. As a result, other SUs are disregarded from any spectrum usage and have to wait for the next auction [5]. Moreover, each auction occur for different amount of spectrums. Therefore, the VCG model has some limitations in offering optimum resources to the SUs.

In order to minimize spectrum holes, a new utility function was introduced to allocate spectrum in [4] which is more close to the actual environment based on Cournot game model where two authorized users and multiple cognitive users can perform at the same time. Charges of the users are determined by a pricing function in order to ensure maximum profit [4], [6] and reach Nash equilibrium state. This model is much popular where it follows the oligopoly market policy by restricting entry into and exit from the game. This model is more suitable for spectrum allocation for cognitive users as compared to Bertrand Game model that mostly applies to interactions with the main system [4].

1.2 Goals

In this work, we propose a technique where the unused idle spectrum of authorized user is effectively utilized by allocating spectrum to the unauthorized user while being universally charged. In this model, we focus on maximum allocation of unused spectrum in PU without causing any harm to them while SU simultaneously receive demanded spectrum at a time. Our technique provides an optimal solution to overcome the constraints of the VCG model as well as Cournot model.

1.3 Problem Statement

The unbalanced usage of spectrum, under-utilization of some parts of spectrum while over-crowed in the others, has stimulated a flurry of research efforts in engineering, economics and regulation communities in searching for better spectrum management policies. Some new ideas have been proposed to provide more flexible and efficient usage of spectrum.

The concept of *dynamic spectrum access* (DSA) or *open spectrum* is discussed in [8], which aims to dynamically manage spectrum access and spectrum sharing by using new technology and standards, in place of the current static band allocation through bureaucratic command and control. DARPAs approach on dynamic spectrum access network, the so-called NeXt Generation (xG) embraces the goal of developing enabling technology and system concepts to dynamically redistribute allocated spectrum along with novel waveforms in order to provide dramatic improvements in assured military communications in support of a full range of worldwide deployments [9]. The IEEE 802.22 working group on Wireless Regional Area Networks (WRAN) is currently developing a new standard, focusing on constructing a consistent, national fixed point-to-multipoint WRAN that will utilize free UHF/VHF TV bands for communication [10].

The key enabling technology of the projects mentioned above is the cognitive radio, first presented officially in an article by Joseph Mitola III [11]. 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 without interfering with licensed 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 behavior and network state. More specifically, the cognitive radio technology will enable the users to (1) determine which portions of the spectrum are available and detect the presence of licensed users when a user operates in a licensed band (spectrum sensing), (2) Select the best available channel (spectrum management), (3) coordinate access to this channel with other users (spectrum sharing), and (4) vacate the channel when a licensed user is detected (spectrum mobility) [7].

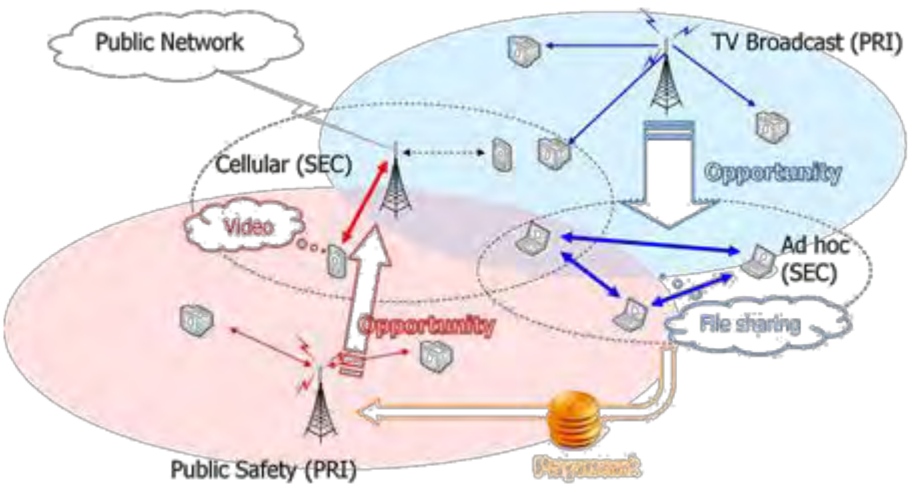


Figure 1.1: A dynamic spectrum access scenario.[7]

1.4 Solution and Methodology

There are some paper where there spectrum allocation is based on VCG auction model. In that model primary user can allocate the rest of his unused spectrum to the secondary user based on how much spectrum is needed to that secondary user. If there is a lot of user primary user can give his rest of the unused spectrum to one user. The condition of gating that unused spectrum depends on how much bit the secondary user can give to the primary user but the bit will provide by the secondary user will be second height. That means primary user will get second height bit of all bidder and give his rest of the frequency to the bidder who offer height bit. Some disadvantage of using VCG model can be:

1. The bid of each frequencies is not fixed. Each time when the auction happen the bid may change. This is not a fair process. For example, if A, B, C are auctioning for getting spectrum form a primary user for 10 minutes. An offers 40 bids, B offers 20 bids and C offers 70 bids. From VCG model C will get the frequency by paying 40 bids. In next 10 minutes X, Y, Z are auctioning for the same frequency. In that time X offers 60 bid, Y offers 90 bids and Z offers 40 bids. At that time primary user will provide his rest of the frequency to Y by receiving 60 bids. So, for the same frequency first time secondary user will give 40 bids and second time 60 bits. It is not fair enough.
2. Again in VCG model primary user will give his rest of the unused frequency to only one bidder but rest of the bidder will get nothing. Their auction is just useless for them.
3. Though they can’t get anything their time must be waste. So, VCG auction is always act as selfish node. Because only who have the higher capability of giving number of bids will get the frequencies.
4. Another thing is, in VCG model the proper use of unused spectrum will not happen. Because primary user will give his rest of the frequency to one user without knowing how much frequency is needed to that secondary user. For example the unused frequency of primary user is 80 but frequency needed by the secondary user (who have been selected by auction) is 20. So at that time 60 frequency will be remain unused until that secondary user will act as primary user for his rest of the frequency. Though it act like primary user but at the end some leaf node may have some unused spectrum.

Therefore, by overviewing this constrains we proposed Shapley value in spite of VCG model. By using Shapley value concept those problem should be solved.

First of all, the question may be arise what Shapley value is. In game theory, the Shapley value, named in honor of Lloyd Shapley, who introduced it in 1953, is a solution concept in cooperative game theory. To each cooperative game it assigns a unique distribution (among the players) of a total surplus generated by the coalition of all players. The Shapley value is characterized by a collection of desirable properties. Hart (1989) provides a survey of the subject. The main idea of Shapley value is, a coalition of players cooperates, and obtains a certain overall gain from that cooperation. Since some players may contribute more to the coalition than others or may possess different bargaining power (for example threatening to destroy the whole surplus)

Formally, a coalitional game is defined as: There is a set *N* (of *n* players) and a function V that

Maps subsets of players to the real numbers: $v: 2^N \rightarrow R$ with V (0) = 0, where denotes the empty set. The function is called a characteristic function.

The function V has the following meaning: if *S* is a coalition of players, then *V*(*S*), called the worth of coalition *S*, describes the total expected sum of payoffs the members of S can obtain by cooperation.

The Shapley value is one way to distribute the total gains to the players, assuming that they all collaborate. It is a "fair" distribution in the sense that it is the only distribution with certain desirable properties listed below. According to the Shapley value the amount that player *i* gets given in a coalitional game (V,N) is

$$\phi_i\,(v) = \sum_{S \subseteq N\{i\}} \frac{|S|!\,(n - |S| - 1)!}{n!} (v(S\ \cup \{i\}) - v(S))$$

Where *n* is the total number of players and the sum extends over all subsets *S* of *N* not containing player *i*. The formula can be interpreted as follows: imagine the coalition being formed one actor at a time, with each actor demanding their contribution $v(S \cup \{i\}) - v(S)$ as a fair compensation, and then for each actor take the average of this contribution over the possible different permutations in which the coalition can be formed.

That's how all the bidder that may auction for the frequencies will get at least some of the frequencies proportional to how much frequencies is needed and how much frequencies are there to the primary user and number of bidder. That will overcome the problem in VCG model. We may consider the bid per frequencies is fixed and universal.

1. As each frequencies bid is pre-configured and universal for each secondary user the bid will give by the secondary user will depends on how much frequencies that he will use. For each period of time bid per frequencies will not changes. So there will not any possibility of being loose. Each and every one will be in win-win situation. That policy will be fair.
2. All the bidder who want to get frequencies will must get at least some of the frequencies and by that frequencies it can work with, and rest of the frequencies what it needed may receive from another primary user. Their participation of auction will never be useless.
3. As each time all bidder will get some of the frequencies time must be not waste. Everyone will be in win-win situation.
4. It will utilized properly of unused frequency. Each time primary user will give its rest of the frequencies based on how much frequencies is needed by the secondary users. So there is not even any option of remaining any unused frequencies.

1.5 Thesis Contribution

There are already some existing models for allocating spectrum based on game theory. As we found some lacking in those research area, so we came out with a new idea which is Shapley Value to propose a better and efficient algorithm to overcome those lacking.

CHAPTER 2

RELATED WORK

This chapter is mainly focused on the related work what has been done for cognitive radio in terms of spectrum allocation. How many theories should be in consideration while this is a matter of allocation is also focused. Before providing the view of related work we discuss about some terminologies which is been used in cognitive radio networks.

2.1 Terminologies

In this section we discuss about some common terminologies in cognitive radio networks. Why the term is being used, what it comes from, what is the definition of each terms, what is the significant of that term what it effects in cognitive radio networks everything is discussed.

2.1.1 Cognitive Radio

Cognitive Radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior. Cognitive radio uses a number of technologies including Adaptive Radio (where the communications system monitors and modifies its own performance) and Software Defined Radio (SDR) where traditional hardware components including mixers, modulators and amplifies have been replaced with intelligent software. [12]

A CR is a radio that can be programmed and configured dynamically to use the best wireless channels in its vicinity. Such a radio automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. This process is a form of dynamic spectrum management. In response to the operator's commands, the cognitive engine is capable of configuring radio-system parameters. These parameters include "waveform, protocol, operating frequency, and networking". This functions as an autonomous unit in the communications environment, exchanging information about the environment with the networks it accesses and other cognitive radios (CRs). A CR "monitors its own performance continuously", in addition to "reading the radio's outputs"; it then uses this information to "determine the RF environment, channel conditions, link performance, etc.", and adjusts the "radio's settings to deliver the required quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints". [13]

Some "smart radio" proposals combine wireless mesh network dynamically changing the path messages take between two given nodes using cooperative diversity; cognitive radio—dynamically changing the frequency band used by messages between two consecutive nodes on the path; and software-defined radio—dynamically changing the protocol used by message between two consecutive nodes.

J. H. Snider, Lawrence Lessig, David Weinberger, and others say that low power "smart" radio is inherently superior to standard broadcast radio.

2.1.2 Spectrum

Spectrum relates to the radio frequencies allocated to the mobile industry and other sectors for communication over the airwaves. Because the mobile industry has demonstrated time and time again its potential to generate economic value and social benefit, operators are urging national regulators to release sufficient, affordable spectrum in a timely manner for mobile. Additional spectrum, including both coverage and capacity bands, means mobile operators can connect more people and offer faster speeds [14]. Cognitive radio is such a radio automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. This process is a form of dynamic spectrum management [12].

2.1.2.1 Cognitive Radio Spectrum Sensing basics

In many areas cognitive radio systems coexist with other radio systems, using the same spectrum but without causing undue interference. When sensing the spectrum occupancy, the cognitive radio system must accommodate a variety of considerations:

- ***Continuous spectrum sensing:*** It is necessary for the cognitive radio system to continuously sense the spectrum occupancy. Typically a cognitive radio system will utilise the spectrum on a non-interference basis to the primary user. Accordingly it is necessary for the Cognitive radio system to continuously sense the spectrum in case the primary user returns.
- ***Monitor for alternative empty spectrum:*** In case the primary user returns to the spectrum being used, the cognitive radio system must have alternative spectrum available to which it can switch should the need arise.
- ***Monitor type of transmission:*** It is necessary for the cognitive radio to sense the type of transmission being received. The cognitive radio system should be able to determine the type of transmission used by the primary user so that spurious transmissions and interference are ignored as well as transmissions made by the cognitive radio system itself [15].

2.1.2.2 Types of cognitive radio spectrum sensing

There are a number of ways in which cognitive radios are able to perform spectrum sensing. The ways in which cognitive radio spectrum sensing can be performed falls into one of two categories:

- ***Non-cooperative spectrum sensing:*** This form of spectrum sensing, occurs when a cognitive radio acts on its own. The cognitive radio will configure itself according to the signals it can detect and the information with which it is pre-loaded.
- ***Cooperative spectrum sensing:*** Within a cooperative cognitive radio spectrum sensing system, sensing will be undertaken by a number of different radios within a cognitive radio network. Typically a central station will receive reports of signals from a variety of radios in the network and adjust the overall cognitive radio network to suit.

Cognitive radio cooperation reduces problems of interference where a single cognitive radio cannot hear a primary user because of issues such as shading from the primary user, but a second primary user acting as a receiver may be able to hear both the primary user and the signal from the cognitive radio system [15].

2.1.2.3 Cognitive radio spectrum sensing methodologies

There are a number of attributes that must be incorporated into any cognitive radio spectrum sensing scheme. These ensure that the spectrum sensing is undertaken to meet the requirements for the particular applications. The methodology and attributes assigned to the spectrum sensing ensure that the cognitive radio system is able to avoid interference to other users while maintaining its own performance.

- ***Spectrum sensing bandwidth:*** There are a number of issues associated with the spectrum sensing bandwidth. The first is effectively the number of channels on which the system will sense whether they are occupied. By sensing channels apart from the one currently in use, the system will be able to build up a picture of alternative channels that can be used should the current one become occupied. Secondly the actual reception bandwidth needs to be determined. A narrow bandwidth will reduce the system noise floor and thereby improve the sensitivity, but it must also have a sufficiently wide bandwidth to detect the likely transmissions on the channel.
- ***Transmission type sensing:*** The system must be capable of identifying the transmission of the primary user for the channel. It must also identify transmissions of other units in the same system as itself. It should also be able to identify other types of transmission that may be spurious signals, etc.
- ***Spectrum sensing accuracy:*** The cognitive radio spectrum sensing mechanism must be able to detect any other signal levels accurately so that the number of false alarms is minimized.
- ***Spectrum sensing timing windows:*** It is necessary that the cognitive radio spectrum sensing methodology allows time slots when it does not transmit to enable the system to detect other signals. These must be accommodated within the frame format for the overall system [15].

2.1.2.4 Spectrum sensing instabilities

When developing a methodology it is necessary to ensure that the overall system remains stable. There are instances where levels of occupancy increase where cognitive radio systems will continually move from one channel to another. This considerably reduces the efficiency and at the worst case could almost render the system inoperable.

To illustrate the types of scenario that could be encountered, consider the case where channel occupancy is high and a limited number of channels are allocated or are available. The first cognitive radio system may have settled on a channel, but then detects another user so it moves to the next channel. This second channel may have been in use by another user which detects the new channel occupancy and moves. This could continue until the final user then moves into the first channel and the whole procedure repeats.

While it is possible that events may not occur in exactly this fashion, these types of scenario will occur and the cognitive radio spectrum sensing algorithms must be designed to take account of these forms of scenario, and ensure the optimum usage of the available spectrum.

Also with cognitive radio usage increasing, there will be an increase in signal frequency agility and signals will often appear on new frequencies. Accordingly this must be built into the decision algorithms to ensure that CR systems only move when it is necessary.

Cognitive radio spectrum sensing is one of the key algorithms associated with the whole field of cognitive radio. As experience grows, the cognitive radio spectrum sensing techniques will be refined and they will be designed to accommodate the increasing use of the spectrum as well as any malicious attacks that could be presented to CR systems [15].

2.1.3 Users

Users are those who are willing to use spectrum in cognitive radio for excessing in the network by exchanging money. Users can be two type. Primary users and secondary users.

2.1.3.1 Primary Users

Primary users are known as authorized users who buy spectrum band from the higher authority or the government for a certain period of time by exchanging some amount of money which is fixed for all bands of all primary users.

2.1.3.2 Secondary Users

Secondary users are not authorized by the government known as unauthorized users who are willing to use spectrum of primary user when there is a spectrum excess in primary users which is not in used. They use those spectrum by exchanging some amount of money depending on which game theory has been followed by the authority.

2.1.4 Game Theory

Game theory is the study of conflict and cooperation among individuals, groups or firms. It provides an analytical framework with a set of mathematical tools for the analysis of inter-active decision-making processes. It is a multi-player optimization approach and the concept applies whenever the actions of several players are interdependent.

A game is formed by three fundamental components:

A set of players, a set of strategies and a set of payoffs for given set of actions. A player is the one that makes decisions in the game. A strategy is a complete contingent plan, or a decision rule that defines an action that a player will select in every distinguishable state of the game. Payoff is the revenue or satisfaction of the player for a given strategy. Payoff is often expressed through utility functions. Game theory combined with market principles and price theory serves as a strong ground for modeling the economic activities of cognitive radio networks for spectrum sharing.

2.1.4.1 Cooperative and Non-cooperative Games

Games can be classified into different categories based on different criteria. A common approach is to classify games as cooperative and non-cooperative games. A cooperative game in game theory is one where players form groups or coalitions and these coalitions enforce coop-iterative behavior. Here, the game is a competition between coalitions of players, rather than between individual players. A non-cooperative game is one in which players make decisions independently, without coordination with other players and each players have their own objectives towards which they move. In this case, the players see only their own payoff and they don't consider the payoff others or the whole system. Thus, while they may be able to cooperate, any cooperation must be self-enforcing. In a cognitive radio framework, each user usually makes its own decisions (possibly relying also on the information collected from other users). These decisions may be dominated by the rules of the operating protocol, but ultimately each user has some freedom in setting parameters or changing its own mode of operation. These users are autonomous agents, taking their own decisions about transmit power, packet forwarding etc. The users can exhibit three kinds of behavior:

1) Users may work towards overall good of the entire network community as whole.

2) In some cases, the same users may behave selfishly, looking out for only their own interests.

3) Finally users may behave maliciously, seeking to ruin network performance of other users.

Game theory can be applied in all the three cases.

Cooperative Game

In a cooperative game, there is no competition between players in a group and they act as a single entity to maximize the total group utility. An example is a bargaining game, which is often used to formulate the interaction among cooperative players provided that a player can influence the action of other players. In a bargaining game, the players can negotiate and bargain with each other. A general solution of the bargaining game is the Nash bargaining solution, which can ensure efficiency as well as fairness among the players.

Non-Cooperative Game

A non-cooperative game is the one in which players are selfish and each individual player makes decisions independently. In a non-cooperative environment, players have different (often conflicting) interests. Non-cooperative game theoretical framework is used to obtain an equilibrium solution that optimizes the payoff of all players. One of the most widely used solutions for non-cooperative games is the Nash equilibrium. Nash equilibrium is the solution at which any player in the game cannot achieve a better solution by deviating unilaterally, given the actions of the other players.

2.1.4.2 VCG

VCG is usually used to determine preferences for Public Goods. Its key strength is that all players have an incentive to be honest about how they value the good. Its key weakness is that individuals may be subject to a Tax that must then be 'thrown away' (at least not spent on any of the individuals benefitting from the public good).It works thus: Ask all players to state their personal valuations of a public good. If the total valuation is greater than the cost of supplying the good, then supply the good, & pay for it by charging everyone an equal price. Otherwise do not. For every single individual in the auction, check whether the outcome (supply or not supply) would have been different had they not been participating in the auction. IF the result would be different, then levy an extra tax on that individual. The extra tax should equal the difference between that individuals' valuation, and the minimum valuation that individual could have made, to maintain the current outcome of the auction [16], [17].

2.1.4.3 Cournot Game

In Cournot game the competition is in terms of the quantity of the commodity. The decision of each user is affected by the strategies of other users and the decisions are made simultaneously. These games, used when considering a game where players move or play their strategies simultaneously, are commonly used in many fields. From military strategies to collusion agreements, the analysis of these situations as simultaneous games can help us discover the best way to act. Cournot duopoly, also called Cournot competition, is a model of imperfect competition in which two firms with identical cost functions compete with homogeneous products in a static setting. It was developed by *Antoine A. Cournot* in his "Researches into the Mathematical principles of the Theory of Wealth", 1838. Cournot's duopoly represented the creation of the study of oligopolies, more particularly duopolies, and expanded the analysis of market structures which, until then, had concentrated on the extremes: perfect competition and monopolies [18].

2.1.4.4 Bertrand Game

In a Bertrand game there are a finite number of firms that decide on the service prices simultaneously. Given the price offered by a service provider, based on a demand function, the amount of commodity requested from the users can be determined. Then, the profit is computed and used in a profit maximization problem for a service provider to obtain the best response in terms of setting the service price. For a spectrum trading scenario, the service providers are the primary users, the consumers are the secondary users and the size of the spectrum will change according to the price set by the primary users. When the service providers offer their prices simultaneously (i.e. imperfect information), Nash equilibrium is the solution. The interaction in Stackelberg game is more dynamic due to the timing in strategy adaptation compared to the Bertrand model. If the assumption of perfect information is released and all firms decide their service prices simultaneously, Stackelberg model reduces to Bertrand model

2.1.4.5 Shapley Value

The Shapley value is a solution concept in cooperative game theory. It was named in honor of Lloyd Shapley, who introduced it in 1953. To each cooperative game it assigns a unique distribution (among the players) of a total surplus generated by the coalition of all players. The Shapley value is characterized by a collection of desirable properties. Hart (1989) provides a survey of the subject. The setup is as follows: a coalition of players cooperates, and obtains a certain overall gain from that cooperation. Since some players may contribute more to the coalition than others or may possess different bargaining power (for example threatening to destroy the whole surplus), what final distribution of generated surplus among the players should arise in any particular game? Or phrased differently: how important is each player to the overall cooperation, and what payoff can he or she reasonably expect? The Shapley value provides one possible answer to this question [19].

2.1.5 Desired Properties of Spectrum Auction

From the seller's point of view, the spectrum auction ideally should fulfill certain objectives, such as revenue generation, truthful bidding and computational efficiency.

Revenue

As already mentioned, the spectrum seller naturally would like to maximize its potential revenue given the bids from buyers. If the seller does not care about whether the bids are truthful, then this leads to a revenue maximization problem. Obviously, the price charged for winning buyers must be no greater than their bidding price. An efficient resource allocation algorithm is then needed for the revenue maximization.

Truthfulness

The seller may also desire truthful bids from buyers. Truth-telling prevents market manipulation, and eases the bidding of buyers since bidding with their true value is the best strategy in theory. Single-unit secondary pricing and multiple-unit Vickery-Clarke-Groves (VCG) mechanism are the typical rules to enforce truthfulness. However, truth-telling may result in revenue decrease for the seller, depending on the particular auction rules used.

Computational Efficiency

In some situations when the amount of resources is large or the time granularity is small, the auction needs to be efficient in that the computational complexity needs to be low to work in real-time or near-real time. For example, even though the VCG mechanism can enforce truthfulness, its computational complexity is high.

2.1.6 Auctions Followed by Competition

In 1994 the Federal Communications Commission sold sections of the radio spectrum. This auction essentially sold the right to participate in the mobile telecommunications oligopoly. Firms bid for the right to provide digital mobile phone service for a region. Current 'incumbents' in the mobile phone market, the Cellular providers, were allowed only limited participation in the auctions to provide digital mobile service. Cellular and digital are different mobile communication technologies. However, digital winners will compete with the current cellular providers to provide mobile service.

If the information revealed by the auction effects the post auction competition, then the information revealed by the different possible auction formats and its effects, should be examined. According to McMillian(1994) the FCC chose an English auction format because a main concern was the reduction of the winner's curse.1 We have not read where the impact of the release of information on the future market competition was considered. We abstract from many of this auction's complicated aspects2 to focus on how information released by the auction would affect the equilibrium quantities, prices and welfare if different forms of competition follow the auction. And, we consider how the differing forms of competition affect the bids, participation, expected revenue and the optimal reserve price in various auctions. In an auction for an oligopoly position, firm bids depend on their cost structure. Thus, the bids reveal information about these costs. Incumbent firms will attempt to invert revealed bids to learn about the cost structure of their future competitor. Therefore, potential entrants into this market have an incentive to distort the incumbent's perception of their own costs to raise their profits. Whether this distortion requires that they raise or lower their bid is shown to depend on the type of competition that follows the auction. Section I examines First Price, Second Price, and English auctions followed by standard Cournot competition between the winner of the auction and an incumbent who did not participate in the auction.3 Since the competitors' quantity choices are strategic substitutes, a Cournot duopolist earns higher profits if his competitor believes that his costs are lower. Thus, when bids are observed, bidders raise their bids to display their low-cost status. This leads to a Second Price auction, with information revelation, in which bidder's bid above their value! A higher bid's effect on future competition is greater than the higher expected payment. In an English auction the bid of the winner is not revealed (since he stopped bidding at the second highest bid). Thus, the winner's bid does not influence the incumbent and the incumbent does not accurately learn their type. Therefore, the bidders have no incentive to raise their bids. However, because of the incumbent's lack of information a bidder may expect to make more or less than they would if their costs were known. For example, when the incumbent does not learn that the highest cost player (who would expect no profits were his costs known) has won the auction, the incumbent must get an expectation of the winner's costs over all types. The incumbent's expectation of the winner's costs is, therefore, lower than the truth. Under Cournot competition, this increases the worst type's profit from winning, and causes the player with costs just higher than him to now want to participate in the auction. Since the bidders' profits are altered, bidders change what they are willing to bid and their decision to participate. Bidder participation becomes an endogenous variable that depends on the information release. In a standard auction model the incumbent's information is independent of the auction. Therefore, bidders' values for winning the auction are fixed ex-ante. In this case, revenue equivalence insures that the expected revenue of a seller

is the same if they use a First Price, Second Price or English auction. If instead the incumbents update their beliefs with the information from the auction then First and Second Price auctions are still revenue equivalent but the influence of the Cournot competition raises both revenue predictions. The increase in revenue derives from the bidders increasing their bids in an attempt to convince the incumbent they have lower costs. Expected revenue from an English auction is higher than the standard prediction but lower than the First and Second Price auctions. As shown above, bidders raise their bid in an English auction but the incentives are different from a First or Second Price auction. In the oligopoly example the First and Second Price incentives are greater than the incentives in the English auction. In section II the same three auction formats are followed by differentiated Bertrand competition. The effect on bids is the opposite of above since price decisions are strategic complements. Bidders' objectives are now to convince their future competitor they have high costs. High cost beliefs because the Incumbent to choose a higher price in the future Bertrand competition. The effect on participation is also opposite. In an English auction bidders have no incentive to lower their bid since it will not be observed? Low incumbent expectations of the worst player's costs when the worst player wins, now mean a lower price decision by the incumbent and lower profits for the worst type. Since the worst type did expect zero from the auction, they now expect negative profits and choose not to participate. Expected revenue in the First and Second Price auctions is lower than in the

English auction which is lower than the standard prediction. Section m looks at the results of the auctions on the duopolistic market equilibrium. Many interesting conclusions and policy recommendations follow from this examination. A seller's desire for either efficiency or revenue may lead to a different auction choice. The incumbent and the government both have larger expected revenue with a reservation price than without. With a reservation price, however, the consumers expect less surplus, and the entrants expect to pay more. Different auction formats affect the equilibriums in the auction and following games. Any party interested in a particular equilibrium desires a different auction format. Each group lobbies for different auction rules depending on their preferences and position in the game. This model makes it clear that the implications of the situation following an auction need to be considered before any recommendation about the optimal auction format can be made [20].

2.2 Related work

In this section we discuss about the related thesis work. How the work is being done and how the mathematically proved the work.

2.2.1 Dynamic Spectrum Auction for Revenue Maximization

Traditionally, spectrum allocation has been done in a centralized, static, and wholesale fashion, where long-term (on the order of tens of years) spectrum leases/contracts are sold covering very large geographical regions (see for instance the regional spectrum allocation in the recent FCC's 700 MHz auction, and the 27GHz allocation in Australia). As a result, the type of buyers who can meaningfully participate in this type of allocation is limited, due to the large amount of capitals needed.

Under this type of static allocation, there is increasing evidence that spectrum re-sources are not being efficiently utilized [21], and that there exists abundant spectrum opportunity currently unexploited within licensed bands. At the same time, wireless de-vices are enjoying even greater capability to detect spectrum availability and flexibility to adjust operating frequencies. These observations have led to a push for the original license holders and operators, a primary example being TV broadcasters[1], to open up access to secondary unlicensed users [22], so as to improve spectrum utilization, a concept known as *dynamic spectrum access* [23]. With dynamic spectrum access, secondary unlicensed users may take advantage of (instantaneous) spectrum opportunities that exist in spectrum owned by a primary user. This has motivated a large number of recent studies on how a secondary user should perform opportunistic spectrum access and how primary and secondary users could co-exist [24].

2.2.1.1 Spectrum Allocation based on VCG model

The definition of cooperative game is given in the form of characteristic function, like (*N,v)*. We make *N*= {1, 2, 3 ….*n} indicates* the set of participants. N is an integer. It shows the number of participants. *S* is a subset of N. It shows the coalition among participants, $S⊆N$ .Given a limited set of participants. The characteristic of cooperative game is ordered pair (*N,v)*. Thereinto eigenfunction *v* is the mapping from 2^N ={S / *S⊆N}* to the set of real numbers R^N namely *v:* $2^N \rightarrow R^N$, and *v (*ϕ) =0. v is the corresponding eigenfunction with every coalition *S* in namely *N. V(s)* is the utility that participants in a coalition *S* cooperate with each other. There have been a lot of researches which using the cooperative game theory toanalyze the resource allocation problem in cognitive radio. Reference [11] described the problem of spectrum allocation process with the cooperative game theory in cognitive radio, the procedure is as follows:

They signed a spectrum use agreement before cognitive users accessing spectrums. The agreement ensured that the user could get more revenues through the cooperation than that of acting alone. The core could be used to test whether the cooperation was stable. When considering the principle of average and fairness, we can use Shapley value to allocate cooperative income of cognitive users. When considering maximizing the minimum fair principle, we can use the kernel to allocate the benefit of cooperation of cognitive users. The spectrum allocation problem of the cognitive radio combined auction theory with cooperative game theory is analyzed in [12]. In the cognitive radio secondary users (SUs) cooperatively sensed spectrums to identify and obtain free spectrums and share them. The sensing and sharing scene of spectrum is modeled as a transferable utility (TU) cooperative game in the paper. They used Vickrey-Clarke-Groves (VCG) auction mechanism to allocate spectrum resources for each secondary user fairly. The secondary users formed alliances to sense spectrum together. Each secondary user's value could be calculated according to the activity information of the primary user which was obtained from spectrum sensing in the joint.

The resulting game was balance and super additive. Every secondary user got a sum of income according to their value in the league. According to the secondary users' demand of spectrum, they used the income to bid for free spectrums through the VCG auction. VCG auction mechanism made secondary users bid honestly according.

2.2.1.2 Spectrum Allocation based on Cournot game model

Cournot game model belongs to the complete information static game, game participants compete for output. Reference [26] used this model to study selfish non-cooperative spectrum allocation behavior among primary users. The price of spectrum of the primary user was the same, but the sale quantity was not identical. The primary user always knew other primary users' spectrum history strategies and determined the current strategy according to the historical information. The number of spectrum which was sold by primary user achieves stable equilibrium state after many games. Therefore, the purpose of the cournot game model was to maximize spectrum number which was sold by primary users system, the method was to maximize the utility function of primary users. Reference [4] studied cognitive radio dynamic spectrum allocation based on the game theory, considering the difference of spectrums; this paper used a cournot game model and added the spectrum similarity matrix to original pricing function. They put forward a new utility function to make the spectrum allocation closer to the real network environment. The simulation analysis showed that the allocation algorithm was more diversified than the original algorithm in considering the differences of spectrums. It was applicable to the actual network allocation. Reference [6] used game theory to analyses primary users' leasing spectrum behavior in the cognitive radio. First of all, the system model of spectrum allocation was established. Secondly, the cournot algorithm was designed based on the system model. Finally, the simulation completed the situation that the total number and the price of the lending spectrum vary with the increasing of the number of the primary users. The simulation results showed that the lease spectrum quantity increased a lot. Compared with static spectrum allocation algorithm, using cournot algorithm reduced the price of the spectrum.

The basic concept of game theory

Game theory is a kind of theory which studies the strategy and the equilibrium when the strategy dominators influence each other. It can be described as follows:

In a n persons game, assuming the strategy space of the participator is S_1 , , S_n , the function is u_1 , ,u_n , gain n and the game is expressed by $G=\{S_1 \quad , S_n ;u_1 , \quad ,u_n \}$, then every participator chooses his optimal strategy at the conditions of known all others strategies, and all the strategies chosen by all participators construct a strategy group. If the strategy group is consist of optimal strategies a Nash equilibrium is achieved.

According to the Cournot double-oligarch model in economics, if a strategy (s_1^* , s_2^*) is Nash equilibrium in a standard two persons game, then for every participator *i*, s_i^* should meet the following formula:

$$u_i (s_i^* , s^*_j) \geq u_i (s_i , s^*_j) \qquad (1)$$

Formula (1) is correct for all $s_i \in S_i$. Which means that for every participator *i*, s_i^* must be the optimal solution for the following question:

$$\max u_i (s_i , s^*_j) \qquad (2)$$

Game theory model of spectrum allocation

The spectrum allocation of cognitive radio is a game process that every primary user selects his strategy. The licensed frequency user which lends spectrum is called primary user, and the un-licensed frequency user which rents spectrum is called secondary user. The spectrum allocation is a process of primary user gaming, secondary user gaming, and combination gaming of primary user and secondary user. In secondary user gaming, the participators are the secondary users, and the game process is that the secondary users decide to use which primary user's spectrum and how much spectrum they need. In primary gaming, the participators are the primary users, and the game process is that the primary users decide how much spectrum to lend. In combination gaming of primary user and secondary user, the participators are the primary users and the secondary users, and the game process is that the primary users decide how much spectrum to lend and the secondary users decide how much spectrum they need.

According to game theory the game theory model of spectrum allocation is as follows:

$$G = \{ S_1 , \ , S_N ; u_1 , \ ,u_N \} \qquad (3)$$

Where N is the number of the participators. Now in this paper the participators are the primary users because we just study the spectrum allocation of the primary users. S_i is the i^{th} primary user's lending spectrum. u_i is the i^{th} primary user's gain function.

The cognitive radio system is consist of three parts, which are primary user, secondary user and spectrum manager. All the secondary users are regarded as a single considering the gaming is just for primary users in this paper. The role of the spectrum manager is to distribute the available spectrum in specified area or specified position, adjust the sharing spectrum process among terminals, monitor servers and track the idle spectrum of the primary user.

During the operation of the cognitive radio system every primary user sends its idle spectrum message to the spectrum manager in a fixed time, and every secondary user detects the idle spectrum. When the secondary user detects an idle spectrum it will contact with the spectrum manager and apply to rent the idle spectrum. Once the secondary user occupies the spectrum it cannot be halted until this communication ended. Assuming the holding time of every secondary user is same and at one time just one primary user or one secondary user occupies one spectrum in this paper.

Whether the secondary user wants to buy the primary user's spectrum at the price determined by the spectrum manager is decided by the utility function. The arguments of the utility function is the spectrum utilization rate, spectrum occupy rate of the primary user and the spectrum price. The lending spectrum quantity of the primary user, which equals to the spectrum quantity of the secondary user needed, depends on the transmission speed of the self-adaption modulation and the lending spectrum price of the primary user. The utility of the primary user is defined as the difference of the income made by lending spectrum with the cost result by sharing spectrum. The sharing cost is influenced by the transmit speed of the primary user and the actual spectrum application. The competing aim of the primary users is to make themselves' utility maximum. In this paper the un-cooperation game is used to discuss the competing of the primary users and the spectrum allocation is described as the oligarch competing model of game theory. The Cournot algorithm is designed to get the Nash equilibrium of the primary user game so as to make the idle spectrum utilization rate raise and the utility maximize of the primary user.

The spectrum allocation scheme is as follows:

(1) The secondary user detects the idle spectrum and contacts with the spectrum manager, then sends its utility function, spectrum requirement, expected BER to the spectrum manager and applies to rent spectrum.

(2) The spectrum manager announces the renting spectrum information and orders that the lending spectrum price of every primary user is same but changes with the market supply and demand.

(3) Every primary user changes his lending spectrum quantity according to the market supply and demand so as to get maximum utility.

(4) The spectrum manager judges whether the primary user game has reached a steady state that is the total lending spectrum quantity and the lending spectrum quantity of every primary user don’t change. The game has been considered reaching a steady state if the successive three games’ results are same. If the primary user game has not reached to the steady state the game continues, otherwise the spectrum manager announces that which primary users are selected to lend their spectrum.

(5) The primary user contacts with the secondary user and lends his spectrum to the secondary user at the steady market price.

(6) The secondary user uses the renting spectrum to work and returns the spectrum to the primary user when his work is finished.

2.2.1.3 Spectrum Allocation based on Bertrand game model

Bertrand game model also belongs to the category of complete information static game, game participants compete for the price. Reference [27] used bertrand game model to study the selfish non-cooperative spectrum allocation behavior among primary between users. The primary user always knew other primary users' history sale price of the spectrum, and determined their own current price according to this historical information. After many games, the primary user sell spectrum price to reach the Nash equilibrium state. Therefore, the purpose of bertrand game model was to optimize the sale price of the primary user' system. The method was to make to maximize the utility function of the primary user. Reference [28] constructed the behavior of the primary user in spectrum allocation as bertrand game model. This paper put forward an oligopoly pricing framework for dynamic spectrum allocation. In this model, the primary user sold excessive spectrums to secondary users to get rewards. The paper put forward strict constraint and QoS punishment two kinds of methods to simulate the primary user whose ability was limited in the actual situation. In the oligopoly model which had strict constraints, the author proposed a low complexity searching method to get Nash equilibrium and proves its uniqueness. When reducing to a duopoly game, the analysis showed interesting gap in the leadership-subordinate pricing strategy. In the QoS punishment based on oligopoly model, this paper proposed a novel variable transformation method and deduced the unique Nash equilibrium. When the market information was limited, this paper provided three short-sighted optimal algorithm "StrictBEST", "StrictBR" and "QoSBEST", to make the price adjust principles based on the best response function (BRF) and bounded rationality (BR) for duopoly primary users.Numerical results demonstrated the validity of the analysis and proved that the

"StrictBEST" and "QoSBEST" converged to the Nash equilibrium. "StrictBR" algorithm revealed the chaotic behavior of the dynamic price adaptation in response to the learning rate.

The problem is modeled of dynamic spectrum sharing under competition as an oligopoly market. In economics, oligopoly is defined as a situation where a small number of firms (i.e., oligopolists) dominate a particular market. In this market structure, the firms compete with each other non-cooperatively and independently to achieve their objectives (i.e., maximize profit) by controlling the quantity or the price of the supplied product. The decision of each firm is influenced by other firms' actions and action of one firm may be observed by other firms. This Bertrand game model for price competition can be applied to analyze and obtain the equilibrium pricing scheme for a cognitive radio system consisting of multiple primary services which are willing to share the allocated spectrum with the secondary service. While the spectrum demand of the secondary service is determined from the utility of the shared frequency spectrum and the price charged by the primary service, the cost of the primary service in sharing the spectrum is computed from the degradation of the QoS for the primary service. The primary service searches for the equilibrium by adjusting the price offered to the secondary service so that the profit is maximized.

In this section, we establish a model for spectrum pricing competition based on game theory. First, a utility function is used to quantify the spectrum demand of the secondary service. Then, for a primary service, the cost for offering spectrum access to the secondary service is formulated. This cost function is based on the degradation in the QoS performance for the local connections. Next, a Bertrand game formulation is proposed. The Nash equilibrium is considered as the solution of this game.

To quantify the spectrum demand we consider the utility gained by the secondary service (e.g., if the spectrum creates high utility, the demand is high. The commonly used quadratic utility function is:

$$u(b) = \sum_{i=1}^{N} b_i k_i^{(s)} - \frac{1}{2}\left(\sum_{i=1}^{N} b_i^2 + 2v \sum_{i\neq j}^{N} b_i b_j\right) - \sum_{i=1}^{N} p_i b_i$$

where b is the set consisting of the size of shared spectrum from all the primary services, i.e., b = $\{b_1, \ldots, b_i, \ldots, b_N\}$, p_i is the price offered by primary service i. Note that $k_i^{(s)}$ denotes the spectral efficiency of wireless transmission by a secondary user using frequency spectrum F_i which is owned by primary service i.

This utility function takes the spectrum substitutability into account through the parameter v. This spectrum substitutability parameter (i.e., $v \in [-1.0, 1.0]$) is defined as follows. When $v =$

0.0, a secondary user cannot switch among the frequency spectra, while for $v = 1.0$ a secondary user can switch among the operating frequency spectra freely.

When $v < 0$, spectrum sharing by a secondary user is complementary. That is, when a secondary user wants to share one frequency spectrum, it will require to buy one or more additional spectrum simultaneously (e.g., one spectrum for uplink transmission and another for downlink transmission) from the same or different primary services.

The motivations for using the quadratic utility function in can be stated as follows:

- The function is concave, and therefore, it is able to represent the saturation of user satisfaction as the transmission rate increases. Concave utility functions are widely used to quantify the satisfaction of best-effort users as a function of allocated bandwidth.

- Differentiating this quadratic utility function results in a linear bandwidth demand function, which makes the subsequent analysis tractable (e.g., standard methods can be used for stability analysis of the distributed strategy adaptation algorithms).

- The function is able to incorporate the impact of spectrum quality as well as the spectrum substitutability factor.

To derive the demand function for spectrum F_i at the secondary service, we differentiate U (b) with respect to b_i as follows:

$$\frac{au(b)}{ab_i} = 0 = k_i^{(s)} - b_i - v \sum_{i \neq j} b_j - p_i$$

CHAPTER 3

SPECTRUM ALLOCATION BASED ON SHAPLEY VALUE

This chapter is focused on how our algorithm works, how our main system model has been designed and how the function design works.

3.1 System Model

Cognitive Radio Networks contains a cluster of PUs and SUs with a middle broker system where the primary sharing and allocating algorithm is processed. A set of available channels (C) of spectrum band is assumed, which is desired to be shared by primary transmitter (PT). A group of SUs is also considered to attempt to segment the available channels among the band of spectrum. Un-interfered priority should be set high for the PUs if they are licensed to idly exploit the spectrum. Therefore, we consider separate groups of PTs and STs (secondary transmitter) as well as some channels C for available spectrum band. The Broker (B) has the excess to control over the C and communicate with PUs and SUs.

According to the VCG model [5], there should be one channel C for each ST and each PT will transmit for one receiver ST. This relation is presented in Equation (1).

$$A_{p,c} = \begin{cases} 1, & \text{pth ST is using the channel C} \\ 0, & \text{Otherwise} \end{cases} \qquad (1)$$

In our model, Each PT will share their idle spectrum with ST who are willing use the spectrum. Consider that there are n numbers of primary transmitters, m numbers of channels and p numbers of STs. Requirement meets for SUs defined as equation (2) where every time requirement will be fulfilled partially or fully depending on availability of channel. Here Φ, Φa and Φb could be any value from 1 to p, n and m respectively.

$$A_{PT_{\Phi a}C_{\Phi b}} = 1, \Phi\text{th ST using channel } \mathrm{C}_{\Phi b} \text{ of } \mathrm{PT}_{\Phi a} \qquad (2)$$

Figure 3.1 depicts groups of PUs and SUs that have been considered in our proposed model. To allocate resources to them, there is a broker in intersection point which has a direct communication with each PT and each ST. We are assuming here broker can detect the idle spectrum of PTs as well as the requesting spectrum of STs through sensing. Broker has the responsibilities allocate idle spectrum of PT to ST depending on the demand and availability of the spectrum. If there is a need and availability of spectrum simultaneously, broker will process the Shapley value algorithm and ensure that there will always be an allocation of spectrum for each request. Broker have to track which C of PT is used by which ST.

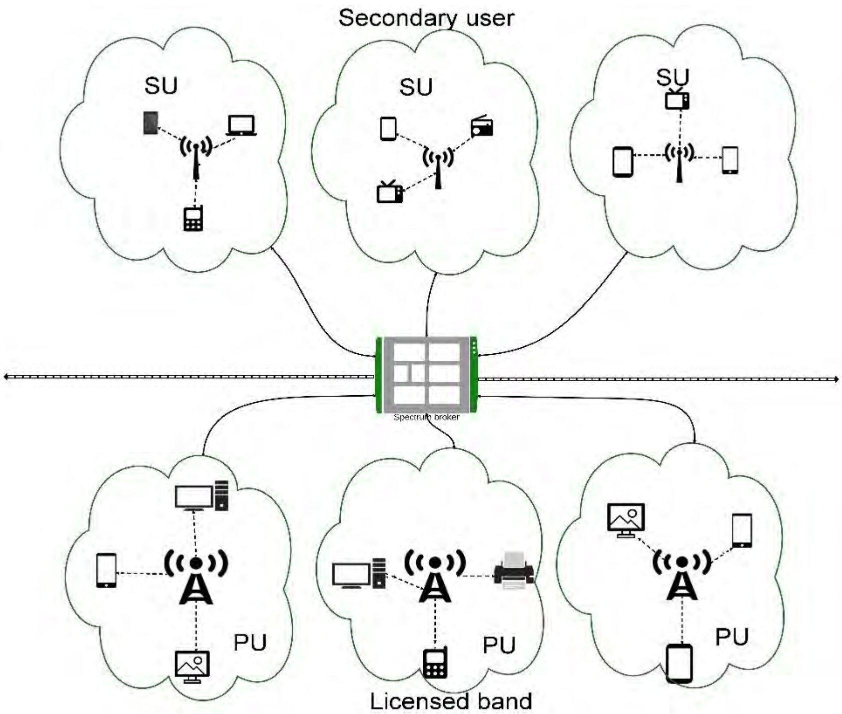


Figure 3.1: A diagram demonstrating the work flow of the proposed network model.

3.2 Function Design

The utility function designed for VCG model is given in equation (3) [3]

$$u_n = \sum_{c=1}^{c} w_n.\log\left(1+R_{n,c}\right), \forall n \in [1, N] \qquad (3)$$

Here, w_n is the number of players play the game during the auction to meet their requirement. Their transmission data rate is:

$$w_n = \mathrm{R}_n^{req} \quad . \qquad (4)$$

$$\varnothing_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(n-|S|-1)!}{n!}(v(S \cup \{i\}) - v(S)) \qquad (5)$$

Here, n is the total number of ST who have requested spectrum. Each ST demands their contribution $v(S \cup \{i\}) - v(S)$ and receives the average of different possible permutation of all the candidates of STs [7].

In our proposed model, we have focused on maximize the throughput of Cs as well as utilizing the idle spectrum of STs. According to our theory, how idle spectrum is shared or allocated with the SUs without harming the PUs is given based on the following flow of actions:

- Is there any need of spectrum?
- Is there any idle spectrum?
- Which kind of transmitter is the spectrum required for?
- If the requested spectrum is from secondary transmitter, then run Shapley Value algorithm and allocate spectrum which resulted from Shapley Value algorithm to that particular secondary transmitter via secondary Channel Cs.
- If the requested spectrum is from primary transmitter to get back its own spectrum, then determine whether the SU's is idle or not. If the SU's spectrum is idle, then proceed to use it. However, if the interested spectrum is not used by the SU, then run Shapley Value algorithm to all the secondary transmitter to regain spectrum from the secondary transmitter who has been using the interested primary transmitter's spectrum.

A flowchart of this process is shown in figure 3.2.

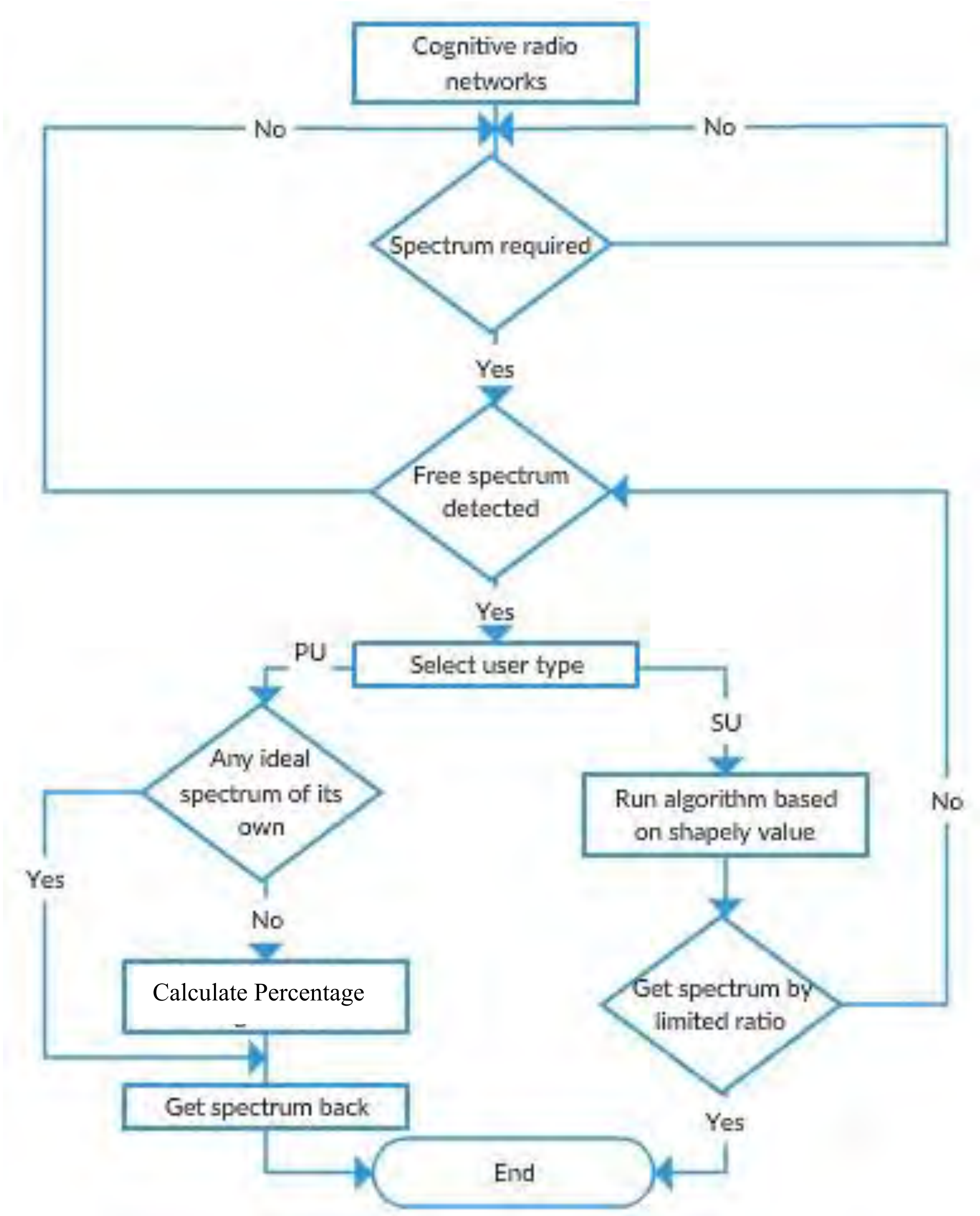


Figure 3.2: A flow chart demonstrating the proposed algorithm.

Two conditions are considered in the proposed algorithm to decide if the process should advance or not. It evaluates the availability of the spectrum in C and SU's request. The algorithm runs only when the two conditions are met simultaneously. The analysis starts by finding out the permutation based on the number of SUs requirement and availability of spectrum in PUs. Then the calculation proceeds by allocating spectrum to SUs depending on the average value of that permutation which will be taken from result of that calculation. A pseudo code of the proposed algorithm is given below:

```
WHILE    AvailableSpectrum && SecondarySpectrumReq
      //continue
       IF   requestcode ==100 THEN
                 CALL  Permutation(NumberOfSecondaryUser)
                  FOR  X=1 to N    //N=number of combinations
                         IF RequestedSpectrum<AvailableSpectrum
                                    CALL Allocate(Node,RequestedSpectrum)
                                    IF AvailableSpectrum>0  THEN
                                    CALL  Allocate (Node,AvailableSpectrum)
                                    END IF
                                    CALL  Allocate (Node,0)
                          END IF
                          FOR  Y=1 to N //N=Number of combinations
                          CALL  FindAverage();
       ELSE
                         IF isFreeSpcetrum THEN
                         CALL allocateFromFreeSpectrum();
        ELSE
                         CALL  AllocatePU();
         ENDIF
      ENDIF
                           CALL  Deposit();
ENDWHILE
```

CHAPTER 4

SIMULATION AND RESULT

In this chapter we show our simulation and result, we compare our result with VCG model and Cournot game model. We prove why our algorithm is better than others.

4.1 Utility Allocation

The proposed spectrum sharing algorithm is simulated and analyzed using JAVA. In order to proceed with our algorithm, we have considered a set of three PUs, 4 four SUs and a broker as a liaison. We have created an environment where a set of SU request as per their requirement and each PT hold multiple Cs. Total available spectrum of C from PT is calculated when ST request the broker for their necessary of spectrum. If any available spectrum is found, the broker proceeds according to the algorithm to calculate the ratio that each ST is allowed to receive from the available spectrum. Because of the unavailability of resources, SU may not receive all of his or her requested spectrum. In such cases, the algorithm further requests for additional allocation of spectrum. Therefore, the proposed algorithm proceeds with two conditions.

As we are ensuring no harm in PU we have to give back its spectrum while needed. Now what if PU needs its spectrum back before lease time? Here we have maintained a flag table to detect which C that are already assigned to ST are sitting idle before its lease time ended. When any of the Cs of PT is free before time lease it will show a true flag which have been shown in fig-4.1, because the more time secondary transmission will hold the spectrum It need to pay a fixed amount of monitory value to the PU. If at the moment when the entire lease spectrum is busy then PT will get back its own spectrum by running Shapley value algorithm based on PU's need by calculate the ratio of the spectrum that all SU need to release. And the win- win situation will be arisen that SU will not pay the rest of monitory value if PU takes back its spectrum before agreement ends. From a user perspective they need to gain enough statement so it can estimate the C statistic. The main objective is to run this algorithm to fair distribution among the all SU rather than who paid more and create an environment where any of user will not act like shellfish node.

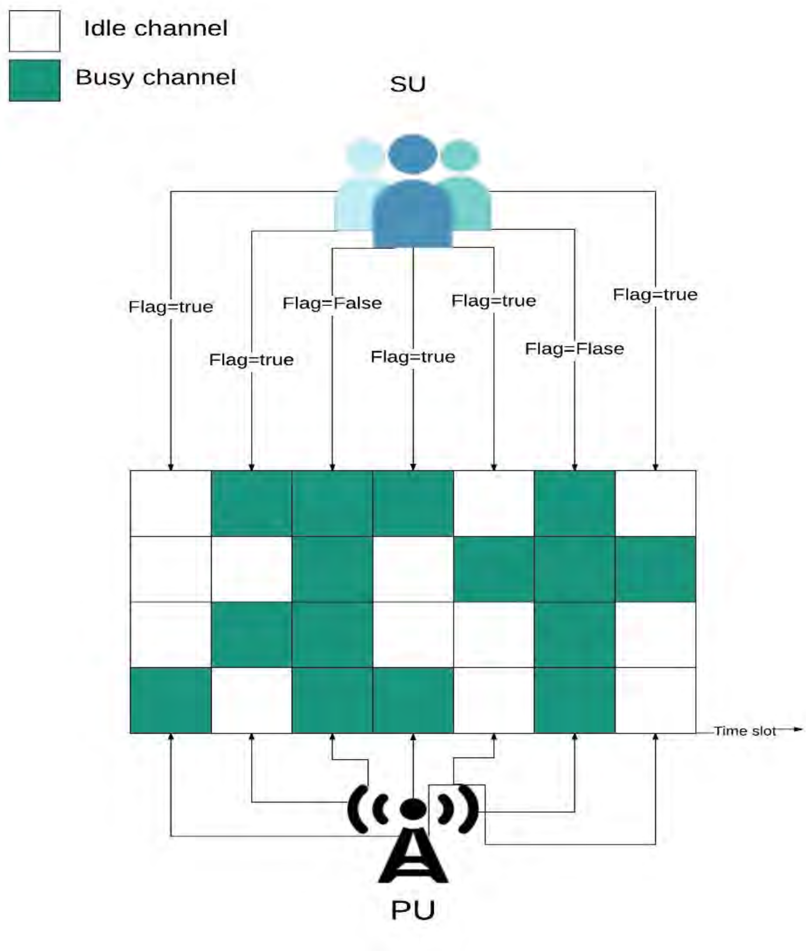


Figure 4.1: A diagram demonstrating how demand of ST has fulfilled

4.2 Compare the sharing efficiency of VCG and Shapley value:

In this part we consider number of SU and percentage that one SU get over its need. For Shapley value algorithm if we consider

$p = Need\ of\ spectrum\ for\ SU(p_1, p_2, p_3 \ldots \ldots \ldots . p_n)$ (6a)

$$q = Spectrum\ given\ (q_1, q_2, q_3 \dots \dots \dots q_n) \qquad (6b)$$

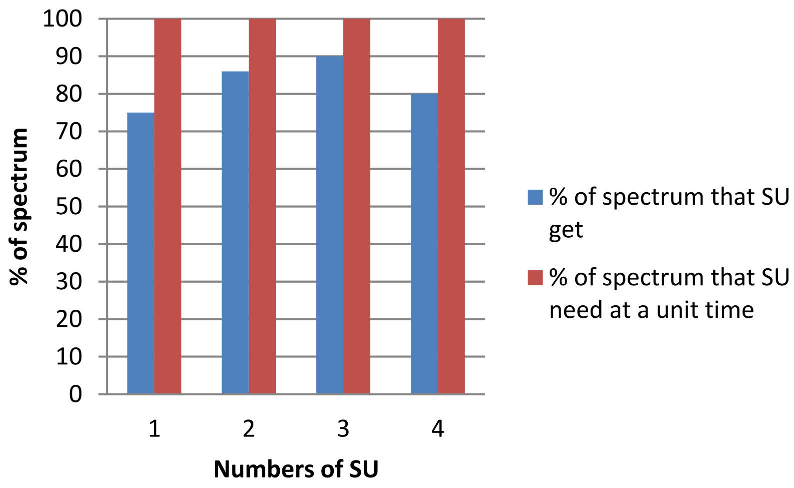
Then after algorithm

$$q! = 0 \qquad (7a)$$

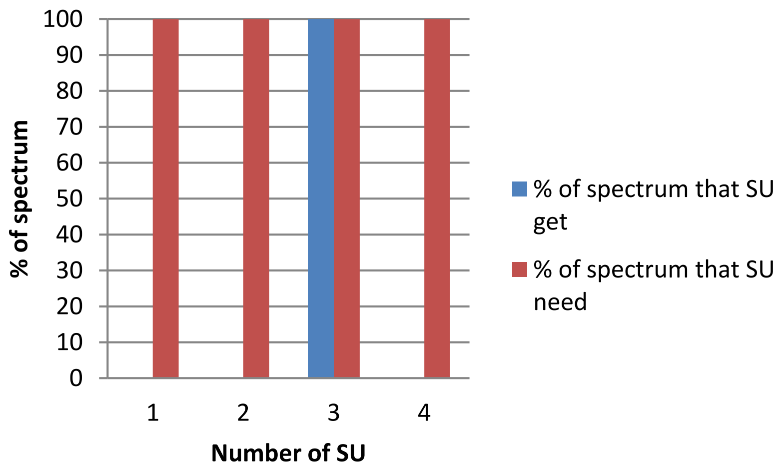
$$q_{total} = x \qquad (7b)$$

$$p_n \leq q_n \qquad (7c)$$

Here observation is taken on the basis of random need of spectrum and random availability of spectrum. If we consider the total need of SU spectrum is 100 percent.



(a)



(b)

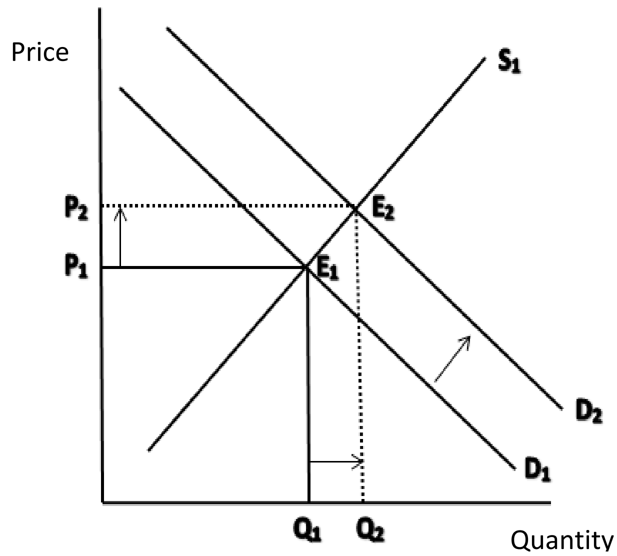
Figure 4.2: Shapley value (a). VCG (b)

Then after calculate the ratio in one iteration algorithm SU_1 get 75%, SU_2 get 86%, SU_3 get 90% and SU_4 get 80% of its needed spectrum. One the other side in VCG algorithm in one iteration only one SU will get 98% to 100% but others will get nothing, it is also fair distribution but act like selfish because PU will consider the only SU who will pay better. Shown in fig-4.2.

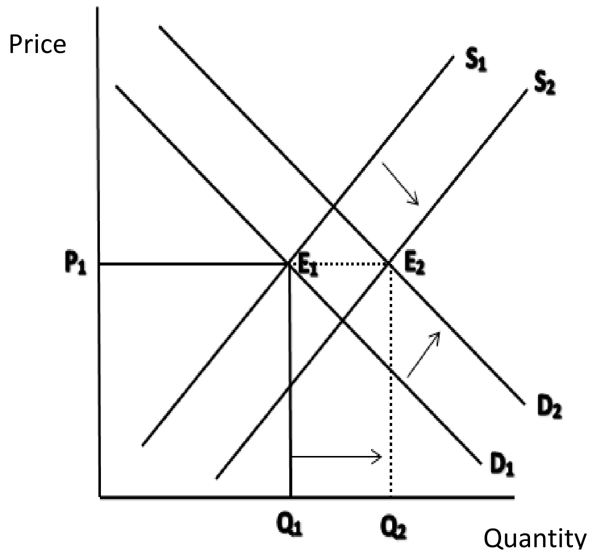
4.3 Compare the sharing efficiency of Cournot and Shapley Value:

Cournot game theory is based on oligopoly market strategy which restricts entrance in the cognitive radio network. No new primary user/secondary user can enter in the game proving existing user's selfishness. Whereas Shapley Value allows entrance of any number of users any time. On the other hand, all the primary users in Cournot game enter in the market with an arbitrary price which changes over time based on market supply/demand. Primary users can halt the spectrum when the price is low and create crisis in the market. However, they can supply more spectrum when the price is high which makes primary users biased and unfair. On the contrary, Shapley Value ensures a steady price regardless market demand and supply, making a win-win situation. In terms of market benefit and domination only primary users are getting highly benefited moreover they are dominating the game. In contrast, there is no dominating user in Shapley Value and everyone is benefited keeping other users in mind.

In the figure 4.3 Primary user increases price per unit spectrum depending on the market demand at a particular time acting as selfish competitor. After many games all the primary users get themselves into equilibrium state (E1, E2) where maximum utility is gained. In the above figure demand curve (D2) shifts upward due to demand increase of the secondary users. Since the demand is increased price and quantity increases as well. Total revenue for P2 and Q2 is maximized from P1 and Q1 for the primary users which proves selfishness behavior. Figure 4(b) Primary users and secondary users cooperate each for a win-win situation. Here price per unit remains steady regardless the quantity throughout the whole game ensuring that primary users are fair but price may increase due to other factors (Govt. tax). With the demand increment spectrum quantity increases which allows secondary users to get more spectrum with the same unit price. Total revenue will increase from P1 and Q1 to P1 and Q2 with the quantity increment for the steady price.



(a)

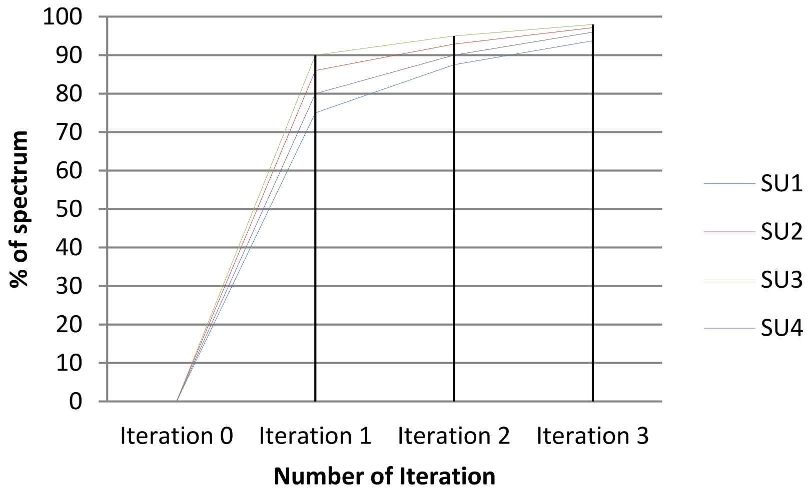


(b)

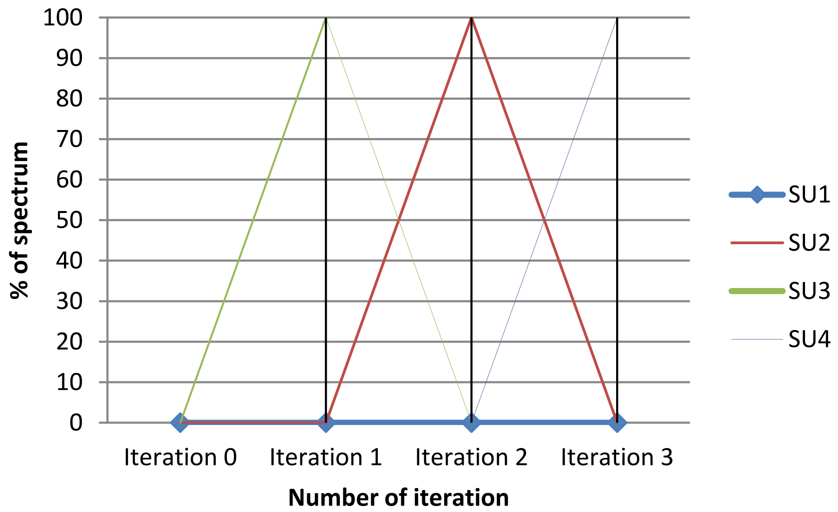
Figure 4.3: Cournot (a). Shapley value (b)

4.4 Evaluation and Increase Percentage of Spectrum:

In this portion we define the whole scenario of our given environment. We plot graph basis on percentage of spectrum VS each iteration times. From previous evaluation we saw there is a lack of spectrum among secondary transmission but they can request further of the rest of the spectrum they need. Then the broker will run the algorithm till the condition of the algorithm is satisfied.



(a)



(b)

Figure 4.4: Shapley value (a). VCG (b).

Here we take 3 iterations for both VCG and Shapley value algorithm. After one iteration we can see the percentage of getting spectrum for each Secondary transmission is increasing and after 3 iterations is almost above 95%. So algorithm is serving almost 95% correctly shown in fig-4.4(a). From the same environment we can observe that in each iteration only one user is getting above 90% and others are null, it works almost 98% correctly but for one SU. The problem might occur when one SU with least monitory value will fall in a recursive loop but because of it priority it will not get any spectrum and also it will exterminate an amount of time. So it will reduce efficiency shown in fig-4.4(b).

In this paper we share our idea of spectrum allocating based on Shapley value algorithm. Herein, idle spectrum is effectively allocated to the secondary transmitter without harming the primary transmitters. As we undertake the floor function while allocating spectrum we cannot allocate 100% of free spectrum all the time but most of the cases it can allocate 99% of spectrum to the secondary users through the network. In the intersection point there is a broker for monitoring the channel so that each channel updates may manipulated and run over the algorithm while needed. For each transmitter (ST or PT) there will be individual channels. So that each channel will be collision free and will have highest data rate.

CHAPTER 5

CONCLUSION

In this thesis, we study spectrum allocation based o game theories and dynamic allocation process. First we proposed our methodology and compare our methodology with many of the existing methodology. We prove our methodology why it is better than others. We present our view of future dynamic spectrum management and its enabler cognitive radio networking. An algorithm is proposed to embrace both economic and technology aspects of cognitive radio networking for dynamic spectrum management. Under this framework, we propose solution and conduct analysis for several critical issues.

The proposed spectrum sharing algorithm is simulated and analyzed using JAVA. In order to proceed with our algorithm, we have considered a set of three PUs, 4 four SUs and a broker as a liaison. We have created an environment where a set of SU request as per their requirement and each PT hold multiple Cs. Total available spectrum of C from PT is calculated when ST request the broker for their necessary of spectrum. If any available spectrum is found, the broker proceeds according to the algorithm to calculate the ratio that each ST is allowed to receive from the available spectrum. Because of the unavailability of resources, SU may not receive all of his or her requested spectrum. In such cases, the algorithm further requests for additional allocation of spectrum. Therefore, the proposed algorithm proceeds with two conditions.

5.1 Future Work

Cognitive radios offer the promise of being a disruptive technology innovation that will enable the future wireless world. The rapid proliferation of wireless technologies is expected to increase the demand for radio spectrum by orders of magnitude over the next decade. This problem must be addressed via technology and regulatory innovations for signify cant improvements in spectrum efficiency and increased robustness and performance of wireless devices. Emerging cognitive radio technology has been identified as a high impact disruptive technology innovation that could provide solutions to the “radio traffic jam” problem and provide a path to scaling wireless systems. In addition to support for the long-term research agenda, we believe that there is also an immediate need for shared cognitive radio network test beds that can serve as shared research infrastructure. So our aim is to use our algorithm in real life environment also.

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