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Proposed methodology for assignment of spectral bands in wireless cognitive radio networks

Propuesta metodológica para la asignación de bandas espectrales en redes inalámbricas de radio cognitiva

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ABSTRACT

This paper raises a proposal starting from the current state that improves the process of allocation of spectral bands at the decision-making stage in cognitive radio, decreasing the time that the system takes to select a channel to transmit data from unlicensed users, assuming the existence of free spectrum and estimating the behavior of the secondary user and primary user.

Keywords: Cognitive radio networks, licensed and non-licensed users, proposal within conceptual diagram framework, spectral decision-making.

RESUMEN

El artículo plantea una propuesta enmarcada desde el estado actual, que mejore el proceso de asignación de bandas espectrales en la etapa de toma de decisiones en radio cognitiva, disminuyendo el tiempo que le toma al sistema la selección de un canal para transmitir datos de usuarios no licenciados, suponiendo la existencia de espectro libre y estimando el comportamiento de los usuarios primarios y usuarios secundarios.

Palabras clave: propuesta enmarcada en diagrama conceptual, usuarios licenciados y no licenciados, redes de radio cognitiva, toma de decisiones espectrales.

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INTRODUCTION

Multiple studies show that one of the main problems with the inclusion of new applications in cognitive radio transport structure is associated with the inefficient distribution of available spectrum by governmental agencies (Shulka, 2013). That is, there are some currently licensed regions where radio space is underutilized (VHF / UHF bands) (FCC, 2010: Taher, Bachus, Adnek & Roberson, 2011) and other spectral regions (cellular bands) where a degradation in service quality has occurred. Researchers like Mitola (Mitola & Maguire, Cognitive radio: making software radios more personal, 2002) and Akyildys (Akyildiz, Lee, Vuran, & Mohanty, 2008) have concluded that dynamic spectrum access (DSA) is a good strategy to address the issue of electromagnetic band administration. In Mitola, Software radios - survey, critical evaluation and future directions (1999), the possibility that administration of electromagnetic bands can be performed dynamically via Cognitive Radio (CR) is raised.

Therefore, this article is intended to generate an initial proposal (as a conceptual diagram) and supported from the current state, that solves the problem of spectral band assignment (Masonta, Mzyece, & Ntlatlapa, 2013) at the decision-making stage in cognitive radio (CR), since it is one of the issues that has been dealt with less in the CR paradigm.

CONTEXTUALIZATION AND RELEVANT ASPECTS OF THE CURRENT STATE IN CR

In Mitola & Maguire, Cognitive radio: making software radios more personal (2002), Mitola argues that a network based on CR is defined as a complex structure in which devices are able to adapt to the environment. Within the characteristics of adaptability, is the capacity to use the spectrum in an opportunistic way, using their intelligence and autonomy. In general, a CR should be able to perform four tasks efficiently: sensing, decision-making, sharing and spectrum mobility (figure 1).

Sensing, sweeps the frequencies in the area of interest to identify the blank spaces most likely to be used in a given space of time, frequency, and power within a specific geographic region.

The decision identifies with the selection of the channel or group of channels in accordance with two factors: 1) the features available in the environment; 2) the needs requested by the SU to transport data (Akyildiz, Lee, Vuran, & Mohanty, 2008).

Sharing means properly managing the frequency bands to maximize their use without disrupting the PU and other CR users (Mitola & Maguire, Cognitive radio: making software radios more personal, 2002), (Akyildiz, Lee, Vuran, & Mohanty, 2008).

Mobility is the ability of CR to leave a portion of the frequency spectrum occupied when a PU starts using it, and also search for another suitable empty space for communication (Mitola & Maguire, Cognitive radio: making software radios more personal, 2002). The CR devices should therefore have the ability to detect, recognize and adapt to the specific features offered by the environment.

One of the most important properties of cognitive radio networks (CRNs) is the ability to dynamically access the spectrum. However, users of cognitive radio (CRU) may also be able to recognize patterns of occupation (Bolívar, 2012), to reduce energy used in detection, signaling and transmission. Therefore, CR is also considered as an alternative capable of reducing power consumption in radio communications and has also been selected as a solution to the so-called shortage of wireless spectrum (Mitola & Maguire, Cognitive radio: making software radios more personal, 2002), (Goldsmith, Jafar, Maric, & Srinivasa, 2009). Studying the spectral decision stage involves previously defining the physical topology of the network to be worked, which can be distributed (Ad-Hoc), centralized (infrastructure-based) or hybrid (Figure 1).

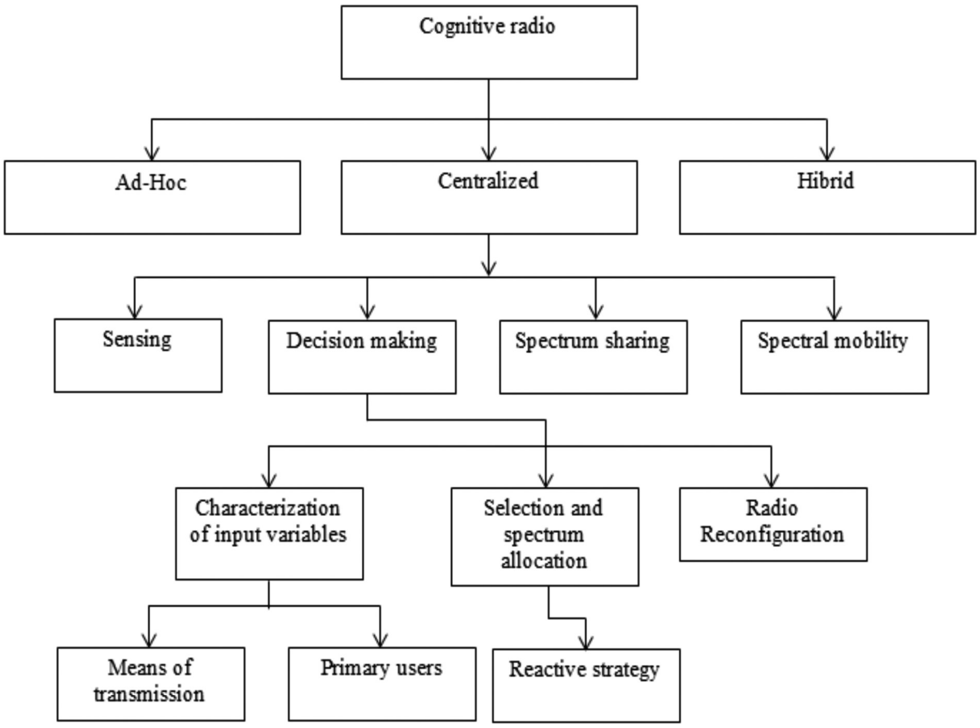

Figure 1. Contextualization of cognitive radio and decision making

Source: The authors.

In an infrastructure-based system, all users within the area of operation manage their decision requests through a central device, as in specification (IEEE 802.22, 2012), (Wireless Regional Area Network-WRAN), (Wang, Ghosh & Challapali, 2011).

Since the cognitive radio network (CRN) operates within the licensed users' coverage region, it uses DSA techniques to opportunistically access the primary network spectrum without causing harmful interference to the licensed users, as is also the case of Ad-Hoc. To this end, the SUs observe the spectrum in the specified bands, then send them to the base station (BS) which acts as a broadcasting center (Kolar et al., 2009).

Both the BS and its associated clients can detect the presence of the PUs using detection techniques such as that based on energy, or cycle seasonality among others. In some cases, as in (Akyildiz, Lo & Balakrishnan, 2011) two physical media are used, one to observe the behavior of the primary channel and the other to constantly update the BS. Once the information is analyzed and there is clarity regarding available channels, the BS will build the definitive list of bands together with the quality of service (QoS) available in each case, so that they can be exploited opportunistically by the SUs. Once the prior stage of sensing has been defined, characterization, channel selection and radio reconfiguration are the elements that make up the spectral decision (Figure 1).

Characterization

Since there is no guarantee as to what spectral band is available during the transmission of a SU, it is important to consider how often PUs appear. Using the learning ability of the CR, the use of spectrum history is utilized to predict the future profile of the spectrum (Akyildiz, Lee, Vuran, & Mohanty, 2008), modeling the activity of PUs and SUs seeking to avoid generation of collisions. The concept of characterization within the spectrum decision has been addressed in many articles from the perspective of channel conditions (evaluating and proposing new strategies to identify and improve aspects related to channel coding, modulation, bandwidth, etc.) and is not addressed here because within the proposed methodology this variable is assumed to be known.

In the characterization of the primary (Vishram, Lau, Syin, & Ashish, Energy aware spectrum decision framework for cognitive radio networks, Electronic System Design (ISED), 2012) it concludes that a significant number of existing approaches have a very high computational cost, making their implementation virtually impossible for nodes whose life is based on battery usage (in rural areas); this is why in spite of being one of the most discussed topics by researchers, it remains a developing research line.

Perhaps one of the critical and less demanding aspects is related to the secondary, where most papers that address the issue, reduce its study to a medium access control problem, relegating in most cases to a backseat the importance that the study of SUs frequency of occurrence could have on the licensed band, on improving the decision-making stages, sharing, and spectral mobility.

Estimated behavior of the PU

Some of the proposals on this topic are in Derakhshani & Le-Ngoc (2012), where PU characterization assumes that there is no synchronization with the SU, causing their dynamic type behavior. Their behavior is simulated as a two state ON/OFF continuous random process to reproduce the PU occupancy periods. As a design and operation criteria of SUs it determines that once the band *i* is detected as inactive during the sensing stage, the chance that it will be busy *t* seconds later is denoted by $\pi\_01^{i\,(t)}$, and that the probability that the PU will once again fill the *i* spectrum since in principle it has been sensed as idle at the beginning of this time interval, is defined as the instant mean (equation (1) that the PU could make a transmission.

$$\alpha_i = \frac{1}{T-\tau}\int^{T-\tau} \pi_{01}^{i}(t)dt \tag{1}$$

While αi is independent of time, it can be considered as a statistical function of spectrum use, and given its value there will be a greater or lesser probability of collision; therefore, to ensure quality transmission for the PU αi must be of a value smaller than a set level.

Brah, Dayoub, & Vandendorpe (2012) consider a main network having j valid primary users for j = 1... J and a bandwidth of B Hz, where its value is divided into N orthogonal narrowband subcarriers for n = 1,..., N, with each range of frequency BS = B/N small enough to ensure that the channel fading is flat. The PU occupies the channel following an ON/OFF type structure, where the ON period represents the interval during which the primary actively uses its channel in a Tc time. Based on this premise, it is assumed that the PU remains active (ON state) with an α probability, or inactive (OFF state) with probability δ = 1 - α in a Tc time period. In the distribution of the underlying spectrum, it is allowed access to the secondary if the impact on its output does not substantially degrade the quality of the signal received from the PUs; this parameter is assessed with the restricted probability of collision in terms of equation (2).

$$\Pr\{I_{j,n} \geq Q_{j,n}\} \leq \eta_{j,n} \tag{2}$$

Where $I_{j,n}$ is the level of interference imposed by transmission from the secondary to the primary j in sub-carrier $Q_{j,n}$; is the maximum level of interference, and $\eta_{j,n}$ is the maximum tolerable collision probability. In fact, the primary user j will experience a collision in sub-carrier n, if $I_{j,n} > Q_{j,n}$.

Channel holding time (CHT) corresponds to the mean average expected period that the PUs may occupy a free slot before being interrupted; the greater the CHT, the better the quality of service (QoS) for the SUs (802.22, 2013), (Masonta, Mzyece, & Ntlatlapa, 2013). The CHT can be determined by the type of secondary services supplied by the CRN or the service provider.

Canberk, B., Akyildiz, & Oktug (2010) exhibit a Markov model to establish the duration of spectrum slot usage. This model is based on the concept of CHT for the PU. Once the downtime is modeled (TTC), matrix analytical techniques can analyze and determine the duration of the spaces available to be accessed by the SUs; however, one of the main drawbacks of this technique is its complexity (Masonta, Mzyece, & Ntlatlapa, 2013). In Daoud, Alanyali, & Starobinski (2007), the concept of time-spectrum block (representing the length of time the SU occupies a portion of vacant spectrum without causing interference to the PUs) was introduced, and established how to calculate it to reduce the probability of network collisions (Masonta, Mzyece, & Ntlatlapa, 2013).

A statistical approach based on binary time series discloses the deterministic and non-deterministic behavior of channel use and predicts future occupancy of the PU (Yarkan & Arslan, 2007). The complexity of analysis and the amount of storing data memory reduces it assuming a sequence of binary states, thus simplifying the spectrum occupancy ("1" is empty, "0" is used). Of tests conducted, the short range prediction factor is quite satisfactory for the first two tests; however, in the third sample, prediction success severely degrades because the model is not updated, and because of the non-deterministic data behavior; this problem could theoretically be solved by increasing its order at the expense of an exponential increase of parameters to generate the prediction. From a deterministic perspective, the estimate is quite robust for the first four time slots as tested for three different bands in a GSM network, while capturing with a duration of 17 ms of which 30 observations per channel were obtained after applying the prediction model in the binary time series. Authors do not record any computational cost analysis inherent in the use of time series and this should be a study variable to validate the methodology because it is usually a limiting factor due to the high computational cost that it entails, in addition to a high collision probability (Masonta, Mzyece & Ntlatlapa, 2013).

Estimated behavior of SUs

Most of the available proposals that involve decision-making focus their work on monitoring the PUs ignoring the modeling of SUs (Masonta, Mzyece, & Ntlatlapa, 2013); it is an important parameter for optimal network functioning because it has a direct impact on the presence or absence of collisions, and their adequate representation will result in a better use of the channel when it is available and there is a significant number of SUs. Within the few existing contributions in mainstream journals there is (Derakhshani & Le-Ngoc, 2012), where a proposal that includes a qualitative and quantitative analysis to improve the use of free bands using opportunistic spectrum access methodologies is shown.

Channel selection

After characterizing the users, the next step is to select and assign the best available spectrum (depending on the network used, which in our case will be centralized (Figure 1) to be assigned in accordance with the requirements requested by the SUs (Masonta, Mzyece, & Ntlatlapa, 2013), using a reactive or proactive strategy. Two of the existing state of the art approaches are:

(Barnes, Maharaj, Prediction based channel allocation performance for cognitive radios, 2014) (Vishram, Lau, Syin, & Ashish, Energy aware spectrum decision framework for cognitive radio networks, 2012) In which the problem to be solved is the ever increasing number of mobile nodes in CRNs, and therefore of communications in the electromagnetic spectrum, with the ensuing shortage of available channels. From this perspective, the algorithm to optimize the allocation of transmission channels for PUs and SUs becomes necessary, supported by availability and performance. Proposers use the of Markov hidden model techniques (HMM), which operate in a sequence of binary states to detect when PUs and SUs coexist serially.

The solution consists on a channel switching simulator for a SU (with centralized infrastructure) and for testing purposes it has a physical layer component that includes modulation, error correction rate, bandwidth, period between frames and maximum number of future frames. It was observed that under heavy traffic conditions, the measurement was consistent with the theoretical calculation, at increasing L values (length of observation) and more precisely at L = 400 and with a number of frequencies equal to 20 (ϑ = 20) the yield doubled, halving PU interruptions and thus minimizing the number of SU switching operations probably due to limited availability. In light traffic conditions and for the same L and ϑ values, performance fell significantly and PU interruptions more than doubled since with more availability, the number of SU switching operations increased.

A decision system in the dynamic and cooperative spectrum is made available to the academic community to determine the appropriate channel, using the paradigm of weighted fusion distributed (WFS) that combines individual decisions to determine the appropriate one using cooperation. It is compared to conventional fusion mechanisms such as the AND, OR type rules and GREATER THAN criteria, comparing the results in variables such as false alarm percentage and high detection probability. Network architecture is based on centralized topology for primary users and distributed for cognitive nodes. The block diagram arrived at and implemented in each SU that monitors the radio space and collects signal-to-noise indicators is shown in Figure 2 (Berk & Sema, 2012).

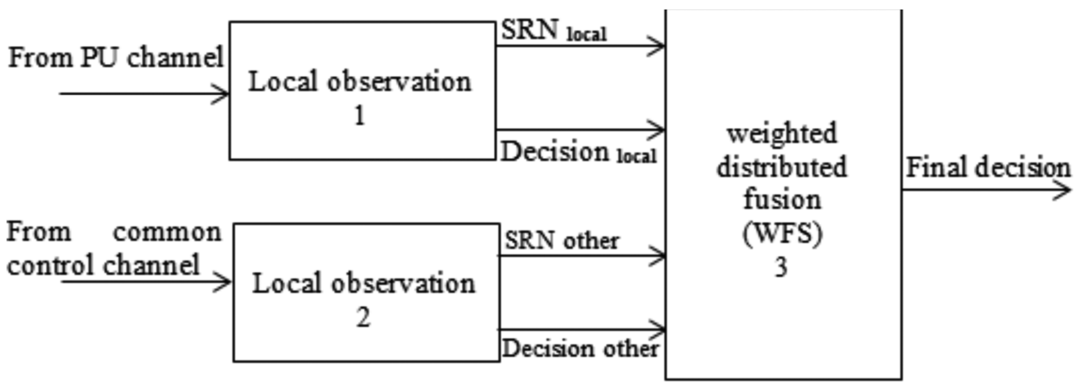

Figure 2. Allocation of frequency bands

Source: Berk & Sema (2012).

In this diagram, the user creates a decision on spectrum (existence or not of PUs); then each node broadcasts this local information to the network through the common control channel (CCC) of the signal to noise tracking system. Once transmitted, received and processed, each node runs the WFS and thus obtains a cooperative decision. Specifically, sub-block 1 is responsible for monitoring enabled channels, and collecting local observation of the CRN.

In 2, a subroutine is shown for transmission of messages handled by all distributed network users to communicate with other nodes. Each SU generates its own messages M_ (i, j), and transmits them through module 2 using the equation (3).

$$M_{i,j} = (D_{i,j} SNR_{i,j}) \quad (3)$$

Where $D_{i,j}$ represents the local decision, and $SNR_{i,j}$ observation of the local signal to noise ratio (SNR) made by the user in the th channel. Additionally sub-block 2, gathers and forwards all $SNR_{i,j}$ observations made and $D_{i,j}$ decisions made by other users to the WFS module. In 3 (Figure

2), all information generated is received and the cooperative decision is calculated using equation (4).

$$w_{i,j} = \frac{SNR_{i,j}}{\sum_{i-1}^{n} SNR_{i,j}.adhoc\_effect_i}, \qquad (4)$$

Where $SNR_{i,j}$ is the observation in DB of the th network user in theth channel, the total number of users, adhoct_ef $fect_i$ is a coefficient of the th user of the localized network in relation to the corresponding user in the ad-hoc network topology.

DISCUSSION

From scientific literature consulted, it has been observed that research has focused on spectrum sensing and mobility; at the decision-making stage in most cases they only propose qualitative solutions, lacking quantitative solutions. In this same vein, studies have focused on characterization of the most important source which is the PU, relegating the SU; variable that should be taken into account because it will lead to a better channel use and distribution. In the context of spectrum selection, the vast majority of authors such as Haykin, Akyildyz, Vishram, Wu, have shifted their models towards reactive strategies (transmission band selection after user requests service) with a major drawback, due to time (crucial variable within the context of telecommunications), which is spent searching and selecting the free frequency for the SU. The implementation of proactive strategies (where selection is decided seconds before arrival of the cognitive user) based on intelligent models such as machine language (machine learning), and support vector machines, will allow the reduction of band allocation time improving the spectral decision stage.

CONCEPTUAL DIAGRAM OF THE PROPOSAL

From the approach described above, we intend to design and build a predictive spectral selection model for cognitive users starting from characterization of heterogeneous users within a centralized network topology for the IEEE 802.22 band. The model will be designed and built during the development of a doctoral research work developed by the main author of the article; and for that the conceptual model of figure 3 is proposed as a basis.

The subfields in which it is expected to generate input are marked in dark, and the overall operation description of the proposed methodology is as follows:

Before the process of characterization, the existence of a range of free channels to be used by SUs (sensing) is assumed.

To characterize the PU we estimate taking an existing model and improving it using the FAHP (Fuzzy Analytical Hierarchy Process) technique, which has a low computational cost and the ability to handle multiple variables without increasing its complexity.

Characterization of the SUs (the number of nodes that attempt to access the CRN will be increased over time), will be performed using the artificial intelligence Machine Learning (ML) concept or starting from layer 2 of the OSI reference model. The characterization process is intended to be carried out by each cognitive node and sent to a database located in the Base Station (BS) with the mission of storing and labelling the information, differentiating it from the information sent by the multiple SUs (through the use of labels) and PU.

This will allow the base station to clearly distinguish the SUs from the PU and the SUs from each other. This historical data will in turn be used by the channel selector algorithm (by implementing a proactive strategy) to assign channels according to the SU requirements (provided there are resources) using the Support Vector Machine paradigm (SVM). Thus the aim is to reduce channel selection time increasing CR performance.

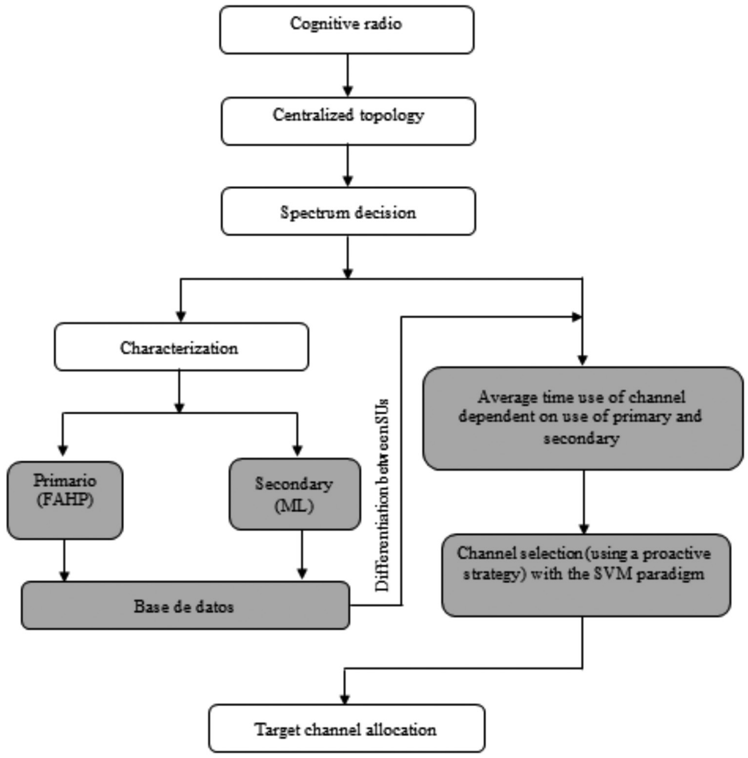

Figure 3. Location of the Doctoral proposal within the context of the CR

Source: The authors.

CONCLUSIONS

The authors of this article pose a conceptual diagram (figure 3) in order to develop a predictive channel selection system in accordance with the quality of service requirements, taking into account not only the behavior of primary users, but also involving the secondary, which will allow a more equitable use and better optimization of the media, by the cognitive nodes that make up the CR network.

Several new aspects that have not been addressed so far are included in the proposal, highlighting the inclusion of a database at the decision-making stage, as support for storing user behavior history as well as their use of channels, information that may be relevant not only at the decision making stage, but also at mobility stage (by applying spectral handoff) to generate more accurate predictive models.

Another important component is included as an active variable within the operation of SUs system which will allow reducing the risk of collision between them (when the number of cognitive nodes that access the network increases) and between the SUs-PUs; making it possible to generate along with the database, a more suitable and equitable spectral selection model for all cognitive nodes.

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