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Role of Game Theory in Utilizing the Spectrum in Cognitive Radio Networks

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Abstract: Cognitive radio technology, a significant communication paradigm, enhances the efficient use of existing wireless spectrum resources and has become a prominent research topic in recent years. Game theory can play a pivotal role in dynamic spectrum allocation because it is very useful in designing and analyzing the systems where an interactive process exists and decision making is required. It is important to note that in cognitive radio networks (CRN) users need to adapt their operating parameters to the dynamic environment where they have different priorities, hence classical or static approaches do not optimally utilize the spectrum. In past, game theory has already been applied to CRN with success. In this paper a descriptive strategy for efficient utilization of licensed spectrum by the users of unlicensed spectrum using the principles of game theory is proposed. It has been observed that utilization of game theory can help in efficient utilization of spectrum while maintaining good QoS.

Keywords: Cognitive Radio Networks; Game Theory; Licensed Spectrum.

1. Introduction

In recent years, cognitive radio technology [1] has appeared as a potential solution to provide fast and reliable wireless services without the need for new spectrum bands [2]. In short, in contrast to traditional wireless networks, cognitive radio networks (CRNs) necessitate that users be conscious of this dynamic environment and intelligently adjust their operational parameters based on real-time interactions with the network environment. Conventional spectrum sharing and management approaches have employed a static environment model based on perfect cooperation among all network users. Note 3, on the other hand, provide a similar way to associate a random variable for these parameters as binary strings; but again these assumptions are not true in cognitive radio networks [1].

The user has a cognitive ability and can watch, learn, listen and act upon what they have learned and seen to get better service with less interference or noise, also in CRN. A full cooperation cannot be expected when users are the part of different authorities and have various goals was seemed. But without gains larger than solo efforts, users will cooperate only as much as that makes sense for them. Moreover, the radio environment is also time-varying because of the wireless channels' unfixed and broadcast nature, user mobility, dynamic topology and traffic load. All these factors give the nature of cognitive radio networks a fundamental difference from traditional wireless networks.

In the scenarios of traditional spectrum sharing, which uses an OL [4], where even some little changes in radio environment can cause the network controller to re-distribute strictly certain proportion of its spectrum resources are shown in Fig. 1. This often requires a lot of communication overhead due to the reallocation process. To solve these problems, the game theory becomes a useful tool to investigate, model and analyze the cognitive interactions in CRNs. Game theory provides essential ingredients for the design of efficient, self-enforcing, distributed and scalable spectrum sharing mechanisms that can automatically adapt to the dynamic nature of cognitive radio environments.

This fact allows the study of strategies to be used by its users to learn of how should act in the use of spectrum in cognitive radio networks through game theory. These strategies account for both the benefits and costs of cooperation, incentivizing users to act in manner which is optimal for their performance while contributing to the collective efficiency of the network. Game theory is essential within cognitive radio networks to construct systems that can adapt to changing environments and are able to cope with the intricacies of contemporary wireless communication. This has the potential to greatly benefit the utilisation of wireless spectrum resources, enabling faster and more reliable services in an ever evolving connected world from this perspective.

Game theory is the study of strategic decision making. In addition to the human decision-making process, game theory has been extended to analyse the decisions of animals, and also at a computer level. Play behaves this way also, it is a multi-filled area, you can find collaborative and non-collaborative games, simetric and asimetric games, zero-sum e not-zero-sum games, simultaneous e sequential action games, the IP (imperfect information) and PI(perfect information), combinatorial games of chess to tic-tac-toe), ultra-infinate forms of Tetris and PuyoPuyo Tetris(99 nexus 47 nonsense). A game is essentially a model of an interactive decision-making process [7]. Every game, whether blatantly or between the lines, contains one of more of the following elements.

- A set of players
- Each player would have following actions [8]
- A system for resolving based on player choices
- For each player, priorities or payoffs
- Model-specific rules such as the turn-play sequence and decision-making mechanisms

Game theory is used as a novel application based on which the spectrum-sharing protocols can be designed, whereas in this paper the focus is put on cognitive radio networking, and hence in more detail we briefly introduce some basic components of game theory at first. Towards the end, we discuss a few challenging research problems in game theoretic modeling approaches along with future directions to advance this field. Moreover, we introduce a novel collaboration scheme for effective spectrum usage in cognitive radio networks.

Game theory forms a powerful toolset in modeling and analyzing the strategic interactions among users in cognitive radio networks. Looking at different properties of a game allows researchers to build models that account for the full range of real-world interactions. As an example, the players of a cognitive radio network can be many users and devices willing for spectrum goodness. For each player, their actions may include selecting which frequencies to use or the power at which they transmit. In that way the proposed ambient prescription algorithm for improving communication quality of a service would be first to define and broadcast specific interference in the area and secondly to observe resulting devices to act appropriately.

When players in this context are specializing for achieving their objectives (e. g., maximize the data throughput, minimize energy consumption...), we refer to the "preferences" in the next sense. The unique rules of cognitive radio model could have relate to regulatory limitations, sure spectrum sensation protocols and war resolution mechanisms [8].

Game theoretic approaches for spectrum sharing in cognitive radio networks help researchers in developing such protocols which encourages both efficiency and fairness of spectrum utilization. In this context, cooperative strategies can be useful to provide significant performance improvements in terms of the spectrum exploitation, by promoting users to cooperate instead of aggressively competing for resources. Lastly, they exist to ensure that the gains from cooperation never fall short of the possible earnings from acting independently (so as to foster a more cooperative and less fragmented edging network).

This paper also presents the frontiers of research in cognitive radio networking from the perspective of game theory based techniques. They can be dynamic spectrum access techniques, incentive-based cooperation models or distributed decision-making algorithms. Through addressing the inherent challenges and identifying potential directions for future research, this will in turn contribute to broadening the horizons of the field to better understand and utilize game theory in industry 4.0 evolution.

In conclusion, game theory provides useful heuristicism and foundation for sophisticated spectrum-sharing protocols in cognitive radio networks. By an exhaustive consideration of its principles and applications, this paper presents a great effort in further potential performance and efficiency improvements of wireless communication systems.

The paper is organized into eight complementary sections. Section I - Introduction: An exposition of the paper. In Section II, an overview of game theory is provided, along with a detailed discussion of its contributions to Cognitive Radio Networks (CRNs). Section IV focuses on WLAN spectrum, and Section V addresses the concept of dynamic spectrum. Section VI explains cognitive radio and cognitive radio network technology. In Section VII, the proposed strategy for resource allocation is presented Finally, Section VIII concludes the paper, summarizing the key findings and contributions, and offers suggestions for future research directions in this area.

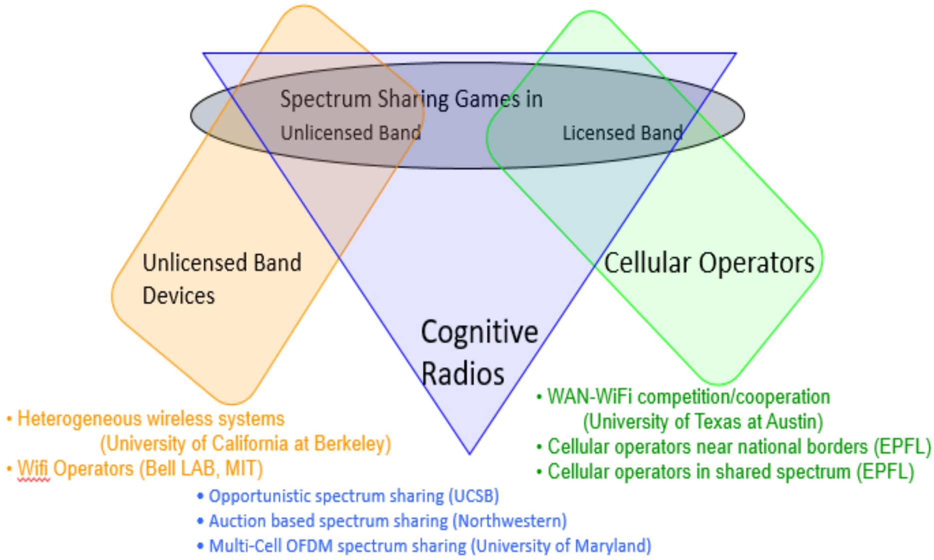

Figure 1. Spectrum Sharing Games

2. Game Theory

It refers to a study of strategic decision-making. Game theory is a branch of applied mathematics that studies strategic interaction between rational decision-makers, with the use of mathematical models [13]. Game Theory has a large number of applications - for example in economics, political science, psychology, logic, computer science and biology. Game theory was originally developed in terms of 'zero-sum games' - where the winnings and losses of each participant add up to zero. The field has long since gone on to include a diverse range of behavioral relations. Game theory Game theory is a series of concepts and methodologies specifically concerned with the analysis of strategies for dealing with competitive situations. Game theory now encompasses a wide variety of logical decision-making procedures given above where one or more players have more than one possible response to the scenario confronting them.

Game theory was established as a field of study in the 1940s by John von Neumann and others, later contributing to the intellectual leaps of modern game theory. Von Neumann's original proof used a Brouwer fixed-point theorem for continuous mappings into compact convex sets (a method later shown to be standard in both game theory and mathematical economics). This led to his 1944 book "Theory of Games and Economic Behavior" (published with Oskar Morgenstern. A game is defined as we might in (model of an) interactive decision making process. Almost every game has these six components in it, even if they are more or less hidden upon a first inspection:

1. A set of players who are involved in the game,
2. A range of actions available to each player,
3. A method for determining the outcomes based on the actions chosen by the players,
4. Preferences for each player, which are defined over all possible outcomes,
5. Rules specific to the model, such as the order in which players make their decisions.

Each of these components of a game corresponds to a specific aspect of the interactive decision-making process. These elements are critical for constructing models that can simulate and analyze strategic interactions in various scenarios. For example, in economic models, the set of players might represent firms or consumers, the actions could be different business strategies or purchasing decisions, and the preferences would reflect the utility or profit associated with each possible outcome.

In summary, game theory provides a comprehensive framework for understanding and analyzing the strategic interactions between rational decision-makers. By formalizing these interactions into mathematical models, game theory enables researchers to predict and explain behaviors in competitive and cooperative environments. This approach has deep implications across multiple disciplines, offering insights that drive advancements in economics, political science, psychology, and beyond. Table 1 illustrates how each component of a game corresponds to elements of the interactive decision-making process, providing a structured way to analyze complex strategic situations.

Table 1. Relationships between Game Elements and Interactive Decision Process Components

Game	Interactive Decision Process
Player	Decision Maker
Actions	Inputs
Outcomes	Outputs
Preferences	Decision Maker Objectives
Rules	Decision Timings, Radio Capabilities

3. Radio Spectrum

The radio spectrum is the part of the electromagnetic spectrum with frequencies from 1Hz up to 3000 GHz (3 THz). It is separated into around 40 different radio communications services which are defined by the International Telecommunications Union's Radio Regulations (RR) [13]. National administrations regulate the transmission and reception of radio wave s for general telecommunicatio n pur poses.SetKeyName4].

Various radio transmission technologies and applications also share different parts of the radio spectrum. Its this allocation that keeps whatever services you are using from stepping on each other. For example, some parts off the spectrum have been set aside for cellular telephone networks and some for broadcast television. For example, parts of the radio spectrum are sometimes sold or licensed to private operators. These operators can be a radio and TV stations, satellite service providers so forth each of whom use frequency allotted to them in order to offer a particular communication services passed on to the public. These intended uses are usually referred to by the name of the frequency band [5] for allocated frequencies.

The process of allocation plays an important part in the organization and management of radio frequencies that is a limited resource. Regulators can reduce interference and ensure effective communication by assigning certain bands to specific services. One of them is the cellular spectrum, which is assigned for use only by mobile phone operators to offer seamless voice and data services to customers. The television spectrum is also assigned to broadcasters to enable them to deliver audible and visible audio signals.

National governments are responsible for managing the radio spectrum within their territory. They apply the provisions of the ITU and ensure that they are adapted to local realities. This regulation covers the licensing of the operators, monitoring for spectrum use and enforcement. It thereby ensures efficient use of the radio spectrum enabling seamless performance between diverse communication services.

C) Some other parts of the radio spectrum are allocated to be reserved for use by public and emergency services, in addition to the allocation for commercial services. For example, they reserve frequencies for police, fire and medical emergency communications so that the most-important services have decent bandwidth without interference on these frequencies. Likewise, it is also a settled practice that certain spectrum bands are identified for scientific purposes including radio astronomy and environmental monitoring to promote human knowledge and technologies.

In general, spectrum management and spectrum allocation are the lifeblood of any modern communication systems. This allows for a broad mix of services, ranging from your normal mobile phone calls to emergency response and scientific research, to operate in close proximity without interfering with one another. With the evolution of technology and more use of wireless communication, the regulation and management of Radio Spectrum will be an essential challenge for national administrations and international bodies such as ITU.

4. WLAN Spectrum

A wireless local area network (WLAN) is a wireless computer network that links two or more devices using wireless communication within a limited area such as a home, school, computer laboratory, or office building. IEEE 802.11 defines a set of 14 channels that can be used in these frequency ranges, of which five are different frequencies (centered on different frequencies). These frequency ranges are further segmented into numerous channels, which can be leveraged by Wi-Fi operations.

Different countries have different regulations of which channels in these frequency ranges are allowed and what power levels they may use. Each of these channels has its own set of rules to regulate usage by tech companies making the absolute best use of the spectrum with minimum interference established by national regulatory bodies. This includes more rigorous rules in some countries for the channels that can be used and the maximum transmission power, or more relaxed regulations elsewhere [5].

For example, in the United States, licensed Amateur Radio operators have certain WLAN channels that they are allowed to use at much higher power levels than regular Wi-Fi devices can operate under [6]. It allows for long range transmission, useful in sparsely populated areas or specialized applications.

The 2.4 GHz band is a popular choice because many devices are compatible with it, and offers more of a compromise between range and speed. Yet its weaknesses are that it can be easily thwarted by many of the other machines that fill a modern home - microwave ovens and cordless phones especially. The 5 GHz band has more channels and is generally less congested, which maintains higher data rates with lower interference, but may have a higher loss of signal at long distances relative to the 2.4 GHz band.

The 3.6, 4.9, and (legacy) 5.9 GHz bands pose together a much smaller capability and are also somewhat less used, but do offer some extra choices for targeted uses. Some regions, for example, always designate the 4.9 GHz band to public safety communications, making it free for emergency and critical operations in those areas.

Regulations on a national basis, suited to local particular needs and for an efficient use of the electromagnetic spectrum, are in place in every country. These rules specify, e.g., channel availability, power limits and allowable use, so that WLAN devices can effectively operate without interfering with other licensed services.

In conclusion, the assigning and managing of WLAN channels is involved in a complex interaction between IWs and country, regulatory domains. These channels, following IEEE 802.11 protocols and national regulations, support a wide range of Wi-Fi applications, between regular internet access to dedicated services with long-communication distances like dedicating ISPs [7], and provide reliable and robust wireless data which are also function in various environments.

5. Dynamic Spectrum Management

Dynamic Spectrum Management (DSM) is a key concept of Dynamic Spectrum Access (DSA), which in turn includes a set of advanced technique for improving the overall performance of higher layers of communication networks. Leveraging on theoretical foundations from network information theory and game theory, these techniques have, hence, become a hotbed of R&D in the field [5]. DSM is also based on design principles from cross-layer optimization, AI, ML and etc. The characteristics of these schemes have been made possible by the advent of software-defined radio, which has become feasible due to high-speed processors found both in servers and terminals. It has cooperative optimizations, which is in the sense of performance, trying to obtain equilibrium across the entire network rather than optimizating just one link and degrading another millions.

Its most common application is in optimizing the performance of Digital Subscriber Line (DSL) network, where DSM is definitely proven beneficial. DSM + adaptively changing the spectrum as a function of current network conditions; used to mitigate interference and improve data rates for users DSM can also be applied in cognitive radio, a technology that enables flexible use of limited spectral resources by dynamically changing the operating frequency band of devices to operate in unused wasted frequencies which cannot be used continuously due to existence of narrowband primary users.

Major DSM principles and techniques are link adaptation, (bandwidth shaping) per user throughput throttling (BWMM), multi-user MIMO or coordinated MIMO, interference control for VA-DSM, pre-cancellation of Estimated Interference and/or EDI prediction for upcoming IQ-DSM and channel Bonding.

DSM provides an integrated solution to optimize network performance based on the dynamic and sometimes unpredictable characteristics of wireless communication environments. DSM can use these principles to improve the efficiency and robustness of communication networks, as well as to make them more agile in terms of adapting them to new requirements and/or changes in operating conditions. This is vital for the increasing demand on high-speed, continuous connectivity in the current hyperconnected world.

6. Cognitive Radio/ Cognitive Radio Network

Cognitive Radio is an adaptable device capable of configuring to meet various parameters automatically. It can have its transceiver scan for and hop to the free, awesome channels and give you a solid medium to communicate. This radio will know what channels are free in the frequency spectrum and set its transmit or receive parameters as required. This scheme makes it possible to arrange much more simultaneously coexisting spectrum occupancies within a single spectrum band in the specific location, and is illustrative of the dynamic spectrum management.

A type of data network in which the devices are programmed or pre-configured to find the most advantageous pathway between networks and can change the path as necessary (act autonomously). Core architecture:none Networks-device/Cognitive Network. It is referred as cognitive network (CN) in communication networks that employs some recent techniques from different backgrounds like machine learning, knowledge representation, computer networking etc. and deal with problems against existing systems [2][3]. The CR layer is confined to OSI layers 1 and 2 while Cognitive networks are descended to all seven layers of the OSI model [8].

Thomas et al. [7] A cognitive network is characterized as one that includes a cognitive process that can sense the current network status, plan and select actions based on the state of the network, act upon those actions, learn from past contents, all while transparently to meet end-to-end goals. This process, also known as cognition loop, ranges from: sensing the environment, generating plans according to sensor and network information (including policies), deciding on the best plan using a reasoning engine, and implementing the plan selected. It learns from past situations, plans, decisions and actions that it receives as feedback in order to use this knowledge (in the form of complex models) in order to significantly improve decision-making processes in the future. While this definition focuses on the closed-loop nature and end-to-end objectives, thus making it distinguishable from CR or cognitive layer, unfortunately it lacks reference to network information which is one of the essentials of a cognitive systems as in [8-12].

Social Networking Genre has a LAN example that uses ontological knowledge representation [24] quoting Balamuralidhar and Prasad [13]: "this ontology can be persistent along with the manager enabling pro-activeness and robustness to ignorable events while the ontology is unitary: it enables end-to-end adaptations. This perspective highlights the role of organized knowledge in making such cognitive network flexible and more versatile [25].

In [8], the cognitive network is defined as a communication network together with a knowledge plane, which covers vertically layer to layer (below cross-layer design) and horizontally technology to technology, node to node (allusion towards heterogeneity). The first is the knowledge plane that requires certain conceptual building blocks; entity representing the pertinent attribute knowledge (i.e., device, homogenous network, heterogenous network etc.) and a cognition loop encompassing machine learning techniques (i.e., learning methods and decisional methods) and game theory [15].

Then two works [10, 12] suggest a very holistic cross-layer network architecture for cognitive networks. A cognitive network is presented as a heterogeneity in the spectrum and wireless station resources that opportunistically can be used by this network [16]. Cognitive radio has been designed as a new kind of radio transceiver that can intelligently detect which communication channels are in use and which are not, using spectrum-sensing to help them making decisions in the dynamic spectrum access scenario whereas cognitive network expands this idea by giving the ability to intelligently organize cognitive radios within the network [17] [27]. The game perspective in CRN [21] is depicted herebyTable 2 shows a mapping of components of a CRN to a game, portraying examples of potential interactions and optimization processes.

To sum up, Cognitive radios and cognitive networks are two epoch-making wireless communication technology. These capabilities, combined with embedded dynamic configuration capabilities and intelligent decision-making processes, make it possible to support more adaptive, resilient and intelligent Experian global communication networking solutions [26] [28].

Table 2. Related Modeling Elements in a Game and a Cognitive Radio Network

Game	Cognitive Radio Network
Player	Cognitive Radio
Actions	Actions
Utility Function	Goal
Outcome Space	Outside World
Utility Function Arguments	Observations/ Orientation
Order of Play	Adaptation Timings

7. Game Theoretic Strategy for Better utilization of Spectrum using CRN

In CRN game, our main objective is to utilize the spectrum in best possible way, as the problem is that according to literature [18] the range in which the spectrum is utilized varies between 15% and 85% i.e. even in peak hours 15% of the spectrum remains unutilized, from the given information we may infer that on average half of the spectrum that is allocated to the primary users remains unutilized [19]. CRN is one of the solutions which can better utilize the spectrum and applying game theory for best possible spectrum sensing [20], allocation, de-allocation, preventing congestion, giving the first right to the PU can yield very fruitful results [21].

In CRN Game we consider the following:

7.1. Number of Players

Total 'n' including 'p' primary users and 's' secondary users. It is important to mention here that adding 'p' and 's' will result in 'n'. For ease of understanding, presentation and modeling an example of two player game is taken in this paper to draw the payoff matrix, however, the real game will be between 'n' players.

7.2. Type of Game

This will be a cooperative game, as this will result in better performance of CRN and efficient utilization of the spectrum [18]. By cooperating with each other the chances of conflicts may be reduced. It is to be noted that this game can also be played in a non-cooperative manner where the PU and SU focus on utilizing the spectrum by keeping their objectives and benefits and many examples exist in literature [22]. However, according to this work, if the game is played in a cooperative manner, output of the game is much improved that non cooperative strategy. This is a non zero sum game, as the players that are playing the game are cooperating with each other and at a same point in time, both can be in a win-win position. This game can be played simultaneously by many players i.e. at a given point in time, a PU may be leaving the spectrum and informing others, while another primary user is entering the spectrum, a SU is shifting to the spectrum of PU and another SU is leaving the PUs spectrum after completing its work [23]. In this game both users will have shared knowledge about utilization of spectrum, tradeoff of leaving and joining the spectrum space and better utilization of spectrum. This will help them to cooperate with each to meet the overall objective of the game. This is a repeated game where the game can be replayed with same or different players. This is a multiplayer game and all players are working together to reach the desired output. This game may divide in to smaller games and consequently turn in to a meta game, however, this is not discussed as it is not in the scope of this paper.

7.3. Assumptions

Both PU and SU are intelligent enough that they can perform the following tasks

1. Both PU and SU can perform spectrum sensing
2. PU has capability to inform SU when leaving
3. PU can de-allocate the SU, in case of spectrum shortage
4. PU is always given priority in spectrum allocation
5. SU can allocate the spectrum space when available
6. SU can de-allocate the spectrum space when its tasks is finished
7. SU quits from the licensed spectrum if spectrum utilization is 90% or more

7.4.Actions

For Primary Users (PU):

1. Allow the SU to use the spectrum
2. Does not allow the SU to use the spectrum
3. Inform the secondary users when signing off so the SU can use the spectrum (if required)

For Secondary Users (SU):

1. Use the spectrum of PU for better speed and better utilization of spectrum
2. Do not use the spectrum of PU
3. Only use the spectrum in emergency situation
4. Request the PU to allow the usage of spectrum

7.5. Method and Outcomes

1. Whenever SU feels that there is a decline in quality of service (QoS) due to overutilization of the unlicensed spectrum [19], it senses the licensed spectrum and after confirming the availability it jumps to the licensed spectrum. This results in two benefits:
   a. Space of unlicensed spectrum is freed and QoS for remaining users increase.
   b. Licensed spectrum which is already underutilized is used by SU
2. When there is an emergency situation SU shift to a different frequency due to congestion in unlicensed spectrum. For this it is important that the licensed spectrum has the space available, or in special case, they voluntarily signoff from their licensed space to cater the emergency requirement of the SU (Police, Investigation agencies, Rescue Department, Fire Department etc). This results in the following
   a. Problem of congestion in unlicensed spectrum is solved
   b. Communication problem due to overutilization of spectrum between different departments who are responsible to cater the emergency situation is solved and QoS is increased. Precious lives and resources may be saved by making the communication reliable and efficient
3. PU informs the SU that he is signing off or moving from this area, resulting in availability of spectrum space, so the secondary users can enjoy the speed and quality of licensed spectrum resulting in better QoS. This will result in:
   a. Better utilization of spectrum, better speed for SU, even if their own space is not fully utilized
   b. Reduction of the resources that are utilized in the spectrum sensing process

7.6. Preferences

In this game the preference of both PU and SU will be to better utilize the spectrum, however, as mentioned in assumptions PU will have more priority in its spectrum and this information is known to both PUs and SUs. This means that if there is a shortage of spectrum space SU will automatically leave the licensed spectrum, on the other hand the PU can force its way to the licensed spectrum even if there are SUs using the spectrum. This means that PU can force the SU to leave the spectrum without its will.

7.7. Pay off Table for 2 Players

In this section we will give a simplified model of this game by using two players. This model is presented for ease of understanding and appreciating the importance of game theory in resource allocation.

Table 3. Payoff Matrix for 2-players in CRN

	SU	
	Shifts to PU Spectrum	**Remains in SU Spectrum**
PU		
Informs	**100,100**	80,-50
Does not Inform	0,70	0,0

Table 3 gives a payoff matrix for resource allocation in CRN [20]; we have modeled this game for 2 players only. This is done to keep the model simple and better appreciate the application of game theory in CRN. This model can be extended to ‘n’ players as well. In table 3, we have set two options each for PUs and SUs, PU can inform the SU when it is either signing off or moving away i.e. when it is freeing the spectrum space, on the other hand this process may be done silently without informing anyone. On the other hand SU also has two options in the game; one is to remain in the unlicensed spectrum allocated to the SU, other is to shift from its spectrum and utilize the spectrum of PU. As it is a cooperative game so the results can be different when PU informs the SU from the situation where PU does not inform. It is to be noted that game is played for best utilization of spectrum. There are 4 possible cases

i. PU informs and SU shifts:

This is the best case and may be considered as Nash equilibrium, as both players have maximum benefit in this strategy. If this option is utilized the spectrum will be utilized optimally as PU always informs SUs when leaving the spectrum. On the other hand SU shifts after the spectrum is freed by PU, this gives the opportunity to SU to better utilize the spectrum and enjoy better speed. The payoff for both PU and SU in this case is 100.

ii. PU informs and SU does not shift:

In this scenario the PU informs the SUs but the SU does not shift its spectrum. This results in available space in spectrum that is not utilized by anyone. SU keeps in its spectrum and does not enjoy high speed. Here PU payoff will be 80 as SU has not utilized the spectrum, however SU will be in loss so its payoff will be -50.

iii. PU does not inform and SU shifts:

In this scenario the SU shifts its spectrum, irrespective of the point that PU has not informed. This will take a bit more effort from the SU as it has to perform spectrum sensing and then shift to the licensed spectrum. In this scenario the PU will not lose anything but it will also not contribute to the overall objective of the game, hence its pay off will be 0, on the other hand payoff for SU will be 70 as it has to do some extra steps to shift the spectrum.

iv. PU does not inform and SU does not shift:

In the last scenario both are losing, PU does not inform so it will affect the overall utilization of spectrum, hence its payoff will be 0, on the other hand SU also stays in its own spectrum and does not enjoy the speed, also the spectrum is also underutilized, hence its pay off will also be 0 as it s not gaining any advantage, not contributing to the overall objective but loosing the quality of service.

8. Conclusion and Future Directions

This interview presents the Game theory: Applications to telecommunication as one of the spark that hatched the game theory which became a new form of formal modeling as it is being applied in cognitive radio networks, for understanding and evaluating network behaviors. This framework provide useful hints about how decision-making among the individuals or entities takes place in competitive and cooperative environments, so it could be considered for several problem at complex systems like cognitive radio networks (CRN).

Then, a detailed game-theoretic framework for resource allocation in cognitive radio networks is provided. The approach addresses these difficulties towards more effective use of the spectrum resources that exist. Because of its nature, cognitive radio networks require an intelligent and dynamic management of the spectrum bands in order to achieve optimal performance and quality of service. These complex interactions and resource allocation problems can be accurately modeled using the game theory.

It is mainly because of the gamesque problems in CRNs which motivates to model the resource allocation problem as a strategic game due to application of game theory used for modeling different network entities like primary and secondary users. Each entity is trying to optimise its own performance whilst also modeling the actions and strategies of others. The interaction can be a combination of both, depending on the requirements and conditions of the network concerned. These interactions can be studied using theoretical models from Game Theory, leading to strategies that/maximise/minimise spectrum usage providing better overall network performance. Game theory captures the dynamic and adaptive nature of cognitive radio networks that make it undesirable to try to analyse an optimal behaviour on the basis of a simple object computing technique. The changing network environment makes the problem a moving-target and game theory provides an ideal framework for enhancing the decision-making process of the network entities in real-time. The main factors that take into account here are changes in the user demand, level of interference and spectrum resource availability. Integrating these into our models, we could build strategies that adapt with the network and thus guarantee ressource allocation at it's best, all the time.

Besides, game theory allows to consider the heterogeneous selfishness and resource paths of various network users. Primary users, for example, might want less interference and more spectrum usage, while secondary users would like to make sure that they can use available spectrum without bothering the primary users. Spreading game-theoretic insight allows us to strike a balance among them by devising mechanisms that promote collaboration and result sharing among peers. A novel game theoretic resource allocation strategy for Cognitive Radio Networks, AdHOC_proposedAlgorithm, has been illustrated with the desired performance in term of both spectrum efficiency and quality of service. The efficient and worldwide harmonised use of scarce radio spectrum can be achieved as we systematically analyse the interactions between different network entities and develop strategies based on this knowledge. This not only makes each user faster, but also strengthens the network as a whole and ensures very high reliability.

Finally, applying game theory in designing algorithm for managing cognitive radio networks helps to solve the challenges of resource allocation and spectrum utilization. Game models: Utilizing game-theoretic models can help us to delve deeper into how these networks are interacting with each other and develop strategies which will allow for proper utilization of resources. Our results demonstrate the power of game theory for re-thinking the control of cognitive radio networks leading to smarter and more agile communication systems that can satisfy the requirements of contemporary high data rate wireless services..

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