



Measurement of the Performance of a Cognitive Radio Spectrum Handoff Model

Ghada A. M. Abdu, Mohamed A. H. Abbas, Hamid A. Ali

Department of Electrical and Electronic Engineering University of Khartoum Faculty of Engineering
Khartoum, Sudan (E-mail: ghadataima@gmail.com)

Abstract: Wireless access has become an essential part of modern society. Consequently, new wireless applications and services, as well as the number of wireless users, are sharply increasing. Cognitive radio has improved the spectral efficiency of licensed radio frequency bands by accessing unused part of the band opportunistically without interfering with a licensed primary user. Spectrum mobility improves fast and smooth transition that lead to minimum performance degradation. An important requirement of mobility management protocols is a good performance in relation to spectrum handoff. To reduce the adverse effects of spectrum handoff interrupted secondary users may be provided with a higher priority over new secondary users for utilizing the available spectrum band. In this paper a queuing model of a spectrum handoff scheme for cognitive radio wireless networks is proposed. The handoff performance of the secondary users operating in a heterogeneous spectrum situation composed of licensed channels and unlicensed channels is tested. Three types of users: primary users, new secondary users, and handoff (Interrupted) secondary users are considered. The discrete event Simulator Matrix Laboratory (MATLAB) package tool is used to carry numerical calculations illustrating the effect of a priority queuing system on the performance of handoff of Secondary Users (SUs).

Keywords: cognitive radio, queuing systems, retrial queuing systems, performance measures.

1. INTRODUCTION

In recent years, there has been a huge increase in the access of the limited spectrum for mobile services, so the fixed spectrum assignment policy to the licensed spectrum began to be inefficient, in addition to the large portion of the spectrum assigned to license holders or services that remain unutilized. A new communication technique named Dynamic Spectrum Access for Cognitive Radio networks or Next Generation (xG) communication networks was proposed to provide the SUs with the capability to access the licensed spectrum opportunistically without interfering with its original users [1].

Cognitive radio networks (CRNs) idea is to allow secondary. (Unlicensed) users to use the free spectrum gaps without causing any harm to primary (licensed) transmissions. For that purpose cognitive radios should be able to adapt their transmission parameters to the changing spectrum opportunities [2]. Cognitive radio technology is on the way to resolve the spectrum delay issues regarding licensed user (PU) and unlicensed user (SU). PU has full access right to utilize the spectrum anywhere and SU has secondary priority to access the spectrum if any spectrum hole is available. In general, the availability of substantial numbers of licensed. Spectrum channels are the key benefit of using this type of radio spectrum channel. Whereas, accessing with equal rights. For all types of users is the main advantage of using unlicensed spectrum channels. In this respect, no transmission.

Interruptions occur once a user obtains an unlicensed channel. This enables the user to resume interrupted transmission in the case of the spectrum handoff operation. [3] Available spectrum bands for data transmissions are composed of licensed spectrum bands and unlicensed spectrum bands. According to [9, 10, 11], secondary users in future networks can access and operate on both the spectrum bands. However, most of the existing spectrum handoff schemes as in [13, 14].

With OSA do not investigate the performance of secondary users in a heterogeneous spectrum environment. This means that most of the existing models do not take into consideration that secondary users can operate on both of the spectrum band environments. In other words, they ignore the possibility of unlicensed bands to become available after some time and hence can be used for transmission.

In order to reduce the handoff delay of the secondary users, interrupted secondary users may be provided with a higher priority over the new secondary users to utilize the available spectrum bands.

2. SYSTEM MODEL

A queuing model of a spectrum handoff scheme for cognitive radio wireless networks is proposed. The proposed model analyses the performance of the secondary users handoff while operating in a heterogeneous spectrum environment composed of licensed channels, unlicensed channels, and three types of users: primary users, new secondary users, and handoff

(Interrupted) secondary users. The model consists of a number of independent wireless channels. There are N_1 licensed channels and N_2 unlicensed channels. The licensed channels are shared by three priority queues: First-priority queue for primary users and second and third-priority queues for secondary users' transmissions. Newly arriving SUs enter the third-priority queue. Handoff SUs are given priority over new SUs and hence are queued in the second-priority queue. The queues are implemented with an infinite size and the M/M/C queuing model is suggested to manage the spectrum handoff process in the system.

In Fig.1, the general assumptions for the proposed model are given. Primary users can utilize only the licensed band. If there is at least one idle licensed channel, then an arriving primary user will occupy this idle channel and send its transmission. If all the licensed channels are busy by primary users, then the arriving primary user will join the First-priority queue of the licensed channels and will be served according to the FIFO queuing discipline. Also, if all licensed channels are busy and at least one licensed channel is occupied by a secondary user, then the arriving primary user will select and preempt the licensed channel occupied by the secondary user.

Secondary users may utilize the licensed or unlicensed band. A new secondary user will be served immediately if there is at least one idle channel. If all channels are busy in licensed and unlicensed bands then a new secondary user will join the third-priority queue and at the same time join the Orbit queue and wait for service. It will be served by either a third-priority queue licensed channel or an orbit queue channels whichever is available earlier.

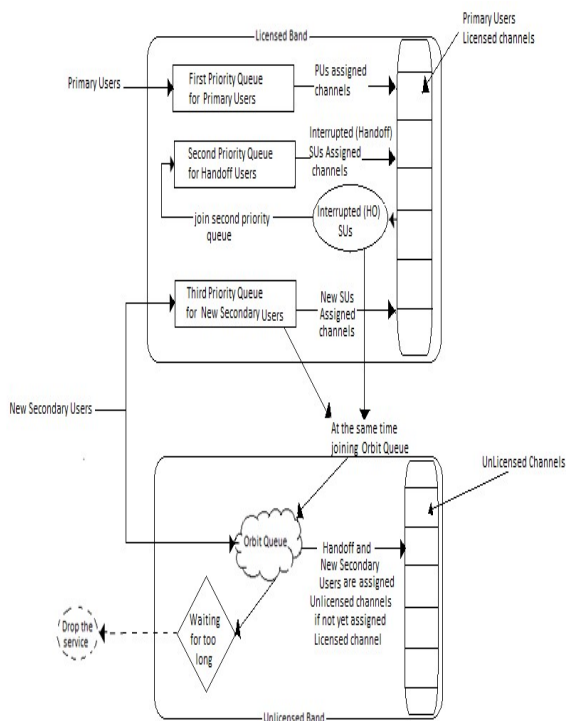


Fig. 1. Queuing model for Cognitive radio using heterogeneous channels

If a secondary user occupying a licensed channel is interrupted due to arrival of a primary user then the SU may wait in the second-priority queue in licensed band and at the same time join the Orbit queue in unlicensed band and will be served by either a second-priority queue licensed channel or an orbit queue channel whichever is available earlier. Interrupted secondary users have a higher priority over new secondary users to utilize the idle channel with respect to transmission resumption in the new channel. By giving such priority to the interrupted users, the handoff users will be served before any uninterrupted users. This can compensate the handoff delay resulting from multiple interruptions and consequently reduce the handoff delay which leads to improvement of the performance.

3. SECONDARY USER BEHAVIOR

The generated requests from secondary users are explained by the proposed model chart given in Fig. 2. Anew SU requests a channel. They must sense channels at the beginning of each time slot by the order of idle probability. If a channel is idle the SU will be assigned that channel and it transmits its data and finishes the service. New secondary users will be served either by the third-priority queue for licensed channels or by Orbit queue for unlicensed channels whichever happens to assign it a free channel first.

When the SUs are interrupted due to arrival of a PU they may;

1. be assigned to an idle channel to resume transmission otherwise,
2. Handoff SUs join second-priority queue and Orbit queue at the same time and will have the chance to transmit on either a licensed channel or an unlicensed channel whichever is assigned to it earlier.

Interrupted secondary users also move to the unlicensed spectrum channels and compete with new secondary users, who are assigned a longer back-off (retrial) time in the orbit so that handoff secondary users have higher priority in orbit on them. When the number of SUs increases, the probability that they may be interrupted increases, so the handoff probability will also increase and a user may be handed off more than once, so the waiting time for these users will increase. If this waiting time is too long, the SU may be dropped.

4. PERFORMANCE METRICS

In this subsection, the performance parameters for a cognitive radio spectrum handoff model, with the secondary users operating in a heterogeneous network composed of licensed channels and unlicensed channels, are listed and defined.

1. Average Through

Average throughput is defined as the average rate of packets delivered successfully per one second. It's preferable to retain it as maximum as possible [12].

$$\frac{\text{Average throughput} = \text{number of packets reached their destination}}{\text{simulation end time} - \text{simulation start time}} \quad (1)$$

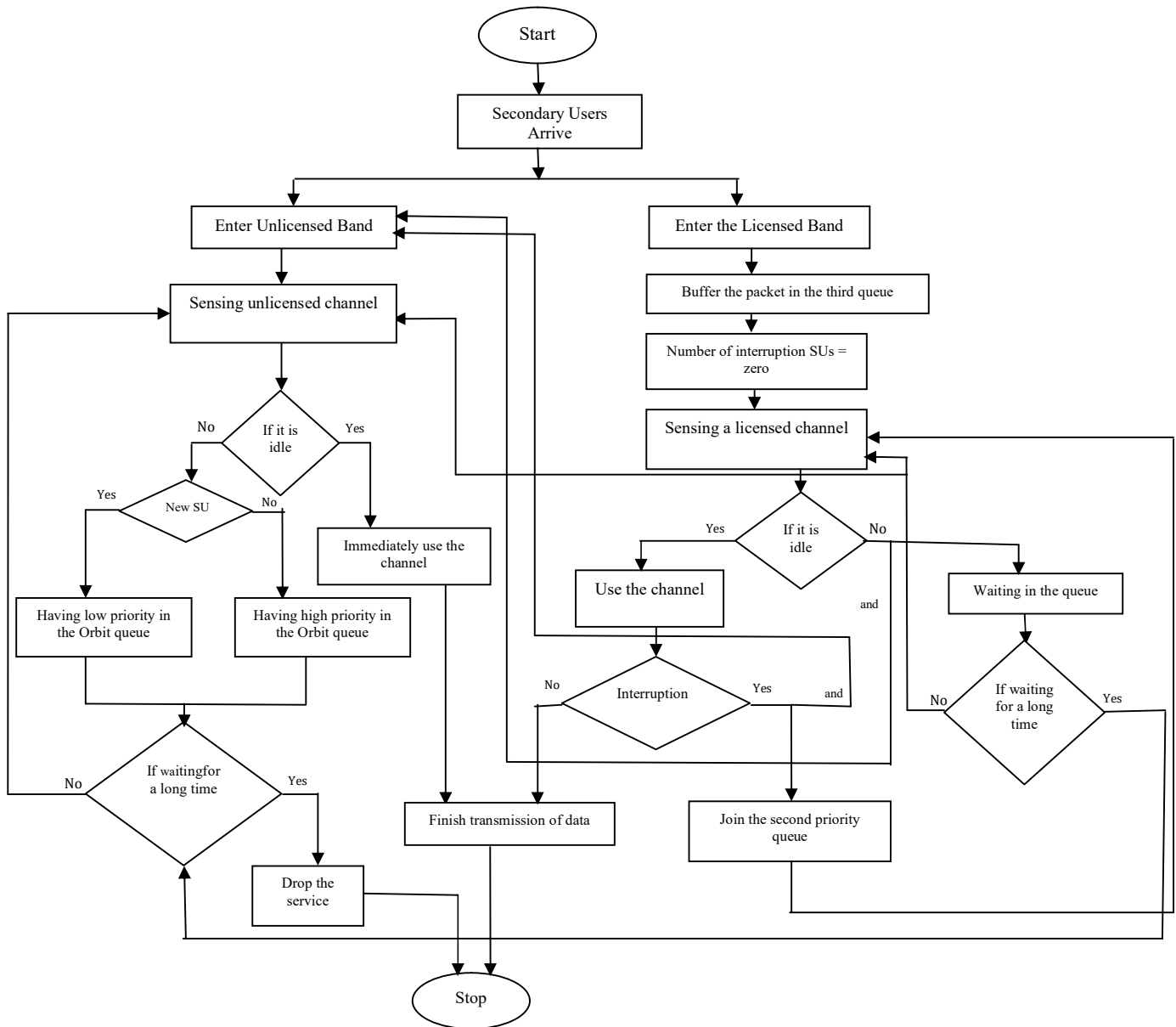


Fig. 2. Flowchart of the handoff process of the secondary users

2. Average Delay

Average delay is defined as the average time taken for a packet to be transferred from the source to the destination. It's preferable to retain it as minimum as possible [12].

$$\text{Average delay} = \frac{\sum \text{packets (Arrival Time - Sent Time)}}{\text{Number of packets}} \quad (2)$$

3. Average Throughput

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4. Average Delay

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$$\text{Average delay} = \frac{\sum \text{packets (Arrival Time - Sen Time)}}{\text{Number of packets}} \quad (4)$$

5. Channel Utilization

Channel Utilization is defined as how efficient the channels are being used. Or it can be defined as how much time the channel is being used from the beginning of the simulation till its end.

$$\text{Channel Utilization} = \frac{\sum \text{Time the chann is used}}{\text{Simulation End Time - Simulati Start Time}} \quad (5)$$

5. SIMULATION RESULTS

A performance evaluation of the spectrum handoff process with priority classes was carried out for reactive decision schemes by using simulation scenarios. Due to their importance, the waiting time delay, queuing length and channel utilization were taken into account when evaluating the spectrum handoff scheme. The results of the simulation of the handoff model (Model-1) proposed in Section (2) above are obtained with MATLAB simulation software. These results are compared with the results for the model (Model-2) proposed in Chapter.6 of [6], where SUs are given second priority for licensed channels and when interrupted by arrival of PUs they join the unlicensed channels orbit queue and contend for a channel therein.

a) Channels utilization

Results have shown that licensed channels utilization in the proposed model (Model-1) is 20% lower than in the model of [6] (Model-2), but the reduction is compensated by an increase in utilization of the unlicensed channels by approximately the same percentage.

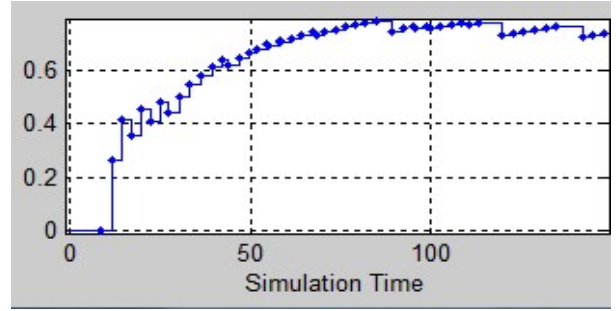


Fig. 3. Channel Utilization for Model-1 in licensed Band

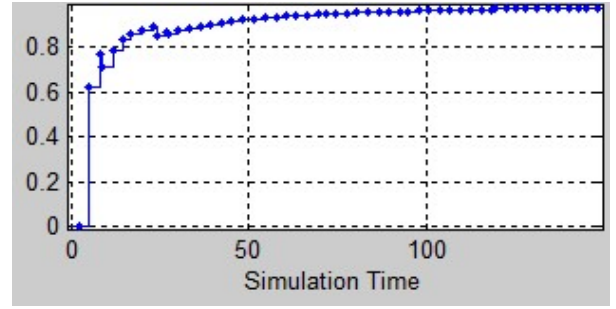


Fig. 4. Channel Utilization for Model-2 in licensed Band

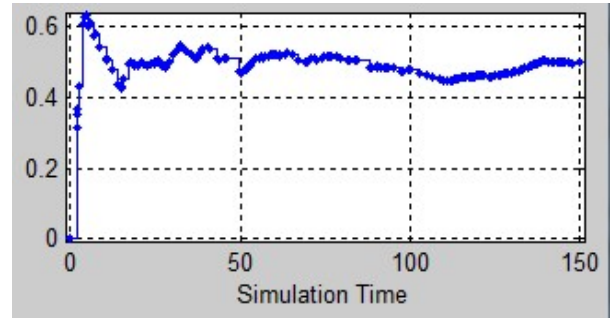


Fig. 5. Channel utilization for Model-1 in Unlicensed channel.

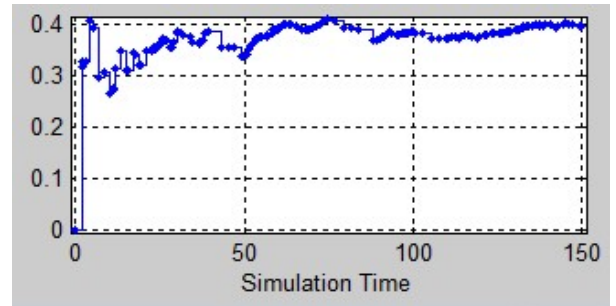


Fig. 6. Channel Utilization for Model-2 in Nlicensed Band.

b) Waiting time in queues

In licensed band the First priority queuing delay for the PU in Model-1 is lower than in Model-2 as shown in Fig. 7 and Fig. 8.

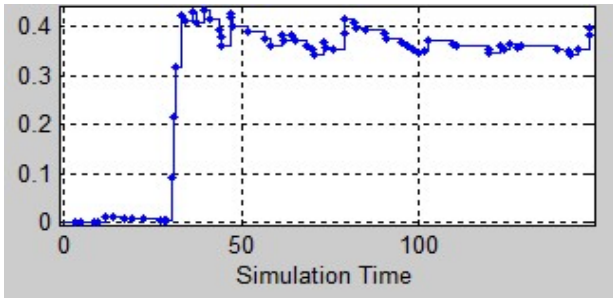


Fig. 7. Waiting Time Delay of Model-1 for First Queue.

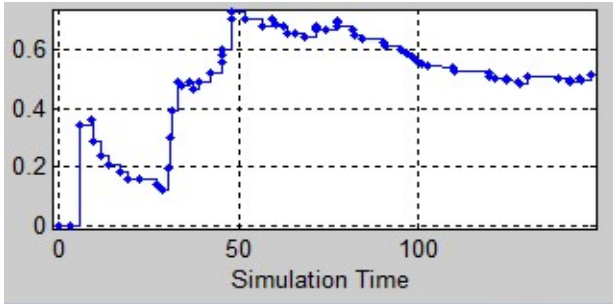


Fig. 8: Waiting Time Delay of Model-2 for First Queue.

In Model-1 the Second-queue is just for the interrupted users and in Model-2 it is for interrupted and new users. As shown in Fig. 9 and Fig. 10, the waiting time for interrupted users in Model-1 is much lower than in Model-2 which leads to decrease the probability of dropping the service.

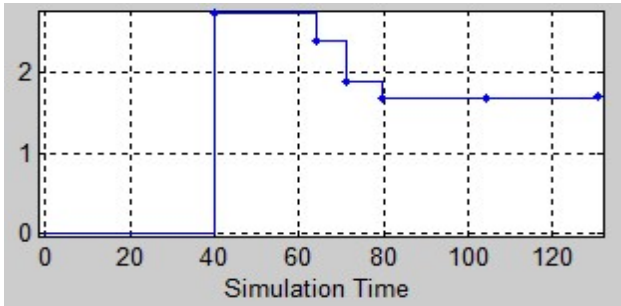


Fig.9. Waiting Time delay of Model-1 for Second Queue in licensed channel.

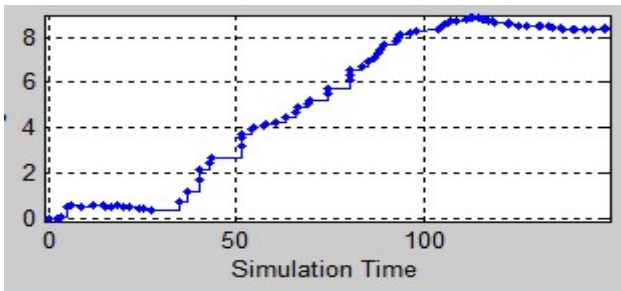


Fig. 10. Waiting Time Delay of Model-2 for Second Queue in licensed Channel.

Fig. 11 shows that waiting delay of the third queue in Model-1 is lower than the waiting delay in second queue. If the number of interrupted users is high, SU must switch to unlicensed band instead of waiting for a long time. So, this leads to decrease the wasted time in queue.

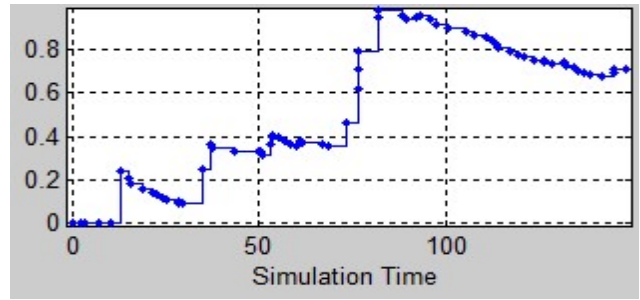


Fig. 11. Waiting Time Delay of Model-1 for Third Queue.

Fig.12 and Fig. 13 show the waiting time in priority queue for the unlicensed band in the two models. The waiting time of the priority queue in Model-1 is higher than in Model-2. Model-1 assumed that interrupted and new SUs assigned the orbit queue instead of waiting long time in licensed band. So, number of users assigned orbit queue is higher than in Model-2.

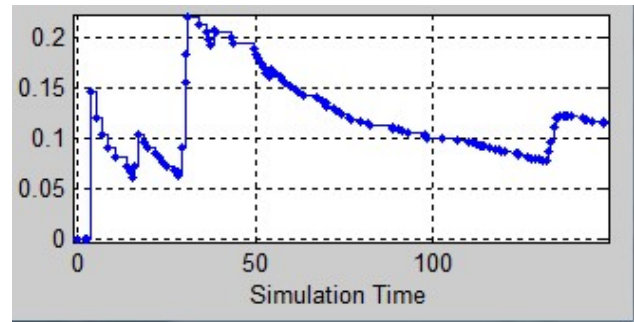


Fig. 12. Waiting Time Delay of Model-1 for Unlicensed Queue

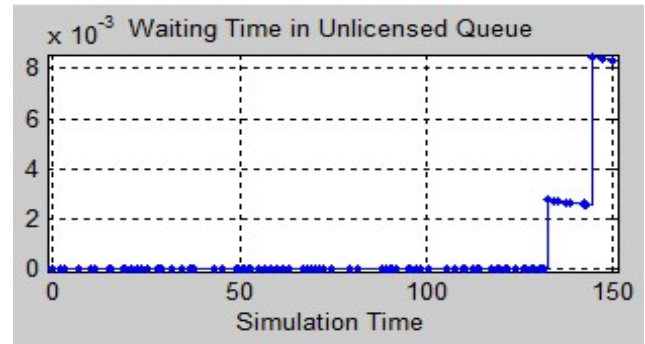


Fig. 13. Waiting Time Delay of Model-2 for Unlicensed Queue

c) Queuing Length

Increasing the queuing length, means increasing the user waiting time, which will lead to increasing the probability of user being interrupted before finishing transmission.

Increasing the number of interruptions will lead to more retransmission resulting in more transmission overhead, i.e. more time to transmit a packet successfully, leading to low throughput.

Fig. 14 and Fig. 15 show that the queuing length of the First queue (PU queue) in Model-1 is shorter than in Model-2.

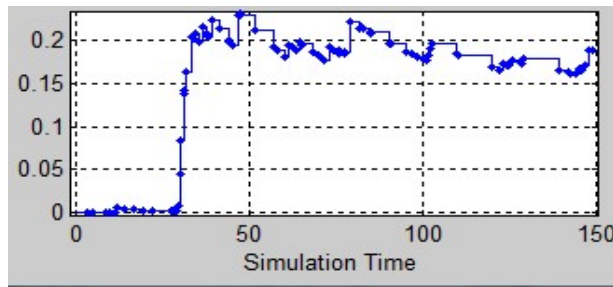


Fig. 14. The Queuing Length for the First Queue in Licensed Band for Model-1

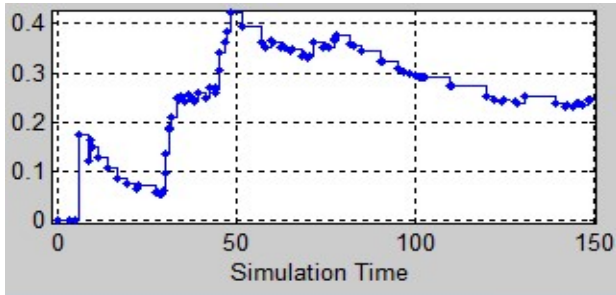


Fig. 15. The Queuing Length for the First Queue for Model-2

Fig. 16 and Fig. 17 show that the queuing length of the Second-queue (Handoff queue) in Model-1 is shorter than in Model-2. Interrupted users have shorter waiting transmission time than in Model-2.

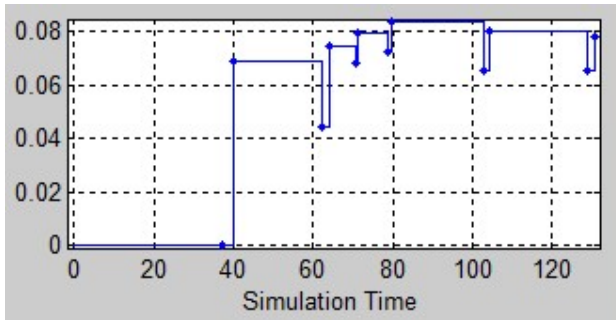


Fig. 16. The Queuing Length for the Second Queue in Licensed Band for Model-1

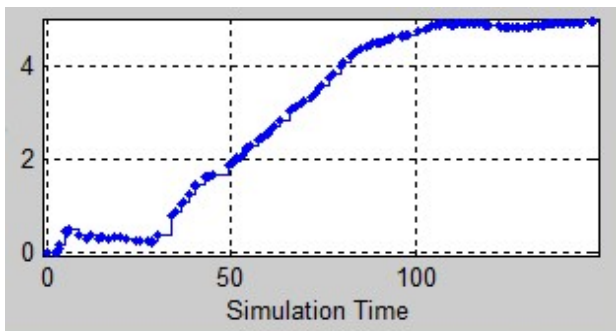


Fig. 17. The Queuing Length for the Second Queue in Licensed Band for Model-2

The third queue has a little waiting delay so; the queuing length will be low as shown in Fig. 18

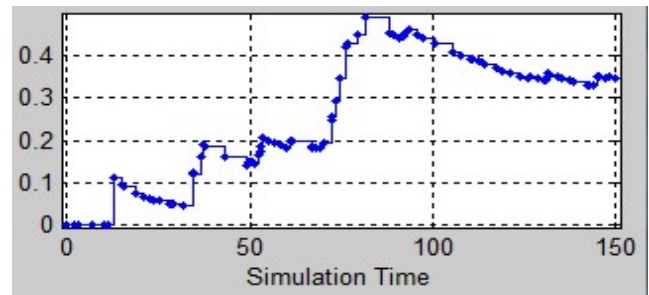


Fig. 18. Queuing Length for the Third Queue in Licensed Band for Model-1

Fig. 19 and Fig. 20 show the queuing length in priority queue for the unlicensed band in the two models. The priority queue for the unlicensed channels in Model-1 is higher than that in Model-2 because only handoff users compete for unlicensed channels in Model-2 while both new and handoff secondary users do in Model-1.

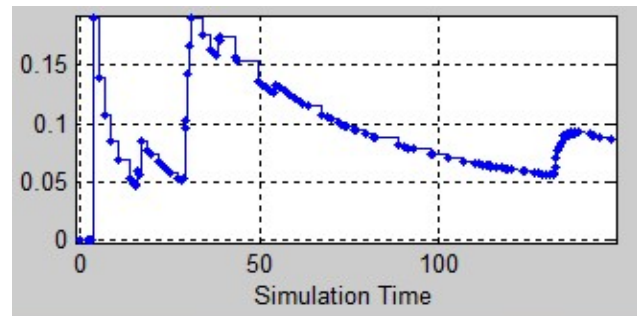


Fig. 19. The Queuing Length for the Unlicensed Queue in Model-1

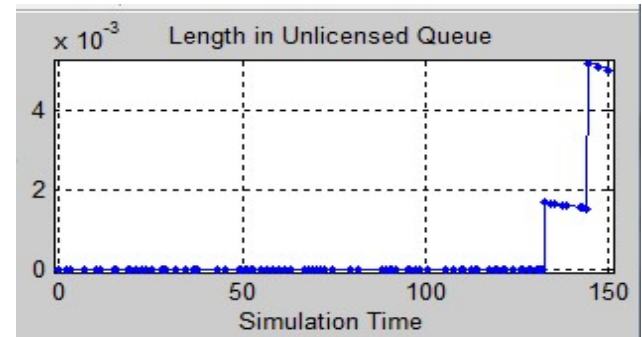


Fig. 20. The Queuing Length for the Unlicensed Queue in Model-2

Tables 1-5 summarize the results and illustrate the comparison between using two priority queues and three priority queues in licensed band.

Table 1 shows that the number of users served in Model-1 with three priority queues in the licensed band are more than the number of users served in Model-2 with two priority queues. The number of interrupted users is much lower for Model-1 than that of Model-2. The differences between the values obtained using the two models highly increase with the increase of number of users. Increasing number of users will lead to increase the interrupt probability; so as the need to retransmit the interrupted users, i.e. the time each user will take from the source to the destination will increase by the

retransmission overhead, so the number of packets arriving per second (throughput) will decrease.

Table 1. Number of users arriving and departing for the two models

	Model -2 [10]	Model1(proposed model)
Users arrive in Licensed band	71	71
Users arrive in Unlicensed band	147	147
Number of PUs arrive in First-queue	71	71
Users arrive in Second-queue	85 (no. of new + Interrupted users in second queue)	2 (no. of Interrupted users in second queue)
Number of all Interrupted users	33	2
Number of new users arrive in Third-queue	-	98
Number of users arrive in Unlicensed queue	90	142

Table 2 and Table 3 show the utilization for the two models in licensed and unlicensed bands. Model-1 shows better utilization in licensed band than Model-2.

Table 2. Utilization of Channel in Licensed Band

Model -2 [10]	Model -1
0.9806	0.5037

Table 3. Utilization of Channel-1 in Unlicensed Band

Model -2 [10]	Model -1
0.396	0.6273

Table 4 shows that there is a slight difference in the waiting time of Model-1 versus Model-2, which means Model-1 served more users than Model-2.

Table 4. Queuing Length and Waiting Time of Queues in Licensed Band.

	Model-2 [10]		Model-1		
Waiting Time (in sec.)	First Queue	Second Queue	First Queue	Second Queue	Third Queue
	0.1495	8.377	0.1495	0.6548	0.02367
Queuing Length	0.1876	4.962	0.1876	0.07141	0.102

Table 5 shows that the waiting delay in Model-1 is higher than in Model-2. The two models consist of interrupted and new SUs but in Model-1 new SUs in licensed band will switch to unlicensed band if the numbers of interrupted users are high. Where in Model-2 the new SUs will wait in licensed band till interrupted users finishes their services.

Table 5. Queuing Length and Waiting Time of Queues in Unlicensed Band

	Model-2 [10]	Model-1
Waiting Time (in sec)	0.008285	0.4951
Queuing Length	0.004978	0.4691

The interrupted secondary users have been given a higher priority to utilize the available unlicensed channel in order to reduce the average handoff delay and improve the network performance.

The results have shown that the proposed scheme improves the average handoff delay and increases the performance of the proposed heterogeneous cognitive network. Model-1 shows that using three queues will decrease the waiting delay for the secondary users and lead to better utilization channel than using two queues like in [6].

Conclusions

The novelty of this paper lies in the fact that we consider the effect of retrial mechanism of SUs in performance modeling. Moreover, the performance of the scheme under different scenarios and various parameters such as total delay and channel utilization has been investigated. The results have shown the performance of the proposed model relative to that of [6].

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