IJDACR
ISSN: 2319-4863

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

Impact of Cognitive Radio in Spectrum Allocation

Anilkumar Dulichand Vishwakarma
Research Scholar
KBCNMU, Jalgaon (India)
anil_karma@yahoo.com

Dr. Girish Ashok Kulkarni
Research Supervisor
KBCNMU, Jalgaon (India)
girish227252@gmail.com

Abstract – **Cognitive radio is born as a method that proposes a solution to the problem, dynamically managing the resource. One of the stages that integrate this technology is the spectrum decision, in which the frequency bands are selected and assigned based on the quality of service requirements of the cognitive users. This paper analyses the fundamental elements that make up the cognitive radio and the allocation of spectral bands. Among the main problems in the insertion of new applications and wireless technologies, there is the lack of radio spectrum for its allocation, due to the inefficient way of distribution of the available radio spectrum, which is currently assigned statically. In addition, a synthesis of the development platforms most used in the research on this technology and of the activities developed in order to find guidelines for the adaptable use of the spectrum.**

Keywords – **Cognitive Radio, Dynamic Spectrum Access, Spectrum Allocation, Spectrum Mobility, Spectrum Detection, etc.**

I. Introduction

At present, the exploitation of much of the radio spectrum allocated under license is inefficiently performed due to the fixed allocation policies of the frequency bands. The inefficient use of spectrum, when examined as a function of frequency, time and space, has been demonstrated by recent studies [1]. The constraints imposed by current regulatory policies are the main constraints on the efficient use of spectrum. As a result, some frequency bands are used intensively and are congested, while other regions of the spectrum are partially or totally unoccupied most of the time. To support the increasing demands of new wireless communications technologies and services, more efficient spectrum management schemes are needed. On the other hand, the success of the services in the bands of free access has motivated the development of novel technologies that allow the use of the spectrum in an intelligent, coordinated and opportunistic way, without harming the existing services. Cognitive radio (CR) is a technology with the potential to dramatically change the way the radio spectrum is currently used and at the same time increase its availability for new wireless communications services [2].

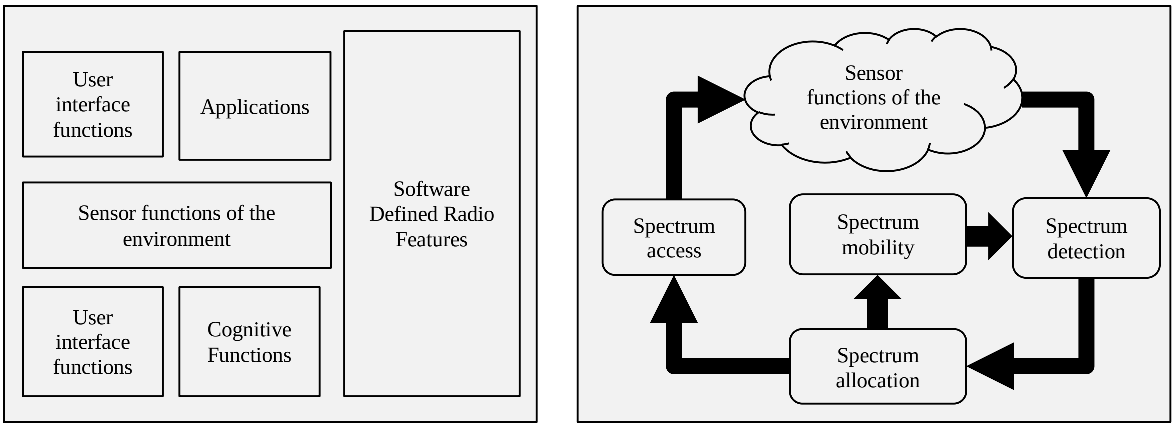
The original idea of cognitive radio was introduced by Mitola in [3], where it was defined as “the point at which wireless PDAs and related networks are, in computational terms, sufficiently intelligent with respect to radio and The corresponding terminal-to-terminal communications to detect the eventual communication needs of the user as a function of the context of use and to provide the radio resources and wireless services best suited to their needs.” The research highlights the potential of radio cognitive technology to increase the flexibility of current wireless communications services through a knowledge representation language called RKRL (Radio Knowledge Representation Language).

Cognitive radio differs from conventional radio in three fundamental aspects: 1) cognitive ability; 2) ability to learn and adapt; 3) self-reconfiguration capability [4]. Cognitive ability refers to the ability to obtain information from the environment and the internal state of the system through multiple sensors. The ability to learn and adapt allows the use of this information to dynamically and autonomously adjust the operating parameters through the ability to auto-reconfigure, in order to optimize system performance. The use of the term system implies that the above three capabilities may be scattered through multiple layers of protocols and devices in a network. Figure 1 (a) shows the minimum functional components that the ideal cognitive radio architecture should have: 1) user interface functions, 2) environment sensors, 3) system applications, 4) reconfigurable radio interface, 5) Cognitive functions and 6) output functions for interaction with the user. Between each of the functional components several interfaces are established through which data exchange and control signals are produced that define the operation of the system.

IJDACR
ISSN: 2319-4863

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)



(a) (b)

Figure 1: (a) Cognitive radio architecture (b) Cognitive cycle for dynamic spectrum access

Taking this architecture as a starting point, the operation of a cognitive radio system can be described through a model called the cognitive cycle [3]. The cognitive cycle represents a state machine of the different stages of the cognitive process. The idea of the cognitive cycle initially proposed in [3] was modified by several authors to adapt it to the concept of cognitive radio as a technology of dynamic access to the spectrum. As shown in Figure 1 (b), the cognitive cycle for dynamic spectrum access comprises spectrum analysis and detection, selection of frequency bands best suited to user requirements, coordination of spectrum access with other users and spectrum mobility of frequencies used when required by authorized users [1].
This paper presents the development platforms for cognitive radio technology, as well as the regulations and standards related to its application.

A. Dynamic Access to the Spectrum

At present, the term cognitive radio is usually associated with a radio system that dynamically accesses the spectrum based on observation of the radio-electric environment. According to the frequency bands used, two models of dynamic access to the spectrum can be distinguished: free access model and hierarchical access model [1]. The first of these models refers to the use of spectrum in free access bands, such as the Industrial, Scientific and Medical (ISM: Industrial, Scientific, and Medical) band. In these frequency bands all users have the same rights to use the spectrum and does not require a license, provided that the established regulations are respected. These regulations include the definition of spectrum limits, carrier frequencies and maximum transmission power. Some of the most popular applications that use the ISM band are WiFi (802.11) and Bluetooth.

In the hierarchical access model, a distinction is made between two types of users: primary users (PU) and secondary users (SU). For the access of the secondary users to the spectrum legally allocated to the PUs, three communication paradigms can be distinguished: interweave, underlay and overlay.
In the interweave scheme, SUs are able to identify available portions of the spectrum, commonly denoted to as "spectrum holes", which they use for their own transmissions without interfering with authorized users [5]. The dynamic access strategy to the underlay spectrum, also called concurrent access to the spectrum in [2], executes simple restrictions on the transmission power of the SU so that when operating concurrently with the PUs, interference in the primary receiver is Find below a pre-set threshold [5]. For concurrent operation with PUs, secondary users should be able to estimate the level of interference generated at the primary receivers. In the overlay scheme SU uses some of its resources to assist PU communications. According to this model, it is necessary for the SU to have information on the coding schemes used by PUs, information that can be obtained if the PUs use a pubic code based communication standard.
The distinctions made between these dynamic access strategies to the spectrum are useful for theoretical study, but this does not imply that any model of dynamic access to the spectrum can be categorized univocally as underlay, interweave or overlay. In a general sense, dynamic access to the spectrum requires four functionalities closely linked to the cognitive cycle:

- Identify opportunities for spectrum access.
- Select the frequency bands to use (spectrum decision).
- Coordinate access to spectrum with other secondary users (spectrum sharing).

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

- Unoccupied channels used when required by the spectrum handoff.

B. Identification of Spectrum Access Opportunities

In [4] spectrum opportunity is defined as "a frequency band that is not used by the primary user of that band at any given time in a specific geographic area". In [6] the author considers that this definition of spectrum opportunity is insufficient, since it only exploits three dimensions of the radio-electric spectrum: frequency, space and time. Other dimensions are proposed in which opportunistic access to the spectrum can be exploited, such as the extended-spectrum code and the angle of arrival of the signal. Methods of identifying opportunities for spectrum access can be classified as liabilities or assets. In the first case, the information on spectrum availability is received from external sources to the cognitive radio system. In the second case, SUs identify opportunities for spectrum access by detecting the individual or cooperative spectrum.

II. Spectrum Sensing Methods

In the case of passive spectrum detection methods, PUs directly distribute information about the available frequency bands to secondary users and spectrum resources can be obtained through negotiation with the primary systems. The negotiation may include technical parameters (transmission power, modulation scheme, carrier frequency, location). These parameters depend on the characteristics of the services offered by the primary and secondary users. Similarly, frequency bands allocated under license and used inefficiently by PUs can be identified by regulatory authorities and released for their dynamic exploitation, establishing a set of guidelines and restrictions regarding their use. In this case, the SU must periodically update policies relevant to its regulatory domain and adapt its operating parameters to comply with the established regulations.

In [7] a dynamic spectrum access structure is presented that uses a database to obtain spectrum usage information. The database, maintained by the regulatory authorities or the primary systems themselves, can be accessed and updated by secondary and primary users. When a SU wants to transmit, it queries the database, selects an accessible frequency band and reserves it for its use. When a secondary or primary user terminates the transmissions, the accompanying band is unconstrained and becomes accessible to other users. PUs can initiate transmissions on a frequency reserved by a SU at any time and therefore, SUs have to check the database periodically to avoid interference to the primary system. This method has the disadvantage that it requires a dedicated infrastructure or network for access to the database. In addition, compared to other methods, it is less flexible and efficient for dynamic access to the spectrum.

In order to allow the operation of the secondary users in the TV bands, one of the methods proposed by the FCC uses a database to facilitate the access of the SUs to the spectrum. According to the proposed scheme, the PUs (in this case TV transmitters) must estimate their location and provide this information, together with the patterns of use of the spectrum, to a centralized database that emits broadcast messages with the information provided By all PU. The SUs, equipped with devices that allow them to estimate their location, send their location and requests for the use of the spectrum to a cognitive base station, which is responsible for allocating channels for communication with secondary users and disseminating the database.

Another alternative to provide information on spectrum availability is the periodic dissemination of messages to authorize or deny access to the spectrum to the SU. Like the above scheme, the use of broadcast messages eliminates the need for spectrum detection by the SUs. However, the performance of this method degrades significantly when messages cannot reach SUs due to wireless channel phenomena such as shadowing, path loss and fading.

A. Local Spectrum Detection

The objective of the local spectrum detection is to decide between the hypotheses of absence (H_0) and presence (H_1) of the primary transmissions from the observation of the received signal. The performance of a particular detection method can be characterized from the probability of incorrect detection $\delta = P\{H_0|H_1\}$ and the probability of false alarm $\xi = P\{H_0|H_1\}$.

In [6] the author considers that in the context of cognitive radio, the detection of the spectrum, rather than a binary decision on the free or occupied state of a frequency band, involves obtaining characteristics of the radio spectrum. On the other hand, as the author himself acknowledges, in order to achieve practical implementations of detection methods that fit this definition, advanced digital signal processing techniques with additional computational complexities are required.

Local spectrum detection can be accomplished using two frameworks: dual radio interface (DRI) and single radio interface (SRI) [6]. In the DRI

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

architecture, a receiver is used for the detection of the spectrum and a transmitter / receiver for the transmission and reception of the data, which implies a higher hardware cost. The SRI architecture employs a single transmitter / receiver and therefore the communication stage alternates with the detection step. As the detection process is performed in finite-time time slots, only limited accuracy in PU detection is guaranteed. With respect to the DRI architecture, this architecture makes less efficient use of the spectrum, since part of the time is used for the detection instead of transmitting data. In the design of detection algorithms, there must be a compromise between the detection of opportunities for access to spectrum and the exploitation of identified opportunities. The higher the value of the detection interval the more effective the detection of the PU, but the lower the efficiency in the use of the spectrum by the SU.

In the literature, several techniques have been extensively investigated to recognize the occurrence of primary transmissions. Among the most common are the energy detector, the cyclostationary detector and the adapted filter detector.

Power Detector: A pre-set threshold is compared with the output of the energy detector to recognize the signal. This detector can be implemented in the frequency or time domain. This method of detection is one of the most used due to its generality, due to its simplicity of execution and low computational requirements [8]. However, through this method only signals whose energy is above the detection threshold can be detected. Accordingly, selection of an appropriate value for the detection threshold is a problem due to the variability in the noise level and interference of the signal to be detected. In addition, its performance degrades against low SNR values and it is not possible to distinguish between noise, interference from other secondary users and primary transmissions. Theoretical analyzes show that when $SNR > 1$ the number of samples required to reach a given probability of detection and false alarm is proportional to $1/SNR^2$ asymptotically. The enactment of the energy detector is very sensitive to the error in the estimated noise power. These errors in the detection of the spectrum can be minimized by a correct selection of the detection threshold.

Cyclo-Stationary Detector: In this method, the implied periodicities of the modulated signals are exploited for spectrum detection [1]. A signal is cyclo stationary when any of its statistical parameters such as mean value or autocorrelation is a periodic function of time [5]. Cyclo-stationary signals exhibit a correlation between spectrum components that are widely separated due to spectrum redundancy caused by periodicity. These characteristics can be detected by analyzing the cyclic spectrum density (CSD) of the received signal [8]. Cyclo-stationary characteristics can be used to distinguish and classify different types of signals. Because noise is a stationary process, the main benefit of the cyclo-stationary detection is that it differentiates the noise energy of the signal to be detected. With regard to the energy detector, it has the advantage that it can operate at lower values of SNR. It has as disadvantages that it requires a high sample rate of the signal, sampling time error and calculation of the CSD requires large number of samples and frequency shifts can affect the value of the cyclic frequency [9].

Adapted Filter Detection: When secondary users have information on the characteristics of the signals transmitted by the PUs, the adapted filter detection is the optimal method [1]. Such features include center frequency, modulation type, bandwidth, pulse shape, and frame format. If the SU has partial information of the PU signals available, the use of the adapted filter is still possible for the detection of the spectrum. The main advantage of the method is the reduced number of samples and consequently the short time required to obtain a low probability of false alarm or incorrect detection compared to other methods [6]. Theoretical analyzes show that when $SNR > 1$ the number of samples required to reach a given probability of detection and false alarm is proportional to $1/SNR$ asymptotically. Its fundamental disadvantage is the complexity of implementation and the increase in power consumption when it is necessary to detect signals of several types [5].

B. Cooperative Detection

Implications for signal propagation as a result of noise, interference, shadowing and fading present in the wireless channel prevent local detection techniques from ensuring satisfactory execution at all times. This problem has been resolved in previous research works [6, 9]. Collaboration between several secondary users allows exploiting spatial diversity in spectrum detection, thereby increasing the probability of detection and decreasing the occurrence of false positives.

In [10] a feasibility study of spectrum detection techniques is presented using an experimental platform for the development of radio cognitive systems. Energy detectors, cyclo-stationary characteristics and pilot signals are considered.

IJDACR
International Journal Of Digital Application & Contemporary Research
International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

Through experimental results it is demonstrated that the theoretical performance of these methods is not achievable in practice for the detection of signals with low levels of SNR. In addition, it is shown that it is possible to increase the effectiveness of detection methods by exploiting the multipath diversity of the wireless channel through the use of antenna arrangements and spatial diversity through cooperative detection methods in closed environments.

Cooperative detection of the spectrum can be done in a scattered or consolidated way [6]. In a centralized cooperative detection architecture the multi-user secondary spectrum detection information is sent to a central unit which is in charge of identifying available frequency bands from the analysis of the individual observations of the detector nodes. On the other hand, in a distributed cooperative detection architecture, local spectrum detection information is shared between multiple secondary nodes, but the final decision about the estimation of the vacant frequency bands is taken independently by each node. With respect to the centralized architecture, the distributed architecture has the advantage that it does not require infrastructure [1].

Taking into consideration that shared information may be the result of hard or soft detection by individual nodes, cooperative detection methods can be classified according to the way in which individual observations are reported [9]. When nodes share observed or processed data, the detection scheme is called cooperative detection based on data fusion. Alternatively, if the detector nodes share their 1-bit decisions (H_0 or H_1), it is called cooperative detection based on the fusion of decisions.

Data Fusion: Observations can be reported in a compressed or processed form in order to minimize the traffic generated, instead of sending the original samples of the received signal. In [9] schemes are proposed based on the energy detector, where the energy of the signal observed by each node is sent to a central unit, where the detection metric is obtained as the linear combination of the individual observations by assigning a coefficient of weight to each sample [2].

Decision Fusion: In this case, information from several detector nodes is combined by AND, OR, or K-out-of-N operations. In the AND operation the final decision is H_1 if all observations are H_1. In the OR operation, the final decision is H_1 if at least one of the observations is H_1. In the K-out-of-N operation the final decision is H_1 when at least K of the N observations are H_1, where the value of K is a design parameter that can be optimized from several criteria.

III. Spectrum Allocation

Depending on the availability of frequency bands, SU requirements and regulatory policies, the system must allocate one or more channels to each SU. The decision to use a given frequency band is based on the estimated characteristics of the channel, such as its capacity, bandwidth, interference level, path loss, delay, error ratio and channel usage patterns by the channel of the PU. The spectrum decision mechanisms can also exploit the historical results of the detection, based on the uncertain distribution of the availability of the frequency bands. From these results can be constructed a statistical model for the accessibility of utility spectrum in the monitoring of spectrum opportunities.

The decision mechanisms of the spectrum can be categorized as centralized or distributed [11]. In the first case, the allocation of channels to all SUs can be formulated as an optimization problem. In the centralized decision-making mechanisms of the spectrum a large amount of information must be exchanged between a central control unit and the network users, resulting in overloads of the signaling traffic. In [12] the problem of the allocation of frequency bands between an SU set is formulated as a problem of colouring of graphs, where each vertex of the graph represents an SU and the colours to be assigned to each vertex correspond to the channels available for such SU. An edge between two vertices represents a band of frequencies that cannot be assigned simultaneously to these two vertices due to mutual interference. Taking into account the previous restriction, the objective is to obtain a channel allocation that maximizes the utility function of the system.

In [13] an infrastructure-based cognitive radio network (CRN) is considered, where a central node coordinates the allocation of resources between the SUs. The SU sends spectrum detection information to the central coordinator and allocates resources in two phases. In the first phase, from the received detection information, PU features such as bandwidth, allowed interference level and activity patterns are extracted using a CRN. In the second phase the identified characteristics of the PUs are used to calculate the capacity available for each cluster of the CRN. Finally, the allocation of the transmission rate for SUs is formulated as an optimization problem where the objective is to minimize the difference between the sum of the available capacities and the sum of the allocated transmission rates, subject to a set of constraints that

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

Guarantee PU protection and other system requirements.

In [14] the authors investigate opportunistic access to TV bands in a mesh architecture based on clusters. The objective is to equitably distribute the traffic load of the cognitive network between the secondary and primary bands by limiting the generated interference. The header nodes of each cluster share network state information (number of clients and location of their access points) and detection results to estimate the interference generated by the secondary network in the center of the mesh blocks. The spectrum allocation problem is then modelled as an integer linear programming problem where the solution guarantees not to exceed the interference threshold of the primary network.

In distributed spectrum mapping schemes, channels are selected by the SUs individually and dynamically. In order to uniformly distribute the entire traffic load of the SUs between multiple channels, in [11] a channel selection scheme based on the estimated occupancy probability is proposed according to the spectrum usage statistics

By the PU. The optimal value of the selection probability is obtained as the solution of a nonlinear optimization problem that each SU formulates in order to minimize the total access time to the spectrum.

In [15] the performance of a spectrum allocation protocol is investigated where the SUs are organized autonomously in local groups to perform coordination over a common control channel. The MAC layer frames are structured in super-frames consisting of signaling period, a coordination window and data transmission period. During the coordination window users switch to the coordination channel and use the CSMA / CA protocol to communicate and coordinate access to data channels. Through a negotiation protocol, the selection of the channels is performed according to a selection metric that equally deliberates the traffic load, the interference and the connectivity in the available channels.

IV. Access to the Spectrum

When multiple secondary users share the same frequency band, spectrum access must be coordinated between SUs in a way that minimizes collisions and mutual interference. Usually, the MAC layer is responsible for coordinating access to the spectrum. Multiple spectrum access strategies can be static, random, time division (TDMA) or frequency division (FDMA). In the design of a MAC protocol for cognitive radio networks, practical issues such as the accessibility of a common control channel to share information and the number of transmitters / receivers available per user should be taken into account [2]. In [2] MAC protocols for cognitive radio networks are categorized taking into consideration the following aspects:

- Operation architecture: distributed or centralized.
- Time access scheme: in allocated time slots, random access or a combination of both schemes.
- Need for a common control channel.
- Required system information: global or local.

In the IEEE 802.22 protocol the contention between neighbouring cells is made through the CBP (Coexistence Beacon Protocol) protocol. In this protocol, the base stations of each cell, at the end of each MAC frame, transmit a message that allows communication and synchronization within a cell community. When a base station receives a synchronization message it differs its transmissions to avoid interference between neighbouring cells.

Within the most widespread MAC protocols for wireless networks is the IEEE 802.11 standard, where access to the wireless channel is regulated through the exchange of RTS / CTS control messages. When a user A wants to send a packet to a user B, he first issues a Request to Send (RTS) control message, which contains his identification, the destination node identification, and the data packet size. If user B is in the transmission range of A, he receives the RTS message and, if possible, the communication, he replies with a Clear to Send (CTS) message. If the CTS message is received by A, the data transmission starts and waits for the correct reception ACK message of the data. Control and data packets are transmitted using a fixed (maximum) power level. Any node that hears these control messages delays their own transmissions until the transmissions in progress are completed. To limit collisions, each node maintains an ongoing transmission vector that is updated each time an RTS, CTS, or ACK message is received.

A. Power Control

Media access control protocols based on the exchange of RTS / CTS control messages at fixed power levels have several shortcomings. Take the example shown in Figure 2, where node A uses the maximum transmission power to send the control packets to node B, resulting in contention of the transmissions of nodes C and D. However, both transmissions (A→B and C→D) can, in principle, take place simultaneously if the nodes are able to

IJDACR
ISSN: 2319-4863

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

adapt their power levels according to the interference and characteristics of the propagation of the link. Demonstrated that Transmit Power Control (TPC) techniques can provide significant benefits in terms of reducing power consumption and increasing the capacity of the wireless channel.

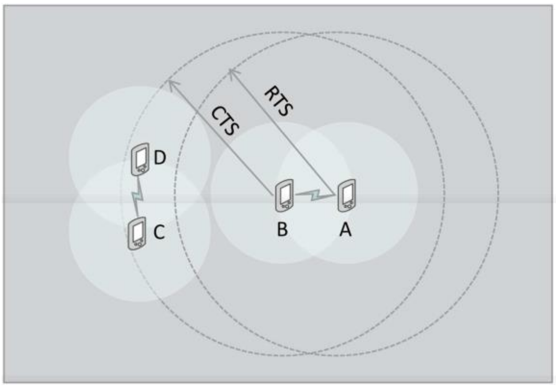


Figure 2: Access to the medium based on the exchange of RTS / CTS control messages at fixed power levels [17]

The problem of allocation of power levels has been investigated comprehensively in the literature, both in the context of cognitive radio and in the context of the MANET (Mobile Ad-Hoc Network) and WSN (Wireless Sensor Networks). In the absence of competition, the TPC problem is able to express as an optimization problem, where the objective is to maximize or minimize a single utility function for all SUs subject to the constraints mentioned above. The relationship between minimization of energy consumption and maximization of performance for a secondary link is investigated in [16]. In [17] the authors propose a TPC algorithm which demonstrate how the performance of the network can be increased by combining the power control with directional antennas. In the majority of previous power control algorithms it is assumed that the SUs have complete system information, including the location of all devices and the characteristics of the wireless channel.
During the transmission of a data packet, the TPC algorithm can assign a fixed or variable power level. In the first case, the assigned power level is a function of the state of the system at the moment the transmission of the packet begins. Any change in the values of these variables during transmission (due to the start of other transmissions or variations in the wireless channel) can have a destructive influence on the performance of the TPC algorithm. In a decentralized network, in order to dynamically modify the power levels of the current transmissions, it is necessary for each node to constantly update its information on the state of the system. A generalized control channel may be utilized for this purpose, but the distribution of the complete state of the system to all nodes implies an additional traffic overload that can significantly makes an influence on the system performance.
In infrastructure-based wireless communications systems, the transmission power levels are controlled by a base station that has complete system status information at its disposal. In this case, it is less complex to formulate the power allocation as a global optimization problem. In cellular systems each time a session is initiated or terminated, the power levels of the current transmissions are renegotiated.
As an alternative to the formulation of a global optimization problem, the design of TPC decentralized algorithms can be addressed using non-cooperative game theory [4]. During the game, the goal of each player is to select an action from a space of possible actions to maximize a given utility function. In the case of power control, the TP levels represent the strategies that each player can adopt. The central concept in the theory of non-cooperative games is a state, called Nash equilibrium, in which no player benefits by modifying his strategy as long as the others do not change theirs. A game may have no Nash equilibrium, or have more than one.
In [18] cooperation between secondary and primary users in a dynamic overlay spectrum access scenario is investigated using a model based on game theory. This scheme is compared with a dynamic access model to the underlay spectrum in terms of quality of service, probability of interruption and interference temperature. In the underlay scenario, the strategies that each player can adopt consist of selecting a frequency band and a transmission power level. The usefulness of the strategy followed is a function of the interference that is generated to the PUs and other SUs operating in the selected frequency band, the perceived interference of other SUs and the power of the received signal. In the overlay scenario, the SUs can select as part of their strategy, in addition to the power and the channel, the power levels that they allocate to their own transmissions and to the repetition of the PU messages cooperatively. In this case, the utility function incorporates, in addition to the terms considered for the underlay scenario, a fifth term that represents the benefit reported to the primary network as a result of the cooperation.
In [19, 20] we study the impact of uncertainty on the information on channel status and interference levels on the total performance of a set of SUs using game theory. The interference level plus noise perceived by each user, normalized with respect to the transfer

IJDACR
International Journal Of Digital Application & Contemporary Research
International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

function of the channel, is modeled as the sum of its nominal (or estimated) value and an additive error. Based on the available information of the additive error, it is considered a TPC algorithm based on robust optimization theory. Two methods are proposed to ensure the robustness of the algorithm. In the first case the performance of the network is guaranteed probabilistically, taking into account the statistical distribution of the error. In the second of the proposed methods the performance of the network is guaranteed for any value of the uncertain parameters within certain limits.

V. Spectrum Mobility

In a radio environment with dynamic spectrum access, the availability and quality of wireless channels can change frequently over time. When the presence of a PU in the frequency band in use is detected in a cognitive radio system, said band must be released immediately for use by licensed users. The procedure that allows the transition from one channel to another with minimal performance degradation is known as handoff. The delay that occurs during the handoff or spectrum mobility has a negative impact on the performance of the system and is an element to take into account in the design of communication protocols for cognitive radio. Another important factor is the delay that occurs between the moment the presence of the primary transmissions in a frequency band is detected and the moment in which said band is vacated, since SU transmissions during this period can cause harmful interference to the PU.

Spectrum mobility mechanisms can be classified as reactive or proactive [11]. Proactive mechanisms allow you to mitigate latency by reserving a certain number of frequency bands, so that they can be used immediately in case of handoff. According to the long-term observations of the activity of the primary users in certain frequency bands, the patterns of use of the spectrum of the PUs can be inferred and thus predict in advance the events, mobility and degradation of quality of the channel, which originate the handoff. The number of reserved bands must be chosen carefully, so that there is a balance between the efficiency in the use of the spectrum and the performance of the handoff mechanism [8]. Proactive mechanisms require complex algorithms for estimating network behaviour and at least two transmitters / receivers are needed to perform out-of-band detection and parallel communication. On the other hand, reactive handoff mechanisms, with greater latency, determine the channels available on demand. A comparison between both strategies can be found in [11].

The IEEE 802.22 standard proposes the management of the spectrum handoff through the IDRP (Incumbent Detection Recovery Protocol) protocol. The proposed procedure exploits a list of backup channels to rebuild the communication link. To limit signaling overload and delay, the transceiver pairs know in advance what band to use to restore services when a PU is detected in the band in use.

VI. Development Platforms

Although research on dynamic access and spectrum detection is numerous, most of them focus on theoretical analysis and simulation of mathematical models. Considering the volume of these theoretical investigations, very few of the results obtained have been verified in practice. Until now, some experimental platforms have been presented in various research centers and universities. A review and analysis of the most relevant results in this context for recent period can be found in [21].

Within the software / hardware platforms are the OSSIE, GNU Radio and Iris projects. The OSSIE (Open Source SCA Implementation Embedded) project is an open source software package for the development of Linux-based SDR systems, developed at the Virginia Institute of Technology. Because SCA (Software Communication Architecture) is an architecture designed specifically for SDR and not for cognitive radio, the OSSIE platform does not support real-time configuration.

The most widely used SDR system is the GNU Radio open source project, which supports hardware independent signal processing. In this system the signal processing blocks are written in C / C ++, while the visualization tools are developed in Python. One of the fundamental disadvantages of the GNU Radio platform is that the latency in the data processing can be severe, imposed by the block structure design in which the system is implemented.

Iris is a software design for the research and development of reconfigurable radio systems. It has been the basis of a wide range of demonstrations on cognitive radio and dynamic spectrum access technologies presented at several international conferences between 2007 and 2010. Focused on real-time reconfiguration, Iris provides support for all layers of the protocol stack and offers a platform not only for the improvement of point-to-point radio links but also for a complete implementation of cognitive radio networks. In addition, Iris is compatible with a wide variety of hardware architectures and operating systems.

In the previous platforms, most of the functionalities such as modulation, coding and access to the medium are carried out by software and the

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

functionalities of the RF stage are minimal. There is another group of composite platforms that contain all the required components (dedicated software and hardware) for the immediate development of CR systems [10].

VII. Regulations and Standardization

In recent years several institutions have made significant efforts to accelerate the processes of standardization and establishment of regulations for the opportunistic use of the spectrum.

A. Coexistence in Free Access Bands

In the free access frequency bands, wireless communications devices must include the ability to coexist with other devices that operate on the same channel and that use different communication protocols. The coexistence mechanisms specified in standards such as Bluetooth, WiFi (IEEE 802.11), ZigBee (IEEE 802.15.4) and WiMAX (IEEE 802.16) share similarities with dynamic spectrum access techniques, which can be seen as an evolution of the coexistence mechanisms Coexistence does not require the use of cognitive techniques, but cognitive techniques can be used to facilitate coexistence.

The Bluetooth standard includes a feature, called adaptive frequency hopping, introduced with the aim of reducing interference between wireless technologies that share the 2.4 GHz frequency band. The adaptive frequency hopping requires a detection algorithm to determine the presence of other devices in the ISM band. Frequencies identified as occupied are avoided. The detection algorithm uses several channel statistics, including the power indicator of the received signal and the carrier ratio to interference plus noise, to classify the different channel categories according to their availability [6].

In the IEEE 802.11k specification, proposed extension of the IEEE 802.11 standard, several statistics of the wireless channel are used to make the use of radio resources more efficient. Some of these statistics include the report of the channel load and the noise histogram. Access points (APs) obtain channel information from each mobile unit and make their own measurements. The AP then uses the available information to regulate access to the channel and make an equitable distribution of network traffic. In other specifications of the 802.11 standard, mobile devices usually connect to the AP with the strongest signal level, which can result in the overload of some APs and the inefficient use of others. In 802.11k, when the strongest signal AP is at maximum capacity, new connection requests are assigned to unutilized APs.

The IEEE 802.15.2 standard defines a series of collaborative and non-collaborative techniques that can be applied based on improving coexistence with other types of systems, particularly with systems based on the IEEE 802.11 and IEEE 802.15 standards. The 802.11h specification includes Dynamic Frequency Selection (DFS: Dynamic Frequency Selection) and TPC capabilities. In this case, DFS functions are aimed at detecting military radars and reallocating a basic set of services potentially interfering with other frequency bands. IEEE 802.16-2004 is another standard that includes DFS and TPC capabilities. The dynamic channel selection techniques, similar to DFS techniques, are included in the IEEE 802.15.4 standard.

VIII. Conclusion

In this work an overview of cognitive radio has been presented as a key technology to deal with the current problem of spectrum scarcity, through dynamic access to the spectrum. The exploitation of spectrum reuse opportunities constitutes the basic function and the most distinctive feature of cognitive radio, being also one of the most researched in the scientific literature. However, cognitive radio represents a much broader wireless communications paradigm. In this regard, it should be noted that the original formulation of the ideal cognitive radio, where an autonomous agent perceives the user's situation and proactively assists the user in their needs, remains insufficiently developed.

The implementation of cognitive radio, as an emerging technology, raises interesting questions and challenges from a practical point of view. In general terms, among the fundamental challenges we face to make this new horizon of technological applications possible are the following:

- Design of the common control channel: The use of a common control channel is an effective method for the exchange of information during the stages of detection and coordination of access to the spectrum. Several investigations assume the existence of a common control channel for the exchange of information, without describing its design. In addition, in a system that relies exclusively on a common control channel for the exchange of control information, the unavailability of said channel can seriously compromise the operation of the system. To ensure optimal performance, more advanced research is needed in relation to the use of a common control channel.
- Channel estimation: In order to guarantee the protection of primary users and optimize the performance of the secondary

IJDACR
International Journal Of Digital Application & Contemporary Research
International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 8, Issue 03, October 2019)

network, the status information of the channel between secondary and primary users is of great importance. In practice, it is difficult to obtain exactly this information due to the cooperation requirements of the primary system. On the other hand, the estimation of the channel from the location information requires the use of location techniques and propagation models that fit the system requirements.

- Integration of the stages of detection and access to the spectrum: To optimize the detection time, the integration between the detection and access modules to the spectrum must be taken into account in the design of the architecture of a cognitive radio system. However, in multiple investigations both stages of the cognitive cycle are considered independently.

Reference

[1] Wang, Beibei, and KJ Ray Liu. "Advances in cognitive radio networks: A survey." *IEEE Journal of selected topics in signal processing* 5, no. 1 (2010): 5-23.
[2] Liang, Ying-Chang, Kwang-Cheng Chen, Geoffrey Ye Li, and Petri Mahonen. "Cognitive radio networking and communications: An overview." *IEEE transactions on vehicular technology* 60, no. 7 (2011): 3386-3407.
[3] Mitola, Joseph, and Gerald Q. Maguire. "Cognitive radio: making software radios more personal." *IEEE personal communications* 6, no. 4 (1999): 13-18.
[4] Haykin, Simon. "Cognitive radio: brain-empowered wireless communications." *IEEE journal on selected areas in communications* 23, no. 2 (2005): 201-220.
[5] Rehmani, Mubashir Husain, and Riadh Dhaou, eds. *Cognitive Radio, Mobile Communications and Wireless Networks*. Springer, 2019.
[6] Kakalou, Ioanna, Danai Papadopoulou, Theofanis Xifilidis, Kostas E. Psannis, Katherine Siakavara, and Yutaka Ishibashi. "A survey on spectrum sensing algorithms for cognitive radio networks." In *2018 7th International Conference on Modern Circuits and Systems Technologies (MOCAST)*, pp. 1-4. IEEE, 2018.
[7] Brown, Timothy X. "An analysis of unlicensed device operation in licensed broadcast service bands." In *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005. DySPAN 2005.*, pp. 11-29. IEEE, 2005.
[8] Lu, Lu, Xiangwei Zhou, Uzoma Onunkwo, and Geoffrey Ye Li. "Ten years of research in spectrum sensing and sharing in cognitive radio." *EURASIP journal on wireless communications and networking* 2012, no. 1 (2012): 28.
[9] Zeng, Yonghong, Ying-Chang Liang, Anh Tuan Hoang, and Rui Zhang. "A review on spectrum sensing for cognitive radio: challenges and solutions." *EURASIP Journal on Advances in Signal Processing* 2010, no. 1 (2010): 381465.
[10] Cabric, Danijela. "Addressing feasibility of cognitive radios." *IEEE Signal Processing Magazine* 25, no. 6 (2008): 85-93.
[11] Wang, Li-Chun, and Chung-Wei Wang. "Spectrum management techniques with QoS provisioning in cognitive radio networks." In *IEEE 5th International Symposium on Wireless Pervasive Computing 2010*, pp. 116-121. IEEE, 2010.
[12] Wang, Wei, and Xin Liu. "List-coloring based channel allocation for open-spectrum wireless networks." In *VTC-2005-Fall. 2005 IEEE 62nd Vehicular Technology Conference, 2005.*, vol. 1, pp. 690-694. IEEE, 2005.
[13] Vizziello, Anna, Ian F. Akyildiz, Ramon Agustí, Lorenzo Favalli, and Pietro Savazzi. "Cognitive radio resource management exploiting heterogeneous primary users and a radio environment map database." *Wireless networks* 19, no. 6 (2013): 1203-1216.
[14] Chowdhury, Kaushik R., and Ian F. Akyildiz. "Cognitive wireless mesh networks with dynamic spectrum access." *IEEE Journal on Selected Areas in Communications* 26, no. 1 (2008): 168-181.
[15] Zhao, Jun, Haitao Zheng, and Guang-Hua Yang. "Distributed coordination in dynamic spectrum allocation networks." In *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005. DySPAN 2005.*, pp. 259-268. IEEE, 2005.
[16] Sanchez, Samuel Montejo, Richard Demo Souza, Evelio MG Fernandez, and Vitalio Alfonso Reguera. "Rate and energy efficient power control in a cognitive radio ad hoc network." *IEEE signal processing letters* 20, no. 5 (2013): 451-454.
[17] Montejo, Samuel, Richard Demo Souza, Evelio MG Fernandez, and Vitalio Alfonso. "Impact of power allocation and antenna directivity in the capacity of a multiuser cognitive ad hoc network." *Radioengineering, Dec* 21, no. 4 (2012): 1110-1116.
[18] Kumar, Bhoopendra, Sanjay Kumar Dhurandher, and Isaac Woungang. "A survey of overlay and underlay paradigms in cognitive radio networks." *International Journal of Communication Systems* 31, no. 2 (2018): e3443.
[19] Sharafat, Ahmad R. "Worst-Case Robust Distributed Power Allocation in Shared Unlicensed Spectrum." *arXiv preprint arXiv:1105.2989* (2011).
[20] Fan, Rongfei, Qi Gu, Xuming An, and Yu Zhang. "Robust Power Allocation for Cognitive Radio System in Underlay Mode." In *International Conference on Internet of Things as a Service*, pp. 426-430. Springer, Cham, 2018.
[21] Abbas, Nadine, Youssef Nasser, and Karim El Ahmad. "Recent advances on artificial intelligence and learning techniques in cognitive radio networks." *EURASIP Journal on Wireless Communications and Networking* 2015, no. 1 (2015): 174.