Resource Allocation in Cognitive Radio Networks: A Review

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***Abstract*: The current and rapid development of wireless technologies (WiFi, WiMAX, UMTS, etc.) has resulted in a strong demand for spectral resources so much that current bandwidth (spectrum) management techniques have reached their limit and are not being used optimally. To overcome this problem, good spectrum management is required and therefore more efficient use of the spectrum is required. Cognitive radio is a system that allows terminals to interact with their environment. This allows free frequencies to be recognized and used and thus contributes to better spectral efficiency. Cognitive radio (CR) is an intelligent radio device that explores the radio environment, makes decisions, and can be tuned to optimize spectrum use or other criteria such as the efficiency of a communication system. This development, inevitable in the modern world of radio communication, allows communication devices, which have become more autonomous, to choose the best communication conditions. This paper presents resource allocation in cognitive radio and its challenges in the field of radio communications, its functions as well as important notions concerning its architecture and its operating principle. Its basic functionalities allow it to detect the spectrum while avoiding interference while capturing the best available frequencies. Thanks to artificial intelligence, the cognitive radio allows the user to adapt to any spectral conditions. It multitasks using its many components, format, and the cycle of cognition that aids it in making decisions about spectral occupancy.**

***Keywords*: AI, CR, CRN, DAI, GA, MAS, NC-OFDM, Resource Allocation, etc.**

I. INTRODUCTION

The emergence of new tools for e-mail, file transfer and remote connection of Internet services has resulted in an explosion of subscribers to wireless networks, creating higher demands in terms of performance, data-flow, speed and fluidity. Requirements that mobile network operators must meet in order to ensure optimal quality of service for users and above all to avoid network saturation and paralysis. This task is all the more restrictive because of the scarcity of the radio resource which is the radio spectrum.

Many solutions exist in theory to allow better use of the spectrum and prevent it from reaching saturation, such as increasing frequency for mobile telephone services, i.e. going beyond the 5GHz limit for unclog the spectrum areas between 500MHz and 3GHz. To multiply the antennas by integrating more antennas in transmission and reception thanks to MIMO (Multiple Input Multiple Output) technology, which would increase the capacity of the channel. All these techniques remain difficult to put into practice and have certain drawbacks such as the difficulty of integrating sufficient computing power into a terminal for excessively high frequencies, or integrating several antennas in a telephone.

Another solution exists, it is the concept of cognitive radio (CR) which is the subject of our study. It consists of allowing mobile services to connect opportunistically to frequencies that are underused by other users. Using its techniques for learning and decision-making in its knowledge base, it assimilates information about its environment, making it an intelligent, dynamic and adaptive technology to the changes occurring in cognitive radio networks (CRNs).

The world of wireless networks continues to evolve over time, with more and more subscribers and a scarce and expensive spectral resource, mobile radio operators face a real challenge in order to meet these requirements and offer a better quality of service. These must adapt to withstand high flow rates while avoiding overloading the cells. Cognitive radio emerged in response to this need to better exploit the frequency spectrum while ensuring increased throughput.

Wireless networks have undergone tremendous changes in recent decades thanks to new technologies, thus meeting user needs. The different generations of mobile networks vary mainly in the access technique used. The latter was the technology that enabled cellular networks to overcome the constraint that a frequency band could only be used by a limited number of mobile stations. This paper is devoted on the theoretical review of resource allocation in cognitive radio networks. Moreover, the paper discusses the problems of spectrum allocation in CRNs and its approaches; a brief reminder of the spectral band allocation criteria is given there.

II. RESOURCE ALLOCATION IN COGNITIVE RADIO NETWORKS

The dominance of wireless networks in recent years is no longer to be demonstrated, in particular thanks to the explosive growth of subscribers to these services.

Whether for television or mobile telephony, wired networks seem to be nothing more than a spectre of the past giving way to radio waves. But these are a natural resource that is likely to be depleted. Cognitive radio networks are therefore ideal in order to better exploit this precious resource. The allocation of resources in cognitive radio networks determines the most efficient way to allocate the spectrum while using the right methods. This section presents those techniques for achieving a good allocation and define the allocation criteria and what it consists of.

A. Definition of Radio Spectrum Allocation Problems in CRN

The allocation of radio resources in CR is the assignment of the appropriate frequency bands to SUs according to a few criteria, unlike traditional wireless networks where the allocation of channels, the number of channels, the bandwidth and their availability are known and fixed in time. In an CR there are no strict specifications for the channels in terms of channel width, number of channels and center frequency; however, it is necessary to take into consideration the variable aspect of availability over time, which greatly increases the complexity of the spectral allocation problem in CRNs compared to the channel allocation problem in wireless networks which is already present (Non-deterministic Polynomial) [2].

In traditional wireless networks, fixed, dynamic and hybrid algorithms are already available. In CRNs, a fixed allocation scheme cannot have a real application due to the variability of **its** spectrum characteristics over time, only dynamic access techniques exist.

The problem encountered by CR is that of interference caused to PUs by SUs; reducing these improved the performance of the CRNs, the interference causes noise at the receiver level which causes a decrease in the value of the SINR, thus causing:

- Reduced transmission time at the radio interfaces.
- Reduced use of radio resources.
- Higher frame loss rate.
- Higher packet retransmission delay and lower receive rate.

B. Spectral Band Allocation Criteria

In cognitive radio, we encounter various constraints related to the problem of access of secondary users to the channels of primary users, for this in DRR we find several allocation criteria; we cover a few in what follows.

1) Interference/Power

In order to maximize the overall capacity of the CR network, interference between SUs and interference created by SUs to licensed users should be kept below a certain threshold. For this, interference is considered the most important criterion [4-9].

- The nodes are supposed to be cooperative and to exchange data concerning their transmission powers.
- If the SINR calculated at the transmitter is greater than a certain threshold, the nodes can transmit with maximum power. The value of a node's SINR is assumed to be known by all neighbouring nodes.
- Cognitive nodes can transmit with maximum power as long as the interference temperature limit (ITL) of neighbouring PUs is below a certain threshold, which implies the exchange of this information between PUs and SUs.

The ITL indicates the amount of interference detected by a receiver, it is given by the following formula:

$$ITL = \frac{P_r}{W * K} \qquad (1)$$

Where P_r is the power received by an antenna, W the associated bandwidth and K is the Boltzmann constant (K = 1.3807 Watt-sec / Kelvin).

On the other hand, the transmit power must be carefully selected in order to keep the SINR above the allowed threshold to ensure that transmissions are established.

In fact, the calculation of the SINR makes it possible to determine the feasibility of a secondary transmission and it is continuously recalculated to take into account the interference generated by the transmissions of new users.

2) Throughput

As in traditional wireless networks, maximizing throughput is also a very common criteria when allocating channels in CR networks. There are works that consider the sum of SUs throughputs as a main allocation criterion in order to maximize the total capacity of cognitive nodes [4]. The maximum data rate for each user is calculated as follows:

$$R = W \log\left(1 + \left(\frac{1}{K_b}\right)\left(\frac{P_t}{I_{d\alpha}}\right)\right) \qquad (2)$$

With W is the bandwidth used, P_t the transmission power of the node, I the interference subjected by the use of the band and dα the distance between the transmitter and the receiver, with $K_b = -\frac{2}{3}\ln\frac{P_{BER}}{2}$ (P_BER: Probability of the error rate).

While other work [5] relies on the question of maximizing the individual throughput of SUs, the first SU served will be able to select any bandwidth with maximum transmit power without taking into account the need of other cognitive users of the network. The downside here is that there can be concurrent access to the RF bands and unfairness in frequency distribution.

Among the common assumptions that goal to exploit the throughput of SUs:

- Fixed cognitive nodes, or else mobile but in such a way that the topology of the network remains stable.
- Co-channel type interference from adjacent channels is the only source of noise at receivers.
- The possibility of several simultaneous transmissions on the same channel or of a single transmission.

3) Maximization of Spectral Occupancy

Maximizing spectral utilization is an important criterion for implementing efficient allocation algorithms. An allocation method has been proposed which consists of reusing fragments from the assignment of contiguous frequencies. This method relies on the aggregation of fragments for reuse, which can dramatically improve spectral efficiency. With the techniques of multiplexing and coding of NC-OFDM (Non-contiguous Orthogonal Frequency-Division Multiplexing) data, access to non-contiguous frequencies and their aggregation at a radio interface becomes possible.

Indeed, the optimization of the spectral use is obtained under the following assumptions:

- Minimization of interference during channel allocation.
- A fixed number of channels: in general the number of channels as well as the bandwidth of the latter are known to the SUs and fixed in time.
- Most of the work assumes that all users work in organized manner to exploit the overall use of the spectrum, that is, they exchange information relating to their maximum allowable transmit powers.

4) Equity among Cognitive Users

A non-uniformity of band allocation can be observed, particularly in the case where an SU is allowed to use multiple frequency bands in order to maximize the total capacity of the network or the throughput of each cognitive user.

To avoid this, all channels are anticipated to have the identical capability, so equality can be recorded by the number of channels allocated to each SU and each SU should have a single air interface [6].

C. Spectrum Allocation Approaches

The allocation of the radio resource is a basic functionality in CRs networks, which allows the allocation of the most appropriate frequency bands to users who do not have licenses in order to transmit on licensed bands. There are a multitude of methods that allow efficient spectrum allocation and management, we will briefly introduce them in this section.

1) Centralized / Distributed Model

Centralized Model: In this type of scheme, a central node is used for decision making regarding the allocation of channels to the different cognitive nodes, the central node usually being a secondary base station. Decision making becomes more complex when an SU has multiple objectives such as maximizing performance while minimizing disruption. Conversely, decision-making turns out to be simpler in a cooperative environment, i.e. where the CRs communicate with each other, and in this case, the central controller takes care of the management of the spectrum.

The centralized model is called Spectrum Broker, it is able to measure the level of interference and interacts dynamically to minimize them and to improve spectrum usage while maintaining good quality of service QoS. It also makes it possible to equitably distribute the bands allocated to the SUs by minimizing the number of SUs transmitting over several frequency bands.

Distributed Model: Used mainly in wireless mesh networks, this model does not require any central entity. Decisions on channel allocation as well as the exchange of information on essential parameters governing radio transmissions such as frequency bands and bandwidths are made by the users themselves. Such a model has several advantages such as the distribution of tasks and data which makes this system flexible and tolerant to faults because if an entity is no longer functioning, the rest of the network would not be paralyzed and users easily adapt to the changes that may occur such as power, frequency, etc.

Table 1: Differences between a centralized system and a distributed system

Centralized systems	**Distributed systems**
Centralized task and data processing.	Distributed task and data processing;
Difficult to achieve fault tolerance.	Fault tolerance.
If the main system fails, everything shuts down.	Data and application redundancy is probable.
They have non-autonomous components.	They have autonomous components although they may be multiple.
They are often built using homogeneous technology.	They can be built using heterogeneous technology.
The resources of a centralized system can be shared constantly by multiple users.	The components of the distributed system can be used exclusively.
They have a single point of control.	They are executed in simultaneous processes.
They have only one point of failure.	They have several bridges of failure.
Centralized task and data processing.	Distributed task and data processing;

2) Multi-Channel Transmission

Technique allowing access to several distinct portions of the spectrum thanks to the NC-OFDM. This kind of problem did not arise in traditional networks where users access channels with a fixed center frequency and bandwidth. However, in cognitive radio networks, SUs can access different channels depending on their availability, so it is difficult to switch between several distant channels. This technique, although recent, is proving effective in increasing the total capacity of the network and allows better spectral exploitation.

3) Consideration of Primary Users

In a cognitive radio network, SUs should not interfere with PUs; taking these into account is the major concern to consider in modeling a resource allocation scheme.

In order to manage possible interference caused by SUs, a value called SINR is calculated at the primary receivers [7].

$$SINR = \frac{P_{i,c} G_{i,c}}{N_0 + \sum_{j=1, j\neq 1} P_{j,c} G_{j,c+\epsilon}} \geq \sigma \qquad (3)$$

With σ being the minimum threshold of the SINR, P_(i,c) is the transmission power of node i on channel c, G_(i,c) symbolizes the gain of the antenna on channel c, N_0 is the thermal noise and ϵ is a positive constant which represents the rate of interference that SUs cause on a primary node i.

Thus, when this constraint is satisfied, cognitive users can transmit on the channel used by primary user i.

D. Cognitive Radio and Artificial Intelligence

Artificial intelligence is a collection of theories and methods that create complex computer programs that can mimic certain features of human intelligence (learning and reasoning). This area is closely related to cognitive radio; Learning and decision-making methods are used in the design and implementation of cognitive radio networks. Machine learning concepts can be applied to cognitive radio to maximize spectral coverage. Indeed, cognitive radio includes a knowledge base, a learning engine and a reasoning engine (multi-agent system).

The knowledge base uses information about the spectrum to understand information about its environment such as the behaviour of licensed users. Its information is divided into two types: predicate and action.

An example of a predicate would be to define the modulation type “modulation=QPSK and SNR=5db” while the act can be symbolized as “down modulation mode” with pre-condition “SNR ≤ 8dB” and post- condition “modulation=BPSK”.

By taking into account the results obtained from the measurements (energy detection), the reasoning engine determines the veracity of the information “true or false”, then takes an appropriate decision, and in this case it would be to decrease the modulation mode.

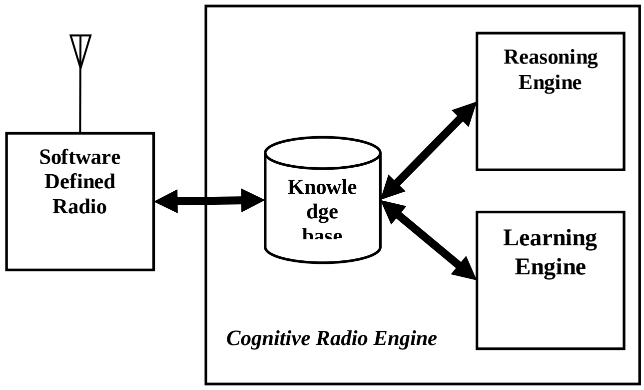

Fig 1: Machine learning based architecture of cognitive radio network

The role of the learning algorithm is to update the system state and current measurements according to the radio environment. To accomplish this, it uses what is called in operations research an objective function, it serves as a criterion to determine the best solution to an optimization problem. For example, reducing the bit error rate by taking into account the input which is the quality of the channel and the available parameters.

E. Multi-Agent System (MAS)

DAI (“Distributed Artificial Intelligence”) systems appeared in the early 80s in order to remedy the problems encountered in AI systems, by distributing tasks on multiple agents which will allow them to work in parallel and thus increase the speed of resolution.

Unlike artificial intelligence (AI), which models the intelligent behaviour of a single agent, DAI deals with intelligent behaviour resulting from the cooperation of several parties [8].

The implementation of MAS in CRNs promises interference-free spectrum sharing between different users, thanks to the cooperative aspect between users to detect and share the spectrum.Multi-Agent Systems (MAS) are nothing more than an extension of DAI systems. The MAS topic concerns the study of general behaviour and distributions identified among more or less independent agents who are able to plan and communicate to solve problems.

SMA is defined as :

A Multi-agent structure consisting of the following components:

- The environment is an area that usually has a measurable value.
- Many objects in the room are inactive and can be viewed, destroyed, created and modified by agents.
- Group agent, which is the active unit of the system. A set of links connecting objects.
- A set of actions that allow agents to discover, destroy, create, modify and manage objects.
- The set of operators responsible for the execution of this action and the reaction of the world to this effort to change (the laws of the universe).

1) **Agent**

To better understand multi-agent systems, we will define what an agent is. The word agent is used in various disciplines; however, in computer science, we find a well-known and answered definition, namely “An agent is an autonomous entity, real or abstract, which is capable of acting on itself and on its environment, which, in a multi- agents, can communicate with other agents, and whose behaviour is the consequence of their observations, knowledge and interactions with other agents”.

Properties and Agent Types: In order to qualify an agent as an intelligent agent it will have to admit some properties, with the help of [9] these are the characteristics of an agent:

- Autonomous: The ability to work independently of other users and agents, without the direct intervention of third parties.
- Flexible: Ability to respond on time.
- Proactive: Ability to take the ingenuity to act at the precise time, besides being proactive, it should also show opportunistic behaviour guided by its goals and its utility function.
- Responsive: an agent should be capable to observe his surroundings, cultivate a response in the required time and react to its changes, whether it is the modification of the user's objectives or the available resources.
- Social: ability to interact with other agents (artificial or human).
- Located: ability to act on one's environment (likely to change it) from sensory inputs received from this environment.

Reactive: Entities without intelligence, which do not have a presentation of their environment, and which show a “stimulus-response” behaviour. A reactive agent has a so-called simple structure, a MAS made up of a group of reactive agents can behave intelligently and solve so-called complex problems, and will have a large number of agents.

Cognitive Agent: Intelligent units, each of which is in its own domain, with a description of its environment and the agents with which they interact. Agents often act deliberately, which means that they have clear goals and plans to achieve them. A media system made entirely of intelligent material has a small amount of material but, unlike a substrate, requires a lot of resources. Below is a table comparing reactive and cognitive agent:

Table 2: Differences between a reactive agent and a cognitive agent

Characteristics	Reactive Agent	Cognitive Agent
Reasoning ability	Low	High
Explicit representation of the environment	No	Yes
Number of agents	Large	Small
Structure	Stimulus response	Complex
Response time	Fast	Slow

Agent Architecture (Cognitive and Reactive): We will describe the structure of an agent, namely; its internal organization, its data, its knowledge, the various operations carried out and the flow of operations control.
We will see in what follows two architectures, the first proposed by Rodney Brooks which is the Subsumption architecture, and the second the BDI (Belief-Desire-Intention) architecture.

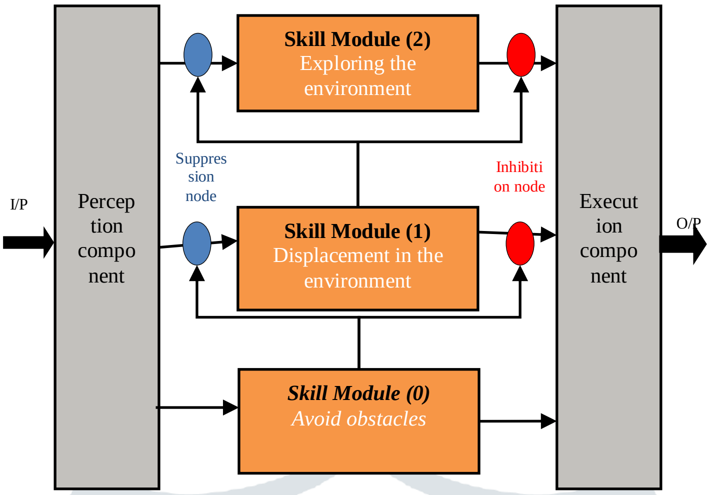

Figure 2: Subsumption architecture

Architecture of a Reactive Agent: The architecture of a reactive agent is represented by the subsumption architecture, the latter is made up of several skill modules; a module is responsible for carrying out a simple task.
As shown in Figure 2; different units can spray on each other to perform an action to select the most important action. Departments are organized into hierarchical levels, each with its own priority.

The upper layers correspond to more abstract tasks which are detailed using the more concrete and simpler tasks, the upper layers have a lower priority than the lower layers. The lower layers correspond to simple tasks and they have a higher priority.
Architecture of a Cognitive Agent: The architecture of a cognitive agent is represented by the "Belief-Desire-Intention" model, commonly called the BDI architecture, where B stands for "Belief=Belief" which refers to the information held by the environmental agent and the agents with whom he communicates, D meanwhile he refers to the word "Desire=Desire" which designates everything that the agent would like to achieve on the environment and on himself, I means "Intention=Intention" which represents the desires that the agent has decided to achieve (to accomplish).

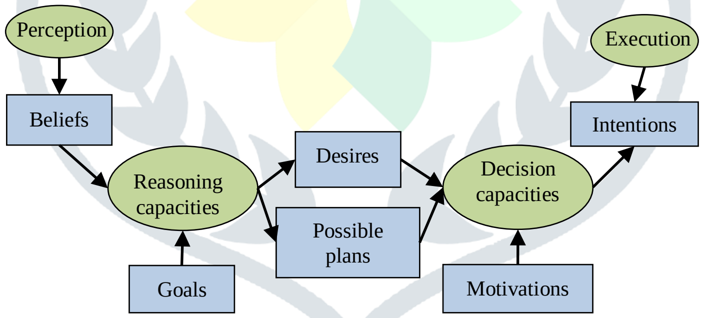

Figure 3: BDI architecture

As shown in Figure 4 above; the agent perceives his environment which allows him to define his beliefs, thanks to his capacity for reasoning he defines his desires and the different possible plans based on his goals and beliefs, by providing himself with his motivations and by using his capacity decision, the agent will choose the best course of action and then carry out his intentions.

F. Dynamic Spectrum Access Techniques

A major issue of wireless network is spectrum allocation. In general, this task becomes all the more onerous in cognitive networks due to the varying parameters of the spectrum over time. To solve this problem, negotiation techniques are used which are protocols directing the interaction between different agents. There are various negotiation protocols, in the following section we will mention the most important.

1) Heuristic Methods

The purpose of using heuristic negotiations is to facilitate obtaining an efficient allocation scheme which is inherently a difficult problem due to allocation constraints. Heuristic methods are based on genetic algorithms (GA) that mimic the procedure of normal progression. These are used to develop biologically inspired models for a cognitive engine.
GAs are ideal for cognitive radio with a changing and dynamic environment because they are powerful and flexible. These algorithms are iterative and are used in our case to allocate SUs to frequency bands to increase the total capacity of the network and present the lowest interference rate to PUs.Many examples of application of heuristic methods exist in the literature such as [9], [10], [11], and [12].

2) Game Theory

When using game theory for dynamic spectrum access, the behaviour of SUs is compared to that of individuals concerned about their own benefit. Indeed, the action of an individual can have an impact on the rest of the individuals in the system just as the verdict of an SU concerning the spectrum distresses the neighbouring SU's performance.

It is also very easy to make the link between game theory and cognitive radio by simply observing the latter's cognitive cycles.

As a reminder, game theory is considered to be a mathematical outline that comprises of prototypes and methods used to analyse the behaviour of the aforementioned individuals. It is a method known to be precise and efficient in this behavioural modeling work.

Game theory is the concept of game which comprises three main modules:

- A finite set of actors, called decision makers, generally noted N={0,1,2,…,N};
- An action space, A, formed from the Cartesian product of each player's action set: A=A_1×A_2×…×A_n;
- A set of utility functions that quantify player preferences about possible game outcomes;

Also in cognitive radio broadcasts, each node on the network represents a decision stage in the player's intellectual cycle (decision making) in a game. The various options available for the node (analysis, prioritization, etc.) form a set of node functions, and the functional space is formed by the Cartesian product of radio options.

The strategic phases of observation and cognitive radio together form the player's utility. When analyzing adaptive algorithms, game theory must answer five questions: the existence of a stable state, the definition of this stable state, the stability of optimization, convergence and stability.

The use of game theory in cognitive radio networks for different purposes. This can lead to a decrease in the transmission power of the additional user in order to avoid interference in the transmission of the primary user.

This theory can also be used to reduce expenses by determining the cost beforehand by the primary user, based on the physical characteristics of the channel; the secondary user, on the other hand, decides how much spectrum to have by looking at the different costs.

The most famous feature of the game theory method is called "Nash Equilibrium (NE)". In NE, it is assumed that each player knows the other's balance method, and neither player benefits from changing direction. These participants can act in concert or compete with each other;

Cooperative Games: all players are concerned about all common achievements and less concerned about personal gain.

- Competitive Games: Each user is primarily concerned with his own personal benefit, so all his decisions are made on the basis of competition and selfishness.

3) **Graph Theory**

Graph theory is one of the most popular optimization tools in solving resource allocation problems in cognitive networks. These are modeled in the form of graphs where the vertices represent the mobile devices or the cognitive nodes, the links in turn correspond to the connections between the cognitive nodes.

It therefore makes it possible to model mathematical problems in graphical form and then solve them using various tools. Several techniques can be used such as the undirected graph technique, the vertices colouring problem or even the conflict graph.

Undirected Graph: In graph theory, an undirected graph G=(V,E) is a pair formed of V a set of vertices and E a set of edges, each edge being a pair of vertices.

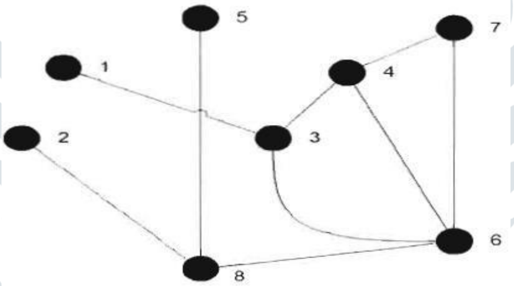

Figure 4: Example of an undirected graph [13]

This technique is used to diagram the interference constraint in the form of a graph also called a dynamic interference graph in order to calculate the interference exerted between a pair of links.

A set of cognitive links are taken into consideration as well as a number of channels with which an undirected graph is constructed; in these cases, the number of vertices is equal to the number of links wishing to transmit on the network.

In Figure 5, an example of an undirected graph is shown of order |G|=8 and composed of nine edges |G|=9.

Conflict Graphs:

- One of the most common techniques in graph theory for schematizing interference between neighbouring SUs; in this type of graph, a vertex represents an element involved, and an edge, an incompatibility or a conflict between two of these elements.
- In centralized diagrams, conflict graphs are also used with the help of the Spectrum broker which builds the graph according to the allocated channels while the SUs themselves form the graph in distributed diagrams while negotiating with neighbouring nodes for interference that can be used to prevent interference.

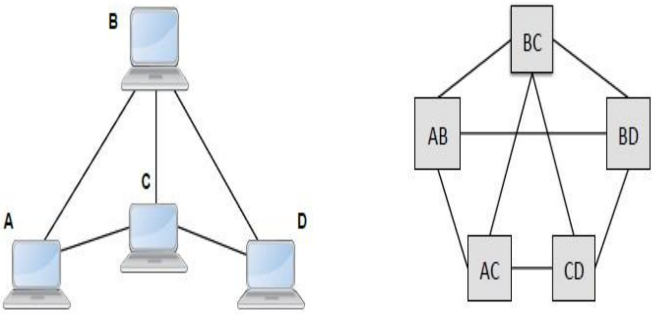

Figure 5: Example of conflict graph construction [13]

Vertices Colouring Problem: The colouring problem consists in colouring the graph G with colours available in C such that two adjacent vertices do not share the same colour. The colouring of the vertices of a graph G=(V,E) is an injective function s:V→C such that s(v)≠s(u) for all adjacent v and u.

The elements in set C represent the available colours.

Assigning frequencies is like colouring each vertex using different colours from a very specific list of colours corresponding to the available spectrum frequencies in order to maximize network performance.

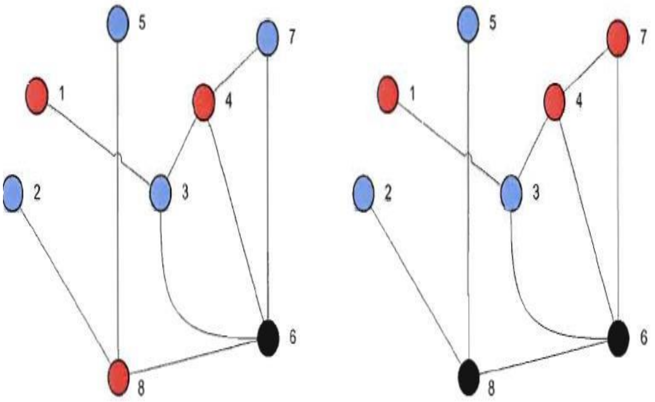

Figure 6: (a) A valid graph colouring and (b) an invalid graph colouring [13]

In Figure 6 (a) the graph colouring is valid and in (b) the graph colouring is invalid because it does not follow the condition:

$$For\ all\ \{u,v\} \in E, \qquad s(v) \neq s(u) \qquad (4)$$

4) **Auction Theory**

This branch of economics is based on a seller, multiple potential buyers, and an auction protocol. The seller is the spectrum, the buyers are the SUs, and there are many auction protocols such as the ascending bid, the descending bid, the sealed envelope auction, and the Vickrey auction.

The main purpose of using auctions on cognitive networks is to encourage secondary users to make the most of their spectrum.

Concretely, a set of nodes compete for access to the same spectral band, a regulator makes a bid to obtain the rights of access to this set of frequencies and then the SUs outbid to obtain the rights of access.

The frequency allocation problem is then decided by the regulator, which decides to maximize profits or satisfy all users.

Ascending Auction:

- It is certainly the most popular and the most common of all. Bidders usually start an auction by announcing a binding price (the minimum price at which they agree to sell an item). Each participant publishes their applications in successive rounds. If none of the bidders wishes to raise their bid further, the auction ends and the highest bidder wins the lot at the bid price.
- The dominant strategy of the buying agent is therefore to offer the smallest possible sum that is greater than that recorded until the outbid reaches the maximum value it can offer.

Descending Auction: The initiator begins by offering a price and, in successive rounds, decreases this price until one of the participants purchases the object at the proposed price.

Sealed Envelope Auction (First Price):

- The organizer of the auction initiates the auction, and each participant places bids in a circle, either by mail or electronically, without knowing other bids. The highest bidder wins the lot and pays the stake.
- It is a "static" process since it only involves one turn. In addition, one of the characteristics of this type of auction is that the bidder does not receive any signal (bid) from the other bidders.
- Here we cannot therefore speak of a dominant strategy, since the buyer has no vision of the stakes of the other agents.

Vickrey auction (Sealed Envelope at Second Price):

- Here, no agent is aware of the bet of the other agents. When the agent wins the auction (having offered the highest amount), he wins the product but at the price of the second stake, i.e. the one located just below the winning stake.
- The dominant strategy of a participant in this case is to submit an offer with its private object value. Because of this strategy, Vickrey Auction is a preferred protocol for software agents. Yet it is less prevalent in human-to-human auctions because of the fact that the initiator can lie about the second highest price and charge the winner more than that price.

III. CONCLUSION

In this paper, we have seen the different criteria and techniques to achieve a good allocation of resources and an efficient management of spectrum sharing between users with a reduced interference rate. The resonance capacity of cognitive radios is remarkable thanks to the multi-agent systems which make its intelligence more flexible and allow it to act more quickly. Graph theory and game theory are the theories most used in spectral band allocation approaches in CRNs, they are two mathematical tools which serve to capture certain nuances of a real situation and allow thanks to rules well-defined and structured problem-solving in various fields.

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