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Research Article

Prioritized Handoff Scheme with Imperfect Sensing for Secondary Users in Cognitive Radio Networks

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Abstract

Background and Objective: Cognitive radio has been proposed to overcome the problem of spectrum scarcity that arises due to fixed allocation of the channel. One of the greatest challenges of this technology is how the unlicensed users can share the licensed spectrum based on required quality of service. In most cases, secondary users may require handoff when licensed users claim back their channels. The objective of this study was to reduce the dropping probability of high priority secondary users during handoff. **Materials and Methods:** To overcome the challenge of handoff when licensed users claim back their channels, a post-reserved channel sharing scheme with imperfect sensing was proposed. In this scheme, high priority and low priority secondary users (SUs) are assigned to general idle sub-channels in a FCFS order. If the general idle sub-channels are full, high priority SUs are assigned to the reserved sub-channels, while the low priority SUs are dropped. The proposed post-reserved channel sharing scheme is modeled using the continuous Markov chain. **Results:** The numerical results obtained from the derived models show that high priority handoff calls perform better under the post-reserved channel allocation scheme than under the pre-reserved scheme in terms of reduced dropping probability. On the other hand, low priority secondary user's calls perform better under the pre-reserved scheme compared to the post-reserved scheme. **Conclusion:** It can be concluded that high priority handoff calls perform better under the post-reserved channel scheme than under the pre-reserved channel allocation scheme.

Key words: Cognitive radio, handoff, imperfect sensing, pre-reserved, post-reserved, quality of service

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INTRODUCTION

In the past, the approach for spectrum allocation was based on specific band assignments designated for a particular service[1]. This approach makes it extremely difficult to reuse these bands once they are allocated, even if these bands are poorly utilized. The above observation has prompted a new design of wireless networks known as cognitive radio networks (CRNs)[2].

In this design, the unlicensed users explore and exploit unused portions of the licensed spectrum while protecting the transmissions of the licensed users. Two basic approaches to spectrum sharing have been identified[3]. The first one is underlay approach where the secondary and primary users coexist on the same channel with the secondary user operating at a lower power such that no interference is caused to the primary user. On the other hand, overlay approach is where the secondary user opportunistically accesses the channel [2]. This is done by the use of the software defined radio which senses the availability of the channel and the arrival of the secondary user[4]. In order to cope with spectrum heterogeneity, the unlicensed users in the CRN implement two basic functions, namely spectrum sensing and dynamic spectrum access (DSA)[2].

Spectrum sensing is responsible for identifying idle channels in the licensed spectrum, while the DSA scheme is used to facilitate the unlicensed user's transmissions over the detected idle channels. An important aspect of a DSA scheme is to give higher priority to the licensed users during spectrum access compared to the unlicensed users. Hence, the licensed user is known as the primary user (PU) and the unlicensed user is known as the secondary user (SU).

In the cognitive radio network, there are many factors that influence system performance. The most important of these are channel usage states affected by PUs, call arrival rates of SUs and sensing errors. The SUs obtain the channel states by spectrum sensing. If an arriving secondary call finds an idle channel, it can make use of the channel. If the channel is busy, the secondary call moves to a waiting pool. However, because of sensing errors, SUs may make incorrect decisions that lead to either conflict with PUs or a waste of spectrum resource.

In a real scenario, the SU traffic can be prioritized based on QoS requirements (e.g., real-time traffic has higher priority than non-real-time traffic). In these works, the SUs' priorities are used for packet transmission during a frame. However, the SU priority does not affect spectrum handoff. Handoff is the process of providing the connection to the backbone network while a mobile terminal is moving across the boundaries of coverage of two wireless points of connection.

Some recent works have evaluated the performance of CRN under different DSA policies using continuous time Markov chain (CTMC)[4-6]. According to the DSA policy used by Wong and Foh[7], secondary users who experience unsuccessful handoff are queued till they find the transmission opportunities. Zhu *et al.*[5] employed a DSA policy where channels are reserved for secondary user handoff. Zhang[6] placed the secondary user arrivals in a queue when a free channel is not available.

In all these works, PU calls have a higher priority over the SU calls during spectrum access.

Tumuluru *et al.*[8] proposed a handoff scheme where SUs have priority for a two class secondary users. In this model, sub-channels are pre-reserved for SUs with higher priority and the rest of the sub-channels are shared. Furthermore, perfect sensing is assumed for idle channel identification. In the pre-reserved sub channel allocation scheme, the high priority handoff calls begin service from the reserved sub channels and then competes with low priority handoff calls for general sub channels. However, in the pre-reserved scheme, when the arrival rate of low priority handoff calls is high, the high priority handoff calls suffer from high dropping probability. Moreover, the assumption of perfect sensing does not portray realistic performance.

This paper derived models for post-reserved channel sharing schemes among secondary users with imperfect sensing based on continuous Markov chain. These models are used to assign channels to high and low priority secondary user's handoff calls.

The main objective of this study was to reduce the dropping probability of high priority handoff calls using the post-reserved channel allocation scheme. This has been achieved as the model derived based on the post-reserved channel allocation scheme reduces the dropping probability of high priority handoff calls.

MATERIALS AND METHODS

The study modeled SU dropping probability using continuous time Markov chain (CTMC). A CTMC can be described by its state transition characteristics. The study used a continuous-time Markov chain because a continuous-time Markov chain is one in which changes to the system can happen at any time along a continuous interval. Unlike discrete-time Markov chain where changes to the system can only happen at one of the discrete time values and therefore, cannot be used to model the dropping probability of secondary users. A Markov process is a stochastic process such that:

$$(X(t), t \in T), X(t) \in E \subset R$$

$$\begin{aligned} P(X(t)) \leq x \mid (t_1) = x_1, \ldots, X(t_n) = x_n \\ = P(X(t) \leq \mid X(t_n) = x_n) \end{aligned} \tag{1}$$

For all $x_1, \ldots, x_n$, $x \in E$, $t_1, \ldots, t_n$, $t \in T$ with $t_1 < t_2 \ldots t_n < |$. Intuitively the above equation says that the probabilistic future of the process depends only on the current state and not upon the history of the process. In other words, the entire history of the process is summarized in the current state. Basically a continuous-time Markov chain is used because a continuous-time Markov chain is one in which changes to the system can happen at any time along a continuous interval. Given the fact that PUs can claim their channels at any time, a continuous-time Markov chain best models the dropping probability of secondary users.

Post-reserved channel allocation scheme: Assume a fully connected CRN, i.e., all SUs observe the same channel status (i.e., PU/SU activity). Imperfect sensing is assumed to detect the PU activity. In addition, it assumed a common control channel is assumed to exist for the coordination among the SUs. The post-reserved channel allocation scheme is composed of one licensed channel which is further divided into N sub-channels. The sub-channels comprise of general sub-channels shared by both SU1 and SU2 handoff calls and the reserved sub-channels used by SU1 handoff calls only. A PU call requires one channel whereas, an SU call requires one sub-channel. An ongoing SU call interfering with the new PU call is handed-off to another vacant sub-channel.

The SUs are classified into two priority classes. The high priority SUs are denoted as SU1 while the low priority SUs are denoted as SU2. Displaced SU1 and SU2 handoff calls are assigned to unique general idle sub-channels in a FCFS order. If the general idle sub-channels are full, displaced SU1 handoff calls are assigned to the reserved sub-channels. If the general idle sub-channels are full, displaced SU2 handoff calls are dropped. If the reserved idle sub-channels are full and the general sub-channels are full, both SU1 and SU2 handoff calls are dropped.

In the post reserved sub channel allocation scheme, SU1 handoff calls begin competing with SU2 handoff calls for general sub channels and when there are no more sub channels, then the SU1 handoff calls get service from the reserved sub-channels. This is quite different from the pre-reserved sub-channel allocation scheme where the SU1 handoff calls begin service from the reserved sub channels and then competes with SU2 handoff calls for general sub channels.

The post-reserved sub channel algorithm is shown in Fig. 1.

Dropping probability of SU1 and SU2 calls with imperfect sensing: Considering a cellular system where each cell consists of a total of N channels, including H reserved channels and N-H general channels. Assume that requests are generated according to Poisson distribution with rates λ_1 and λ_2 for SU1 and SU2 handoff traffic, respectively. Service requirements for both requests are identical and exponentially distributed.

Channel occupancy times for SU1 and SU2 handoff calls are exponentially distributed with mean are $1/\mu_1$ and $1/\mu_2$, respectively. It is generally presumed that a secondary user has perfect sensing of the primary user channels, however, the assumption of perfect sensing is unrealistic. There may be a small probability that a secondary user senses the primary user's channel as being free when it is not, in this case collision occurs which leads to the underutilization of the channel. Let β be the probability that a secondary user has perfect sensing then $\alpha = 1-\beta$ is the probability that a secondary user has imperfect sensing. If λ_1 is the arrival rate of SU cal1 handoff calls, then the effective arrival rate of SU1 handoff calls is $\alpha\ \lambda_1$.

The SU1 calls have higher priority over SU2 calls. In this case, it reserve H sub-channels for SU1 calls and the remaining (N-H) general sub-channels are shared by both SU1 and SU2 calls.

The general sub-channels are first allotted to SU1 and SU2 on a FCFS basis. When the general sub-channels are occupied and a new SU1 call arrives then it is allotted sub-channels from the reserved sub-channels whereas SU2 calls are blocked. When all the sub-channels (both reserved and general) are occupied then SU1 calls and SU2 calls are dropped. Two possible scenarios also arise:

Case I : If the general sub-channels are not fully occupied at time t, i.e., $k \leq N\text{-}H$. In this case, the coming SU1 call will share the general sub-channels along with the coming SU2 calls

According to the state transition diagram shown in Fig. 2, the stationary probability that k sub-channels are occupied is given as follows:

$$P_k = \frac{1}{k!}\left(\frac{\lambda_1 + \lambda_2}{\mu_1 + \mu_2} \cdot P_O\right), k \leq N - H \tag{2}$$

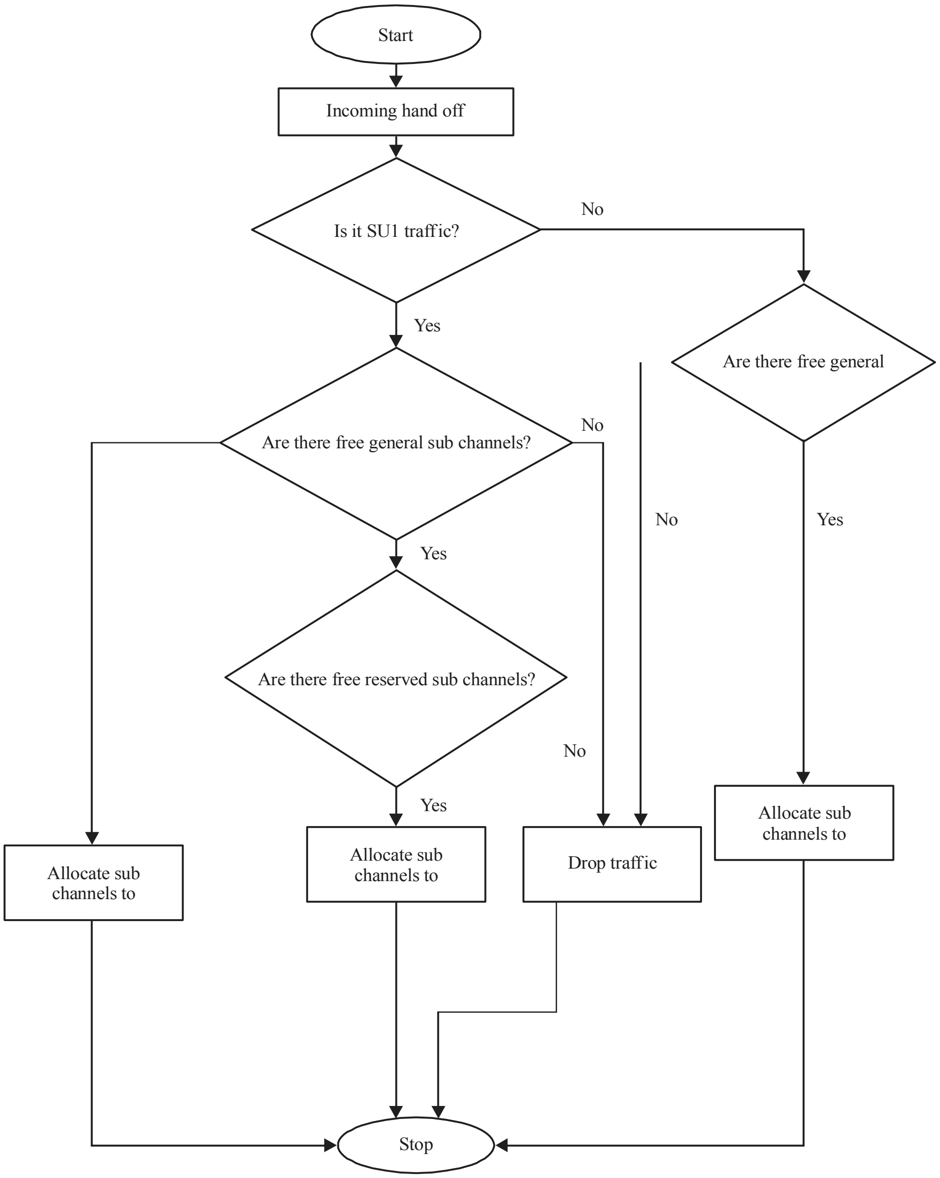

Fig. 1: Proposed post-reserved sub channel algorithm

Where:

$$P_O = \left[1+\sum_{k=1}^{N-H}\frac{1}{k!}\left(\frac{\lambda_1+\lambda_2}{\mu_1+\mu_2}\right)^{k}\right]+\left(\sum_{k=N-H+1}^{N}\frac{1}{(N-H)!}\left(\frac{\lambda_1+\lambda_2}{\mu_1+\mu_2}\right)^{N-H}\cdot\right) \left(\frac{1}{(k-(N-H))!}\left(\frac{\alpha\lambda_1}{\mu_1}\right)^{k-(N-H)}\right)\Bigg]^{-1} \quad (3)$$

where, λ_1 and λ_2 are arrival rates of high priority and low priority Sus, respectively. The μ_1 and μ_2 are the service rates of high priority and low priority Sus, respectively. The P_O is the probability that the channel is idle.

Case II : If the general sub-channels are occupied at time t, i.e., k>N- H. In this case, all general sub-channels will be blocked and SU1 calls are allocated sub-channels from the available reserved sub-channels while SU2 calls are blocked. The stationary probability is given as:

$$P_k = \left(\frac{1}{(N-H)!}\left(\frac{\lambda_1+\lambda_2}{\mu_1+\mu_2}\right)^{N-H}\right)\cdot \left(\frac{1}{(k-(N-H))!}\left(\frac{\alpha\lambda_1}{\mu_1}\right)^{k-(N-H)}\right)\cdot P_O, \quad k > N-H$$

where, P_O is as given in Eq. 3. Therefore:

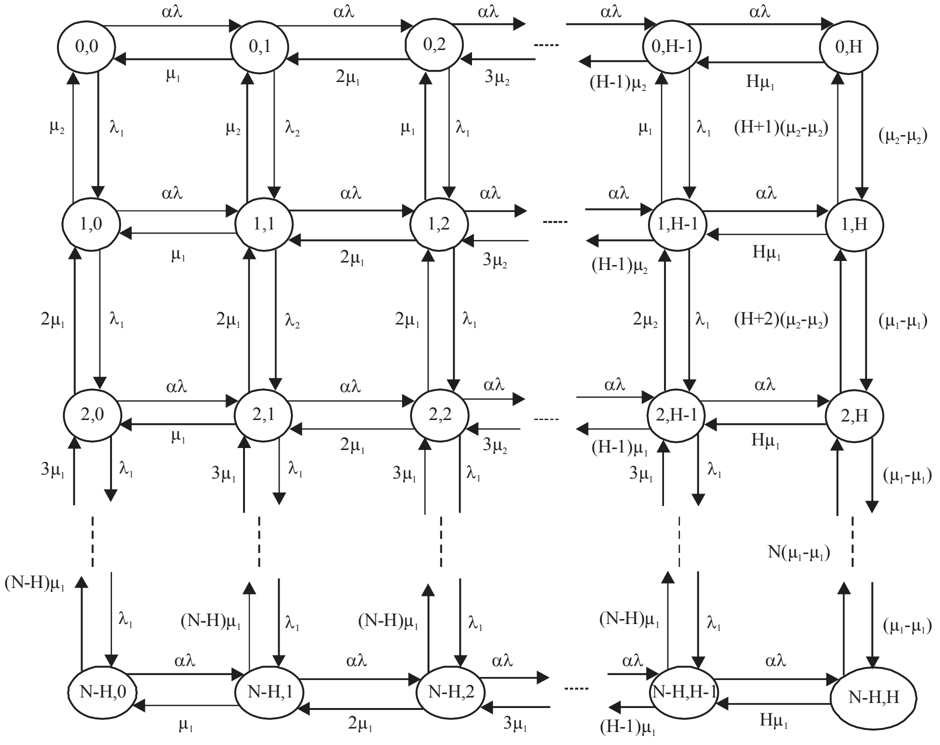

Fig. 2: Transition state diagram for the post-reservation scheme

- The probability that SU1 calls find all the N-H general sub-channels and H reserved sub-channels busy and is dropped is given by:

$$P_{SU1} = \frac{1}{(N-H)!}\left(\frac{\lambda_1+\lambda_2}{\mu_1+\mu_2}\right)^{N-H}\cdot\frac{1}{H!}\left(\frac{\alpha\lambda_1}{\mu_1}\right)^{H}\cdot P_O \qquad (4)$$

- The probability that SU2 calls find all the N-H general sub-channels busy and are dropped is given by:

$$P_{SU2} = \frac{1}{(N-H)!}\left(\frac{\lambda_1+\lambda_2}{\mu_1+\mu_2}\right)^{N-H}\cdot P_O \qquad (5)$$

RESULTS

In this study the performance of the derived models are tested. In particular, the variation of dropping probability against number of reserved channels, arrival rate of SU1 calls, arrival rate of SU2 calls, service rate of high priority secondary user calls (SU1) and service rate of low priority secondary user calls (SU2). The variation of dropping probability against reserved channels for pre-reserved and post-reserved schemes with perfect and imperfect sensing is also analyzed. The tool used for analysis is MATLAB. Evaluation parameters used in the analysis are indicated in Table 1.

Table I: Model parameters

Parameters	Values
λ_1	0.7 calls/second
λ_2	0.6 calls/second
μ_1	0.01 calls/second
μ_2	0.05 calls/second
Probability of sensing	0.04

Next, the results for dropping probability of high priority secondary user calls (SU1) are shown.

Dropping probability of SU1: This section presents the analysis of dropping probability of SU1 against the arrival rate.

The dropping probability of SU1 against arrival rate of SU1 calls when the number of reserved channels are 15 and the arrival rate of low priority secondary user calls, $\lambda_2 = 0.05$ are shown in Fig. 3. It is observed that the dropping probability of SU1 calls increase with increase in arrival rate of SU1 calls for both pre-reserved and post-reserved schemes. This is due to the fact that as the arrival rate of SU1 increases, the number of channels available for use become increasingly fewer and hence increase in the dropping probability. It is further observed that the dropping probability of SU1 calls is lower for the post-reserved scheme as compared to the pre-reserved scheme. However, for low arrival rate of SU1 calls, the dropping probability of SU1 is the same for considered

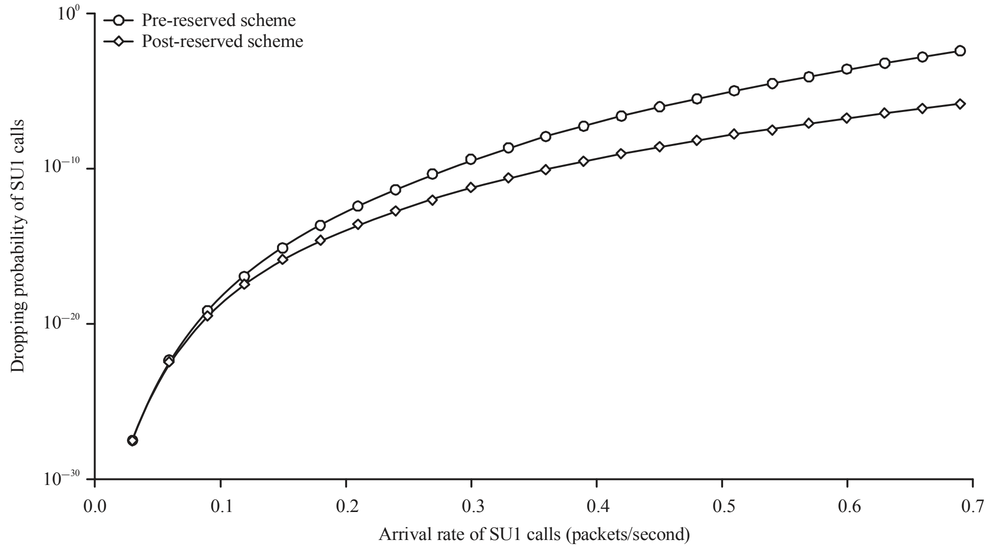

Fig. 3: Dropping probability of SU1 calls against arrival rate of SU1 calls, H = 15, $\lambda_2 = 0.05$

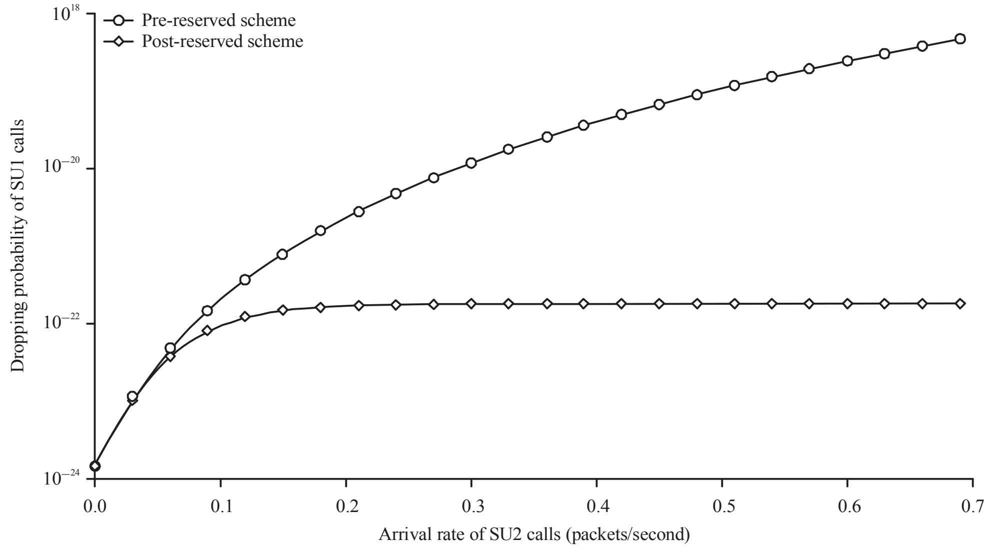

Fig. 4: Dropping probability of SU1 calls against arrival rate of SU2 calls, H = 15, $\lambda_1 = 0.01$

schemes. The post-reserved scheme is better because SU1 calls first access the general channels before utilizing the reserved channels.

The dropping probability of SU1 calls against arrival rate of SU2 calls when the number of reserved channels are 15 and the arrival rate of high priority secondary user calls, $\lambda_1 = 0.01$ is shown in Fig. 4. It is observed that dropping probability of SU1 calls increase with increase in arrival rate of SU2 calls for both pre-reserved and post-reserved schemes. It is further observed that the dropping probability of SU1 calls is lower for the post-reserved scheme as compared to the pre-reserved scheme. However, for low arrival rate of SU2 calls, the dropping probability of SU1 is the same for considered schemes. The post-reserved scheme is better because SU1 calls first access the general channels before utilizing the reserved channels.

Dropping probability of SU2: This section presents the analysis of dropping probability of SU2 calls against number of reserved channels and arrival rates.

The dropping probability of SU2 calls against number of reserved channels varied from 1-15 is shown in Fig. 5. The other parameters being as indicated in Table 1. It is observed that the dropping probability of SU2 calls decrease with increase in the number of reserved channels for both pre-reserved and post-reserved schemes. For number of

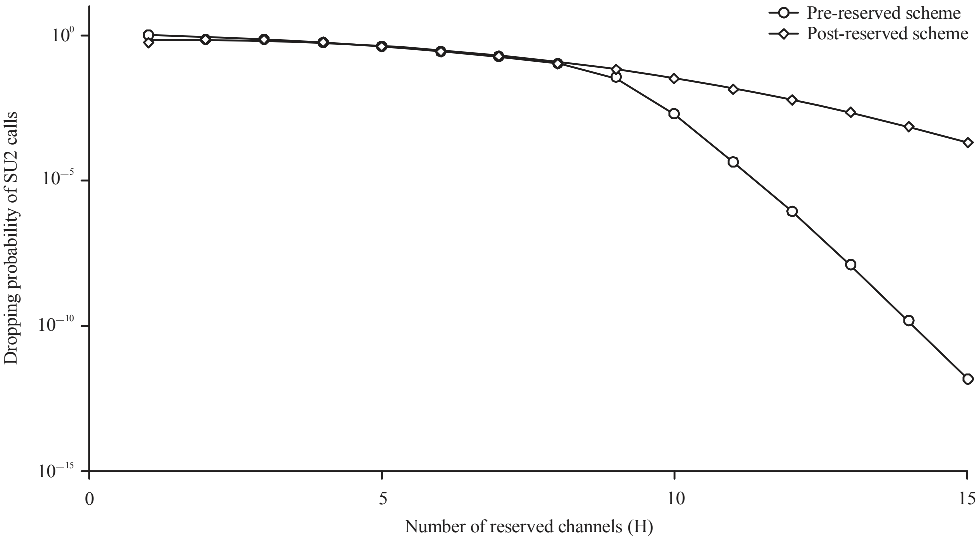

Fig. 5: Dropping probability of SU2 calls against number of reserved channels, H

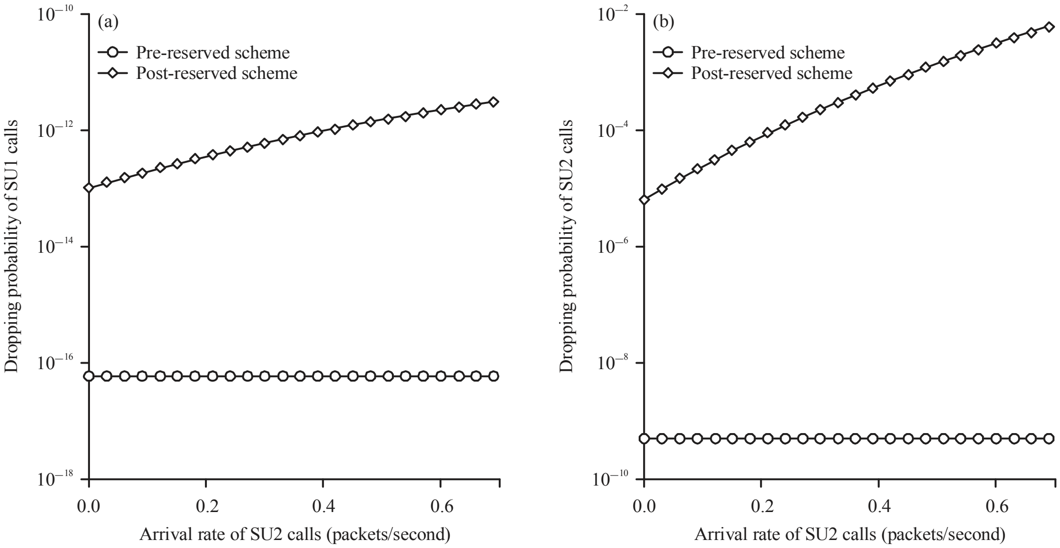

Fig. 6(a-b): Dropping probability of SU2 calls against arrival rate of SU2 calls, $\lambda_1 = 0.6$, (a) Number of reserved channels = 15 and (b) Number of reserved channels = 10

reserved channels 1-8, SU2 calls showed the same performance in terms of dropping probability, however, when the number of reserved channels increase, the performance of SU2 calls are worse under the post-reserved scheme compared to the pre-reserved scheme. This is due to the fact that as the number of reserved channels increase, more channels become available for SU1 calls which reduces the number of SU1 calls which would compete for the general channels with SU2 calls, which in turn reduces the dropping probability. The probability for the pre-reserved scheme is even much lower than for post-reserved scheme as the number of reserved channels increase.

The dropping probability of SU2 calls against arrival rate of SU2 calls is shown in Fig. 6. It can be observed that dropping probability generally increases with increase in arrival rate of SU2 calls irrespective of the number of reserved channels. This is because as the rate of arrival of SU2 increases, less number of channels become available for access of SU2 calls. It is further observe that SU2 calls perform better under the pre-reserved scheme compared to the post-reserved scheme for both considered number of reserved channels. However, the dropping probability is lower when the number of reserved channels are higher, i.e., for number of reserved channels equal to fifteen, the dropping probability is lower

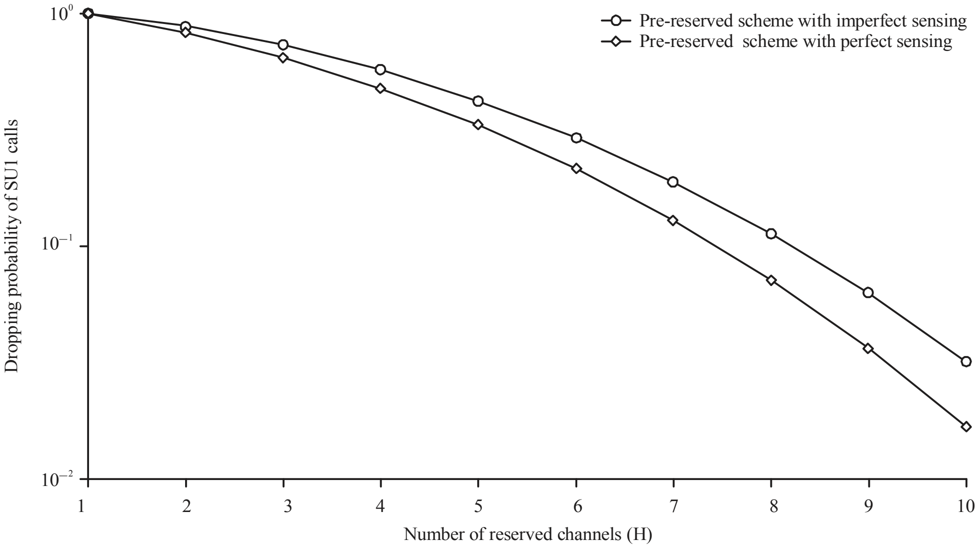

Fig. 7: Dropping probability of SU1 calls against number of pre-reserved channels

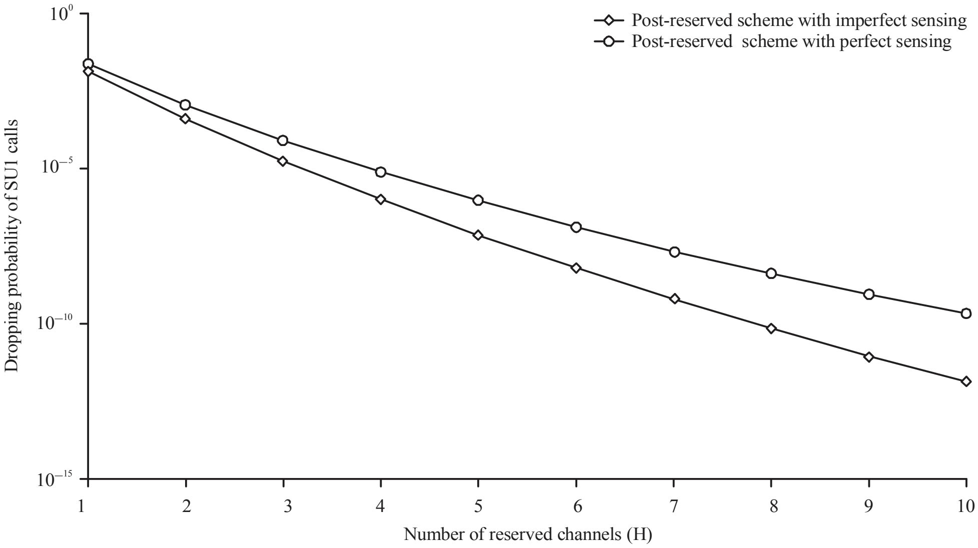

Fig. 8: Dropping probability of SU1 calls against number of post-reserved channels

compared to when the number of reserved channels equal to ten. The dropping probability is also observed to be closer for the two schemes for lower arrival rates, but as the arrival rate increases the difference between the two schemes become more pronounced.

The dropping probability of SU1 calls against number of reserved channels for the pre-reserved scheme with perfect and imperfect sensing is shown in Fig. 7. It can be observed that the dropping probability decreases with increase in the number of reserved channels for pre-reserved scheme with perfect and imperfect sensing. It can further be observed that the performance of SU1 calls are better under perfect sensing compared to imperfect sensing. This is due to the fact that when perfect sensing is assumed the probability of not transmitting on a channel is zero, while under imperfect sensing, a certain probability is considered of not transmitting on that channel. For lower number of reserved channels, the performance of SU1 calls under the perfect and imperfect sensing are closer, however, as the number of reserved channels increase the difference in performance between perfect and imperfect sensing become more pronounced.

The dropping probability of SU1 calls against number of reserved channels for the post-reserved scheme with perfect and imperfect sensing is shown in Fig. 8. It is observed that the dropping probability decreases with increase in the number of reserved channels for post-reserved scheme with perfect and imperfect sensing. It is further observed that the performance of SU1 calls are better under perfect sensing compared to imperfect sensing. This is due to the fact that when perfect sensing is assumed the probability of not transmitting on a channel is zero, while under imperfect sensing, a certain probability is considered of not transmitting on that channel.

For lower number of reserved channels, the performance of SU1 calls under the perfect and imperfect sensing are closer, however as the number of reserved channels increase the difference in performance between perfect and imperfect sensing become more pronounced.

DISCUSSION

Previous study done by Wong and Foh[7] assigned secondary users who experience unsuccessful handoff in the queue till they find the transmission opportunities. In another study, Zhu *et al.*[5] employed a DSA policy where channels are reserved for secondary user handoff. Relatedly, Tumuluru *et al.*[8] proposed a handoff scheme where SUs have priority for a two class secondary users. In this model, sub-channels are pre-reserved for SUs with higher priority and the rest of the sub-channels are shared. In this study, the proposed post-reserved channel allocation scheme for secondary users was found to outperform the pre-reserved channel allocation scheme proposed by Tumuluru *et al.*[8]

Bayrakdar and Calhan[9] proposed priority based non-preemptive M/G/1 queueing model of spectrum handoff scheme in Wireless Cognitive Radio Networks. Channel bonding mechanism with starvation mitigation was employed in order to improve spectrum handoff utilization for secondary users.

Hou *et al.*[10] presented an analytical framework to evaluate the effects of spectrum handoffs on the performance of the real-time traffic in cognitive radio (CR) networks. In order to characterize the channel usage behaviors of primary traffic and CR real-time traffic with spectrum handoffs, a queuing model which consists of preemptive resume priority M/G/1 queues are developed. Based on this queuing model, channel utilization factor was derived. Blocking and forced termination probabilities for real-time traffic are derived. This study also outperforms the study done by Bayrakdar and Calhan[9] and Hou *et al.*[10] in terms of dropping probability.

In this scheme prioritized data traffic with aging solution to starvation is exploited to meet requirements of the secondary users. This study showed that the throughput of secondary users can be increased significantly by employing aging solution to starvation and channel bonding mechanisms. This is due to the fact that for the post-reserved scheme high priority handoff calls first access the general shared channels before utilizing the reserved channels which can only be accessed by high priority handoff calls. It is further observed that dropping probability of high priority handoff calls is lower for post-reserved scheme than for pre-reserved scheme, especially at high arrival rate of low priority handoff calls. On the other hand, low priority secondary users, SU2 handoff calls perform better under the pre-reserved scheme compared to the post-reserved scheme.

CONCLUSION

Models of post-reserved channel sharing scheme with imperfect sensing are developed in this study. The models are used to evaluate the performance of post-reserved channel sharing scheme in terms of dropping probability while comparing it with the pre-reserved channel sharing scheme. The numerical results obtained from the derived models show that post-reserved scheme offers lower dropping probability to high priority handoff calls compared to the pre-reserved scheme. On the other hand, low priority secondary users, SU2 handoff calls perform better under the pre-reserved scheme compared to the post-reserved scheme.

SIGNIFICANCE STATEMENT

This study discover the possibility of using post-reserved channel allocation scheme to reduce the dropping probability of high priority handoff calls, which in turn leads to an increase in the number of calls serviced and revenue. This study will help researchers to uncover the potential of reducing the dropping probability of handoff calls using the post-reserved channel allocation scheme that many researchers were not able to explore. Thus, a new theory on channel allocation scheme may be arrived at.

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