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Model for Matlab Simulation of the Spectral Decision Stage in Wireless Cognitive Radio Networks

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Abstract

The spectral decision stage in Cognitive Radio (CR) wireless networks is responsible for selecting and assigning channels to secondary users (SUs); an optimal selection is directly related to the way in which requests are processed in the base station (BS) of the centralized cognitive wireless network. This article discusses the design and evaluates the results delivered by a software application that simulates the spectrum selection and assignment using reactive and proactive strategies with the TOPSIS methodology used as classifier. The results show that there is a decrease in the processing time of the requests in the BS, when the arrival of cognitive users is predicted in advance and the spectrum is reserved.

Keywords: Cognitive radio, Matlab, Primary users, Proactive and reactive Strategy, Secondary users, Spectral decision, Topsis

1 Introduction

Some studies show that one of the main problems in the insertion of new applications in the structure of cognitive radio transport relates to the inefficient distribution of spectrum available by government authorities [1]. In other words, currently there are some licensed regions where radio space is underutilized (VHF/UHF bands) [2], [3] and other spectral regions (cell bands) where quality of service has been reduced.

Several researchers, including Mitola and Akyildys, have concluded that dynamic spectrum access (DSA) is a good strategy to address the problem of electromagnetic band management. In [4] they propose the possibility that the administration of the electromagnetic bands is performed dynamically through Cognitive Radio (CR). Therefore, we intend to make a contribution in the spectrum decision phase by designing and implementing a software in Matlab [5] that allows to simulate and evaluate the performance of reactive strategies (where the allocation of channels to SUs is performed after the request is made to the BS) and proactive (which anticipates the selection and assignment of the spectrum before the SU arrives at the BS) [6].

2 Description of the simulator channel in the spectral decision stage using a reactive strategy

Fig. 1 shows the block diagram with the main modules and variables that constitute the software application built in Matlab for the reactive system; the system shown is executed for each time slot (the time slot is equivalent to a time span of 290 milliseconds, equivalent to the duration of the availability of PUs (primary users) samples in the database).

PUs Characterization. Script that forecasts the availability of spectral channels for opportunistic use by unlicensed users [7].
SUs Selection. This stage is responsible for selecting SUs that dispute the use of spectral bands in the current time slot, depending on the arrival behavior (exponential or proportional) of the "SUs database"; the selected users make up the "SU_arrival matrix".

SUs Ranking. The sorting or "ranking" of SUs is carried out in this script. In this case the SUs establish an initial communication with the base station (BS) through a presentation layout (Fig. 2 and Fig. 3), identifying each SU and defining the traffic characteristics; from this information a ranking of SUs is made, starting with the one that requires the most resources to the least. In order to do so, we established the "SUs ranking weights" defined in Tables 1 and 2, and weighted the sum of these variables to obtain scores by organizing the list of SUs in descending order according to the scores obtained.

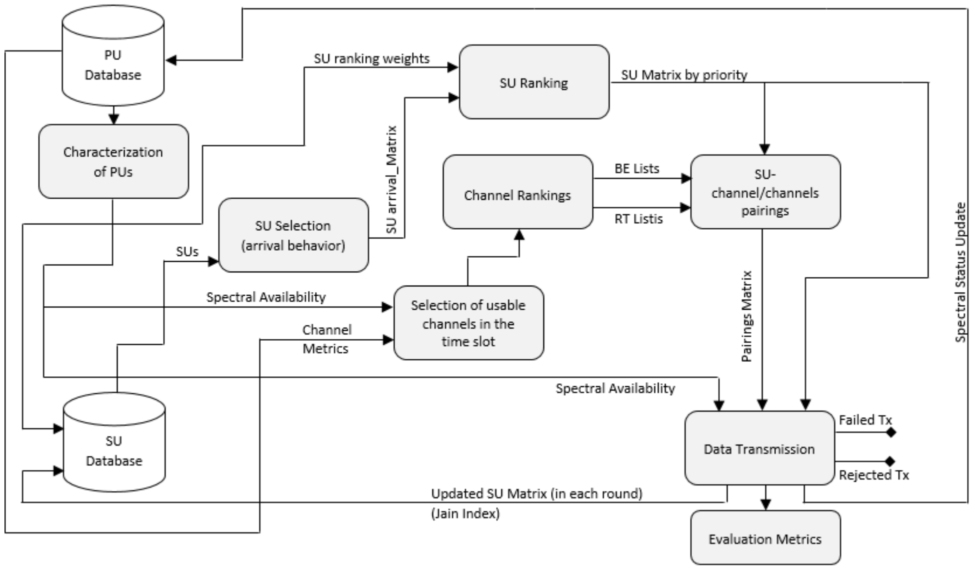

Figure 1. Block diagram of software implemented for the reactive system.

28 bytes

1	1	2	2	2	1	16	3
Start	Control	Source Id	Destination Id	Receiver Id	Service type	Message lenght	End

Figure 2. Presentation layout for BE.

28 bytes

1	1	2	2	2	1	8	8	3
Start	Control	Source Id	Destination Id	Receiver Id	Service type	Delay	Bandwidth	End

Figure 3. Presentation layout for RT.

The values assigned to Tables 1 and 2 were decided in this way, seeking to give greater importance to the bandwidth (which the software interprets as in number of channels), so that the trend is that the best channels are assigned predominantly to the SUs requiring more channels.

Table 1. Weights for sorting RT type SUs.

Characteristics of SUs	Type of Service (BE or RT)	Historical Record	Delay	Bandwidth
Weights	1	-1	-1	2

The values that appear as negative (historical record and delay) imply that there is an inverse proportionality between the value of the corresponding characteristic and the priority that will be given to the respective SU, that is, in this particular case, the greater the delay the lower the priority given to the SU, in order to prioritize those SUs requiring less delay. The Table values are variable and can be modified according to what is required in the system, for example, if we want justice or equity to prevail in they system, we can increase the magnitude of the weight of the historical record, but conserving its sign, in which case the system would start to give priority to the SUs with less historical record, that is to say those with lowest percentage of successful accesses to the system.

Table 2. Weights for sorting type BE SUs.

Characteristics of SUs	Type of Service (BE or RT)	Historical Record	Length of Message
Weights	1	-1	-1

It should be noted that the processing of the data characteristics of the SUs and their organization is independent of the channel classification strategy, which may be ANFIS, FAHP, SVM, TOPSIS or other, notwithstanding the one applied in the article is TOPSIS only [8].
The output of the module is a list of SUs organized by priority or resource request, called "SUs Matrix by Priority".
Selection of available channels in the time slot. In this module the system selects the channels to be assigned in the round or time slot (based on their availability according to the characterization); its inputs are the "PUs database" and the "channel metrics" list (channel availability time, availability probability, delay and bandwidth) that are generated and stored previously.
Channel Rankings. This script performs the ranking of channels according to the methodology used; the outputs obtained are the lists of free channels sorted by ranking for RT and BE.
SU-Channel/Channels Pairings. Its inputs are the organized lists of SUs (according to QoS) and channels; it is responsible for assigning channels to the SUs in such a way that the first SUs of the list, will occupy the first channels according to the type of service; the algorithm defines SU-channel/channels pairings until the requests are processed, or until the available channels can not satisfy the requirements of the cognitive nodes. The output of this script is the pairings matrix, which contains the identifiers of the SUs in its first column, channel identifiers in the second column and in the third column the duration of the corresponding transmissions given in time slots (see Fig. 4).
Data Transmission. This module simulates the transmission of data by the SUs; the inputs to this module are "spectral availability", "Pairings Matrix", "SUs Matrix by priority". The system returns the updated spectral availability and SUs access matrices to the cognitive network updated with the round's results, repeating the entire process for the next time slot. In addition, a record of failed transmissions

(uncompleted transmissions), rejected transmissions (those without channel assignment) and other metrics that evaluate the system operation are obtained.

SU	Channel	Duration	→ Time slots									
11	99	10	0	0	0	0	0	0	0	1	0	0
11	101	10	0	1	0	0	0	0	0	0	0	0
11	84	10	0	0	0	0	0	0	0	1	0	1
11	107	10	0	0	0	0	0	0	1	0	1	0
11	102	10	0	0	0	0	0	0	0	0	0	0
11	87	10	0	0	1	0	0	1	0	0	0	0
11	112	10	0	0	0	0	0	1	0	0	1	0
27	111	10	0	0	0	0	0	1	0	1	0	0
27	88	10	0	0	0	0	0	1	0	0	0	0
27	89	10	0	0	0	0	0	0	1	0	0	0
27	4	10	0	1	0	0	1	0	0	0	1	0
27	115	10	0	0	0	1	0	1	1	1	1	0
27	109	10	0	1	0	0	0	0	1	0	0	0
27	16	10	0	0	0	0	0	0	1	0	0	0

Figure 4. Channel allocation for two type BE SUs.

It is important to note that within the software application once data transmission is initiated, the SU constantly monitors its channels, so that in the event of a PU occupying any of them, the cognitive node stops the transmission by the channel that was occupied and continues transmitting through the others. In a given case that all the channels being used by a SU are simultaneously occupied, the SU will stop its transmission. In the case of an RT type SU, the transmission time is maintained even if some of its channels are occupied, i.e. an RT type user does not extend or shorten its transmission time depending on the quality of the transmission medium, if the medium degrades, it experiences a decrease in the quality of the service (switching from high-definition data stream to standard definition), unless the medium is completely depleted (i.e. all channels are simultaneously occupied by the PUs); that is to say, the eventual occupation of channels will be reflected in the decrease of the quality of service.

As an example in Fig. 5, the behavior over time of the amount of free bands available for use of SU_11 and SU_27 of Fig. 4 is shown; The blue line represents the number of channels that SU_11 can use for each time slot and the red line does the same for SU_27.

For the case of BE type SUs, the scenario is similar; but with the difference that the transmission time of the SU may vary according to channel occupation during the transmission period, in which case the load is redistributed to the remaining allocated spectrum.

Fig. 6 shows an example of load redistribution in which an SU, under ideal conditions (without the existence of a PU), would take three time slots using three channels to perform its transmission (blue graph), but given that in slot 2 one of its channels was occupied by a PU, the transmission had to be extended by a further time slot (red graph).

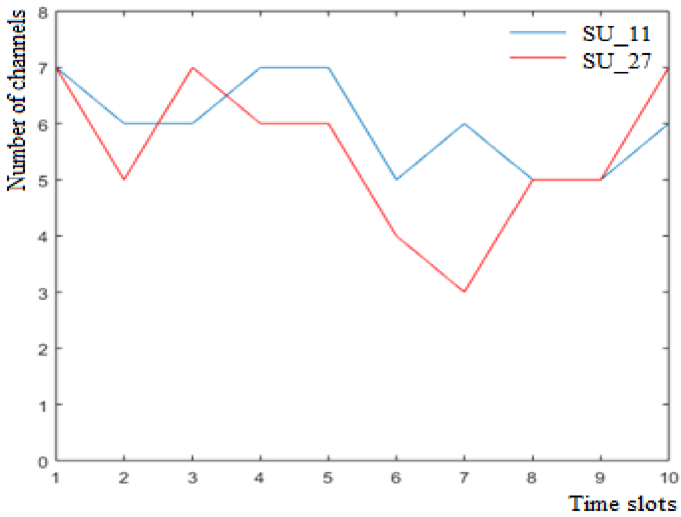

Figure 5. Behavior over time of the number of channels available for the two SUs in the example.

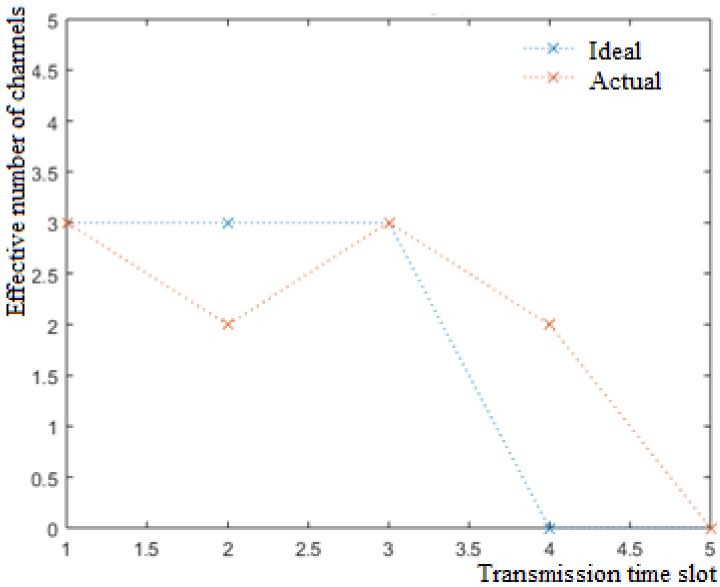

Figure 6. Load redistribution for a BE type SU.

3. Description of the simulator for channel selection in the spectral decision stage using a proactive strategy

Fig. 7 shows the block diagram with the main modules and variables involved in the software application; the unexplained modules function similarly to the reactive case.

SU Selection. This stage works similarly to that used in the reactive system; the most important variation is that the SUs arrival list in each time slot is recorded in a three-dimensional array called the "Three-Dimensional Arrival Matrix" that will be used to execute and evaluate the proactive system.

Prediction or probability of SU arrival. An algorithm that establishes the probability of arrival (or anticipated prediction) of the following SU requesting spectrum based on the type of traffic (RT or BE); depending on the type of RT the number of channels required is defined.

Data Transmission. It works in a similar way to the reactive case, the difference is that part of the script makes the reservation of channels for the next SU or SUs (before the actual request arrives) in agreement with the SU-Channels pairings matrix; additionally, it executes the transmission.

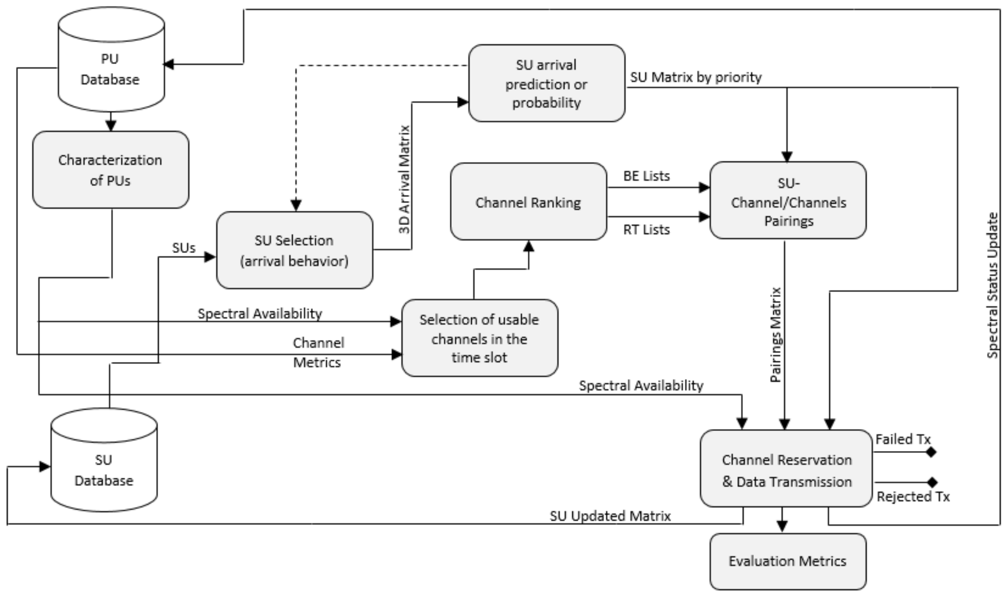

Figure 7. Block diagram of the software implemented for the proactive system.

4 Performance evaluation of the simulator for a proportional arrival of SUs to the cognitive network

The test performed uses TOPSIS as a classifier for the generation of the channel and SUs rankings; and accuracy in prediction of 97% for characterization of PUs (using ANFIS [9]) and arrival of SUs to the BS [10] [11]. We compare the proactive system with the reagent and with the reagent without ranking considering that the software assigns one or three channels for submitting BE applications, and 5 or 7 for RT requests [12].

The arrival behavior of SUs to the BS corresponds to the seventh part of the free channels in each time slot (290 msec), that is to say, in each allocation round, the amount of SUs that try to access the system, is the seventh part of the number of free channels at that time, so that it is guaranteed that at least initially all SUs will get the channels they require.

The spectral availability database (subject to the presence/absence of PUs), which enters the channel selection and allocation system, consists of traces of traffic taken from the WiFi spectral band (2.4 GHz) [13]. From the results shown in Fig. 8, it can be observed that due to the channel congestion level, the probability of success (P. of success) in the transmissions is low and similar for the reactive, proactive and reactive without ranking cases.

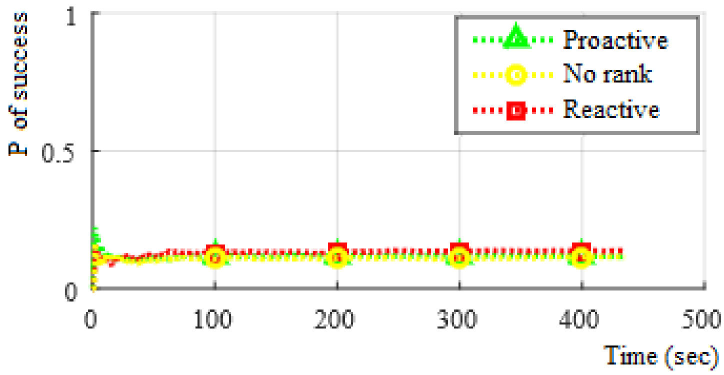

Figure 8. Probability of successful transmissions.

By discriminating the previous graph by flows (see Fig. 9), there is a slight advantage for the reactive case; specifically for RT type SUs, the probability is close to zero for all three cases, since the RT flows in addition to requiring greater bandwidth (channels), have a low spectral availability during the simulation, thus causing these transmissions to have a low probability of successful completion; while the probability for BE is higher because the requests of the SUs are not demanding and can make better use of the channels in congestion conditions.
As for successful transmissions (successful tx), the proactive model (for this particular case) obtained the highest number of successes, followed by the reactive system and finally the system without ranking; it should be noted that the successful transmissions shown in Fig. 10 are cumulative, i.e. each record in the graph takes into account all transmissions made since the beginning of the test, hence its trend.

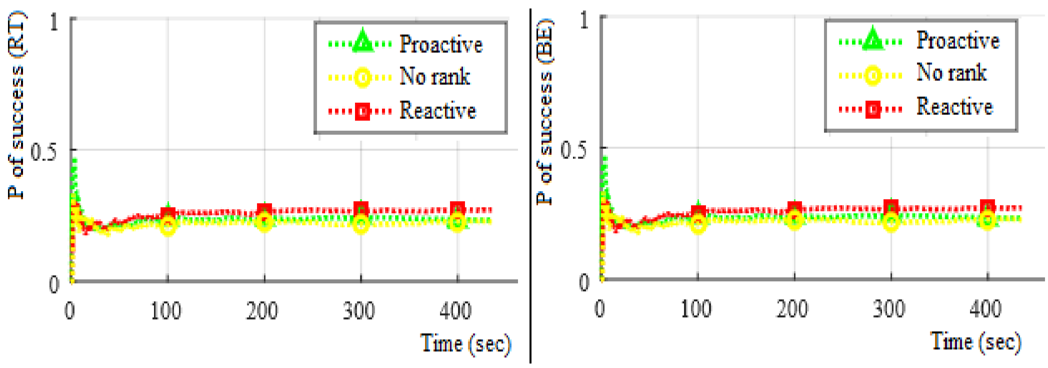

Figure 9. Probability of success discriminated by information flows.

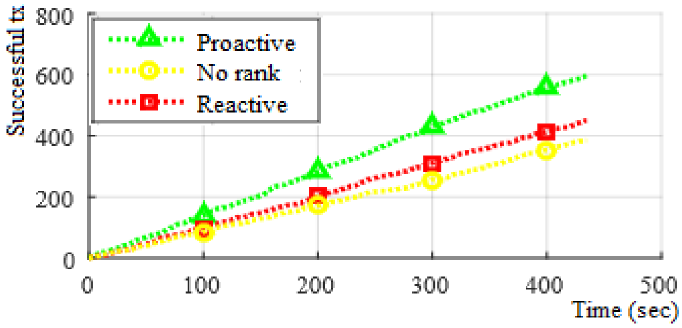

Figure 10. Successful transmission trend for proactive with TOPSIS, without ranking and reactive with TOPSIS scenarios.

The throughput for the three systems is similar, although with a slight advantage in the proactive system for the first 260 seconds that the simulation lasts (Fig. 11).

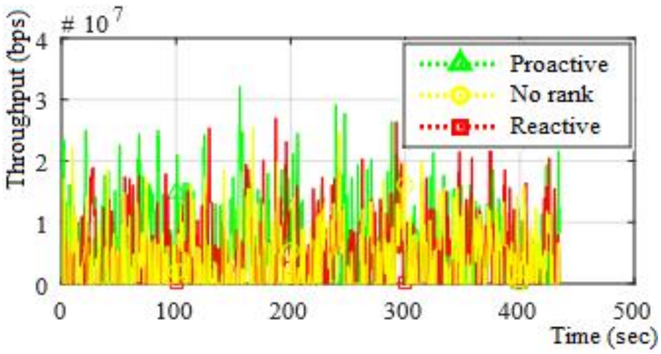

Figure 11. Throughput performance as a function of time.

A detailed analysis of Fig. 12 and Fig. 13 shows that while the proactive system features better performance for the throughput variable, the reactive cases with ranking and without ranking have a better behavior for the Jain index variable approximately until the 250th second; However, in the long term this metric proves to be similar; this tendency is conclusive in the sense that in certain cases to achieve justice (i.e. guaranteeing equitable use of spectrum available for SUs) performance must be sacrificed or vice versa.

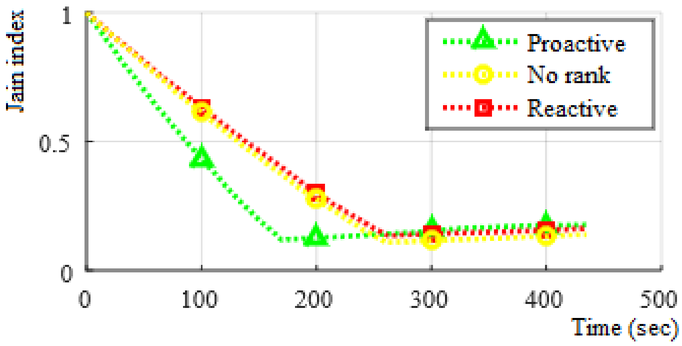

Figure 12. Level of justice or equitability of the proactive/ reactive system with and without ranking.

It is also observed (Fig. 13) that there is a marked difference in the processing time of the systems, where the proactive system has a much lower task processing time than the other two. The time shown in the graphs represents the sum of the times used to perform ranking tasks, session establishment and channel assignment, as the case may be.

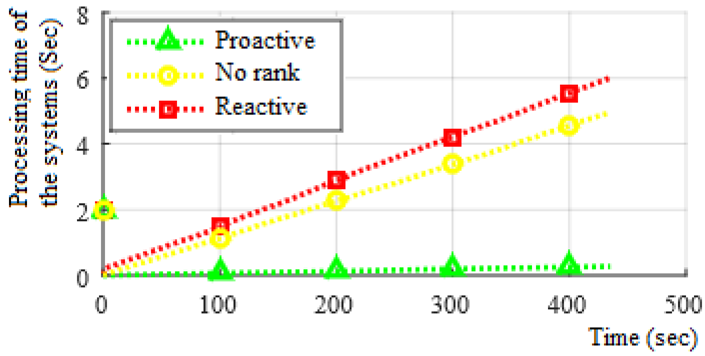

Figure 13. Processing time for requests in the base station of the wireless cognitive network.

5 Conclusions

The article describes the implementation of a simulator for the selection and optimal allocation of channels in the spectral decision stage in wireless cognitive radio networks, which was developed in Matlab, except for the PU characterization and SU arrival prediction phases, developed in the C # programming language. The performance evaluation of the application includes the comparison of three systems that include channel allocation using reactive, proactive strategies with ranking (using TOPSIS), and reactive without ranking for different network metrics, when reserving spectral channels with different quality of service criteria. The results suggest a decrease in the time required for the processing of requests in the BS, when the proactive strategy is used, which optimizes the system, since the time required for the sending of data between the origin and target cognitive nodes is reduced.

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