Centralized Dynamic Spectrum Access in Cognitive Radio Networks Based on Cooperative and Non-Cooperative Game

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Abstract: Cognitive radio (CR) can be presented as a new paradigm coming from the bad use of spectrum resources, the problem of static spectrum allocation produce disequilibrium. The CR proposes opportunist radio spectrum exploitation.

In this paper, we propose a centralized dynamic spectrum access in cognitive radio networks based on a powerful mathematical tool, the game theory on one side, and on multi-agent system on the other side. The problem of dynamic spectrum access (DSA) is modeled as a cooperative and non-cooperative spectrum access game where secondary users (SUs) access simultaneously multiple spectrum bands left available by primary users (PUs). Cooperation is modeled between PUs where non-cooperation is considered between SUs.

Key words: cognitive radio, dynamic spectrum access, cooperative game, non-cooperative game, multi-agent system.

1 Introduction

The development of new technologies has always been dictated by current needs and the availability of the technology. This is how we evolved from analogue to digital radio and the subsequent progress, particularly in the quality, speed and reliability of transfer of information, but also in the network's capacity.

The wireless networking technologies are increasing rapidly in a very diverse aspect (e.g., 3G+ and 4G cellular networks). This dramatic increase of the demand for spectral bandwidth is limited by the deficiency of spectrum resources. The Cognitive radio is viewed as an effective approach for improving the utilization of the radio spectrum. CR is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users. Dynamic spectrum access (DSA) allocates spectrum more dynamically and it is an active area of research. DSA requires not only advances in technology but also new policy and economic models for spectrum use [8].

Among the techniques used for DSA, game theory is considered as a powerful mathematical tool in this context. So, game theory can be defined as a mathematical framework which consists of models and techniques that use to analyze the iterative decisions behavior of individuals concerned about their own benefit. These games are generally divided into two types [11], cooperative (coalition) games and non-cooperative (competitive) games.

A multi-agent system (MAS) is a dynamic federation of agents connected by the shared environments, goals or plans, and which cooperate and coordinate their actions [14]. It is this capacity to communicate, to coordinate and to cooperate which makes interesting the use of agents in cognitive radio networks.

The association of MAS and the CR can provide a great future for the optimal management of frequencies (in comparison with the rigid control techniques proposed by the telecommunications operators). In the case of use of unlicensed bands, the CR terminals have to coordinate and cooperate to best use the spectrum without causing interference [8].

In this paper, we propose a centralized dynamic spectrum access in cognitive radio networks based on game theory and MAS. The DSA problem is modeled as a cooperative and non-cooperative spectrum access game where secondary users access simultaneously multiple spectrum bands left available by primary users.

For the cooperative approach, we have adapted a game based on prisoner's dilemma; this game is between PUs and needs at least two PUs and a coordinator. Use a central element (coordinator) is very interesting to limit the number of messages exchanged between the PUs. For the competitive aspect, it is between SUs, in this case we have adapted the urn game, when the SU allocates some resources from the PU, the PU increment a counter called fidelity. If this fidelity affect a threshold, the PU demands the SU if he wants to play the game. Specifically, we consider a MAS, in which the agents are deployed over PUs, SUs and coordinator.

This paper is organized as follows, the first section defines cognitive radio and its main functions i.e. spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility. The second section presents a brief overview of classifications of games, particularly cooperative and non-cooperative games. The third section presents a synthesis of the research relating to game theory in wireless networks, particularly in cognitive radio networks. The fourth section is a description of our proposed solution with the related spectrum access algorithm proposed in the context of cooperative and non-cooperative spectrum access game. In the last section, we conduct extensive simulations to verify the working of the proposed algorithms for dynamic spectrum access in cognitive radio networks.

2 An overview of cognitive radio

2.1 Software defined radio (SDR)

It's thanks to the work of Joseph Mitola that the term Software radio arised in 1991, to define a reprogrammable and reconfigurable class of radio. In the case of software radio, the standard functions of the radio interface, generally conducted materially, like the carrier frequency, the bandwidth of the signal, modulation and access to the network are done using software. Modern software radio also integrates software for encoding, error correction coding, coding for voice, video or data. The concept of software radio must equally be considered as a way of making users, service providers and manufacturers more independent of standards. In addition, with this solution, radio interfaces can in principal be adapted to meet the needs of a particular service for a specific user, in a given environment at a given moment. There are different stages of progress in the domain: software radio is the ultimate goal, integrating all functionalities into the software, but this includes intermediary steps, combining old and new techniques, this is why we talk about software defined radio (SDR). Constraints in computing power, electrical consumption, costs etc. mean that this intermediary phase is skipped.

A number of definitions can be found to describe SDR. The Wireless Innovation Forum, working in collaboration with the Institute of Electrical and Electronic Engineers (IEEE) P1900.1 group, has worked to establish a definition of SDR that provides consistency and a clear overview of the technology and its associated benefits. SDR is defined as: "Radio in which some or all of the physical layer functions are software defined".

In [4], SDR is defined as a radio communication system which can adapt to any band of frequency and can handle any modulation using the same material.

2.2 Cognitive radio (CR)

The idea of cognitive radio was officially presented in 1998 by Joseph Mitola III in a seminar at KTH, the Royal Institute of Technology, later published in an article by Mitola and Gerald Q. Maguire Jr in 1999 [6].

Known as the "father of software radio", Dr. Mitola is one of the most cited authors in the field. Mitola combines his experience of software radio with his passion for machine learning and artificial intelligence to implement cognitive radio technology. In his own words: "Cognitive radio is able to understand, appreciate and learn from its environment, then act in order to make the user's life more simple".

Cognitive radio is a new technology which, with the help of software radio can set or adjust the operating settings of the radio's frequency in a network node (wireless telephone or wireless access point), like, for example, the range of frequency, the type of modulation or the power output [3].

This allows each device to adapt to current spectrum conditions, therefore offering users a more simple, effective and complete access to the resource. This approach can considerably improve the data transfer rate and the scope of connectivity without increasing bandwidth or transmission. CR also offers a solution to the problem of spectrum crowding, by giving priority to spectrum owner, then allowing others to access it by using available parts of the spectrum.

The principle of CR, based on standard IEEE 802.22, requires an alternate handling of the spectrum, which is as follows: a secondary user can access, at any moment, frequency bands that it deems free, in other words, the frequency bands those are non-occupied by the primary user who possesses a license for that band. The secondary user must give it up once the service is finished or when a primary user attempts to connect.

A cognitive network coordinates transmissions by following different bands of frequency and different technologies, by using available bands at a given moment, in a given place. It needs a base station capable of working with a large range of frequencies, in order to recognize different signals present in the network and to reconfigure itself accordingly.

The components of the cognitive radio network architecture, as shown in Figure 1, can be classified in two groups as the primary network and the cognitive network. Primary network is referred to as the legacy network that has an exclusive right to a certain spectrum band. On the contrary, cognitive network does not have a license to operate in the desired band [12].

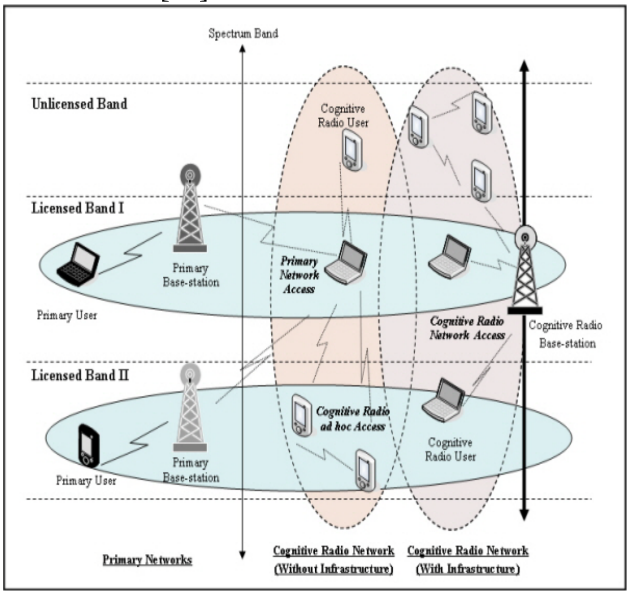

Fig.1 Cognitive radio network architecture [12]

2.3 Relationship between CR and SDR

Software radio is capable of offering functionalities of flexibility, re-configurability and portability inherent to the cognitive radio's aspect of adaptation. The latter must therefore be implemented around a software defined radio. In other words, software defined radio is an "enabling technology" for cognitive radio, SDR can satisfy the required flexibility that cognitive radio needs.

The relationship between CR and SDR is illustrated in Figure 2.

Fig.2 Relationship between CR and SDR [13]

2.4 Cognition cycle

The cognitive components of the cognitive radio's architecture include temporal organization, interference and states of control.

This cycle evidently synthesizes this component. Stimuli enter the cognitive radio as sensory interrupts, dispatched to the cognition cycle for a response. Such a cognitive radio observes the environment, orients itself, creates plans, decides, and then acts [5].

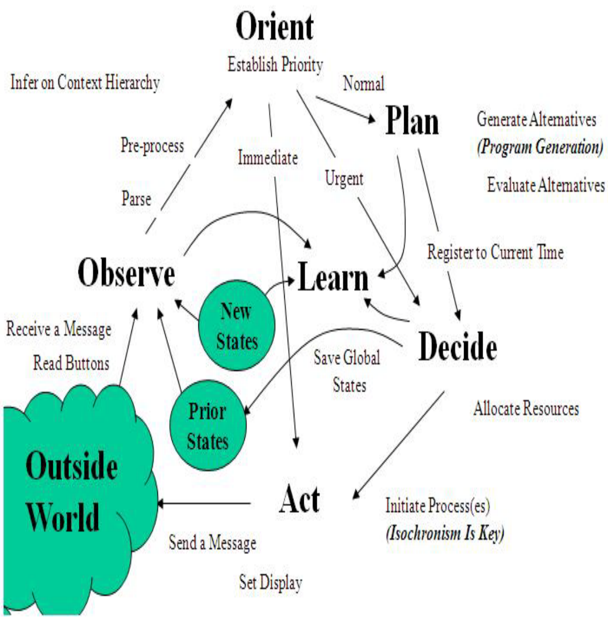

Fig.3 Cognition cycle [5]

Observation phase (senses and perceives): In the observation phase, the cognitive radio reads location, temperature, light-level sensors, amongst others, to decide the communication context. This phase matches stimuli with previous experiences to discern the modules over time.

Orient phase: The orient phase determines the significance of an observation by binding the observation to a known series of stimuli. This phase works in the interior of data structures that represent the short-term memory (STM), that people use to engage in a dialog without necessarily remembering everything as is the case in the long-term memory (LTM). The natural environment supplies the necessary information needed to instigate transfer from STM to LTM. Matching current stimuli with stored experience is done by stimuli recognition or binding. Stimuli recognition occurs when there is an exact match between a current stimulus and a previous experience. The response may be correct or in error. Each stimulus is situated within a larger context, including other stimuli and internal states including time. Sometimes, the orient phase provokes an action which will be immediately launched as a “stimulus-response” reaction.

Planning phase: The majority of stimuli are deliberative as opposed to reactive. A message entering from the network will normally be handled by the generation of a plan (in the planning phase, the normal pathway). The plan should also include the decision phase. Generally, the reactive responses are preprogrammed or learned, whilst other deliberative reactions are provided.

Decision phase: The decision phase selects a plan from the potential ones. The radio can alert the user with an incoming message or report the interruption quickly depending on the levels of QoI (Quality of Information) determined in this phase.

Action phase: This phase launches the selected processes which use the chosen effectors which access the external world or the internal states of the cognitive radio.

Access to the outside environment principally consists of composing messages which must be sent to the environment through audio or expressed in the different appropriate languages. A cognitive radio action can equally update its internal models, for example, adding new models to existing internal models. Acquiring knowledge can be accomplished by an action which creates the structure of appropriate data.

Learning phase: Learning depends on perception, observations, decisions and actions. Initial learning is mediated at the observation stage, in which all sensory perceptions are continuously compared to all previous experience to continuously count experiences and to remember time since the last occurrence of the stimuli.

Learning can arise when a new model is created in response to an action. For example, previous and current internal states can be compared with expectations in order to learn more about a communication mode's efficiency. [1]

2.5 Functions of cognitive radio

Cognitive radio system requires four major functions that enable it to opportunistically use the spectrum [7]. These functions consist in the CR terminal’s main steps for spectrum management. They are: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

Spectrum sensing: Detect unused spectrum and share with other users, without interference. Detecting primary users is the most effective way to detect the spectrum's white spaces.

Spectrum sharing: The results obtained from the spectrum detection are analyzed to calculate the spectrum’s quality. One of the issues here is how to measure the quality of the spectrum, which may be accessed by a secondary user. This quality can be characterized by the signal to noise ratio, average duration and correlation of the spectrum’s white space availability. Information on this spectrum quality available to a user can be imprecise and noisy. Learning algorithms from artificial intelligence are techniques which can be employed by the users of the cognitive radio for spectrum analysis.

Spectrum Decision: A decision model is required for spectrum access. The complexity of this model depends on the parameters considered in the analysis of the spectrum. The decision model becomes more complex when a SU has multiple objectives. For example, a SU may intend to maximize performance while minimizing disturbance caused to the primary user. Stochastic optimization methods will be an interesting tool to model and solve the problem of spectrum access in a CR.

When multiple users (both primary and secondary) are in the system, preference will influence the decision of the spectrum access. These users can be cooperative or uncooperative in access to spectrum.

In a non-cooperative environment, each user has its own purpose, while in a cooperative one, all users can work together to achieve one goal. For example, many SUs may compete with each other to access the radio spectrum (eg, O1, O2, O3, O4 in Figure 4 below) so that their individual throughput is maximized. During the competition between SUs, all ensure that the interference caused to PUs is maintained below the temperature limit corresponding interference.

In a cooperative environment, CRs cooperate with each other to make a decision for accessing the spectrum and maximizing the objective function taking into account the common constraints. In such a scenario, a central controller can coordinate the spectrum management [8].

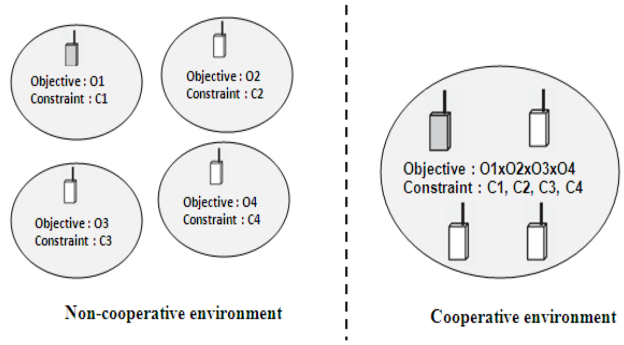

Fig.4 Cooperative and non-cooperative spectrum Access

Spectrum Mobility: Is the process that allows the CR user to change its operating frequency. CR networks are trying to use the spectrum dynamically allowing radio terminals to operate in the best available frequency band, to maintain transparent communication requirement during the transition to a better frequency.

When a secondary user makes a spectrum transfer, two issues must be considered. The target channel must not be in current use by another secondary user (auto-coexistence demand), and the receiver of the secondary connection must be informed about the spectrum non-intervention (synchronization demand) [2].

Figure 5 illustrates the four main spectrum management functions of the cognitive radio cycle as well as the possible transitions between them.

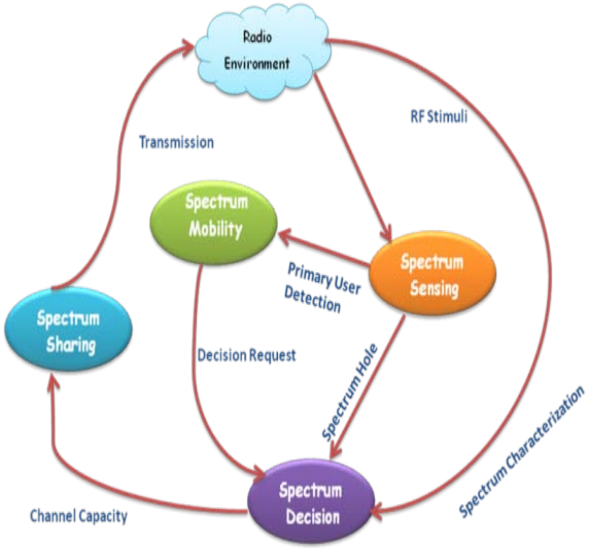

Fig.5 Spectrum management functionality's

3 An overview of game theory

3.1 Introduction: brief game theory history

The ideas underlying game theory have emerged throughout history, apparent in the bible, the Talmud, the works of Descartes and Sun Tzu, and the writings of Chales Darwin. The basis of modern game theory, however, can be considered an outgrowth of a three seminal works [15]. Augustin Cournot's Researches into the Mathematical Principles of the Theory of Wealth in 1838, gives an intuitive explanation of what would eventually be formalized as the Nash equilibrium, as well as provides an evolutionary, or dynamic notion of best-responding to the actions of others. Francis Ysidro Edgeworth's Mathematical Psychics demonstrated the notion of competitive equilibria in a two-person (as well as two-type) economy. Finally, Emile Borel, in Algebre et calcul des probabilites, Comptes Rendus Academie des Sciences, Vol. 184, 1927, provided the first insight into mixed strategies, or probability distributions over one's actions that may lead to stable play.

While many other contributors hold a place in the history of game theory, it is widely accepted that modern analysis began with John von Neumann and Oskar Morgenstern's book, Theory of Games and Economic Behavior and was given its modern methodological framework by John Nash building on von Neumann and Morgenstern's results.

3.2 Classification of game theory

There are diver's game theory models which can be categorized on the basis of factors like the number of players involved, the sum of gains or losses, and the number of strategies employed in the game. The terminology used in game theory is inconsistent, thus different terms can be used for the same concept in different sources [9]. So, there are several types of game, among them: sequential and simultaneous game, games with perfect and imperfect information, games with complete and incomplete information, zero-sum and non-zero-sum game, discrete and continuous games. But the most commonly used classification is non-cooperative and cooperative (coalition) games. This latter classification is detailed and used in this paper.

In game theory, a cooperative game is a structure in which the players have the option of planning as a group in advance of choosing their actions. Unlike a cooperative game, a non-cooperative game is a game structure in which the players do not have the option of planning as a group in advance of choosing their actions. [10]

In non-cooperative game theory there are two alternative ways in which a game can be represented. The first type is called a normal form game or strategic form game. The second type is called an extensive form game. A normal form game is any game where we can identify the following three things:

- The players: in a game are the individuals who make the relevant decisions.
- The strategies available to each player: is a complete description of how a player could play a game.
- The payoffs: is what a player will receive at the end of the game contingent upon the actions of all the players in the game.

To make the ideas discussed more specific we will look at one well known game called "The Prisoners' Dilemma", this game will be used in this paper.

In "The Prisoners' Dilemma" game, the police have arrested two suspects of a crime. However they need sufficient evidence to convict either of them unless at least one of them confesses. The police keep the two suspects in disjoin cells and explain the consequences of their possible actions. If neither confess then both will be convicted of a minor offense and sentenced to one month in prison. If both confess they will be sent to prison for six months. Finally, if only one of them confesses, then that prisoner will be released immediately while the other one will be sentenced to nine months in prison, six months for the crime and a further three months for obstructing the course of justice. The above description of the game satisfies the three requirements of a normal form game. We have two players, each of whom has two strategies (which in this game are the same as the prisoners' actions, to confess or not confess), and payoffs for each possible combination of strategies. The normal form for this game is shown in Table 1. The payoffs are shown as the negative number of months in prison for each outcome and for each prisoner. This assumes that each suspect, if rational, seeks to minimize the amount of time spent in prison. By convention the first payoff listed in each cell refers to the row player, prisoner 1, and the second payoff refers to the column player, prisoner 2.

PRISONER 1 **PRISONER 2**

	CONFESS	DON'T CONFESS
CONFESS	- 6 , - 6	0 , - 9
DON'T CONFESS	- 9 , 0	- 1 , - 1

Table 1 The Prisoners' Dilemma game in Normal Form

In extensive form games greater attention is placed on the timing of the decisions to be made, as well as on the amount of information available to each player when a decision has to be made. This type of game is represented not with a matrix but with a decision, or game, tree. The extensive form for the Prisoners' Dilemma is shown in Figure 6.

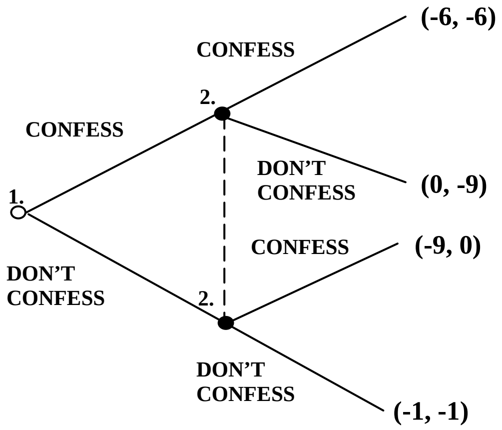

Fig.6 The Prisoners' Dilemma Game in Extensive Form

Generalizing from Figure 6 we can state that extensive form games have the following four elements in common:

Nodes: this is a position in the game where one of the players must make a decision. The first position, called the initial node, is an open dot, all the rest are filled in. Each node is labeled so as to identify who is making the decision.

Branches: these represent the alternative choices that the person= faces, and so correspond to available actions.

Vectors: these represent the payoffs for each player, with the payoffs listed in the order of players. When we reach a payoff vector the game ends.

Information Sets: when two or more nodes are joined together by a dashed line this means that the player whose decision it is does not know which node he is at.

Another game that will be used in this paper is the urn game, in this game, two students are randomly selected and the next game is offered to them, everyone has the opportunity to put 0 or 20 € in the urn. After the decision of the two students, the contents of the urn is multiplied by 3/2 and divided into two equal parts.

Table 2 shows the urn game in Normal Form.

PLAYER 1 **PLAYER 2**

	PUT 0€	PUT 20€
PUT 0€	0 , 0	15 , - 5
PUT 20€	- 5 , 15	10 , 10

Table 2. The urn game in Normal Form

The extensive form for the urn game is shown in Figure 7.

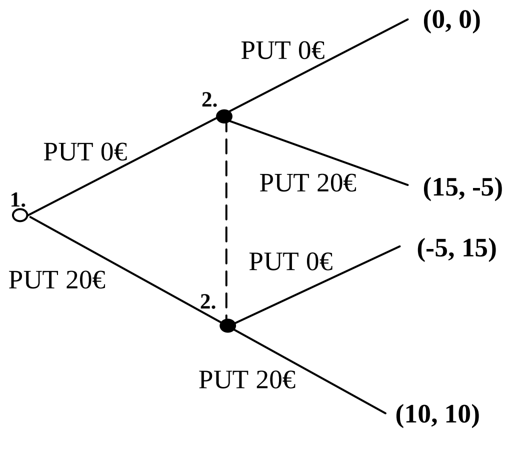

Fig.7 The urn game in Extensive Form

4 Related works

The adaptation of game theory is largely used in modern networks technologies where analyzing and decision have a big impact in network performance, in our paper we'll present some examples of works whose have used game theory.

In [16], the author has used prisoner dilemma as a solution in wireless networks to solve selfish node's deviation problem when refusing packet routing of other nodes in order to conserve energy, the main raison of this problem is that the network in question has mobile nodes add to that every node have a battery which must be preserve and used wisely.

Mobile Ad Hoc networks (Manet), generally are wireless networks without infrastructure, composed of a set of nodes. Packets routing is more complicated in this networks unlike networks with infrastructure where the server is charged of routing packets.

A couple of solution has been proposed for this problem such as optimal routing protocols which consume less energy like Dynamic Source Routing (DSR) [22] and Ad-hoc On-demand Distance Vector (AODV) [23].

However the need of cooperation between nodes to ensure network performance is a conflict with node's individual interest which aims for conserving energy only for the traffic flow destined to it or its own.

In this work, to stimulate the cooperation between nodes in a mobile ad hoc network, the author used a mechanism based on reputation named: CORE, it is a distributed protocol running on every mobile unit. This mechanism is about the traffic observing and analysis that the node has committed in case of cooperation with the neighboring nodes, if the protocol detects that the packets routing rate of the concerned node is lower than a fixed threshold, according to a political management, the node will be punished by a gradually communication service deny. CORE mechanism was modeled by game theory and the application of prisoner's dilemma model.

The authors in [17] have introduced the routing game model of telecommunication networks, they supposed a shared network topology composed of several nodes (routers, switchers, station ...), for each node, a set of links was defined to route the traffic to the node « v », and a set of outgoing traffic links of node « v », it was defined also for each node « v » a route for the traffic (packets sends) as a links succession from source to destination.

Each node « v » can share its demand of transmission on several various routes from source to destination, so the cost of node « v » (time of packets transmission on route r) depends not only of its own strategy but also of others node's strategies on this route, this dependence between nodes can be found only through the sum of traffic on this route.

In paper [18] a packets routing problem in Ad Hoc networks is treated, the authors proposed a routing protocol to send out every source's packet by the shortest route until destination, they says that the routing decisions are done in mobiles terminal while the terminals are considered as routers, the authors used the game theory, the results obtained of this maneuver are identical to those obtained with Wardrop equilibrium [19], this balance consider the packets as players, it's more effective than Nash equilibrium in a such situation because it suppose that the participation of costs or delays by the individual users is null.

The cognitive radio is a wireless communication system that can be aware of the environment around and adjust its radio parameters to adapt to environment variation. This research area is a thematic for many researchers, one of their works in [20] which we'll analyze and study. The authors of this paper have achieved a study where they have considered the radio cognitive terminals as players and they have modeled the scenario of spectrum dynamic access in games strategies forms, the study was comparative and several strategies has been used like : "ALWAYS DEFECT " in which the player choose to betray whatever the others player have chosen, "ALWAYS COOPERATE " the same as the fist but here the player choose to cooperate, there is also " GRIM TRIGGER" and "TIT-FOR-TAT".

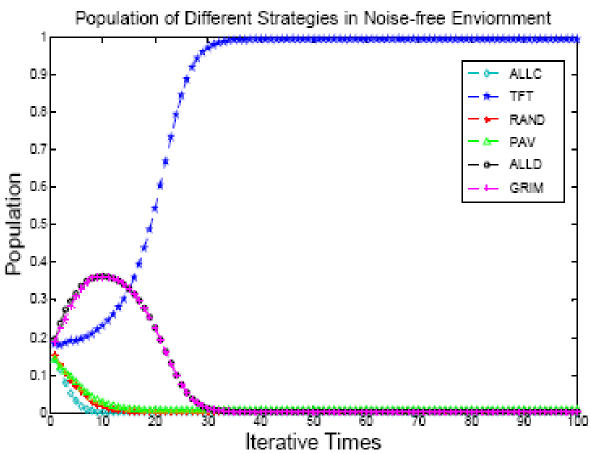

Fig.8 Population with different strategies in a nose-free environment

Figure 8 shows that the best strategy is «TIT-FOR-TAT » despite that « GRIM TRIGGER » seems more effective but not for long time, in this study the authors show with the simulation tool that even with nose the best strategy remains « TIT-FOR-TAT », and they have proven that the radio cognitive towards to the competition more than cooperation.

The authors in [21] investigates the impact of the tradeoff between spectrum sensing and spectrum access on the cooperative strategies of a network of SUs that seek to cooperate in order to improve their view of the spectrum (sensing), reduce the possibility of interference among each other, and improve their transmission capacity (access). The authors have modeled the problem as a coalitional game in partition form and an algorithm for coalition formation is proposed. Using the proposed algorithm, the SUs can make individual distributed decisions to join or leave a coalition while maximizing their utilities which capture the average time spent for sensing as well as the capacity achieved while accessing the spectrum. The authors show that, by using the proposed algorithm, the SUs can self-organize into a network partition composed of disjoint coalitions, with the members of each coalition cooperating to jointly optimize their sensing and access performance.

Simulation results show the performance improvement that the proposed algorithm yields with respect to the non-cooperative case.

Figure 9 demonstrates that, as the amount of time α dedicated for sensing a single channel increases, the time that can be allotted for spectrum access is reduced, and, thus, the average payoff per SU per slot for both cooperative and non-cooperative spectrum sensing and access decreases. In this figure, we can see that, at all α , the proposed joint spectrum sensing and access through coalition formation exhibits a performance gain over the non-cooperative case. This advantage decreases with α, but it does not go below an improvement of 54.7% relative to the non-cooperative scheme at α = 0.5, i.e., when half of the slot is used for sensing a single channel.

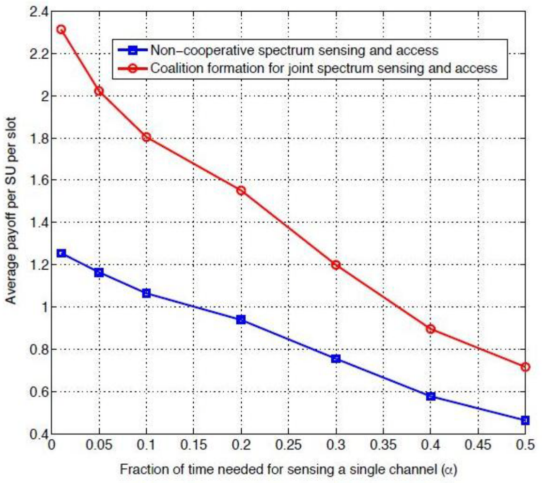

Fig.9 Average payoff achieved per SU per slot for a network with N = 10 SUs and K = 14 channels as the fraction of time needed for sensing a single channel α varies.

5 Proposed solution

5.1 Used network topology

In this paper, we propose to use network architecture without infrastructure or what is generally called an “Ad-hoc network”, because this type of networks differs from the other forms by its ability to organize itself independently without fixed infrastructure. An Ad-hoc network consists only of a variable number of entities that communicate with each other directly. So, we’ll use a radio cognitive network based on a distributed architecture with the presence of a central element named « Coordinator », in this network there are four PUs, five SUs and the coordinator node. This coordinator will coordinate between the PUs when one of them can’t satisfy a demand of a SU. Figure 10 shows the used network topology.

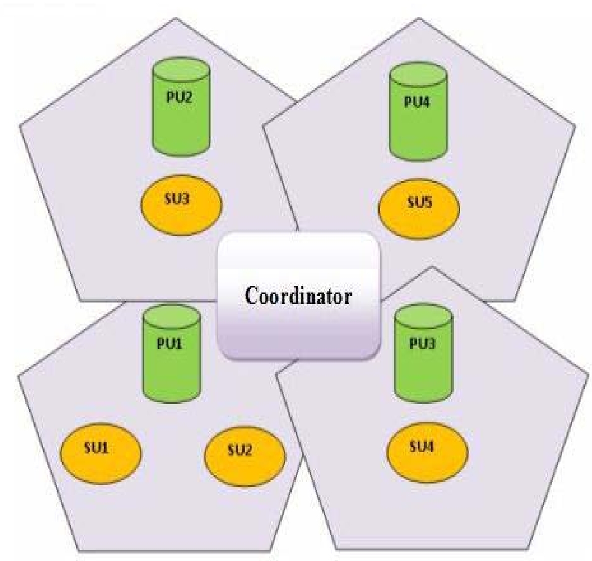

Fig.10 Used network topology

5.2 Scenario

In this work we have proposed a solution for dynamic spectrum access in cognitive radio network, which is inspired from game theory, we have focused on the cooperative and competitive aspects.

Our contribution is composed with two solutions:

A. Cooperative spectrum access game:

For the cooperative approach, we have adapted a game based on prisoner’s dilemma; this game is between PUs and needs at least two PUs and a coordinator. Use a central element (coordinator) is very interesting to limit the number of messages exchanged between the PUs. Specifically, we consider a cooperative MAS, in which the agents are deployed over PUs, SUs and coordinator.

When a PU (for example PU1) receives a demand from a SU (for example SU1), the PU1 verifies the availability of demanded resources (number of channels requested by SU1). If PU1 can satisfy this demand, he affects the resource to SU1, otherwise PU1 consults the coordinator. The coordinator search in his directory for a PU who can satisfy the demand, if he find at least one PU (for example PU3), the coordinator send the id of PU3 to PU1.

When PU1 receives the id of PU3 (the PU who can satisfy the demand), PU1 demands cooperation to PU3. PU3 takes his decision in cooperate or not by testing the state of its energy (threshold of non-cooperation). If PU3 accept to cooperate, it allocates resources to SU1.

Our solution is based on the adaptation of prisoner dilemma game model; its strategic form is shown in table 3.

We suppose that: nb = number of channels requested by secondary user.

PU2 / PU 1	Cooperate	Not cooperate
Cooperate	(nb, nb)	(-nb, 0)
Not cooperate	(0, -nb)	(0, 0)

Table 3. Strategic form of the game between PUs (values in €)

In the case of cooperation between the two PUs, we suppose that the price paid by the SU is 4*nb for the nb channels (4 is the unit price for one channel).

nb is the lost in term of energy for each PU (-nb is the penalty for the PU in this case), so the total benefit is : 4*nb – nb – nb = 2 nb, and since the game is symmetric, every PU will have nb as gain.

If both PUs chose to not cooperate, so they will get noting, but if one of them cooperate and the others don't, the first will get nb and the second will get noting.

The primary user makes its decision of cooperation taking into account the following point:

The remain energy level : if it is superior than a given threshold, he cooperate ; else he don't. When the energy reach a level, the PU keep it to satisfy its own secondary users.

B. Non-cooperative spectrum access game:

For the competitive aspect, it is between SUs, in this case we have adapted the urn game. When a SU allocates some resources from the PU, the PU increment a counter called fidelity (for example, number of used channels). If this fidelity affect a threshold (for example, 1000 channels were previously used by this SU), the SU get his loyalty in the form of money (200€ paid by the PU). Thereafter, the PU demands to the SU if he wants to play the game.

Two conditions are necessary in this case: at least two SUs satisfying the criterion of fidelity (1000 channels were previously used by each SU) and these two SUs accept to play the game.

When a SU accept to play, he can participate in the game by choosing from 0 or 20 and put it on the urn, the usefulness of every SU is calculate like this: Usefulness = sum_participated – ([sum_urn * 3/2] /2).

Where (sum_urn: the sum in the urn, sum_participated: sum given by the SU).

The strategic form of the urn game between the two SUs is shown in Table 4.

SU 1 / SU 2	PUT 0€	PUT 20€
PUT 0€	0 , 0	15 , - 5
PUT 20€	- 5 , 15	10 , 10

Table 4 Strategic form of the urn game between the two SUs

Note well that the two solutions (cooperative and non-cooperative) work simultaneously (in the same time).

5.3 Proposed algorithm

For our algorithm, we use the following notation:
PUID: PU's identifier.
SUID: SU's identifier.
NB_CAN: number of channels requested by the SU.
PUID_found: PU's identifier found by the coordinator.
PUs, SUs and coordinator executes the cooperative and non-cooperative algorithm as seen in the Appendix.

5.4 Evaluation

In this section, we present some simulation results conducted in order to validate the operation and performance of our proposed algorithm. We start by exposing simulation setup then we discuss our numerical results. So, in this work we have used JADE [24] as platform of multi agents system, JADE is a middleware which facilitates the development of multi-agent systems under the standard FIPA, we have used JADE to take profit of java's advantages such as the portability of code and the flexibility.

The simulation parameters are as follows, for each PU, we set the spectrum band to 5 channels, 4 channels are available (free) and one channel is occupied by this PU. Each SU can randomly demands 1 to 4 channels for a channel occupation time between 1s and 4s. The time between two requests by the SU is random and between 1s and 4s. The number of simulation runs is set to 10 and the average results are taken to plot the graphs.

First, we set the threshold of non-cooperation at 50%, so, if the PU's battery level reached the 50%, the PU in question is not going to cooperate with other PU.

Figure 11 shows the spectrum utilization rate (number of used channels/total number of channels) over 20 seconds of simulation. The results are interesting, because we achieved 5 times a maximum utilization rate of 100%. So, for 25% of the simulation time, we have reached the maximum spectrum utilization. Note that we can run the simulation for an indefinite time, the only constraint here is the battery life of the PUs.

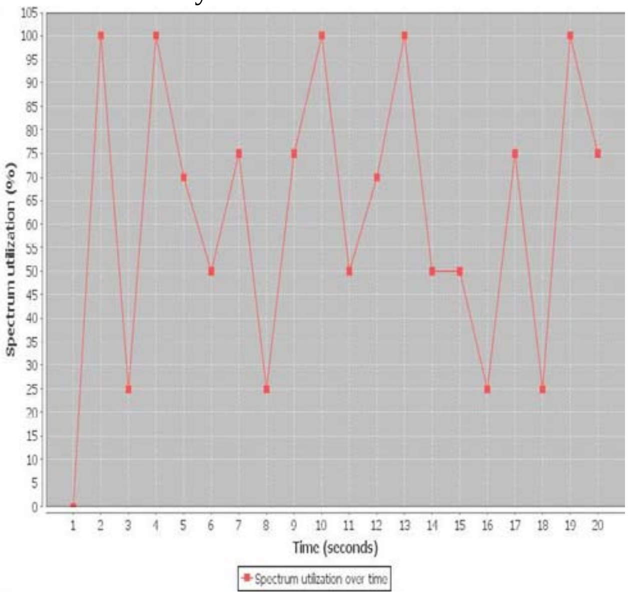

Fig.11 Spectrum utilization over time

Over 5 minutes of simulation (300 seconds), we have reached 52 times a maximum spectrum utilization rate of 100%.

Figure 12 shows the variation of average spectrum utilization according to different values of the threshold of non-cooperation.

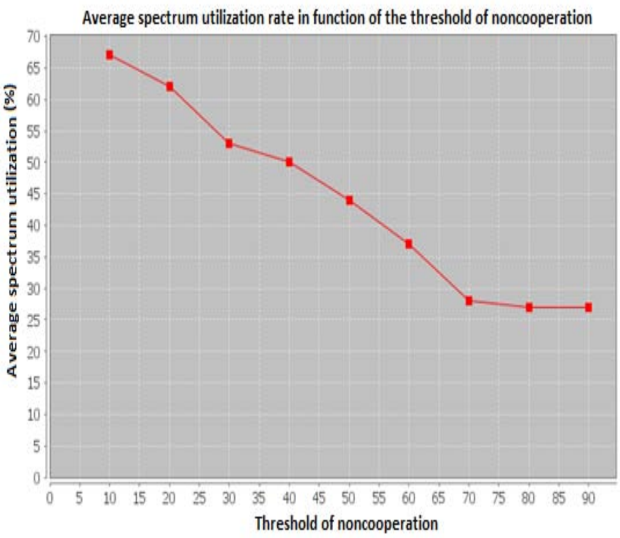

Fig.12 Average spectrum utilization rate in function of the threshold of non-cooperation

From the figure 12, it's clear that the threshold of non-cooperation influences on the average spectrum utilization rate. We see that the average spectrum utilization rate is better when the threshold of non-cooperation is smaller. With a threshold of non-cooperation at 10%, the average spectrum utilization rate is at 67% but with a threshold of non-cooperation at 90% for example, the average spectrum utilization rate is at 27%.

Figure 13 shows the energy consumption for the 4 PUs considering that all PUs have fully energy in the beginning. The PU that makes the most cooperation is PU2. So this is the PU that has consumed the most energy.

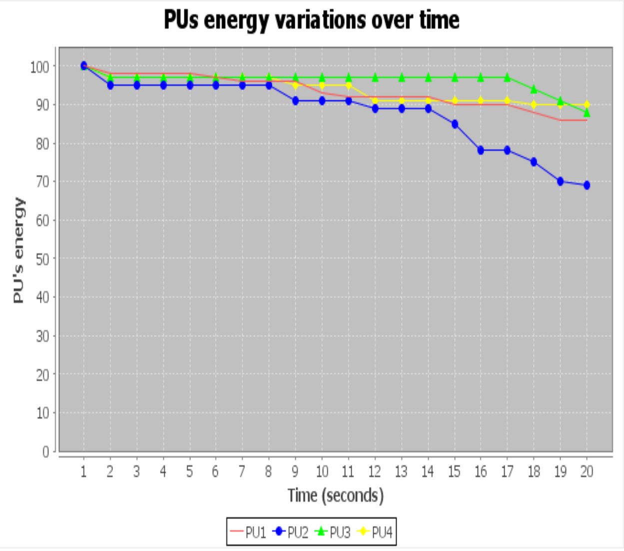

Fig.13 PUs energy over time

Energy consumption shown in Figure 13 is justified by the gain obtained by each PU. Figure 14 shows the gain obtained by the 4 PUs according to their number of cooperation. PU2 has got more gain because he has cooperated more and therefore he lost the most energy.

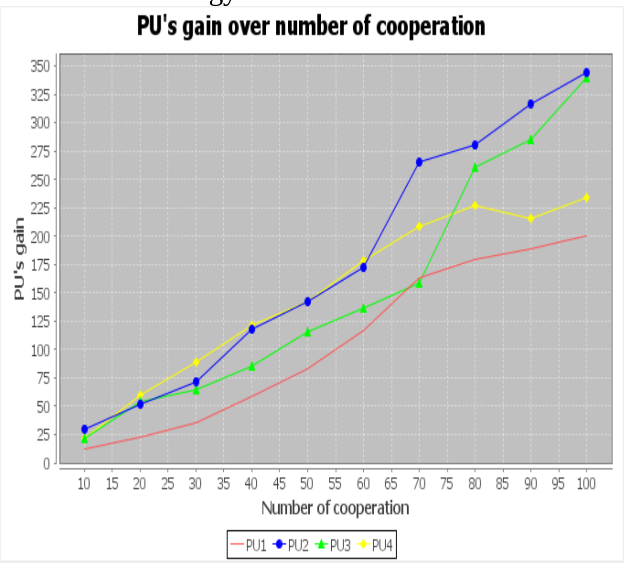

Fig.14 PU's gain over number of cooperation

Figure 15 shows the usefulness of the two SU in 10 rounds of competitive game, for example in the first round, the SU1 has -5 and the SU2 has 15 that because SU1 had put 20 in the urn and SU2 had put 0. Here, SU1 got a total gain of 80 (-5+10+10+15-5+15+0+10+15+15) and SU2 got a total gain of 40 (15+10+10-5+15-5+0+10-5-5).

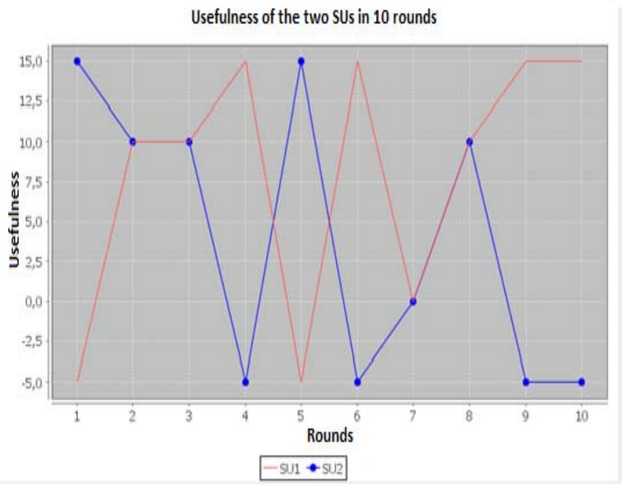

Fig.15 Usefulness of the two SUs in 10 rounds of game

Figure 16 shows a comparison between the gains made by the two SUs with the best case and the worst case for a SU in terms of gain. The best case for SU1, for example, is when he put 0 in the urn and SU2 put 20 and that in every rounds of the game. In this case, SU1 got a total gain of 150 (15 in every round * 10). The worst case for SU1 is when he put 20 in the urn and SU2 put 0 and that in every rounds of the game. In this case, SU1 will lose 50 (-5 in every round * 10).

We note that the game is interesting for the SU, because even in the worst case, the SU will keep a gain of 150 (200-50), which can convert into offered channels by the PU. To summarize, we can say that competitive game and fidelity are very interesting in our scenario, because it allows the PU to keep these SUs but also for the SU, because he can use advantage of spectrum without paying more.

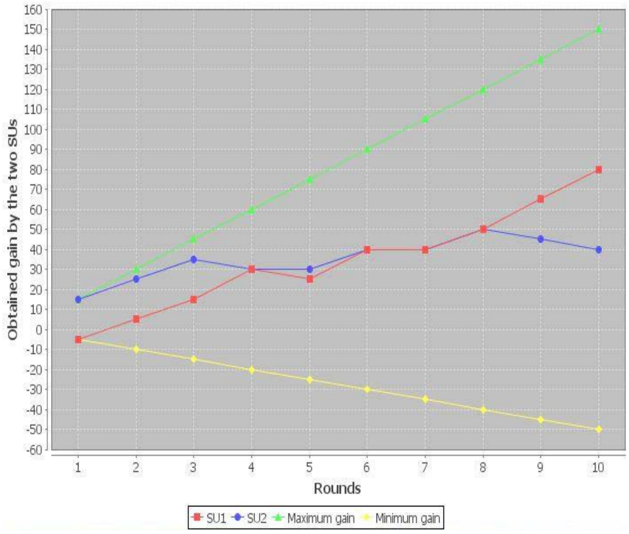

Fig.16 Obtained gain by the two SUs

6 Conclusion and future perspectives

Our approach as we have already presented provides an effective solution for dynamic spectrum access in cognitive radio networks. It enables secondary users to utilize the available spectrum dynamically and opportunistically. Our proposed solution is based on cooperative and non-cooperatives games on one side, and on multi-agent system on the other side. Our proposed algorithm is implemented by deploying agents over PUs, SUs and coordinator. Experimental evaluations confirm the efficiency of our algorithm in the context of CR networks. The results show that our proposal maximizes spectrum utilization. Indeed, often, during the simulation, we reached the maximum utilization rate of 100%. A Further expansion to our contribution is to extend it to the case of mobility with a large number of PUs and SUs. We intend also to work on other dynamic spectrum access techniques like auction to have better validation of our work. However, our approach has a problem of scalability because it is based on a central element (the coordinator). Therefore, a fully distributed approach can solve this problem.

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Appendix:

ALGORITHM: **Cooperative and non-cooperative algorithm**

```
Begin
    SU request resources, (SUID, NB_CAN) sent to PU
    PU receives the request (SUID, NB_CAN)
        If (PU have NB_CAN available) then
            PU satisfy the SUID (resources allocation)
            Increment loyalty points
                    if (SUID has the requested loyalty points to play) then
                        if (there is another SU having the requested loyalty points) then
                            Send the playing decision request to both SUs
                            if (the two SUs accept the PU offer) then
                                PU receives the sums from the two SUs
                                Launch the game
                                Send to each SU his utility
                            End if
                        End if
                    End if
        Else
            PU sends a coordination request to the coordinator (NB_CAN, PUID)
            The coordinator receives the request (NB_CAN, PUID)
                The coordinator check its directory
                    If (the coordinator find a PU satisfying the demand) then
                        Send reply (PUID_found) to PUID
                    Else
                        Reply with (negative) to PUID
                    End if
            PUID Receives the reply from the coordinator
                If (reply != negative) then
                    PUID send cooperation request (SUID) to PUID_found
                    PUID_found receives the cooperation request
                    PUID_found sends reply to PUID with (yes/no) according to its energy level
                End if
                if PUID receives reply (yes) then
                    PUID_found satisfy SUID (resources allocation)
                End if
        Endif
End
```