MULTIUSER SOFTWARE MODULE FOR SPECTRAL DECISION-MAKING

JORGE RODRÍGUEZ, CAMILA SALGADO & CESAR HERNÁNDEZ

Universidad Distrital Francisco José de Caldas, Avenue 68 South Street, Bogotá, Colombia.

ABSTRACT

Research in cognitive radio networks is aimed, among other things, at describing the way in which data packets should be directed in order to optimize the radioelectric spectrum. In this context, methods and tools have been developed to characterize the spectrum and prepare an environment suitable for simulations and tests of the proposed spectral allocation techniques.

Hence, the MULTICOLL-DCRN technique has been developed to offer a friendly and functional environment to simulate cognitive radio networks. This application contains different modules that are intertwined to execute a complete simulation which is closest to reality, or a quick simulation using default parameters.

In this occasion, the development and results of the multiuser module are presented which was implemented under the MATLAB App Designer. The input variables of the module are described followed by the interaction with the application when simulations are executed. This process is divided into two stages: "Multiuser Module" and "Search Algorithm". The first stage describes how the input parameters of the module are processed. The second stage requiring said parameters involves the interaction of the processed variables with the results of the search algorithm in the spectral allocation process.

Lastly, a simulation example is shown along with the results obtained for subsequent analysis. 4 SU intruders were generated at random throughout the simulation resulting in two multichannel bands of 4800 kHz and 2400 kHz for 7 and 2 SU respectively. After analyzing the behavior of total handoffs and the simulation overall, the functionality and benefits granted by both the software and the multiuser module are validated.

KEYWORDS: *Cognitive Radio, Radioelectric Spectrum, Spectrum Allocation, Optimization Algorithms, Simulation Software*

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INTRODUCTION

The increase in wireless devices used everyday leads to an increase in the occupation of the radioelectric spectrum. Research made on this matter by the Federal Communications Commission evidence poor management of the spectrum which is being underused in some areas while it is close to saturation in other areas, with occupation rates going from 15 to 85% (Feng, Shaoping, & Jingyu, 2019). Cognitive radio stems from the idea of managing the spectrum in a better way, where unlicensed users called secondary users (SU) can harness the available sections of the spectrum without affecting licensed users called primary users (PU), seeking to optimize spectrum usage whilst not affecting predefined quality standards (Liping, Ning, Zhigang, & Lin, Spectrum Allocation Based on an Improved Gravitational Search Algorithm, 2018)(Hernández, Páez, & Giral, 2017; Hernández, Pedraza, & Rodríguez-Colina, 2016; Hernández, Pedraza Martínez, & Martínez Sarmiento, 2016).

One of the approaches in cognitive radio consists on defining the spectral allocation of secondary users. Hence, researchers have been using optimization algorithms to find possible solutions to the problem of finding the best path for SU within the spectrum. For instance, different spectrum allocation techniques have been developed based on ant colony optimization (ACO), genetic algorithm (GA) and particle swarm optimization (PSO) (Liping, Ning, Zhigang, & Lin, A Novel Spectrum Scheduling Scheme with Ant Colony Optimization Algorithm, 2018) (Piotr & Krzysztof, 2016) (Najam, Waleed, Naveed, Hyung, Alagan, & Minho, 2016).

In literature, abundant information can be found on the development of algorithms for the spectrum allocation along with simulations where the assessment process focuses in different aspects such as collision rate, delay, spectrum usage or system performance overall. However, in most cases, the development of simulation tools involving spectrum allocation is not specified (Zifeng, Yonghua, & Pin, 2020) (Muhammed, 2019) (Soheil, Sajad, Soheir, Hayder, Kamran, & Predrag, 2016) (Yuanyi, Xiaohui, & Hui, 2018).

Some of the published work regarding the study of the impact of secondary multiusers have been aimed at developing methods based on optimization algorithms in order to improve the performance of a cognitive radio network. For instance, in (Shanshan, Junshan, & Lang, 2010), adaptive algorithms are proposed to reduce the waiting times of SU entering the network based on stochastic methods solved using differential equations. In (Dinh, Dusit, Ping, & Dong, 2015), a model is developed in which SU can harness spectral opportunities for transmission purposes, while also accumulating radiofrequency (RF) energy from PU transmission thus improving network performance in general, based on learning algorithms or Markov decision models.

In terms of software simulation, in (Vahid, Reza, Seyyed, Elahe, & Moein, 2013) a simulation framework based on NS2 is proposed which seeks to assess the performance of the inferior layers (MAC and physical layer) in order to mitigate the loss of packets and improve QoS (quality of service). (Jacek & Cynthia, 2009) present an initial overview of an agent-based framework for cognitive radio studies, in which the environment can be modelled with spectral occupation data captured by the ITT Spectrum Observatory.

It is uncommon to find a software that has both the capacity to simulate multiple secondary users and compare different spectral allocation methods involving multiple variables in addition to being supported on various databases to enrich the analysis of results. Therefore, a software with these features is proposed in this work serving as a starting point in following research stages for a real application.

In the present article, the development and operation of a multiuser module is shown, which consisted on an improvement of the “*Multi-user Collaborative Spectral Decision for Decentralized Cognitive Radio Networks - MULTICOLL-DCRN*” application developed with MATLAB App Designer. This software enables to assess the performance of different spectral allocation algorithms for decentralized or centralized cognitive radio networks, through collaborative and individual strategies, for the access of one or multiple users, based on real spectral occupation data.

Spectral occupation databases that use the proposed software were captured in a previous metering campaign and have been used for many research projects. To capture the spectral occupation data, the energy detection technique was used, from which a power matrix was built. Afterwards, the decision threshold was defined based on the false alarm probability in order to determine the occupation or availability of every monitored frequency channel, resulting in the availability matrix (Hernández Suárez, Rodríguez García, & Mosquera Palacios, 2019). After a statistical analysis of said

matrix, three spectral occupations rates were determined with high, medium and low levels of occupation respectively, which can be chosen in each simulation by the user.

PROPOSED MULTIUSER MODEL

Initially, the multiuser module was conceived as a tool that would allow the simulation of multiple secondary users at the same time within a cognitive radio network to enrich software functions. Nonetheless, although it started as a complementary tool during its development, it became a fundamental part of the software given that all algorithms were substantially modified to materialize the implementation process.

The previous statement is to be validated when the inner pseudocode of the main operation stages is exposed, especially in the spectral allocation section which suffered major modifications. The properties and order for channels and secondary users must be carefully defined depending on the input parameters and the computed frequency ranking.

To begin the analysis of the module, Figure 1 show a diagram depicting the general operation of the software, where the participation of the multiuser module is highlighted. Figure 2 shows the interface of the multiuser module in order to recognize each input parameter. Afterwards each parameter that intervenes in the module is defined.

Figure 1: Software operation strategy, with emphasis on the multiuser module

Figure 2: Interface of the multiuser module

Multichannel Band Section

Multichannel bands (Range: 1 – 4): The user can determine multiple multichannel bands, in order to simulate applications that require different bandwidths at the same time. As exposed in a subsequent section, this input variable controls a cycle in the spectral allocation stage that verifies the fulfillment of the required multichannel band condition, so that the next time step is not attained until the condition is not assessed in all multichannel bands.

Channels (Range: 1 – 10): When the number of multichannel bands is chosen, the number of channels is adjusted for each band in order to characterize the potential application to be simulated in the corresponding multichannel band. As

exposed in a subsequent section, this input variable controls the number of channels allocated to a SU in the spectral allocation stage, so that the next SU is not approached until all required channels have been allocated to the previous SU.

Percent (Options: 25%, 50%, 75%, 100%): When choosing the number of multichannel bands, the percentage of secondary users is adjusted for each band in order to determine the participation share of the corresponding multichannel band in simulation. As exposed in a subsequent section, this parameter is used in the Multiuser Module during the processing phase of the input variables to allocate the number of SU to each multichannel band, keeping in mind that 100% corresponds to the total SU (fixed SU + random SU).

Serial Users Section

Simulation mode (Options: Conventional mode – Real mode): It is possible to choose between two simulation modes, labelled as conventional and real. In the latter, both parameterized and random secondary users enter the simulation to make it more similar to real network traffic. The minimum number of random secondary users is 1 and the number of parameterized secondary users is maximum while the time instant in which they enter the simulation is random and maintained throughout simulation. As exposed in a subsequent section, this input variable controls the generation of random SU and time steps in the “Multiuser algorithm” stage. It also controls the entrance of random SU during the simulation in the “Search Algorithm” phase.

Selection of secondary users: A range must be chosen for the parameterized SU and, when this number is specified, up to 30 parameterized secondary users are admitted in the simulation. This input variable corresponds to the value of fixed SU in simulation that added to random SU correspond to the total SU in the simulation.

After setting the previously described parameters, along with the availability trace corresponding to the *Input data* variable in Figure 1, the values of *Random users*, *Random time* and *Different multichannel SU* are computed:

Random users: Number of random secondary users that enter the simulation (available for *Real mode*). If *Real mode* is selected, a random number in the “Multiuser module” stage is chosen between 1 and the number of fixed SU. Random SU and fixed SU correspond to the total SU in simulation, so that $\text{Total SU} = \text{Fixed SU} + \text{Random SU}$.

Random time: These are random time instants corresponding to the entrance of random SU in the simulation (available for *Real mode*). If *Real mode* is selected in the *Simulation mode* parameter, the “Multiuser module” generates random numbers equivalent to the number of random SU, which correspond to the random time steps in which random SU enter the simulation.

Different multichannel SU: This vector contains the information for different multichannel bands of the simulation. It includes the number of SU for each defined multichannel band, which takes place during the last *for* cycle shown in the pseudocode of the “Multiuser Module” stage using a dynamic assessment of variables depending on the total number of multichannel bands.

Additional input data are required to run the search algorithm such as:

Time range: This is the assessment time indicated by the user in minutes. Its range depends on the size of the assessment trace used to run the simulation. The software assessment trace by default enables assessment times between 1 and 9 minutes. Furthermore, the software offers the option to import a customized assessment trace for each simulation.

Traffic level (Options: Low, Medium, High): Traffic level chosen by the user for the training trace. In order to run

different simulations that consider the level of spectral occupation, the traces included in the software allow to simulate three spectral occupation levels labelled as low, medium and high.

OPERATION

The operation method of the module can be described as the structured base shown in Figure 1, which includes two main stages: “Multiuser Module” and “Search Algorithm”. In the “Multiuser Module” stage, the input parameters are received and processed to deliver internal software variables required in the next stage “Search Algorithm”. This latter involves intrinsic actions of the spectral allocation process.

“Multiuser Module” STAGE

In this stage, the output parameters of the module are obtained such as *Random users*, *Random time* and *Different Multichannel SU*. The following considerations are defined:

- The first two parameters *random users* and *random time* are computed only when the *normal mode* is chosen.
- When the *random users* variable is computed, a random number is obtained ranging between 1 and the value set for *serial users*. A new priority is also obtained for the spectral allocation process, which makes it possible to allocate a channel to a random SU before doing so to a fixed SU. It is noteworthy to mention that the new priority is random. The previous variables comprise the tools needed to simulate a real environment within a cognitive radio network.
- When the *random time* is computed, the *random time step* in which the random users enter the simulation is obtained so that the number of *time steps* corresponds to the number of *random users*. *Random time steps* range between 30% and 70% of the total simulation time, to ensure that the entrance of each *random user* to the simulation will have a pronounced effect on the results.
- The values for the different multichannel bands are concatenated into a vector for their subsequent use in the spectral allocation stage in “Search Algorithm”.

The pseudocode is shown for the first stage previously described:

```
%Time steps
t = floor(Time_range*180);

SU_initial = Serialusers;

%Mode selected
if Real_mode == 1
    SU_rand = randperm(SU_initial);
    t_rand = zeros(t);
else
    SU_rand = 0;
    t_rand = 0;
```

```

end

%Random users and static users

SU_end = SU_initial + SU_rand;

SU = Serialusers;

Priority_rand = sort(randperm(SU_end,SU_rand));

Priority_new = priority(SU_end, Priority_rand);

%Random time steps

t_rand_min = round(t*0.3);

t_rand_max = round(t*0.7);

t_rand = random_time(t, t_rand_min, t_rand_max);

%Multichannel bands

Multichnl_Vector_1 = Multichnl_Percent_1;

Multichnl_Vector_2 = 0;

for i = 2:Multichnl_Total

    w = ['Multichnl_Vector_2 = Multichnl_Percent_',num2str(i),'];

    eval(w);

    Multichnl_Vector_1 = [Multichnl_Vector_1 Multichnl_Vector_2];

End

Multichnl_Vector = round(SU_end*(Multichnl_Vector_1./100));

```

“Search Algorithm” STAGE

In the following stage “Search Algorithm”, the training trace is used to find the ranking of the channels to be used in the spectral allocation process. This ranking depends on the type of algorithm chosen. The developed application enables to use the following algorithms to find the channel ranking:

- Markov Chain
- Genetic Algorithm
- Naive Bayes
- Logistic Regression
- Time Series

When the channel ranking is determined, the assessment trace is used to run the simulation. Hence, each SU is allocated one or more channels in each time step (depending on the number of defined multichannel bands) according to

the ranking delivered by the corresponding algorithm and the priority order for all SU derived from processing the variables of the Multiuser Module.

The following considerations are reviewed:

- The simulation is started with the number of fixed SU and, as random time steps are attained, random SU enter the simulation.
- The results on random SU are not obtained until they enter the simulation, so these results are marked as zero until it happens.
- The next SU is not processed until all multichannel bands are allocated to the current SU.
- The priority of SU in the spectral allocation is implicit by saving the results according to the order of elements of the Priority_new vector

The operation of the spectral allocation is illustrated through a flow diagram in Figure 3. The main conditions assessed during simulation are evidenced such as:

- Validation of random time steps for the entrance of random SU
- Validation of availability for each channel
- Validation of allocated channels in order to define handoff rates
- Validation of allocated channels to meet the multichannel bands required before moving on to the next SU
- Validation of the SU assessed in each time step before moving on to the next one

The control of the previous conditions using the input variables or using the ones processed in the “Multiuser Module” stage enable the execution of the simulation.

Figure 3: Flow diagram of the spectral allocation stage.

SIMULATION EXAMPLE

This section details a simulation example using the “*MULTICOLL-DCRN*” application emphasizing in the developed multiuser module. Hence, the data entered in Figure 4 are described along with the six sections of the developed software application.

Section 1: Project Information: The input variables are:

- Project Name: The project is named “Test”

- Load Database: The “Wi-Fi” database is selected as well as the address of the folder that contains it.
- Save folder: The location of the folder where the results will be saved is chosen.

Section 2: Collaborative Module: The parameters set by default to focalize the simulation on the multiuser module.

Section 3: Multiuser Module: The following parameters are entered into the multiuser module, which are depicted in Figure 4.

- Multichannel bands: Selection of two multichannel bands:
- One band with 4 channels for 75% of the SU
- One band with 2 channels for 25% of the SU
- Serial users:
- Selection of the real mode to include random SU in the simulation
- The random SU are shown in the result charts
- 5 parameterized SU.

Figure 4: Example of data input in the multiuser module.

Section 4: Parameters Module: The variables chosen are:

- Input Data: Parámetros por defecto
- Traffic Level: Low traffic level
- Time: A simulation time of 9 minutes.

Section 5: Prediction Module: The Prediction option is chosen along with the Naive Bayes algorithm:

- Time Step: Default value
- Handoff Models: FFAHP
- Weights: Default value

Section 6: Choosing the “Run NB” button to begin the simulation

RESULTS

The results obtained for the average bandwidth and total handoffs are shown in Figure 5 and 6, respectively.

Figure 5 reveals relevant information such as:

- In this simulation, 4 random SU were generated that correspond to User6, User7, User8 and User9.
- Two random SU entered the simulation in approximately minute 3 (User6 and User7).
- 1 random SU entered the simulation in approximately in minute 4 (User8).
- 1 random SU entered the simulation in approximately in minute 5 (User9).
- The multichannel bands defined for the total SU of the simulation were applied as follows:
- Out of 4 channels for 75% of the SU, close to 4600 kHz of bandwidth were obtained for 7 SU.
- Out of 2 channels for 25% of the SU, close to 1200 kHz of bandwidth were obtained for 2 SU.

On another note, the following information can be deduced from Figure 6:

At minute 3, when the SU User6 and User7 entered the simulation, the slope of handoff increase changed for SU User1, which surely means that one of the random SU had a higher priority than this user, forcing him to use channels with lower rankings and less efficiency.

The difference in terms of the handoff increase rate for SU with different multichannel bands is evident. In this case, the SU of two-channel multichannel bands (User8 and User9) see their handoffs increase in less proportion than other users which require 4 channels.

Figure 5: Results for average bandwidth.

Figure 6: Results for total handoffs.

Figure 7: Results for failed handoffs.

CONCLUSIONS

The work carried out in the development of the proposed multiuser module offers the possibility of a more accurate simulation of a cognitive radio network in the following aspects:

- The possibility to generate random intruder-type SU, as seen in the example simulation which included 5 fixed SU and 4 intruder SU that entered in minute 3, 4 and 5 of the simulation approximately. Hence, it is possible to obtain dynamic results given that increase trend of total and failed handoffs is not maintained when random SU enter the simulation. The results shown in figures 6 and 7 mark a difference in the handoff increase rate in minutes 3, 4 and 5 of the simulation.
- Joint simulation of different bandwidth applications with different numbers of SU in each one. The results led to the spectral allocation of 4800 kHz for 7 SU and 2400 kHz for 2 SU.
- In general terms, the failed handoffs are much lower than the total handoffs, with a maximum of 355 failed handoffs and a maximum of 6100 total handoffs in the SU User3. This can be attributed to the chosen training algorithm, which properly describes the available channels through the frequency ranking system and also to the poor spectral occupation by using a low traffic trace.

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REFERENCES

1. Akyildiz I., Lo B., & Balakrishnan R. (2011). Cooperative spectrum sensing in cognitive radio networks: A survey. *Physical Communication*, 4(1), 40-62.
2. Dinh T., Dusit N., Ping W., & Dong I. (2015). Performance Optimization for Cooperative Multiuser Cognitive Radio Networks with RF Energy Harvesting Capability. *IEEE Transactions on Wireless Communications*, 14(7), 3614 – 3629.
3. Feng Z., Shaoping L., & Jingyu F. (2019). Securing Cooperative Spectrum Sensing against DC-SSDF Attack Using Trust Fluctuation Clustering Analysis in Cognitive Radio Networks. *Wireless Communications and Mobile Computing*, 1-2.
4. Hernández C., Páez I., & Giral D. (2017). Modelo adaptativo multivariable de handoff espectral para incrementar el desempeño en redes móviles de radio cognitiva (Ed.). Editorial UD.
5. Hernández C., Pedraza L. F., & Rodríguez-Colina E. (2016). Fuzzy Feedback Algorithm for the Spectral Handoff in Cognitive Radio Networks. *Revista Facultad de Ingeniería de La Universidad de Antioquia*.
6. Hernández C., Pedraza Martínez L. F., & Martínez Sarmiento F. H. (2016). Algoritmos para asignación de espectro en redes de radio cognitiva. *Revista Tecnura*, 20(48), 69–88. <https://doi.org/10.14483/udistrital.jour.tecnura.2016.2.a05>.
7. Hernández C., Rodríguez García J., & Mosquera Palacios D. (2019). Evaluación de un algoritmo para selección de oportunidades espectrales en redes inalámbricas cognitivas. *Vinculos*, 16 Num. 2, 1-2.
8. Jacek D., & Cynthia H. (2009). An agent-based simulation framework for cognitive radio studies. *Proceedings of the 2nd International Conference on Simulation Tools and Techniques*, 1-6.
9. Liping L., Ning W., Zhigang C., & Lin G. (2018). A Novel Spectrum Scheduling Scheme with Ant Colony Optimization Algorithm. *Algorithms*, 1-2.
10. Liping L., Ning W., Zhigang C., & Lin G. (2018). Spectrum Allocation Based on an Improved Gravitational Search Algorithm. *Algorithms*, 1-2.

11. Muhammed E. (2019). *Exploiting cognitive wireless nodes for priority-based data communication in terrestrial sensor networks*. *ETRI Journal*, 36-45.
12. Najam U., Waleed E., Naveed E., Hyung S., Alagan A., & Minho J. (2016). *Network Selection and Channel Allocation for Spectrum Sharing in 5G Heterogeneous Networks*. *IEEE Access*, 4, 980-992.
13. Piotr L., & Krzysztof W. (2016). *Genetic Algorithm for Routing and Spectrum Allocation in Elastic Optical Networks*. 2016 Third European Network Intelligence Conference (ENIC), 273-280.
14. Shanshan W., Junshan Z., & Lang T. (2010). *Delay Analysis for Cognitive Radio Networks with Random Access: A Fluid Queue View*. 2010 Proceedings IEEE INFOCOM.
15. Soheil R., Sajad A., Soheir N., Hayder A., Kamran A., & Predrag R. (2016). *Spectrum Assignment Algorithm for Cognitive Machine-to-Machine Networks*. Hindawi Publishing Corporation, 1-8.
16. Vahid E., Reza B., Seyyed M., Elahe S., & Moein P. (2013). *CogNS: A Simulation Framework for Cognitive Radio Networks*. *Wireless Pers Commun*, 72, 2849–2865.
17. Yuanyi W., Xiaohui Z., & Hui L. (2018). *Throughput maximization-based optimal power allocation for energy-harvesting cognitive radio networks with multiusers*. *Journal on Wireless Communications and Networking*, 1-10.
18. Zifeng Y., Yonghua W., & Pin W. (2020). *Joint Channel Allocation and Power Control Based on Long Short-Term Memory Deep Q Network in Cognitive Radio Networks*. *Complexity*, 1-9.