Modeling and research of the operation of cognitive radio networks

Ernazar Reypnazarov[1*], *Halimjon* Khujamatov[1], *Debasis* Das[2], *Alisher* Shakhobiddinov[1], *Doston* Khasanov[1], and *Tazakhan* Babazhanova[3]

[1]Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Amir Temur Avenue 108, 100084 Tashkent, Uzbekistan
[2]Indian Institute of Technology in Jodhpur, urpura Bypass Rd, Karwar, Jheepasani, Rajasthan 342030, India
[3]Nukus Branch of Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, 74, A. Dosnazarov street, Nukus, Uzbekistan

Abstract. Cognitive radio networks (CRN) have emerged as a promising technology to address the spectrum scarcity problem by allowing unlicensed users to access the licensed spectrum dynamically. The operation process of CRN involves several steps such as spectrum sensing, spectrum decision, and spectrum sharing. This paper provides information on the model and algorithm developed for researching the operation of cognitive radio networks and describes the results of the research. The model is built in the Matlab software environment, and the relevant results of such processes as occupying channels, detecting spectrum holes, freeing channels, adding noise to signals, and suppressing signals in cognitive radio networks are graphically depicted.

1 Introduction

In recent times, the use of wireless devices has been growing at a very fast pace, so the access and use of limited spectrum bands has increased tremendously. The radio frequencies that any wireless signal uses to travel are divided into licensed and unlicensed bands. A licensed band is a fixed portion of a frequency band assigned to a wireless service or a specific owner for their use, while an unlicensed spectrum band can be used for any wireless transmission [1-2].

This traditional policy of assigning fixed spectrum to wireless spectrum bands has become ineffective because some bands are overused (unlicensed spectrum bands) and some bands are largely unused (licensed spectrum bands). This fact explains the increase in noise and congestion in networks that use unlicensed spectrum bands, which leads to a significant decrease in the throughput of this network, while licensed spectrum bands remain unused. Thus, the widely used wireless spectrum access method remains inefficient [2-3].

To effectively solve this problem, some researchers have proposed allowing a network of unlicensed wireless users to share a large unused portion of licensed spectrum band networks. This type of network initially received several names, such as Dynamic Spectrum Access

* Corresponding author: reypnazar0vernazar@gmail.com

(DSA) networks or Next Generation (xG - NeXt Generation) communication networks, but finally it received its permanent name of Cognitive Radio Networks [4-5]. CRN are opportunistic (taking advantage of the opportunity) to allow unlicensed users called Secondary Users (SU) to access the licensed spectrum range and not affect the operation of the licensed original users called Primary Users (PU). allows sharing [6].

CRNs have gained significant attention in recent years due to their ability to improve the utilization of the radio spectrum. The operation process of CRN involves several steps such as spectrum sensing, spectrum decision, and spectrum sharing. Simulation models are useful tools for evaluating the performance of CRN in different scenarios. Simulation allows researchers to evaluate the performance of CRN under different conditions without the need for expensive hardware and real-world testing. Simulation models can also be used to optimize the design of CRN and to identify potential problems before deploying the network.

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Simulation Model. The simulation model of the cognitive radio operation process is implemented using MATLAB software. The model consists of three main modules: spectrum sensing, spectrum decision, and spectrum sharing.

Spectrum Sensing Module. The spectrum sensing module is responsible for detecting the presence or absence of primary users (PUs) in the licensed spectrum. The module uses energy detection technique to sense the spectrum. The received signal is first passed through a bandpass filter to select the frequency band of interest. Then, the energy of the received signal is calculated and compared with a predefined threshold. If the energy is above the threshold, it indicates the presence of PU, and if it is below the threshold, it indicates the absence of PU. The performance of the spectrum sensing module is evaluated based on two metrics: detection probability and false alarm probability. Detection probability is defined as the probability of correctly detecting the presence of PU when it is present in the spectrum. False alarm probability is defined as the probability of falsely detecting the presence of PU when it is not present in the spectrum [9].

Spectrum Decision Module. The spectrum decision module is responsible for making a decision on whether to use the spectrum or not based on different criteria such as channel availability, quality of service (QoS) requirements, and interference constraints. The module uses a decision threshold to make the decision. If the sensed energy is above the decision threshold, the module decides to use the spectrum, and if it is below the decision threshold, the module decides not to use the spectrum. The performance of the spectrum decision module is evaluated based on two metrics: decision probability and error probability. Decision probability is defined as the probability of making a correct decision on whether to use the spectrum or not. Error probability is defined as the probability of making an incorrect decision on whether to use the spectrum or not [10-11].

Spectrum Sharing Module. The spectrum sharing module is responsible for sharing the spectrum among different cognitive radio users (CRUs) to avoid interference. The module uses time division multiple access (TDMA) technique to share the spectrum. The spectrum is divided into time slots, and each CRU is assigned a specific time slot to transmit its data. The performance of the spectrum sharing module is evaluated based on throughput, which is defined as the amount of data transmitted per unit time.

2 Methods

Simulation of CRN is relevant for several reasons. First, simulation allows researchers to evaluate the performance of CRN under different conditions. For example, researchers can simulate the impact of different interference sources on the performance of CRN. This allows researchers to identify potential problems and optimize the design of CRN before deployment. Second, simulation allows researchers to evaluate the performance of CRN without the need for expensive hardware and real-world testing. This is particularly important for researchers who do not have access to expensive hardware or who want to evaluate the performance of CRN under different conditions. Third, simulation allows researchers to optimize the design of CRN. For example, researchers can use simulation to determine the optimal number of cognitive radio users (CRUs) that can be supported by the network. This allows researchers to design a network that can support a large number of CRUs while maintaining good performance. Fourth, simulation allows researchers to identify potential problems before deploying the network. For example, simulation can be used to identify potential interference sources that may affect the performance of CRN. This allows researchers to design a network that can mitigate the impact of these interference sources [12-14].

To study the working process of cognitive radio networks, a model that reflects the necessary features of the system is required. We used the simulation modeling method in the experimental research of the cognitive radio network. The model was built based on the processes described in Figure 1, which represents the working process of a cognitive radio network.

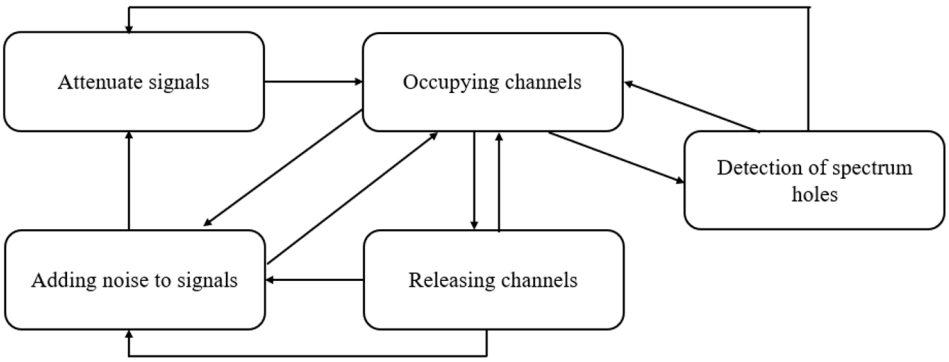

Fig. 1. Block diagram of the simulation model of cognitive radio network operation processAccording to our model, the operation process of the cognitive radio network is conditionally divided into the following sub-processes:

- occupying channels. The process of channel occupancy is critical in CRN as it ensures that secondary users do not interfere with primary users while accessing the licensed spectrum. The process also ensures that secondary users have access to high-quality channels that meet their quality-of-service requirements;
- detection of spectrum holes. The process of detecting spectrum holes involves spectrum sensing, which is the process of detecting the presence of primary users in a particular frequency band. Spectrum sensing can be done using different techniques such as energy detection, matched filtering, cyclostationary feature detection, and machine learning-based techniques;
- release channels. The process of releasing channels involves notifying other secondary users about the channel release and selecting a new channel that meets their quality-of-service requirements and does not cause harmful interference to primary users. This process is called spectrum handoff and involves designing efficient handoff protocols and techniques;

- adding noise to signals. The added noise helps to distinguish between the presence of a primary user signal and the absence of a signal due to noise or fading. By injecting noise into the received signal, secondary users can improve their detection performance and reduce the likelihood of false alarms or missed detections;
- attenuating of signals. Attenuation can be achieved through various techniques such as power control, beamforming, and directional antennas. Power control involves adjusting the transmission power of secondary users based on the availability of spectrum and the proximity of primary users. Beamforming and directional antennas, on the other hand, focus the transmission of secondary users in specific directions, thereby reducing the likelihood of interfering with primary users.

Experimental simulation methods related to cognitive radios are rarely implemented, so we implemented the model using the Matlab simulation modeling environment because it is a simple and efficient tool. To implement the model, the algorithm presented in Figure 2 and the program for the Matlab environment were developed.

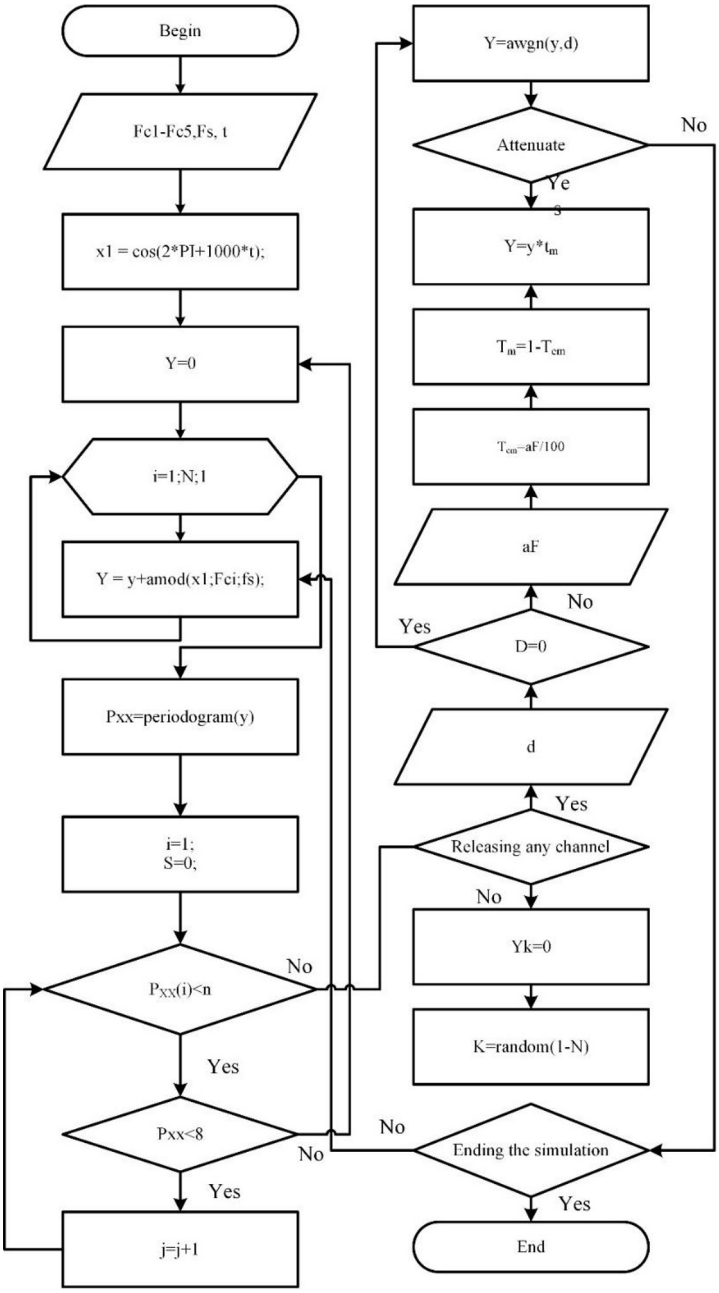

Fig. 2. Algorithm for the implementation of the simulation model of operation of cognitive radio network

3 Results and Discussion

3.1 Assignment of users to the frequency spectrum

We designed our system with 5 different frequency channels and each user is assigned a specific frequency range. After we run our program, it asks to add a user and assign a certain frequency band to it in ascending order. Here in Figure 3, we have not included users 3 and 4, so their respective ranges are still not separated. We can see them in the graph of the power spectral density of the carrier signal, as in Figure 4.

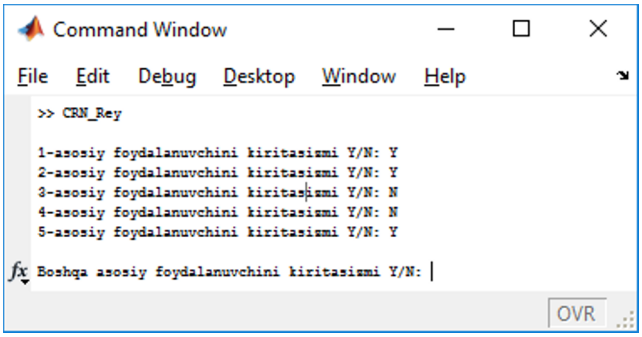

Fig. 3. Adding primary users to the frequency spectrum in the command window

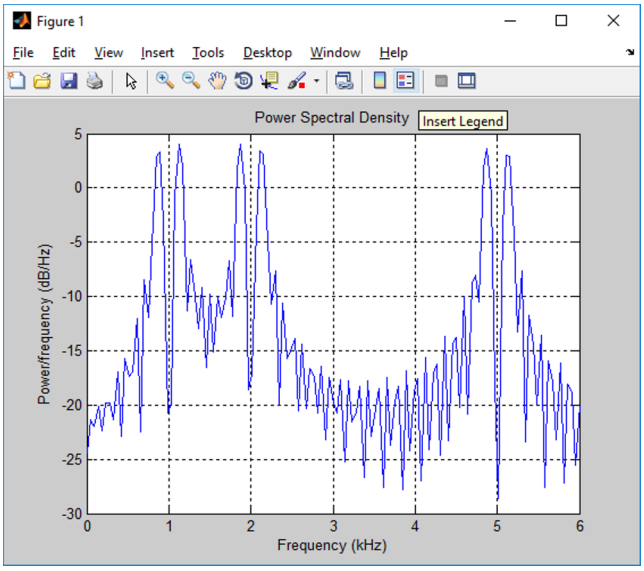

Fig. 4. Power spectral density curve

3.2 Assigning a new user to spectrum holes

Another user can be added using simulation, in which the system searches for the first space in the spectrum (the first free slot) and automatically assigns it to the new user (Figures 5).

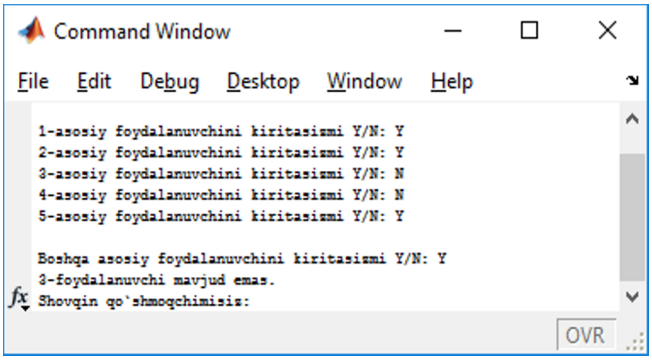

Fig. 5. Assigning a new user to spectrum holes

Here we can see that the first spectral gap is filled by assigning new incoming user data. The first spectral gap belonged to user 3.

3.3 Add noise to user signals and attenuate them

It is also possible to add noise to the user's signals and suppress the signals with the help of simulation (Figure 6). In this case, changes in the power spectrum density of signals when adding 10 dB of noise to the signals, as well as changes in the power spectrum density of signals after reducing the signal power by 20%, were studied.

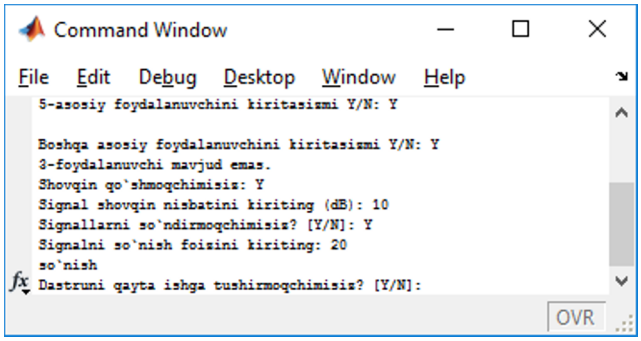

Fig. 6. Add noise to user signals and attenuate them

3.4 Release the slot

After all the slots are assigned, our system does not care about any other user and can release the slots one by one as shown below (Figure 7). If we ask it to free a slot, it deletes the data of that slot and prepares it for the next task.

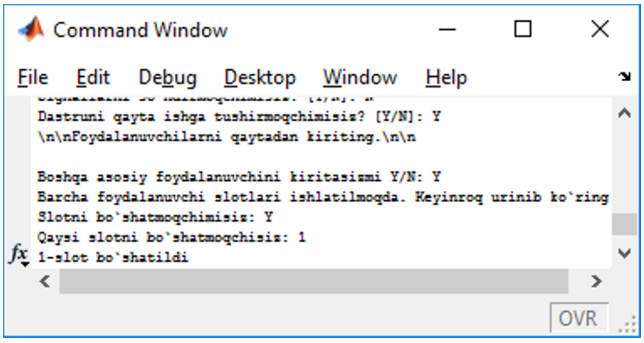

Fig. 7. Release a slot in the command window

4 Conclusion

In conclusion, it can be said that inductive modeling is one of the main methods in the study and research of cognitive radio systems. The Matlab software environment is important as a universal tool for building a general model of a cognitive radio network. With the help of the model discussed above, it is possible to study processes such as occupying channels in cognitive radio networks, detecting spectrum holes, releasing channels, adding noise to signals, and suppressing signals.

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