

## Opportunistic Channel Allocation Model in Collocated Primary Cognitive Network

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(Received February 22, 2020; Accepted May 12, 2020)

### Abstract

The growing demand of radio spectrum to facilitate the primary/secondary users in a cellular network is a challenging task. Many channel allocation models, applying cognition, have been proposed to increase the radio spectrum utilization. The proposed model peruses three types of users: primary users (PUs), opportunistic primary users (OPUs), and secondary users (SUs) that use the radio resources in collocated primary base stations. Out of these users, the opportunistic primary users and secondary users may request for handover as per their requirements. The objective of the model is to enhance the radio spectrum utilization by the opportunistic utilization of radio resources by OPUs and by enabling cognitive radio base stations to collect free channel information dynamically. The cognitive radio base station maintains the centralized free channel at collocated primary base stations to facilitate the SUs opportunistically. The proposed channel allocation technique maintains the Quality of Experience (QoE) of the users as well. The performance analysis of the model is done by simulation which diversifies the importance of the proposed model in the view of minimum blocked services.

**Keywords-** Cognitive radio, Channel allocation, Quality of experience (QoE), Secondary base station (SBS), Spectrum handover, Call admission.

### 1. Introduction

The mobile network is experiencing parlous dissemination and exuberantly growth by the development of diverse applications and its uses (Piran et al., 2016). It is evident from Vodafone which showed that 400 petabytes data was used by its customers on their mobile phone from August to October 2015, which is on average twice of 3G on the 4G network. The increasing popularity of multimedia applications leads to huge network traffic and as per recent Cisco prediction, 69.1% of mobile traffic will be occupied for uploading/downloading the content (Cisco, 2013; Piran et al., 2016).

With the growing demand for the radio spectrum, its effective utilization is one of the key concerns in wireless communication. Cognitive radio (CR) has been considered as one of the

propitious technology for solving the spectrum scarcity (Hu et al., 2018; Tragos et al., 2013). The core idea behind CR technology is its dynamic spectrum access capability which can utilize the idle spectrum, called white space, without affecting the rights of the licensed users. CR technology also enables the reuse of available radio spectrum but often has a limiting factor of spectrum reuse because of the interference caused by environmental factors such as noise or maybe other radio transmissions (Tragos et al., 2013).

In Cognitive radio networks, often two types of users exist; primary and secondary. Primary users are licensed users that are assigned the radio channels for a longer time duration. Secondary users (SUs) often do not own the licensed channels and use the radio channels opportunistically by using the CR technology. Based on this, services are also categorized into two; primary and secondary services. Primary services require immediate attention such as making a phone call. Secondary services are usually delay-tolerant such as sending an email, SMS, or performing some upload/download operations.

A reasoning CR is proposed in (Anandakumar and Umamaheswari, 2017) which is an advancement over the traditional CR with no interference. It can automatically determine the permissible limits for the safe transmission of secondary users' services. CR decisions can further be improved by applying some AI-based machine learning techniques on input data in order to recognize the pattern and for composed decisions. Cognitive radio is used for opportunistic utilization of radio resources, where for centralized management of radio resources, Software Defined Networking (SDN) (Seyedbrahimi et al., 2016) is used. SDN has experienced an overwhelming concern towards wired as well as wireless mobile networks (Radhakrishnan et al., 2017). It has emerged as a proficient and adaptable substitute for data network management including wireless local area networks (WLAN).

This work proposes a CR based channel allocation model in the collocated primary network. In this, we have used a new concept of opportunistic primary users' beside the existing primary and secondary users to minimize the call block and enhance the radio spectrum utilization. Opportunistic primary users will use the radio channels in other primary networks also if the channel is not available in their own network. This OPU's opportunistic utilization of other primary networks minimizes the primary blocked calls and enhances the overall radio spectrum utilization.

The outline of the paper is organized as follows. Section 2 discusses a few recent related works of channel allocation in CR networks. The problem statement along with the notion of primary users, opportunistic primary users, and secondary users are given in section 3. Section 4 discusses the proposed model and explains it with the help of a flowchart. The algorithm, for the proposed model, is also detailed well in this section. The performance study of the proposed model is done with a proper analysis by carrying out simulation experiments in section 5. Section 6 concludes the work.

## **2. Related Work**

For the last few years, there is stupendous growth (Seyedbrahimi et al., 2016) in the popularity of portable devices. This results in huge demand for the wireless spectrum, usually a limited resource. Few techniques, based on fixed and dynamic channel allocation have been projected in the past. To increase the radio spectrum utilization further; a few CR based models have also been developed that apply the Cognitive radio concept. Some of these works are as follows.

A cognitive radio-based spectrum allocation model, given by Han et al. (2018), is a multi-objective optimization model that addresses the issues concerning utilization and network throughput. The model intends to maximize the spectrum utilization by concurrent transmission on the channel. It is well demonstrated that cognitive radio is one of the technologies which could make full use of the radio spectrum and reduce the spectrum scarcity problem.

Multi-objective based resource allocation in the cellular network always has been a challenging task. A hybrid optimization-based model (Bharathi and Jeyanthi, 2018) has been proposed in a cooperative cognitive radio network (CCRN) to handle issues such as load balancing, PSO based energy-efficient cluster formation, multi-factor differential evolution for prioritization of traffic levels and modified gravitational search algorithm for resource allocation throughput. It is shown that hybrid CCRN (HCCRN) performs well and utilizes the radio spectrum quite well.

In traditional wireless networks, communication begins only when the required bandwidth is available. A model is given by Bhattacharya et al. (2015) in which, their proposed channel allocation technique overcomes the limitations of contiguous bandwidth allocation in the cognitive radio network. This technique is based on the utilization of many non-contiguous channels whose bandwidth is smaller than the required bandwidth but collectively is equal to or more than the required bandwidth. It is demonstrated that their proposed technique can accommodate around 96% of the traffic load and also is able to allocate the channels in lesser time.

Secondary users (SUs) use the licensed channels of primary users opportunistically in a conventional cognitive radio network but are interrupted on the arrival of the licensed users. To compensate, a semi-cognitive radio network paradigm is proposed by (Shafiq et al., 2017). In this, a constraint is imposed on the PUs which allows PUs to explore all free channels available in the network before interrupting the SUs. A game-theoretic approach is proposed to converge into a stable equilibrium state.

In any cognitive radio network, an effective spectrum assignment is a challenging task. If a multi-channel selection based spectrum assignment scheme is done then secondary users can enhance the network throughput by the utilization of multiple channels. A model is given by Wei and Hu, (2018), in which a fair multi-channel assignment scheme is proposed for cognitive radio networks. Through simulation, it is observed that a fair multi-channel assignment scheme results in a good tradeoff throughput and fairness of spectrum assignment. Though the model has applied the CR concept but no cooperation with other primary networks is suggested towards further possibilities of improvement in radio spectrum utilization.

A multi-lending based radio channel allocation model is given by Singh and Vidyarthi (2019a) in which a channel may be given to more than one neighbor ensuring no co-channel interference. In the model, services are considered into two categories; real-time and non-real time used by primary and secondary users respectively. Cognitive Radio enabled the opportunistic utilization of licensed channels by secondary users which enhanced the radio spectrum utilization and minimized the call blocking and dropping services.

Cognitive radio has enabled opportunistic utilization of the licensed channels based on the primary user's behavior. A QoS provisioning for a heterogeneous services-based model is given by Ali et al. (2020) in which priority-based secondary users use the licensed channels

opportunisticly. This model aims to minimize the call blocking probability of high priority SU calls while maintaining a sufficient level of channel utilization.

A fuzzy logic-based model for efficient channel utilization is given by Ali et al. (2019). It is stated that cognitive radio technology is a promising extrication for effective radio spectrum utilization. Cognitive users/secondary users opportunisticly exploit the white spaces available in a licensed spectrum and immediately releases the channel on sensing the appearance of the primary users.

A model is given by Hasan et al. (2016) which minimizes the secondary user's interference to the primary networks. It also optimizes the cost paid by secondary users. A revenue-based mechanism is used to accommodate the number of secondary users by applying the particle swarm optimization (PSO) (Singh and Vidyarthi, 2015) and Genetic Algorithm. At the same time, primary network policies are respected. Another revenue-based model is given by Singh and Vidyarthi (2019b) that considers the revenue aspect along with the concept of penalty on the service providers for the dropped services.

It has been observed that any of the above-discussed models do not consider the requirement based channel allocation which may affect the Quality of Service (QoS). The model, proposed in this work, addresses the channel allocation problem for the CR network considering the bandwidth requirement by the services. It also uses the concept of collocated primary networks to enhance radio spectrum utilization.

### 3. The Problem

Most of the proposed models, in the literature, have applied the diverse cognitive approaches for channel allocation. Many of these consider two categories of services; real-time and non-real time with different priorities (Singh et al., 2016; Vidyarthi and Singh, 2015). Further, primary and secondary services are classified as follows; primary services are real-time in nature while non-real time services are secondary services. Few other models such as GA based (Singh et al., 2017) and the pricing based (Singh and Vidyarthi, 2019b) also categorized the services into real-time and non-real time services.

In general, primary and secondary requests reaches to the service providers and utilizes the channels opportunisticly using the Cognitive Radio concept. Although CR has increased the utilization of radio spectrum to some extent, the possibility still exists for better utilization and therefore, this issue is still relevant for the researchers to explore further spectrum utilization.

The proposed model considers two categories of services; real-time and non-real time. Real-time services are delay-sensitive while non-real time services are delay tolerant. This model also considers three kinds of users; primary users (PUs), opportunistic primary users (OPUs), and secondary users (SUs). As mentioned earlier, Primary users are the licensed/privileged users whereas secondary users are the one who uses the radio resources opportunisticly. The third category of users, considered as OPUs, uses the radio spectrum of other primary networks opportunisticly. In case of interruption, by the primary users of the same network, maybe shifted to their own primary network by performing the handover.

Figure 1 depicts three collocated primary radio base stations (PRBS) of different primary networks serving their primary user's requests. CR base station (secondary base station) is

equipped with the sensing ability to collect the free channel information from all the primary radio base stations. And these free channels are being used by SUs and OPUs opportunistically. Opportunistic primary users (OPUs) are those primary users who are using the channels opportunistically in other primary networks.

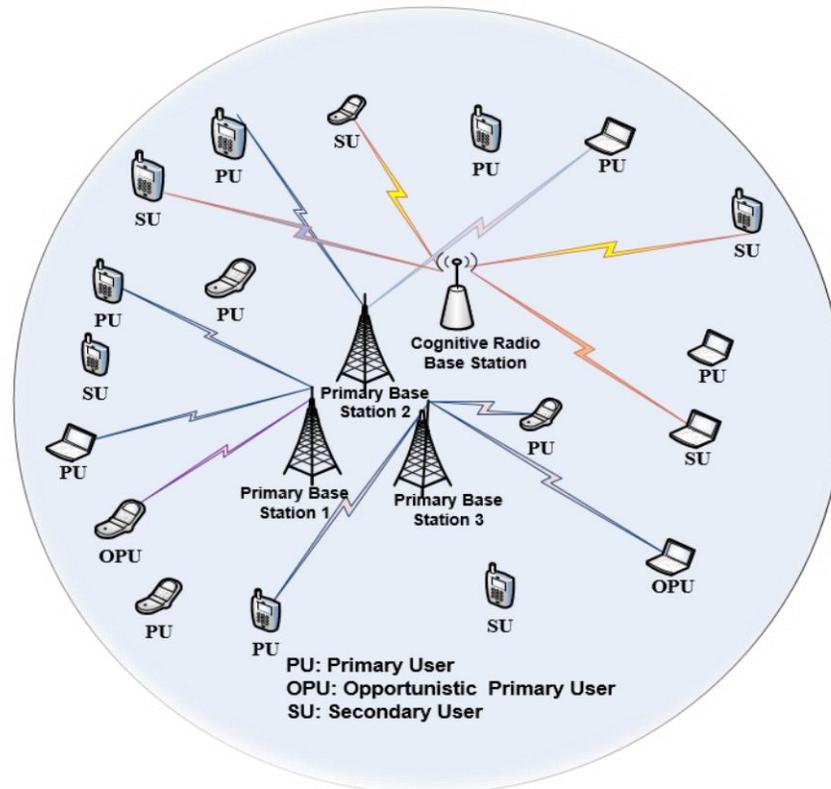


Figure 1. Primary and cognitive communications in collocated PBS

The proposed model aims to increase the utilization of the radio spectrum by allocating the channels for the services' requirement. The model applies the opportunistic utilization of radio resources by other primary users as opportunistic primary users.

#### 4. The Proposed Model

In the proposed model, it is considered that the primary user has the requirement of both delay-sensitive and delay-tolerant services while secondary users have only non-real time (delay-sensitive) services. While falling short of a channel, the primary users can explore other primary networks (owned by some other service providers) to complete their services. When a primary user is running its services in other networks, it will be categorized as the opportunistic primary user.

Let there is  $N$  number of primary networks with their base stations to handle primary requests. For secondary requests, there will be a specialized secondary base station that can locate the free

channels of each primary network. The secondary base station allocates the channels to the secondary users for opportunistic utilization.

Each channel has its specified capacity and it is allocated to the primary/secondary users considering their bandwidth requirements for their services.

The notation and symbol, used in this work, have been listed in Table 1.

Table 1. Notation and symbol

$C_i$	Channel Id of $i^{th}$ Channel
$PR$	Primary Request
$SR$	Secondary Request
$PU$	Primary User
$OPU$	Opportunistic Primary User
$SU$	Secondary User
$RTS$	Real-Time Service
$NRTS$	Non-Real Time Service
$SBS$	Secondary Base Station
$BW_c$	Channel Bandwidth

#### 4.1 Service Vector

Service vector maintains the running status of various PUs, OPUs, and SUs status in terms of real-time and non-real time services.

Table 2. Service vector

Channel id	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$C_6$	$C_7$
Channel Bandwidth (kbps)	219	237	217	223	225	140	212
Service Time (s)/Size (Kb)	169 kb	1523 kb	2	1	3	836 kb	900 kb
Service Category	NRTS	NRTS	RTS	RTS	RTS	NRTS	NRTS
User Category	PU	PU	PU	PU	OPU	OPU	SU

Table 2 shows the running status of channels for  $C_i$  ( $i = 1 \dots 7$ ). The second row, in the table, depicts the bandwidths of the channels, the third row represents the size/time required by the primary and the secondary services e.g  $C_2$  requires 1523 Kb size to upload or download while  $C_3$  requires 2-time units to complete the service. The third row in the table shows that  $C_5$  and  $C_6$  has the service time and service size (kb) respectively which shows real and non-real time. The fourth row represents the service category i.e. real-time or non-real time service. The last row of the table indicates the user's category; a primary user, an opportunistic primary user, or a secondary user. OPU is the user of other service providers. For example  $C_5$  and  $C_6$  are running OPU services, real-time and non-real time respectively.

#### 4.2 Spectrum Handover

Spectrum handover is the process of switching from one channel to another as per the requirement. In this model, the opportunistic primary user (OPU) will participate in the handover operation. It is because OPUs will be using the channels of other primary networks. It is also

possible that OPUs will be interrupted to release the channels for the primary users that belong to that particular network. In this case, OPUs will be migrated back to their own network. In case the channel is not available in their own network and the nature of the service is non-real time then OPU status will be stored in interrupted service vector and will be resumed on the availability of the channels. Otherwise, if OPU is using a real-time service, it will simply be dropped.

Whenever a primary network falls short of channels to facilitate its licensed users, it will interrupt the low priority serving SUs first. Otherwise, it will interrupt the OPUs as stated above. This mechanism may increase the radio spectrum utilization and minimize the drop/block rate of primary services.

### 4.3 Update Channel Status

Channel status information will be updated whenever a channel becomes free or occupied.

$$Service_{time/size} = \begin{cases} Service\ time - time, & \text{if } RTS \\ Service\ Size_{upload/download} - time * BW_c, & \text{Otherwise for } NRTS \end{cases} \quad (1)$$

Service status of both real-time and non-real time services will be updated as given in equation 1. If the service is real-time then it will be delay-sensitive and will require some time to complete. If the service is non-real time, it will be in terms of size (upload/download). After the completion of the service, the channel will be released and will be returned to the free channel list of the respective primary network.

### 4.4 The Flow Chart

The flow chart of the proposed model, which is self-explanatory, appears in Figure 2.

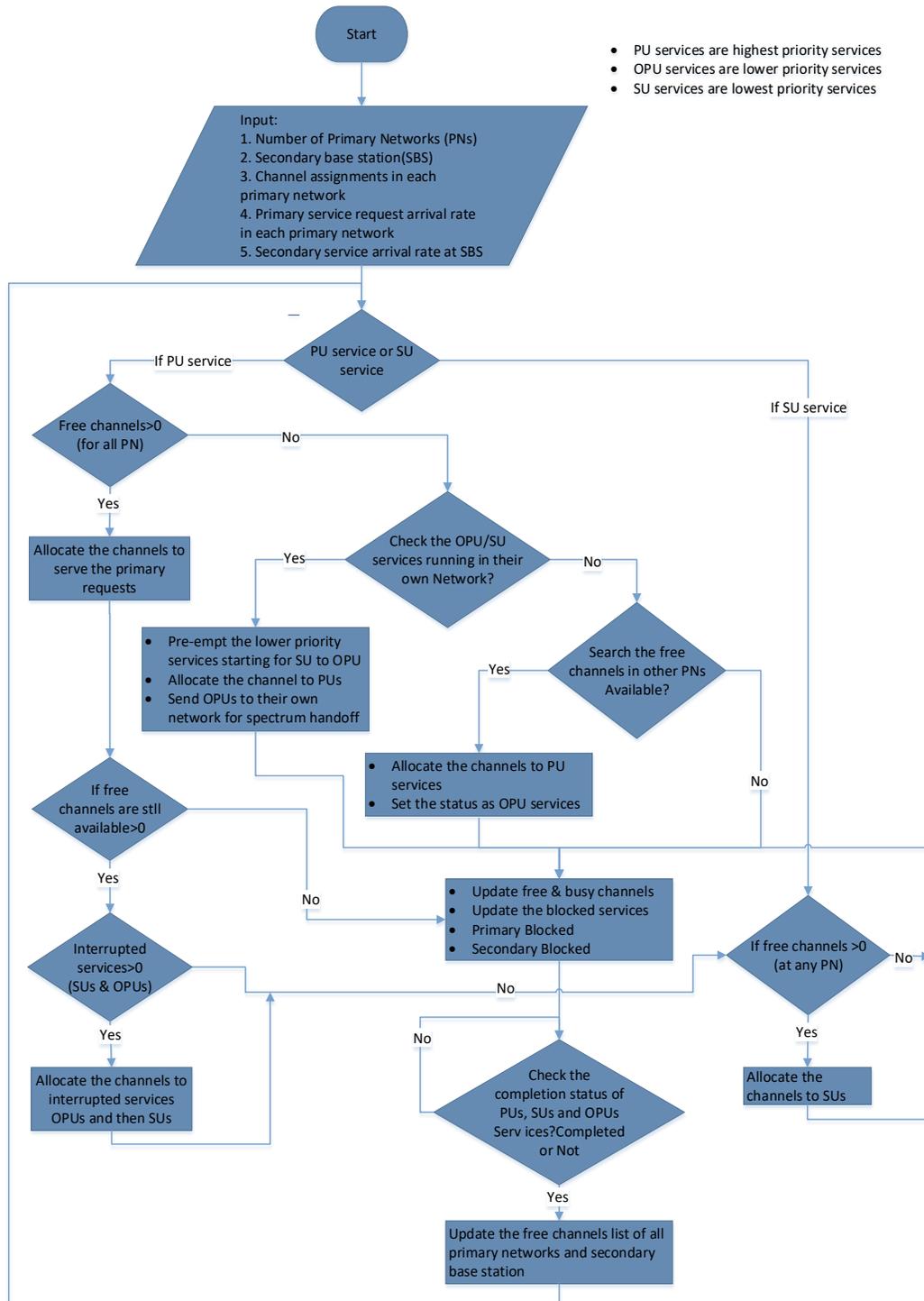


Figure 2. The flow chart

## 4.5 The Algorithms

The algorithm, of the proposed model, is as follows.

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### Algorithm: Cognitive Channel Allocation

**Input:** *Number of Primary Networks, SBS, Channel Assignment in each primary network, PSRAR in the primary network, SSRAR at SBS. PSRAR is the primary service request arrival rate and SSRAR is secondary service request arrival rate.*

**Output:** *Primary blocked services, Secondary blocked services, Opportunistic dropped services*

1. *Set the channels bandwidth*
2. *Set the value of TET*      ▷ *TET: Total execution time of the experiment.*
3. *time* ← 0
4. *while time* ≤ *TET* *do*
5. *Classify the Primary and Secondary services*
6. **For** *each primary network*
7. **If** *free\_channels* > 0
8. *Then allocate channels to primary users services*
9. **elseif** *check the running status of OPUs and SUs*
10. **If** *SUs or OPUs are running then*
  - a. *preempt the lower priority services from SUs to OPUs*
  - b. *Send OPUs to their own network and SUs to interrupted services*
  - c. *allocate the channels to PUs*
11. **else** *search the channels in other primary network, if available*
  - a. *then allocate the channel to PUs*
  - b. *Set the service status as OPUs*
12. **end**
13. **else** *go to step number 17*
14. **end**
15. **If** *free<sub>channels</sub>* > 0      ▷ *In any primary network*
  - a. *Then resume the interrupted services if any otherwise serve the secondary services*
16. *Endif & endfor*
17. *update the free and busy channels*
18. *update the primary and secondary blocked*
19. *check the running status of services if completed then*
  - a. *Release the channels*
  - b. *Update the free channel list*
20. *time* ← *time* + 1
21. **end while** *loop*

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In the above algorithm, line number 1 to 3 initializes the bandwidth of the channels so that bandwidth requirements of the requests can be considered. The total execution of the algorithm is being set in line number 2 to measure the outcome after completion. The timer is initialized to zero to begin the algorithm.

Line number 5 classifies the requests to primary and secondary. Line number 6-8 allocates the channels to the primary requests in each primary network.

Inline number 9-14, if free channels are not available SUs and OPUs will be suspended to facilitate the PUs. Suspended SUs information will be stored in the Interrupted Service Vector to resume later on after the availability of the channels. Suspended OPUs will be shifted to their own primary network.

Line number 15-16 serves the interrupted services and allocates the channels to SUs as per the availability of the channels. Free channel and busy channel information will be updated in line number 17 while line number 18 stores the status of primary and secondary blocked services.

After checking the status of channels to free or occupied, in line number 19, the free channel list will be updated. The algorithm will iterate until its termination criteria are satisfied.

## 5. Performance Analysis

In this section, the performance of the proposed model has been analyzed through simulation. The parameters, used for the performance evaluation have been discussed. In order to conduct the experiments, few assumptions have been laid down.

### 5.1 Performance Evaluation Criteria

The following metrics have been used to evaluate the performance of the proposed opportunistic channel allocation model.

Service request arrival, in the cellular network, is random and follows the Poisson distribution model with some specified mean arrival rate. In the model, primary and secondary requests have been assumed to follow the Poisson distribution (Yawada and Dong, 2019).  $P_n(t)$  denotes the probability of  $n$  number of request arrivals in time duration  $t$  as indicated in equation 2.  $\lambda$  is the mean arrival rate.

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \quad (2)$$

The call holding time of the service request follows the negative exponential distribution (Rajaratnam and Takawira, 2001). It has the probability distribution function (pdf) as given in equation 3. In the negative exponential distribution,  $\mu$  indicate the mean service rate.

$$f(t) = \mu e^{-\mu t} \quad (3)$$

In the model, we have assumed that 60% of the primary services will be real-time services and 40% will be non-real time services.

### 5.2 Simulation Results

This section demonstrates the outcomes of the experimentation of the proposed channel allocation model, which is done in MATLAB. The study is performed on the varying number of primary networks for minimizing the number of blocked primary and secondary services. Cells of the network have three types of requests PUs, OPUs, and SUs. The data, used in the experiments, conforms to that of (Singh and Vidyarthi, 2019b).

### 5.2.1 On Varying Number of Primary Request

This experiment is carried out to observe the performance of the primary requests on varying requests arrival rates. The input parameter of the experiment is indicated as follows: the number of channels per network is 10, mean arrival rate of each primary requests is 5, secondary request arrival rate on the cognitive base station is also 5, the service time of real-time services are in the range of 3 to 5 time units and non-real time services are in the range of (100kb to 2000kb). The experiment is carried out for a 500-time unit and the results of the last 10 iterations are taken i.e. after the system is steadied.

Figure 3, shows that requests are being served even on the high mean arrival rate 5. When the mean arrival rate is diminished to 4, blocked requests are reduced quite significantly as shown in Figure 4.

Figures 5 and 6 show the result of further decreasing mean arrival rates (3 and 2) respectively. The observation from Figure 5 shows the improvement in serving the requests. Figure 6 shows that blocked requests are almost nil.

The overall observations from Figures 3-6 show that when the mean arrival rate is diminished then the number of blocked requests is getting reduced. After decreasing the mean arrival rate to a certain level, almost all the requests are being served and blocked requests are negligible.

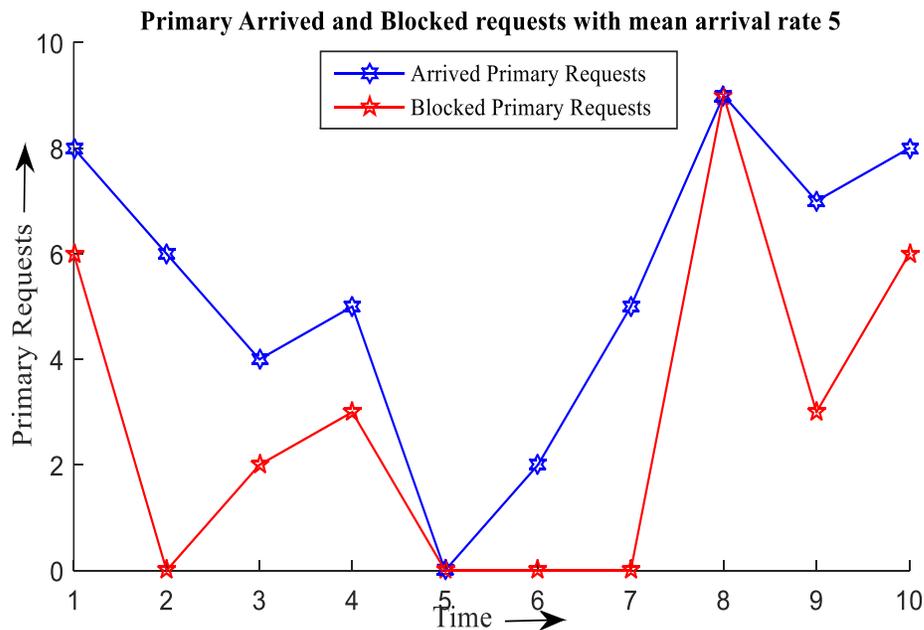


Figure 3. Primary arrived and blocked requests ( $\lambda = 5$ )

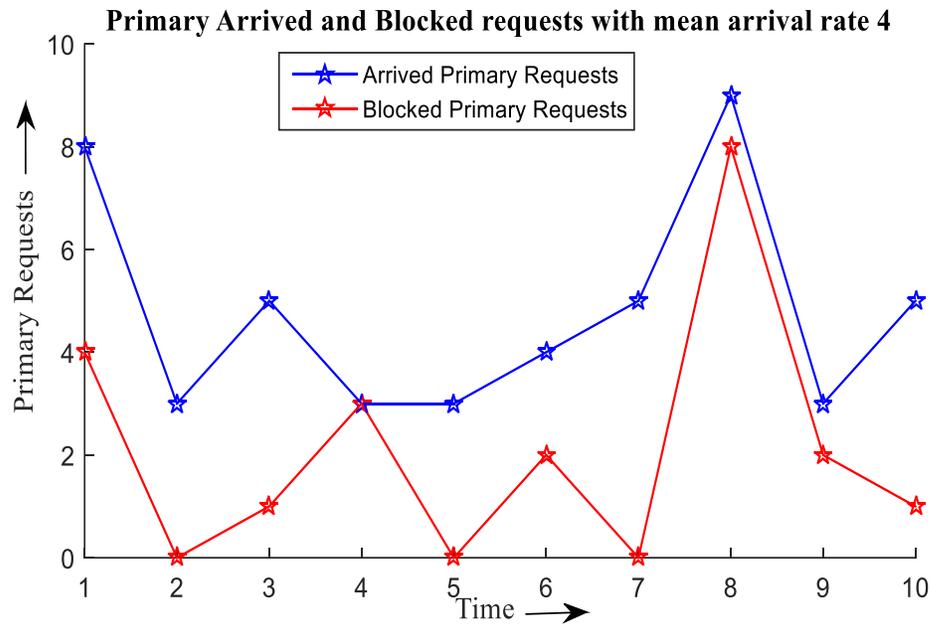


Figure 4. Primary arrived and blocked requests ( $\lambda = 4$ )

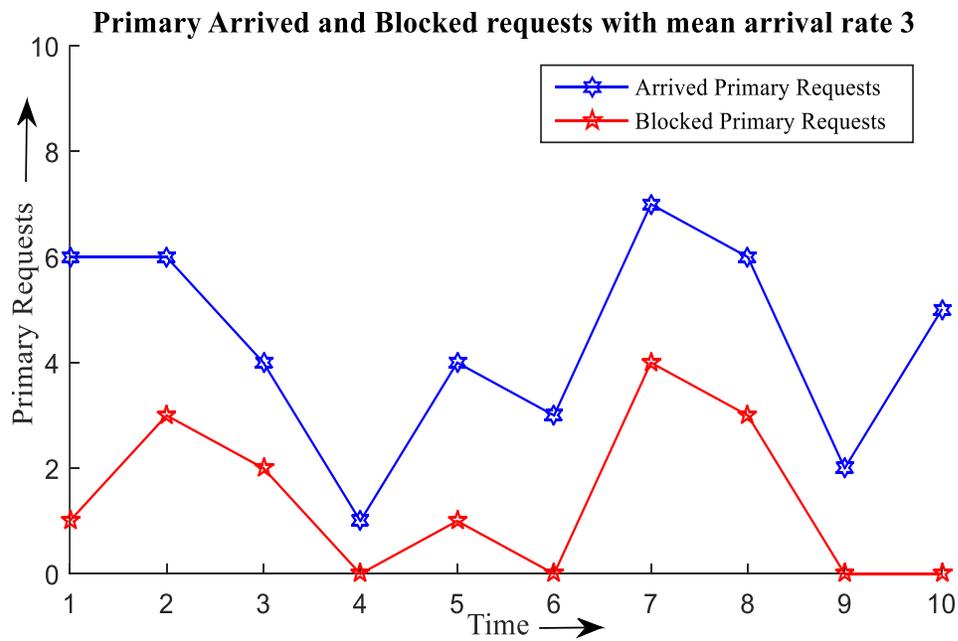


Figure 5. Primary arrived and blocked requests ( $\lambda = 3$ )

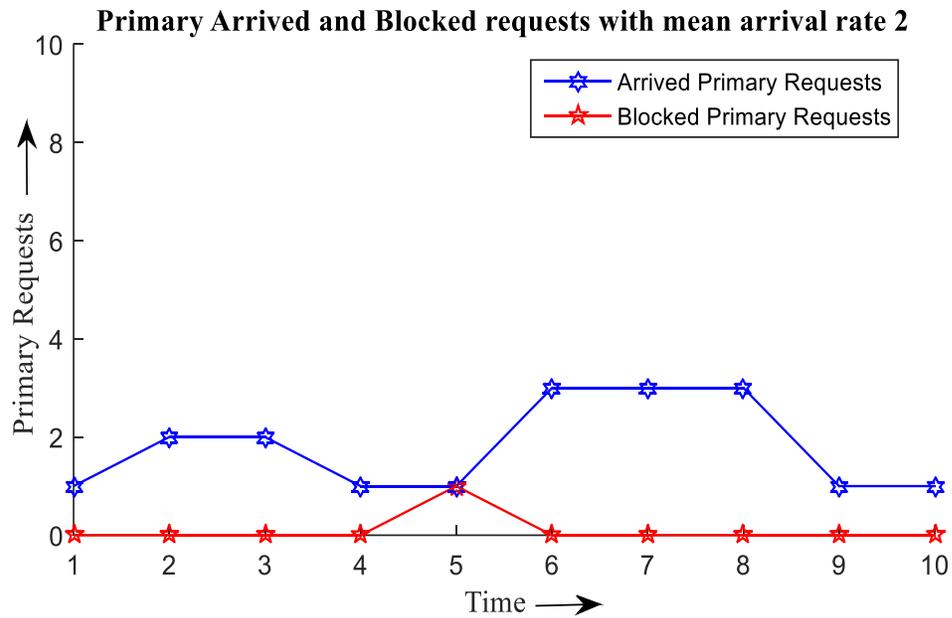


Figure 6. Primary arrived and blocked requests ( $\lambda = 2$ )

### 5.2.2 On Varying Number of Channels with Fixed Arrival Rate

This experiment is carried out to test the average secondary blocked requests. The input parameters for the experiment are as follows: The number of primary networks is 5, primary requests mean arrival rate in each network is 3 and the mean arrival rate of secondary request is 5. The experiment is carried out for 5000 iterations on a varying number of channels as 10, 15, 20, 25. The output is shown as average blocked secondary requests.

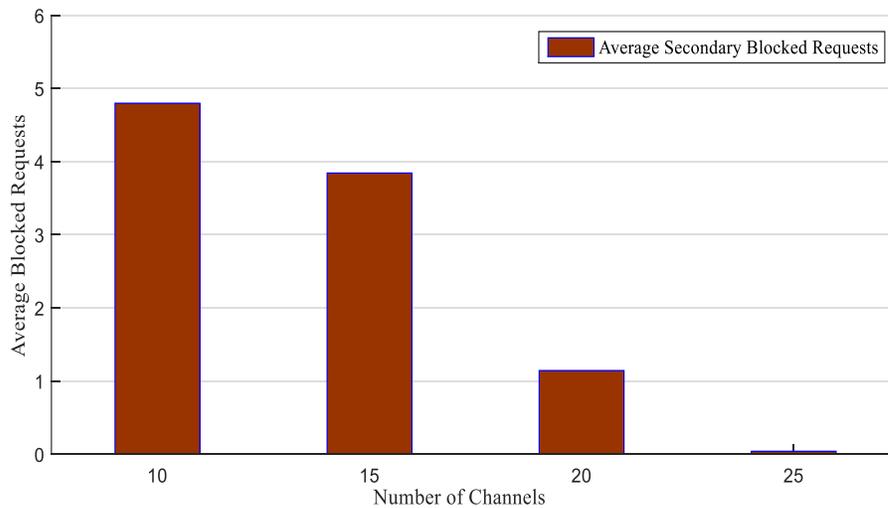


Figure 7. Average secondary blocked requests on the varying number of channels

Figure 7 confirms that secondary requests are also getting served, though opportunistically, very well. It is further observed that on increasing the number of channels in the network, average blocked secondary requests are being reduced. When the number of channels is 25, almost all the secondary requests are being served.

### 5.2.3 On Varying Number of Primary Networks with Fixed Arrival Rate

This section performs another set of experiments to observe the effect on secondary services on a varying number of primary networks. The input parameters are as follows: 10 channels are assigned to each network, the mean arrival rate on each primary network is 2, and secondary requests mean arrival rate is 5. The number of primary networks is varied from 2, 4, 6, 8, 10. The average result of 5000 iterations is taken.

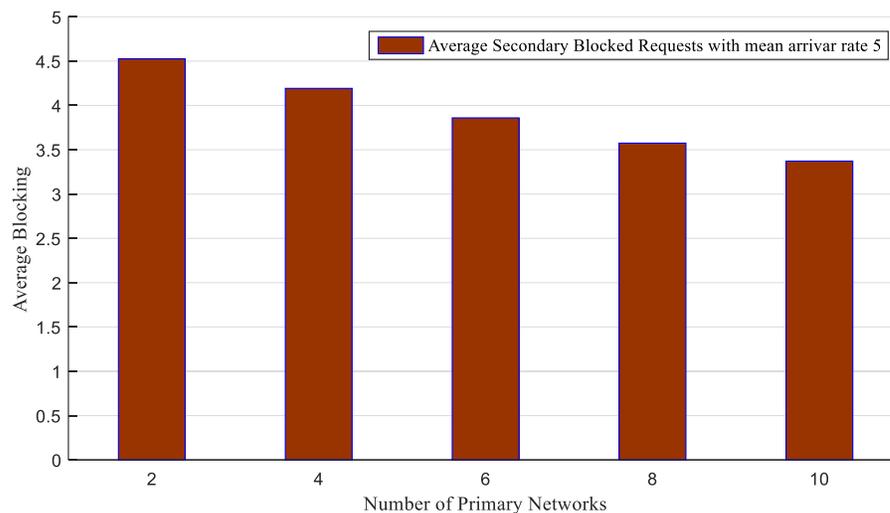


Figure 8. Average secondary blocked requests on a varying number of primary networks

Figure 8 shows that on the varying number of primary networks, average secondary blocked requests are reduced even with the limited number of channels in the network. When the number of primary networks is 10, average blocked requests are quite low.

### 5.2.4 A Comparative Study on Varying Number of Primary Networks

A comparative study has been performed to observe the primary average blocked with and without using OPUs on varying numbers of Primary Networks (PNs). The experiment is carried out to observe the role of opportunistic primary users on average blocked requests. The input parameters for the experiments are as follows: The number of channels per network is 10, the primary service mean-arrival rate is 5 in each network, and the secondary service mean arrival rate is also 5. These parameters remain fixed for all sets of experiments. Average blocking of primary requests has been tested on the varying number of primary networks (PNs); with and without using the opportunistic primary users.

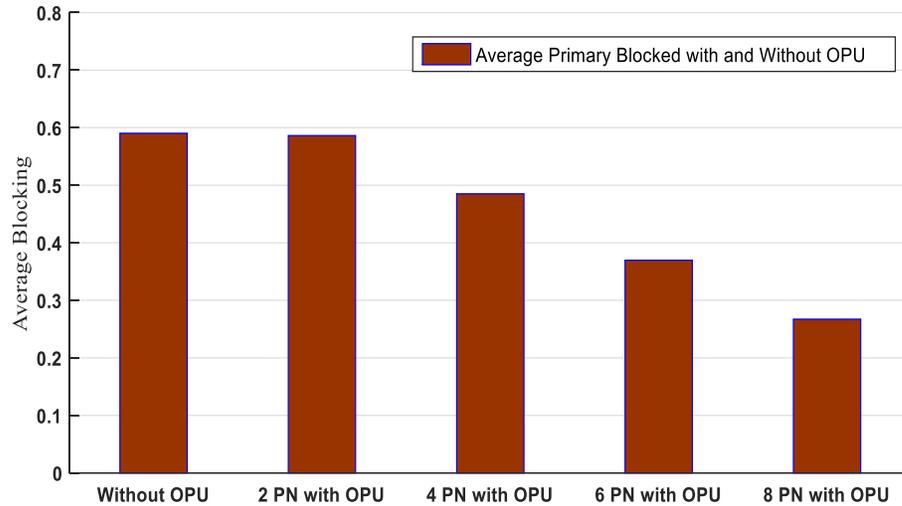


Figure 9. Average primary blocked with and without OPUs

Figure 9 reflects that without using the concept of the opportunistic primary user, average blocked requests are high. On increasing the number of primary networks (PNs) and enabling the opportunistic primary users to use the services opportunistically, average blocked requests are decreased. When the number of PNs is 8, the average blocked requests are significantly low.

### 5.2.5 A Comparative Study on Varying Number of Channels

A comparative study has been performed to observe the primary average blocked with and without using OPUs on varying number of Channels. A set of experiments is performed on varying the number of channels to 10, 15, and 20 to observe the impact of opportunistic primary users. Other input parameters, in the experiment, are as follows: the number of primary networks is 5, primary service mean arrival rate is 5 for each network, and mean request arrival rate on the cognitive base station is also 5. The result, shown in Figure 10, is the average of 5000 iterations.

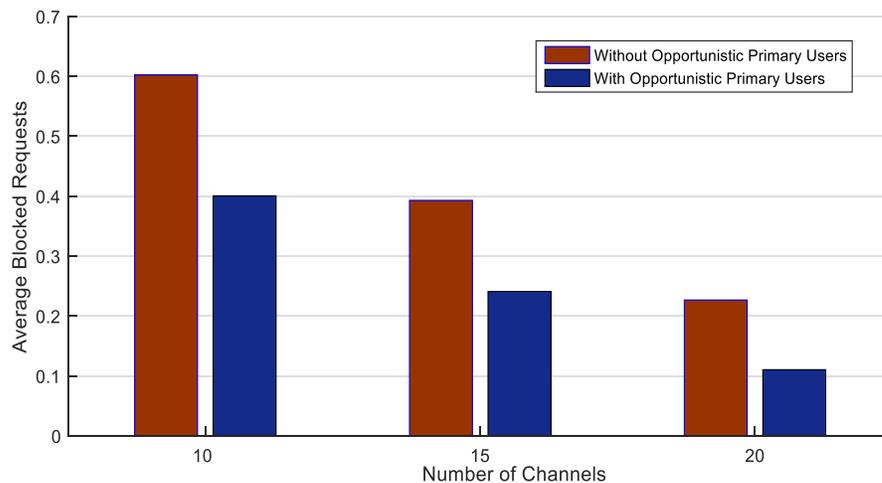


Figure 10. Average blocked requests on the varying number of channels

Figure 10 shows that when primary requests utilize the channels of other primary networks opportunistically, average blocked requests are quite low in comparison to without using the OPU concept. When the number of channels is increased to 20, the average blocked requests of primary services are minimized quite significantly. Figures 9-10 show that opportunistic primary users concept increases the utilization of the radio spectrum and also minimizes the primary blocked requests effectively.

## 6. Conclusion

This model applies the concept of Cognitive Radio to facilitate the Secondary/Cognitive services on the collocated primary network. Services have been categorized into two; real-time and non-real time, which is to be used by three types of users. Primary users and the opportunistic primary users both can use real-time and non-real time services while secondary users will use only non-real time services.

The model has been evaluated by carrying out the number of experiments which depict that when primary users share other collocated primary networks as an opportunistic primary user, the primary users' services are effectively addressed. Also, when the arrival rate of primary services is low then the blocking of the requests is negligible.

The model also studied the performance of the secondary services on the varying number of channels. It is concluded that when the number of channels is increased to a certain level, the average secondary blocked requests are negligible. The performance of the secondary services is also studied on varying numbers of primary networks and is observed to perform very well. Model is also tested with and without opportunistic primary users, which shows that the performance of the model is quite encouraging when it uses the opportunistic primary users to utilize the radio spectrum opportunistically.

The overall study about the proposed model suggests that it can be very well implemented for future communication networks for the channel allocation problem.

### Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

### Acknowledgments

Authors would like to acknowledge the editors and the anonymous reviewers for their useful suggestions resulting in quality improvement of this paper. Also to acknowledge Mahatma Gandhi Central University, Bihar, India, and Indira Gandhi National Open University, New Delhi, India for the support and cooperation.

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