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A hybrid dynamic aggregation and fragmentation cognitive channel allocation model for mobile communication

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Abstract

Cognitive Radio is playing a crucial role to enhance radio spectrum utilization by applying various techniques for real-time and non-real-time services. In this work, we have proposed an aggregation and fragmentation of bandwidth-based channel allocation model which uses the Cognitive Radio concept to allocate the channels effectively. In the model, services are categorized into four heterogeneous classes. Of this, Primary new and Primary handoff services are of real-time in nature while Secondary new and Secondary handoff services are of non-real-time in nature. The network is also categorized into two: fixed network and dynamic network categories to enhance the spectrum utilization and to minimize the call block and call drop. Performance analysis, along with the comparative results, exhibit the effectiveness of the proposed model.

Keywords Cognitive Radio · Channel aggregation · Channel selection · Channel fragmentation · Handover

1 Introduction

The increasing demand of radio spectrum and its limited availability forced the researchers to design better and efficient allocation models for radio resources. As the number of devices, connected to the internet, is increasing day by day and is expected to cross billions, providing smooth radio spectrum access is a real big challenge in the years to come [1, 2].

Dynamic channel allocation and permissible aggregation of the spectrum may prove a key technology to serve the limited spectrum among the increasing number of users. Cognitive Radio (CR) can be used as a key concept to further enhance the radio spectrum utilization at a higher level [2]. CR is an intelligent wireless communication mechanism that is capable of sensing and dynamically accessing radio resources. It shares the resources of primary or licensed users opportunistically or in a negotiated manner among the cognitive users [1, 3, 4]. For this, various models have categorized the services into two; primary and secondary where secondary services can be homogeneous/ heterogeneous [5].

Channel aggregation enables a user to use more than one channel with enhanced bandwidth. In most modern communication systems, channel aggregation is nicely implemented. This is possible only when channel aggregation is done considering orthogonal frequency division multiplexing (OFDM) [6]. Channel aggregation results in enhanced channel capacity. It can improve the quality of service (QoS) especially when a service is running with the least bandwidth. There are two possible variants of channel aggregation; variable channel aggregation (VCA) and constant channel aggregation (CCA) [2, 6]. In VCA, cognitive users use the variable bandwidth which may be the aggregation of more than one channel. Variable channel aggregation is further classified as P-VCA (Probability distribution based VCA) and R-VCA (Residual channels based VCA). Bandwidth of the cognitive users are aggregated with a probability distribution in P-VCA whereas in R-VCA aggregation is on the basis of the number of free residual channels. In CCA scheme, constant bandwidth channels are aggregated which may consist

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of more than one free channels assigned to the primary users [2].

Channel fragmentation (CF) has also been proved to be a better idea to accommodate more number of services. With this approach, it is possible to split a channel into more than one channel to serve the requests with an acceptable quality of service (QoS). At the same time, if the channels are free then they can be assembled to allocate the higher bandwidth to the services. Higher bandwidth will reduce the service duration if the service is of non-real-time nature. However, for real-time services, service duration will not be affected [7].

Quality of Service (QoS) is one of the major concerns for serving the user better. It includes some set of requirements that a user expects from the service provider for a satisfactory service level. From users' point of view, call dropping is highly unacceptable, though, call blockings may be tolerated up to some extent [8, 9]. In general, users in cellular systems have interests in fetching higher bandwidth, flexibility in service provider selection, reliability, security, QoS, QoE (Quality of Experience), and low cost of bandwidth usage. At the same time, service providers are interested in the least complex system, low management cost, scalable, reliable, secure, and a good business model [10].

Channel aggregation and fragmentation can be quite relevant in an advanced LTE standard also for serving the maximum number of users with a decent level of QoS [10–12]. The proposed work uses the channel aggregation and fragmentation concepts, along with the cognitive radio, to serve the maximum number of users with desired QoS/QoE.

The major contributions of this work are summarized as follows.

- It minimizes the call block and call drop by splitting the allocated bandwidth dynamically which also helps in admitting maximum possible service requests/users.
- It increases the spectrum usage by allocating available free bandwidth to the ongoing services in order to improve the QoS.
- It proposes a probabilistic channel allocation for the forced handover of the cognitive services.
- Overall, the model enhances the radio spectrum utilization.

The outline of the paper is as follows. After the introduction in Sect. 1, Sect. 2 highlights a few recent related works. Section 3 defines the problem and explains the proposed model through flowcharts and algorithms. Performance analysis, of the model through simulation experiments, is done in Sect. 4. Finally, Sect. 5 concludes the work.

2 Related work

An effective channel allocation is a key concern for better radio spectrum utilization which is a limited and scarce resource. Many aggregation-based techniques have been proposed, along with a cognition-based technique, for the judicious selection of the radio channels. A few recent works, done in this area, are summarized in this section.

A few heuristic models in [13, 14] have categorized the users' services as real-time and non-real-time services for the judicious utilization of the radio spectrum. Real-time services further are of two types; primary new and primary handoff services. Similarly, non-real-time services are also of two types as secondary new and secondary handoff services. A simple multi-channel lending and borrowing scheme is proposed to enhance the radio spectrum utilization which minimizes the call block and call drop. The study of the model proves its effectiveness in serving the users better than the traditional; fixed and dynamic channel allocation models. A similar type of work is done in [15, 16] which applies a genetic algorithm (GA) to minimize call block and drop of the non-privileged services. A model in [17] introduced a collocated network along with a new variant of primary new services as opportunistic primary new services. This model effectively minimizes the blocking of the primary handoff services.

A dynamic spectrum allocation, in [18, 19], applies the opportunistic channel allocation concept to serve the secondary users in a sender-destination pair. In the model, heterogeneous characteristics of primary and secondary channels are taken care of while allocating the channels. Simulation results exhibit that the model achieves a near-optimum solution with low computation complexity. An availability aware CR-based model is developed in [20], for channel allocation in 5 G network.They have minimized the interference by introducing a novel approach and improved the performance over other contemporary algorithms.

A CR enabled channel selection techniques are used to enhance the radion spectrum utilization in [21, 22]. In [21], channels are grouped together and sensed simultaneously, so that the delay can be minimized and throughput can be maximized for the secondary users. [22] applied the AI based spectrum detection techniques to determine the availability of the licensed channels in order to facilitate the secondary users. The findings of the work, indicate that it detected and allocated the channels effectively.

Channel aggregation has been used as an important tool in [23] to serve the cognitive users in the wireless communication system. The idea is to aggregate the channels to serve the Primary Users (PUs) and the Secondary Users (SUs) in the network. A two-dimensional Markov chain is used and the performance is observed in terms of blocking rate, normalized throughput, and an average latency of the SUs. A pricing scheme is also used by imposing an admission fee on the SU's packets for availing the centralized cognitive channel aggregation-based strategy.

It has been observed that the aggregation of the small fragments of the radio spectrum results in serving the request better. This also enhances the radio spectrum utilization. A dynamic spectrum aggregation-based model in [24] presents a Markov Prediction-based aggregation strategy for multi-user in the multi-relay scenario to ensure the required channel capacity and maximize the network throughput. It works in two steps; (i) prediction of the state of the spectrum, and (ii) applying appropriate aggregation strategy.

To overcome the shortage of wireless radio spectrum, a model in [25] proposed a cooperative cognitive radio (CCR) network. In this, CCR aims to allow the Cognitive Users (CUs) transmission by limiting the Primary Users (PUs) transmission on low power. During transmission, some of the CUs can act as Relay Nodes between PUs and CUs. The model also shows the importance of overlay and underlay using the CCR technique. It is observed that PUs and CUs lead to significant mutual benefits.

Thus in many of the existing works, static channel aggregation and dynamic channel aggregation along with channel fragmentation techniques have been applied. However, they did not consider the bandwidth requirements of the primary and secondary users. The proposed model introduces a hybrid (Dynamic and Fixed) channel aggregation and fragmentation approach by considering the bandwidth requirement of primary and secondary users. The CR concept is applied to provide seamless connectivity to privileged licensed users/primary users. The model not only considers to minimize the call block and call drop of the primary and secondary users but also takes into account their bandwidth requirement.

3 The problem and the proposed model

In this work, four priority levels of heterogeneous services have been considered. Real-time services are categorized into two: primary new and primary handoff services. Non-real-time services are also of two categories; secondary new and secondary handoff services. Preferably, primary services will be served in F-CRN (Fixed CR Network) and secondary services in D-CRN (Dynamic CR Network). During the shortage of channels, primary services may be served in D-CRN by considering the bandwidth requirement and channel fragmentation concepts. Secondary services are having preference over each other while being served in D-CRN but during shortage of channels in D-CRN, even after applying the channel fragmentation technique, secondary handoff services will be served in F-CRN as per the availability of channels.

Table 1 Notation and symbols used

PIC_i	Probability of ith channel for being idle
NI_i	Number of times ith channel was idle
NT_i	Number of trials on ith channel
N_i	ith number of non-reserved channel
R_i	ith number of reserved channel
$D\text{-}CRN$	Dynamic CRN
$F\text{-}CRN$	Fixed CRN
PU_1	Primary new user
PU_2	Primary handoff user
$BW_{SU_i}^{\min}$	Minimum required bandwidth for type i secondary user
$BW_{SU_i}^{\max}$	Maximum bandwidth for type i secondary user
RRS_{size}	Remaining required service (in size)
TRS_{size}	Total required service (in size)

The proposed model, for channel allocation, uses the cognitive radio-based dynamic channel aggregation and channel fragmentation techniques. It also uses the probabilistic channel selection to minimize the handover, especially for low priority services i.e., secondary services.

3.1 Notation and symbols

Table 1 lists the notation and symbols used in this work.

3.2 Probability-based channel selection for spectrum handover

Cognitive users need to perform spectrum handover in order to release the channel for serving the primary users. In this work, we have applied a probabilistic approach [26] to select the best-suited channel for performing the handover operation. For this, the probability of being a channel idle at a time has been calculated as given in Eq. (1). This indicates that the channel will be free at the time of performing the handover.

$$PIC_i = \left\{ \frac{NI_i}{NT_i}, \forall \quad i \in (1, N) \right\} \tag{1}$$

where NI_i is determined as in equation (2). NT_i is the number of trials on ith channel to check whether the channel is idle or not.

$$NI_i = \begin{cases} NI_i = NI_i + 1, & \text{if channel is idle} \\ NI_i = NI_i, & \text{if channel is busy} \end{cases} \quad \forall \quad i \in (1, N) \tag{2}$$

Equation (1) calculates the probability of a particular channel being idle, that can be used to serve a new or handover request. Equation (2) is used to count on how many times a channel i is idle out of NT_i trials. For example, if a channel is accessed 5 times out of which 3 times it is found idle, then NI_i and NT_i will be 3 and 5 respectively.

3.3 Spectrum allocation scenario

Cognitive Radio Network (CRN) based centralized architecture is comprised of two types of networks; Primary Network (PN) and Secondary Network (SN) [3]. Two types of users have been assumed in the network; Primary users (PU) and Secondary Users (SU). Primary users are further categorized into Primary new users and Primary handoff users. Among all, Primary handoff users are considered as the highest priority users. In the proposed work, the entire radio spectrum allocated to the network is divided into two parts (i) Aggregation-based non-reserved dynamic bandwidth, and (ii) Reserved fixed bandwidth. Reserved fixed bandwidth channels preferably will be allocated to the primary users and also to the interrupted or suspended services from D-CRN secondary services as per the availability. In Fig. 1, it is shown that PN is running on $M \in Z^+$ channels, where Z^+ is the set of positive integers. M channels are comprised of Non reserved as well as Reserved channels as shown in Eq. (3).

$$M = L + R \tag{3}$$

where $L \in Z^+$ represents the number of non-reserved channels, not necessarily of equal bandwidth and may vary as per the aggregation and split of the channels. $R \in Z^+$ is the number of equal capacity reserved channels.

3.4 The system model

The proposed model considers four priority levels of the services for four types of users (PU_1, PU_2, SU_1, and SU_2), modeled as a continuous-time Markov-chain in $F\text{-}CRN$ and $D\text{-}CRN$. Users' arrival follows a Poisson distribution with the rates as $\lambda_{PU_1}, \lambda_{PU_2}, \lambda_{SU_1}$, and λ_{SU_2} and Service time follows an exponential distribution with the rates $\mu_{PU_1}, \mu_{PU_2}, \mu_{SU_1}$, and μ_{SU_2} for the users PU_1, PU_2, SU_1, and SU_2 respectively.

In the model, PU_1 and PU_2 can access the entire cognitive radio network spectrum of which PU_1 has priority over PU_2 i.e. during the shortage of free channels PU_2 may be preempted to facilitate PU_1. SU_1 and SU_2 will be served in $D\text{-}CRN$ by applying the best possible channel aggregation and fragmentations approach. In case arrival rates of SU_1 and SU_2 are too high and cannot be served in D-CRN then as per the availability of channels in $F\text{-}CRN$, it may be served there also.

Dynamic splitting and aggregation of channels are shown in Fig. 4. It is obvious that allocation of higher bandwidth to non-real-time services will minimize the service time i.e. will increase the throughput. There is no bandwidth constraint for primary and secondary services over each other i.e. primary users' bandwidth can be greater or less than secondary users' bandwidth and vice-versa. Service duration of secondary user's may vary as per the allocated channel bandwidth after the aggregation. If larger bandwidth is allocated, service duration will be reduced and vice-versa. In this work, BW_{PU_1}, BW_{PU_2}, $BW_{SU_1}^{min}$ to $BW_{SU_1}^{max}$ and $BW_{SU_2}^{min}$ to $BW_{SU_2}^{max}$ refers to the bandwidth for each category of users PU_1, PU_2, SU_1, and SU_2 respectively. Where $BW_{SU_1}^{min}$ to $BW_{SU_1}^{max}$ indicates the allocation bandwidth range to SU_1, and similarly for SU_2.

In the model, primary users PU_1 and PU_2 can access the entire CRN ($F\text{-}CRN + D\text{-}CRN$) spectrum. Preferably, they will access $F\text{-}CRN$ in case of a normal traffic load. SU_1 and SU_2 will access $D\text{-}CRN$, in which the number of channels may vary as per the aggregation and fragmentation of the radio spectrum. States of all four types of services can be represented as a 4-tuple (i, j, k, l) where i, j, k and l are the number of active PU_1s, PU_2s, SU_1s and SU_2s respectively. Its possible state space can be represented as shown in Eq. (4).

$$\Omega = \left\{(i, j, k, l) \middle| \mathcal{C}_1, \mathcal{C}_2, \mathcal{C}_3, \mathcal{C}_4, \, where \quad \eta \le TRS\right\} \tag{4}$$

Where

$$\mathcal{C}1 = 0 \le i \le \left\lfloor \frac{TRS}{BW_{PU_1}} \right\rfloor,$$
$$\mathcal{C}2 = 0 \le j \le \left\lfloor \frac{TRS}{BW_{PU_2}} \right\rfloor,$$
$$\mathcal{C}3 = 0 \le k \le \left\lfloor \frac{TRS - F\text{-}CRN}{BW_{SU_1}} \right\rfloor,$$

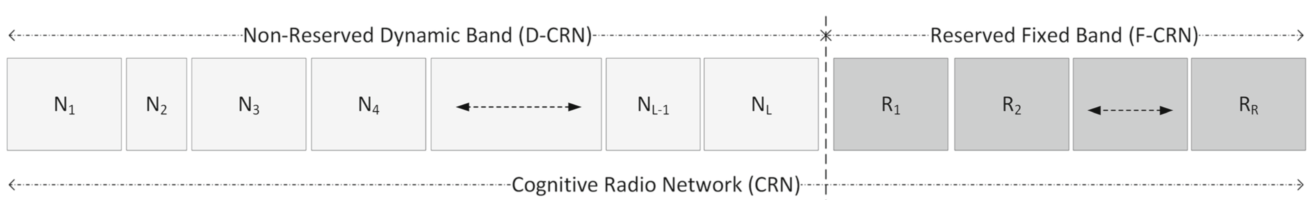

Fig. 1 Non-reserved dynamic and reserved fixed band channel

$$
\begin{aligned}
C4 &= 0 \le l \le \left\lfloor \frac{TRS - F\text{-}CRN}{BW_{SU_2}} \right\rfloor, \\
\eta &= (i \times BW_{PU_1}) + (j \times BW_{PU_2}) + (k \times BW_{SU_1}) \\
&\quad + (l \times BW_{SU_2}) \\
TRS &= F\text{-}CRN + D\text{-}CRN
\end{aligned}
$$

In case of high traffic in the network, the bandwidth to SU_1 and SU_2 will be allocated as shown in Eq. (5) i.e. minimum required bandwidth will be allocated.

$$
BW_{\frac{SU_1}{SU_2}}(i,j,k,l) = \begin{cases} \min\left\{BW^{max}_{\frac{SU_1}{SU_2}}, \max\left\{BW^{min}_{\frac{SU_1}{SU_2}}, \chi\right\}\right\}, \\ if \quad 0 \le (i \times BW_{PU_1}) + (j \times BW_{PU_2}) \le \varphi) \\ 0, \quad \text{otherwise} \end{cases} \tag{5}
$$

where $\chi = \frac{TRS - F\text{-}CRN - (i-x) \times BW_{PU_1} - (j-y) \times BW_{PU_2}}{k+l}$ and $\varphi = (TRS - max\left\{BW^{min}_{SU_1}, BW^{min}_{SU_2}\right\}$

$$
x \times BW_{PU_1} + y \times BW_{PU_2} \le F\text{-}CRN \tag{6}
$$

where x and y are the numbers of active PU_1 and PU_2 in $F\text{-}CRN$. If the system state indicates (i, j, k, l) as the number of requests in the system, then the idle bandwidth can be calculated as shown in Eq. (7).

$$
\begin{aligned}
idle = TRS &- (i \times BW_{PU_1}) - (j \times BW_{PU_2}) \\
&- (k \times BW_{SU_1}(i,j,k,l)) \\
&- (l \times BW_{SU_2}(i,j,k,l))
\end{aligned} \tag{7}
$$

3.5 Free channel update

Channel status will be updated from busy to free state when $RRS_{size} \le 0$ and $RRS_{time} = 0$, and the free channel will be returned to $F\text{-}CRN$ or $D\text{-}CRN$.

$$
RRS_{size} = TRS_{size} - BW_{\frac{SU_1}{SU_2}} \times time \tag{8}
$$

$$
RRS_{time} = TRS_{time} - time \tag{9}
$$

Equation (8) is used to calculate the remaining required data size for non-real-time services, and Eq. (9) gives the required time to complete the real-time services. After completing the services, channels will be returned into the respective free channels pool.

3.6 The flowchart

The flowcharts of the primary and secondary users' arrivals, proposed in the model, are shown in Figs. 2 and 3 respectively.

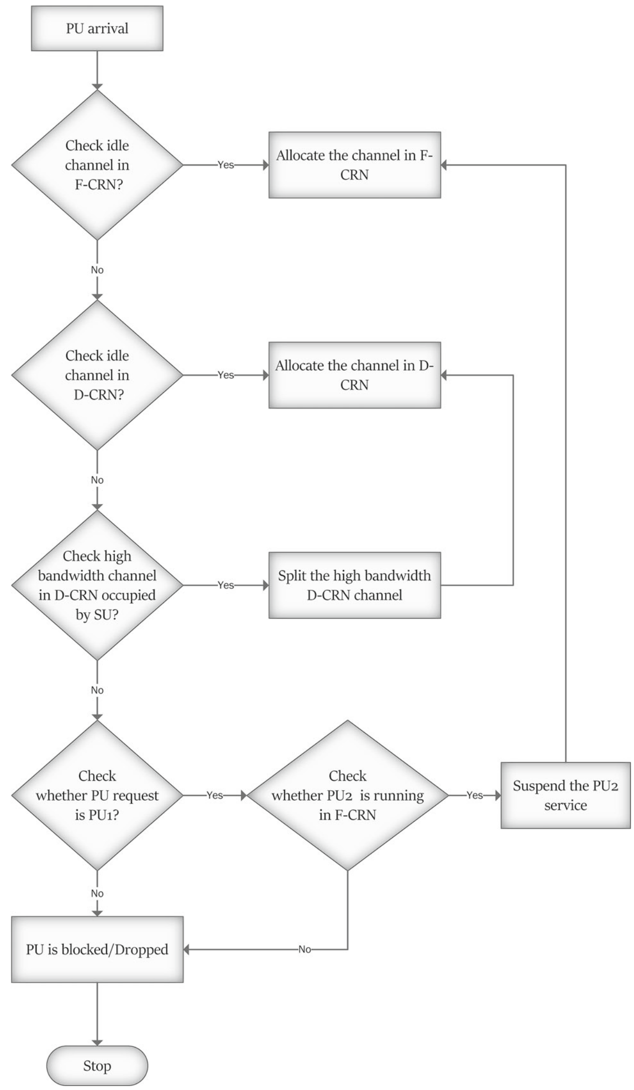

Fig. 2 Channel allocation on a PU arrival

3.6.1 PU arrivals

The arrival of primary users' is possible in two categories; primary new users and primary handoff users. Among them, primary handoff users will have more priority. Both; primary handoff and primary new users can use the channels in $D\text{-}CRN$ as well as in $F\text{-}CRN$. The flowchart of the activities, on the primary users' arrival, is shown in Fig. 2

3.6.2 SU arrivals

The channel allocation activities, on the arrival of secondary users, are shown in Fig. 3.

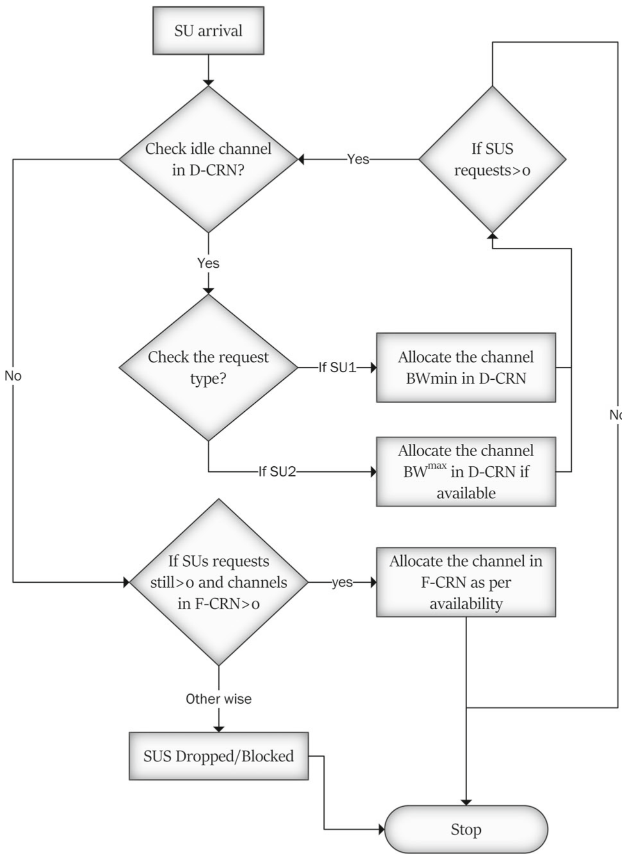

Fig. 3 Channel allocation on SU arrival

3.6.3 Channel fragmentation and aggregation

Channel aggregation follow the concept of buddy memory management algorithm which considers the aggregation of the same fragment of the channels where from the split took place earlier. The aggregation concept helps the system to provide a better QoS especially when traffic is low. In the buddy algorithm [27], the split takes place in equal fragments but in the proposed model split is done as per the requirement. The aggregation concept is same as in the buddy algorithm [27, 28]. The entire aggregation process is shown in Fig. 4.

3.6.4 Channel selection for handover

To minimize the PU_1 handover, on the arrival of PU_2, we have applied the probabilistic channel selection if more than one channels are available. A channel with high probability value indicates that it will remain idle for a long period of time whereas channel with low probability has higher chances to be occupied soon. Therefore, for handover, channel with high probability will serve better as it will minimize the chances of repeated handover. The probabilities, of the channels, are calculated using Eqs. (1) and (2) respectively.

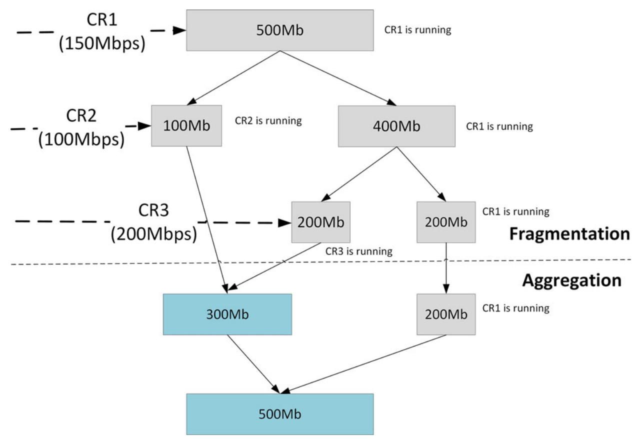

Fig. 4 Heterogeneous fragmentation of channels

3.7 The algorithm

The algorithm for the channel allocation, based on the concept of aggregation and channel splitting, is given as Algorithms 1, 2, and 3.

Algorithm 1 Channel Allocation using Aggregation and Splitting

Require: Enter the Mean Arrival rate of PU_1, PU_2, SU_1, and SU_2. Initialize BW^{min} and BW^{max} for each request of PU_1, PU_2, SU_1, and SU_2. Initialize the number of channels for $F\text{-}CRN$. Initialize the bandwidth for $D\text{-}CRN$. Enter the Max_{ITR} for taking the observation.
Ensure: Average blocking of PU_1 and SU_1
Average dropping of PU_2 and SU_2

1: **if** $F\text{-}CRN_{channels} > 0$ and $PU_1 requests > 0$ **then**
2: **if** $F\text{-}CRN_{channels} > PU_1 requests$ **then**
3: Allocate the channel to all the PU_1 requests
4: Update the $F\text{-}CRN$ free channels
5: Update PU_1 requests=0
6: **else**
7: Allocate the channels to PU_1 requests as per
8: Update the PU_1 unserved requests
9: Update $F\text{-}CRN$ free channels=0
10: **end if**
11: **end if**
12: Similarly steps 1 to 11 executes for channel allocation to PU_2 requests.
13: **if** any one of PU_1 and PU_2 requests are unserved **then**
14: **if** $D\text{-}CRN_{BW} > 0$ **then**
15: Split the channel from $D\text{-}CRN_{BW}$ as per BW^{max} requirements for PU_1 and PU_2.
16: Update the $D\text{-}CRN_{BW}$ by removing the allocated part.
17: Repeat step 13 till all the PU_1 and PU_2 requests are served.
18: **else**
19: Block the PU_1 requests.
20: Drop the PU_2 requests.
21: **end if**
22: **end if**
23: ▷ Go to the Algorithm 2 to allocate the channels to SU_1 and SU_2

Algorithm 2 Channel Allocation to SU_1 and SU_2

1: **if** $SU_1 requests > 0$ and $D\text{-}CRN_{BW} > 0$ **then**
2: Split the channel BW^{min} and allocate the channel to SU_1 requests.
3: Update the $D\text{-}CRN_{BW}$ by removing the allocated part.
4: Repeat step 1 to 5 until all the SU_1 requests are served.
5: **end if**
6: **if** $SU_2 requests > 0$ and $D\text{-}CRN_{BW} > 0$ **then**
7: Allocate the maximum required BW if it is available.
8: **end if**
9: **if** $D\text{-}CRN_{BW} > BW^{max}$ required for SU_2 **then**
10: Split the channel BW^{max} and allocate the channel to SU_2.
11: Update the $D\text{-}CRN_{BW}$ by removing the allocated part.
12: Repeat step 9 to 13 until the condition is true.
13: **else if** $D\text{-}CRN_{BW} < BW^{max}$ and $D\text{-}CRN_{BW} > BW^{min}$ **then**
14: Allocate the entire $D\text{-}CRN_{BW}$ to SU_2.
15: **else**
16: Allocate the entire $D\text{-}CRN_{BW}$ to SU_2.
17: Update $D\text{-}CRN_{BW} \leftarrow 0$
18: **end if**
19: if SU_1 and SU_2 requests are still unserved then allocate the channel in $F\text{-}CRN$ as per channel availability.
20: Drop the SU_1 requests.
21: Block the SU_2 requests.
22: Go to Algorithm 3 to update the free channel information and merge the $D\text{-}CRN$ free channels.

Algorithm 3 Update the $F\text{-}CRN$ free channels and $D\text{-}CRN_{BW}$

1: **if** channel $tag = 0$ and $(RRS_{size} \leq 0)$ OR $(RRS_{time} \leq 0)$ **then**
2: Return the channel into $F\text{-}CRN$ free channel list.
3: **end if**
4: **if** channel $tag = 1$ and $(RRS_{size} \leq 0)$ OR $(RRS_{time} \leq 0)$ **then**
5: Merge the released $BW = (BW^{min}$ OR BW^{max} OR $BW)$channel into $D\text{-}CRN_{BW}$.
6: $D\text{-}CRN_{BW} = D\text{-}CRN_{BW} + BW$
7: **end if**
8: Update the channel status using equation 8 and 9. ▹ Channel have two tags: $tag \rightarrow 0$ indicates that service is running on $F\text{-}CRN$ channel and $tag \rightarrow 1$ indicates that service is on $D\text{-}CRN$ channel.

In Algorithm 1, the initial steps are for the initialization of input parameters. Steps 1–11 are the channel allocation process for PU_1 and PU_2 in $F\text{-}CRN$. Unserved PU_1 and PU_2 requests will be served in $D\text{-}CRN$ by performing the channel split, which is stated in steps 13–22. The output, in terms of primary blocked and dropped requests, is depicted in steps 19 and 20.

Algorithm 2 depicts the channel allocation process for SU_1 and SU_2. In this, step 1 to 5 shows the channel allocation to SU_1 if the free channel is available otherwise it will split the channel as per the possibility of min and max bandwidth requirement for the channel allocation. Steps 6 to 19 indicate the channel allocation to SU_2 along with updating the bandwidth status. Storing the blocked and dropped information of secondary services are done in steps 21 and 22.

Algorithm 3 is for updating the free channel information with the help of tag$\rightarrow$ 0 and tag $\rightarrow$ 1 that are used for identifying the real and non-real-time services.

4 Performance analysis

To analyze the performance of the proposed model, simulation is done by writing the program in Matlab. Heterogeneous services, i.e. real-time and non-real-time services, are considered that are used by primary and cognitive users. Primary services are of two types; new services and handoff services. Similarly, non-real-time services are also categorized into new and handoff services. Radio spectrum is categorized into two categories; fixed band spectrum and dynamic band spectrum. In fixed band, the channel is fixed with its specified bandwidth while in the dynamic band, entire dynamic band is treated as one channel initially and dynamic split takes place as per the requirement of the bandwidth and the availability of the radio spectrum. Aggregation takes place as per the availability of different free slots.

4.1 Experiment 1

In this experiment, it is assumed that the mean arrival rate of all four types of services PU_1, PU_2, SU_1 and SU_2 are quite high i.e. 5 for each. Bandwidth for fixed channels is in the range of 250–300 Kb and dynamic spectrum is allocated as a whole to serve the requests. It splits and merges as per the requirement. In the experiment, fixed channels and dynamic bandwidth for each types of users (shown in tuple) are as follows: $< 20, 4096 >$, $< 30, 8192 >$, $< 40, 16384 >$, $< 50, 32768 >$, and $< 60, 65536 >$. Experiments are repeated for 5000 times and average results are shown in Fig. 5.

From Fig. 5 it is observed that even at high mean arrival rate, requests are being served quite effectively i.e. almost none are blocked when fixed channels and dynamic frequency band is $< 40, 16384 >$.

Figure 6 shows that primary handoff requests are also being served quite effectively using the dynamic channel aggregation concept.

Figures 7 and 8 show that though the block and drop rate of secondary services are bit high, it is reduced effectively after increasing the fixed and dynamic channels and eventually becomes negligible.

Thus, it can be concluded that even with high mean arrival rate of requests, the proposed model serves the requests effectively using the concept of dynamic split and aggregation for CRN.

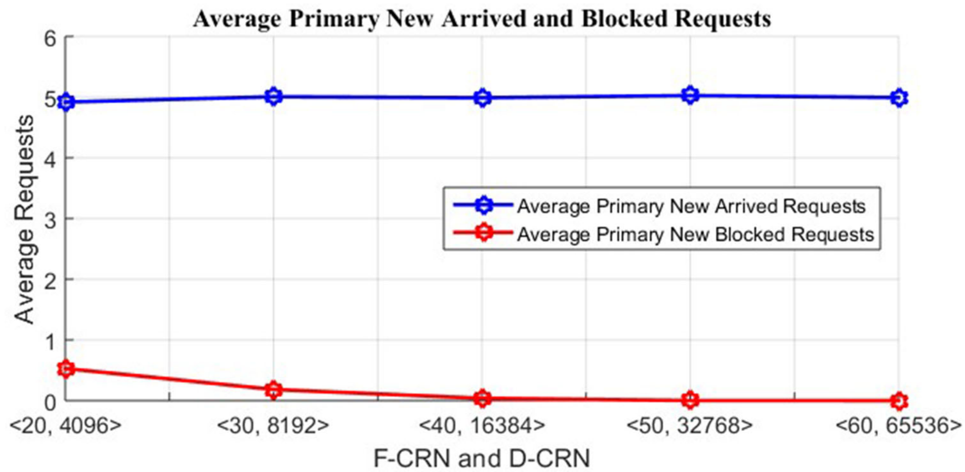

Fig. 5 Average primary blocked requests with mean arrival rate 05

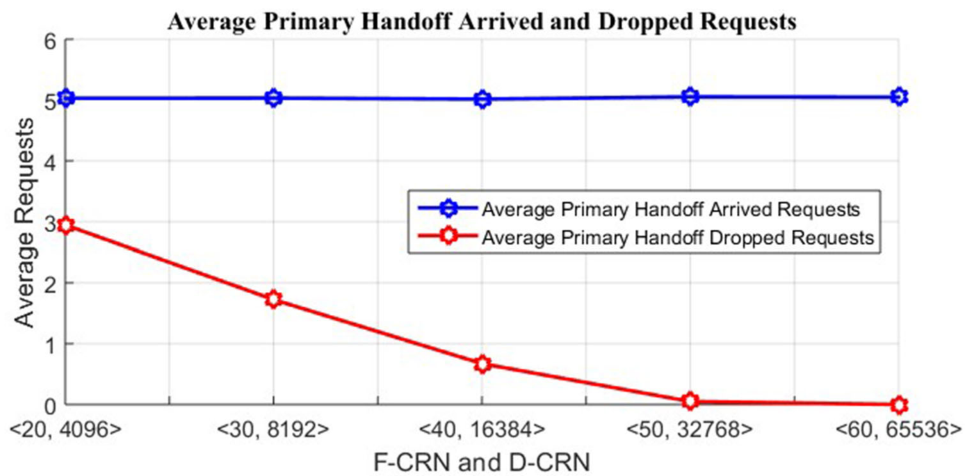

Fig. 6 Average primary dropped requests with mean arrival rate 05

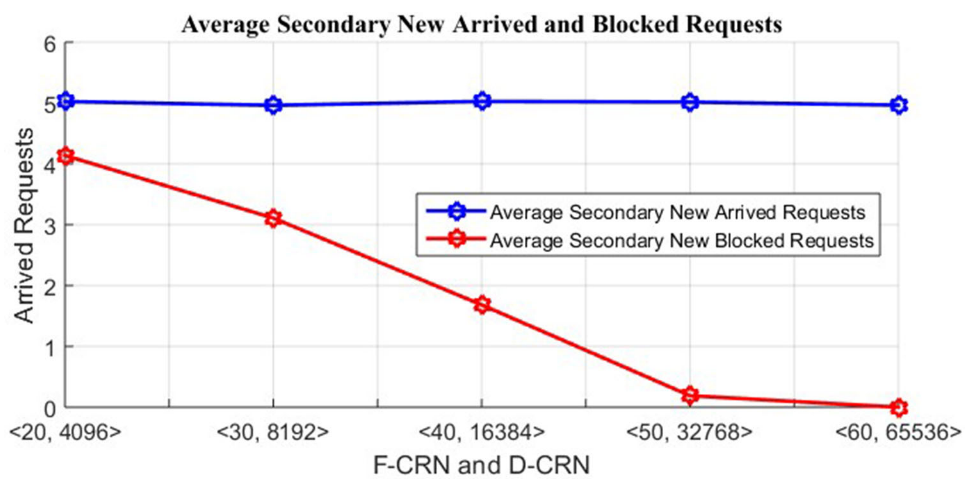

Fig. 7 Average secondary blocked requests with mean Arrival rate 05

4.2 Experiment 2

This experiment is conducted for the performance study of the secondary services by reducing the traffic of primary services. In this experiment, the mean arrival rate of primary new and primary handoff is kept low i.e. 2 for each. Secondary services rate are kept quite high i.e. secondary handoff and secondary new services are 5 each. The fixed number of channels considered is 20. $D\text{-}CRN$ channel is varied from 10,000 to 50,000 Kb.

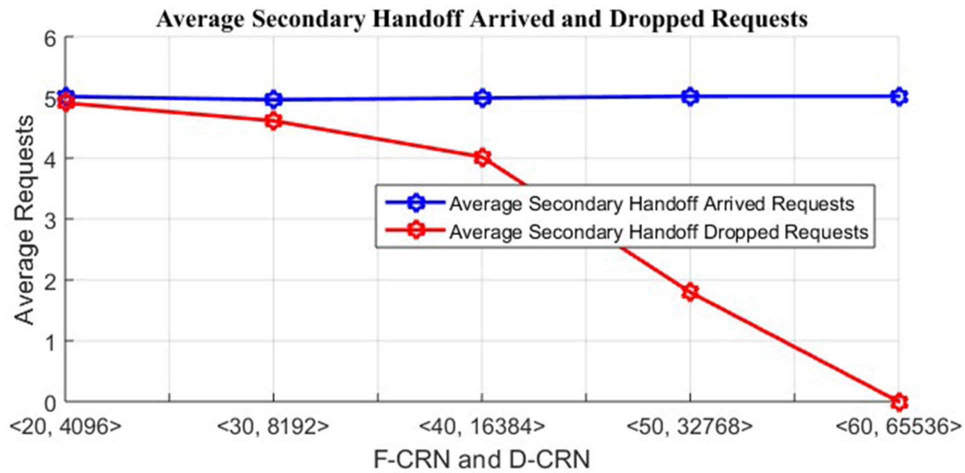

Fig. 8 Average secondary dropped requests with mean arrival rate 05

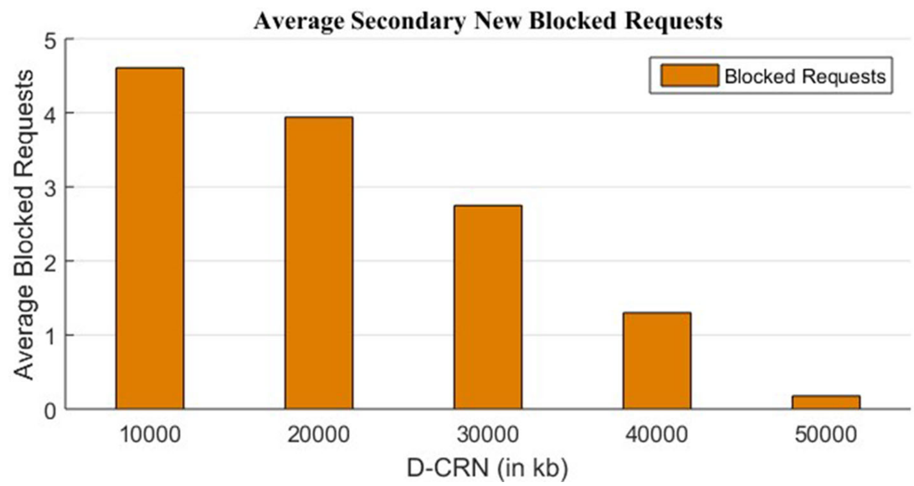

Fig. 9 Average secondary blocked requests on increasing D-CRN bandwidth

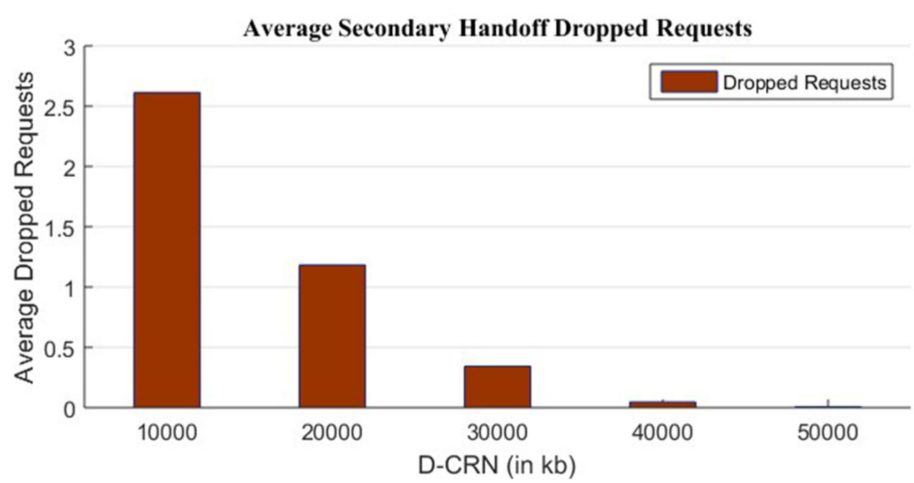

Fig. 10 Average secondary dropped requests on increasing D-CRN bandwidth

Figure 9 reflects that on increasing the $D\text{-}CRN_{BW}$, the average blocking of the requests is reduced. When $D\text{-}CRN_{BW}$ is 50000 Kb, the average blocking is quite low.

Figure 10 shows that the average drop rate is almost negligible even when there is no increase in $F\text{-}CRN$ channels. Therefore, one can conclude that on comparatively high $D\text{-}CRN_{BW}$, there is no need to increase the number of $F\text{-}CRN$ channels and it will serve the requests effectively using the concept of channel fragmentation and aggregation.

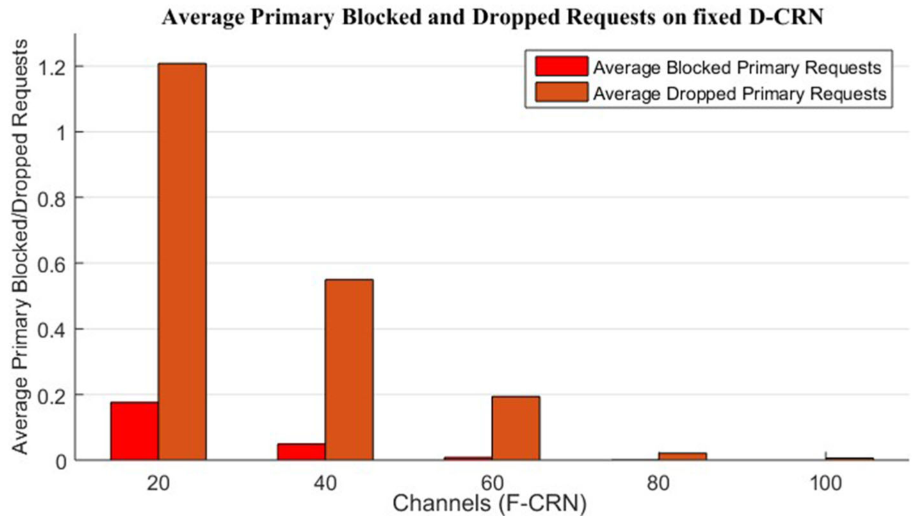

Fig. 11 Average primary blocked and dropped requests on increasing F-CRN channels

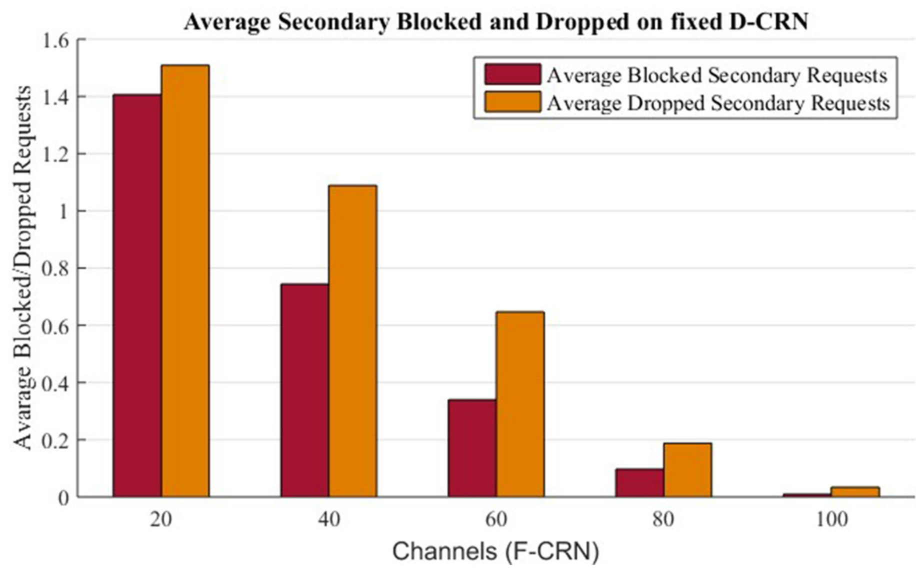

Fig. 12 Average secondary blocked and dropped requests on increasing F-CRN channels

4.3 Experiment 3

This set of experiments are conducted to observe the average blocked and dropped requests by changing the $F\text{-}CRN$ while keeping $D\text{-}CRN$ the same. The input parameters for the experiment are as follows; mean arrival rate of PU_1 and PU_2 are 5 and 4 respectively while mean arrival rate of SU_1 and SU_2 are comparatively low to 3 and 2 respectively. Bandwidth for $D\text{-}CRN$ (in Kb) is 10240 and channels in $F\text{-}CRN$ are varied from 20, 40, 60, 80, and 100. Average results of 1000 iterations are considered. In this experiment, it is assumed that PU_1 and PU_2 can share $D\text{-}CRN$ bandwidth as per the requirement but SU_1 and SU_2 will not share the $F\text{-}CRN$ channels.

Observation, from Fig. 11, shows that on increasing the number of channels in $F\text{-}CRN$, average primary blocked and dropped requests are reduced significantly. Also, when the number of $F\text{-}CRN$ channels are 100, primary blocked and dropped requests are almost negligible.

From Fig. 12, it can be observed that with the increase in the number of channels in $F\text{-}CRN$, average secondary blocked and dropped requests are being reduced significantly even when SU_1 and SU_2 requests are not sharing the $F\text{-}CRN$ channels. It inferes that with comparatively high number of channels in $F\text{-}CRN$, PU_1 and PU_2 requests negligibly share $D\text{-}CRN$ channels and $D\text{-}CRN$ bandwidth is able to serve almost all SU_1 and SU_2 requests. Figure 12 depicts that with 100 number of channels, average secondary blocked and dropped requests are almost negligible.

4.4 Comparative analysis

A comparative study with the model in [5] by Falcao et al. has been done to show the effectiveness of the proposed model

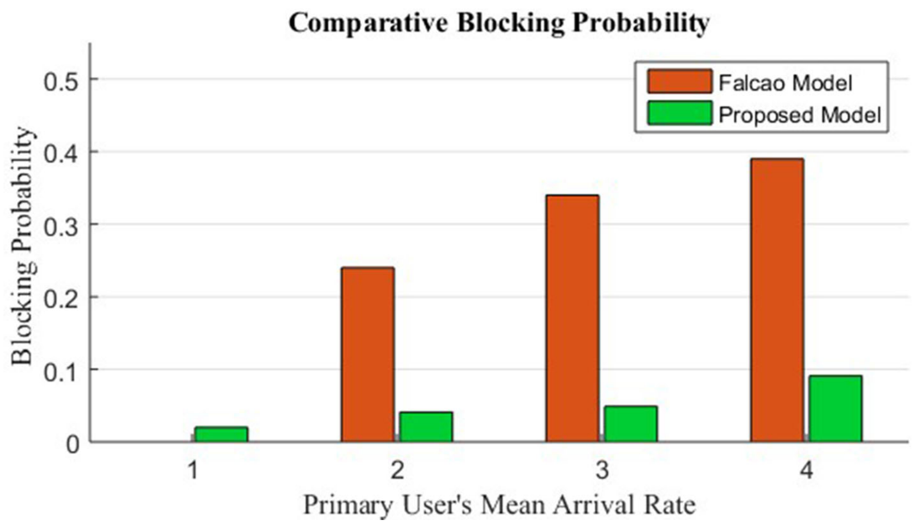

Fig. 13 Blocking probability of SU_1 on varying primary users arrival rate

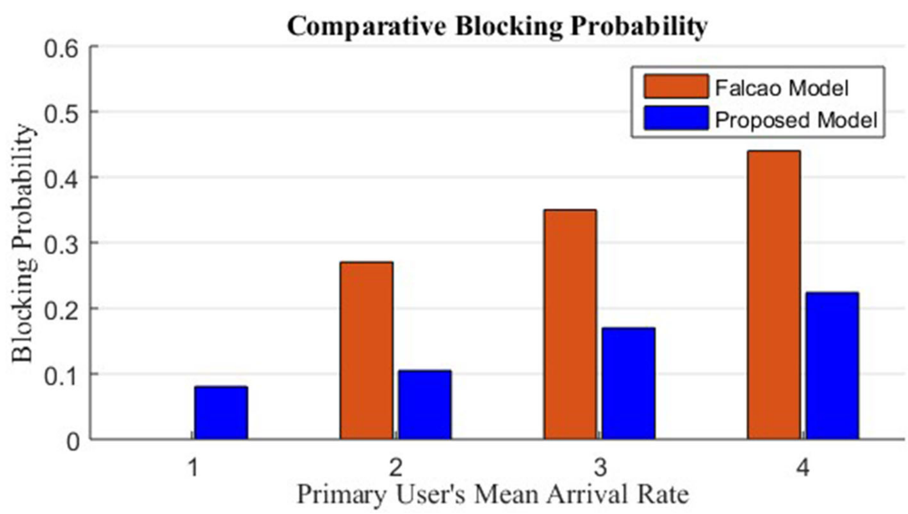

Fig. 14 Blocking probability of SU_2 on varying primary users arrival rate

in terms of blocking probability of SU_1 and SU_2 services. To perform the comparative study, PU_1 and PU_2 are collectively considered as PU of the model in [5] which does not distinguish PU_1 and PU_2. Therefore, mean arrival rate is mapped as $\lambda_{PU_1} + \lambda_{PU_1} = \lambda_{PU}$. The input parameter, for the experiment, are as follows. Mean arrival rate of secondary users are $\lambda_{SU_1} = 1$ and $\lambda_{SU_2} = 1$. Number of $F\text{-}CRN$ channels is 4 and $D\text{-}CRN$ bandwidth is considered to perform channel aggregation and fragmentation dynamically. The observation is taken for 1000 iterations on varying λ_{PU} as 1, 2, 3, and 4.

Figure 13 shows the comparison of blocking probabilities of SU_1 of the proposed model and the Falcao model [5]. It can be observed that when the primary arrival rate λ_{PU_1} is low then Falcao model performs better but with the increase in the primary user's arrival rate, the proposed model performs better and gives lower probability for SU_1 users.

Figure 14 exhibits the comparison of blocking probability of SU_2 with the Falcao model. It can be observed that on low arrival rate of primary users, Falcao model performs good but with the increase in the arrival rate of primary users, the blocking probability of the proposed model is significantly lower than the Falcao model.

Observations from Figs. 13 and 14 are derived as follows. With the increase in the mean arrival rate of primary users, blocking probabilities of the proposed model for both SU_1 and SU_2 are lower than the Falcao model.

5 Conclusion

This work proposes a CR-enabled channel aggregation and fragmentation-based model to serve the bandwidth requirement of the services. In the model, four types of services are considered as primary new, primary handoff, secondary new, and secondary handoff. Primary services are served in $F\text{-}CRN$ on a priority basis considering their bandwidth requirement. Secondary services are served by applying channel split and channel aggregation. Probabilistic channel handover is applied to minimize the multistage handoff.

Experimental evaluation indicates that $F\text{-}CRN$ and $D\text{-}CRN$ networks are collectively able to minimize the call block and call drop effectively. It also provides a better quality of service because channels are allocated as per the bandwidth requirement. Further, it is observed that on varying the $D\text{-}CRN$ bandwidth, secondary new and secondary handoff requests are being served well. Furthermore, with good number of $F\text{-}CRN$ channels, $D\text{-}CRN$ can serve all the secondary services by performing the channel split and channel aggregation only.

A comparative study on varying mean arrival rate of primary services has been done to observe the impact on secondary services wherein it has been observed that the proposed model effectively serves both kind of secondary services (SU_1 and SU_2). Thus, blocking probability is minimized for both types of secondary services. The low blocking probability, in comparison to a recent model, signifies the importance of the proposed model. The proposed model has high possibility to be used for 5 G and 6 G services in order, to satisfy the rising demand of the radio spectrum and improve the quality of service.

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Declarations

Competing interest The authors declare no competing interests.

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