An Efficient Spectrum Handoff Method to Improve the QOS of Secondary Users in Cognitive Radio Networks

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Abstract

In Cognitive radio Networks unlicensed users are temporary visitors to the licensed spectrum, they may be required to vacate the spectrum when a licensed user reclaims it. This process is called spectrum handoff. Spectrum Handoff has a large overhead for secondary users. This overhead includes the time required for sensing the spectrum and finding new channels, communication delay between secondary transmitter/receiver as well as packet loss. To decrease this overhead it is necessary to reduce the number of handoff as much as possible. To this end secondary users should have a proper decision about going to a new channel or to stay on the current channel, during the handoff procedure. Also they have to select target channel so that the channel be available with a high probability and long idle period to avoid unnecessary handoff. In this paper a proactive approach is proposed for spectrum handoff reduction in cognitive radio networks. The preemptive resume priority (PRP) M/G/1 queuing network model is used to characterize the spectrum usage behaviors in secondary and primary users. Then, based on this model, a value is calculated for each channel to demonstrate how much a channel is suitable for handoff, when interrupt occurs. In this scheme the value assigned to each channel is depends on channel idle probability and average waiting time in the channel queue. Moreover a dynamic threshold which is known as hysteresis value is used to reduce redundant handoff. The proposed method is compared to other proactive handoff scheme based on preemptive resume priority (PRP) M/G/1 queuing network model. Simulation results show that proposed spectrum handoff scheme reduces the handoff rate of secondary users significantly with the same data delivery rate and a slight increase in service time at the light traffics.

Keywords: cognitive radio, cognitive radio networks, primary user, secondary user, spectrum handoff, preemptive resume priority (PRP) M/G/1 queuing network model, hysteresis.

1. Introduction

Cognitive radio is the key enabling technology to realize for dynamic spectrum access. With the aim of this technique, unlicensed users (secondary users) are able to adapt themselves with the operating environment parameters and they can utilize the licensed users' spectrum in an opportunistic fashion without interfering with the primary users. Using spectrum dynamically, it may lead to create unprecedented challenges for adapting network protocols with the available uncertain spectrum. The most important challenges of this technology is spectrum mobility which it has been studied less than other the capabilities of cognitive radio network such as: spectrum sensing, spectrum management and spectrum sharing.

Spectrum mobility leads to develop a new class of handoff as spectrum handoff for CR networks. Once a primary user appears in the secondary users' operating channel, the SUs have to suspend transmitting data and find out other available channel to maintain their transmission. Due to randomness nature of appearing of primary users in the channel, accessing smoothly and rapidly to a vacant channel with preventing performance degradation is a great challenge of this sort of networks, especially in ad hoc networks where there is not any centralized control and management [1].

Furthermore, handoff process may impose extra overhead on secondary users in terms of spectrum sensing time and finding an available channel, latency due to reestablishing a new connection between transmitters and receivers and packet loss because of interruption. Regarding additional overhead of handoff procedure, the main purpose of this paper is to present an approach for spectrum handoff which reduces unnecessary handoff. The spectrum handoff mechanism based on destination channel selection methods can be categorized as preventing spectrum handoff and reactive spectrum handoff [2]. In preventing spectrum handoff method, target channels for handoff have been predefined. In this approach, secondary users should monitor the channels status to obtain channel usage statistics. Based on such experiments, secondary users have to determine a collection of target channels. Nevertheless, once reactive spectrum handoff approach is used, a user has to find a target channel in an on-demand manner. In another words, channels sensing and selecting will be performed once a handoff procedure is required. Although the disadvantage of this method is the imposed delay due to spectrum sensing, user does not need to sense channel dynamically in preventing spectrum handoff approach because the target channels are predefined [3].

2. Related work

Numerous researches have been performed on the subject of handoff spectrum in CR networks. For instance, authors in [4] presented several methods for spectrum handoff for Cr networks with multi-channels for supporting sensitive to delay applications such as VOIP where data transmissions can be done through several parallel channels. In this approach, CR users decide to perform handoff based on calculating probability delay density function. In [5], a novel three dimensional discrete-time Markov chain to demonstrate the process of spectrum handoffs and analysis the performance of unlicensed users. Authors of [6] suggest a new technique based on Opportunistic Spectrum Access with Backup channels (OSAB) which is a spectrum access model for managing and increasing the spectrum capacity for ad hoc networks. The main aspect of this model is reducing the spectrum handoff rate. Although in this scheme utilizes the licensed channels as the operating channels, it uses unlicensed channels as backup channels on condition of the appearance of the PUs.

In [7], authors proposed a multi-cell spectrum handoff scheme as a supplement on the coverage of Underlay. Using Simple additive weights decision algorithm with dynamic weights (SAW-DW) in spectrum handoff, it selects optimal target cell for secondary users to prevent service interrupt once secondary users surpass Underlay constraint. The authors combined the idea of spectrum access in multi-cell underlay and handoff since spectrum handoff may be influenced in spectrum sensing results directly. The combined optimization problem of spectrum handoff and spectrum sensing for CR networks considered in [8] to improve scheme performance. Accordingly, it have been minimized the performance parameters of spectrum sensing –the probability of false positive and the probability of false negative- to reduce negative aspect of them on handoff process. In [9], it has been proposed four metrics to characterize both short-term and long-term spectrum handoff performance such as link maintenance probability, the number of spectrum handoff, switching delay, and non-completion probability. In addition, the authors explored both opportunistic and negotiated spectrum access strategies with regard to the minimization of interruption time of secondary users due to spectrum handoff process. A new spectrum management scheme for CRNs termed as Voluntary Spectrum Handoff (VSH) presented in [10]. VSH unlike the other handoff schemes, it is not recognized the primary user in secondary users' operating channel. Estimating time remaining of appearing primary users in channels, secondary users perform voluntary spectrum handoff.

Authors in [11] introduced a new type of losses termed as service interruption loss which occurs once a secondary user accomplished handoff as a result of primary user arrival in the operating channel. This new form of loss is different from losses in consequence of network congestion and channel errors. Therefore, they proposed a TCP rate adapting algorithm that ensures seamless spectrum handoff as primary users appear. Also a preventing spectrum handoff method for ad hoc network proposed in [12, 13]. In this approach to avoid collisions, the adaption of channel switching policies allows the secondary users perform handoff before appearance of licensed users. Moreover, researchers in [14] proposed a spectrum handoff management scheme based on SVM where considers spectrum handoff in a case of mobility of PUs and SUs. According to this model of SVM, a mobile secondary user can predict the right location of handoff before channel is occupied by licensed users. Learning broadcasted neighbors' information, this model is able to predict handoff point and idle channels for mobile SUs.

Authors of [15] proposed a spectrum handoff scheme founded on time estimation (TPSH) to reduce communication disruptions to primary users and enhance the channel utilization efficiency. SUs utilize past channel histories to maintain an estimation vector of the channel remaining idle period (CRIP) and forecast on future spectrum availability, and subsequently they perform handoff process to a channel with the highest CRIP devoid of collisions with licensed users. Also, researchers in [16-20] employed queuing theory PRP M/G/1 to characterize affect of handoff process on behavior of using spectrum by PUs and SUs.

Unlike the other works which measured spectrum handoff in single-hop cognitive networks, authors of [21] investigated spectrum handoff problem for multi-link and multi-hop networks. In this approach, numerous links accomplish handoff process in a cooperative manner. Alternatively, there are multiple hops between source and destination node and it may be performed handoff by links occasionally. The main purpose of this problem is to maintain link connectivity and to minimize total handoff completion time (THCT) for achieving handoff process cooperatively.

The remainder of the paper is organized as follows: section 3 presents system model and assumptions used in proposed scheme. Proposed handoff algorithm is described in section 4. Section 5 reports the simulation results and compares the proposed approach with greedy and random schemes. Section 5 concludes the work.

3. Problem Modeling

The main objective of this problem is to satisfy QOS requirements of secondary users, such as decreasing handoff rate as well as service time. Although dynamic handoff may raise delay due to spectrum sensing when a handoff is required, we use a preventing handoff approach where target channel is predefined. Due to the fact that increasing handoff rate may significantly influence in secondary users performance and raising packet dropping rate as well as extra overhead for coordinating between transmitters and receivers, in proposed approach we define declining handoff rate as a metric for QOS of secondary users. Therefore, we divide this problem into two sub problems:

- What the channel should be selected by secondary user for transmitting?
- What the right strategy should be opted for handoff by secondary user? In other words, when and how should hand over to target channel by the secondary user in order to decreasing the probability of additional handoff?

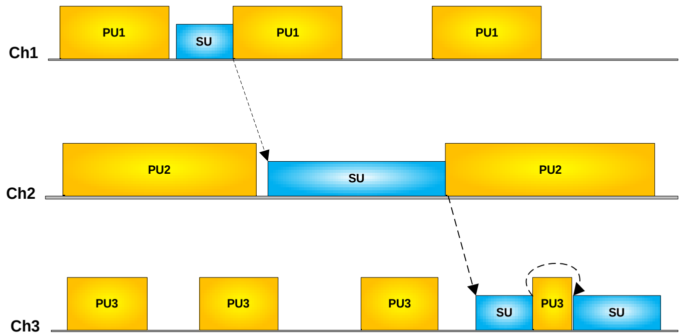

Fig. 1. With the arrival of a PU, SU can handoff to another channel.

4. System Model and Assumptions

We consider a cognitive radio network with N primary users and M secondary users. It is assumed that each primary user has its own dedicated channel. Moreover, it is supposed that each channel can be modeled as an M/G/1 queue with two priority class with preemptive manner. A higher priority class is defined for primary user which they have preemptive right and the lower one can be used for secondary users with a FIFO strategy queuing. Also, we assume that in this kind of network there is a time-slotted mechanism where each time-slot is collected as sensing phase and transmitting phase. Sensing channel and being idle a time-slot, a secondary user can transmit its own packet through the channel. Otherwise, SU go through target channel selection state and decide for handoff with the intention of transmuting of its unfinished flow. In addition, it is supposed that transmission rate of users in the network follows the Poisson process and packet length can be any arbitrary distribution. Also, it is assumed that arrival rate and service time of each user in the network may be varied. Furthermore, it is given that a packet is divided to several frames and a single frame can be sent out through a time-slot. Hence, in a case that a user can not send a frame in a time-slot due to collision, it is supposed to retransmit it. Also, we assume that there is common control channel to facilitate coordinating via control packets.

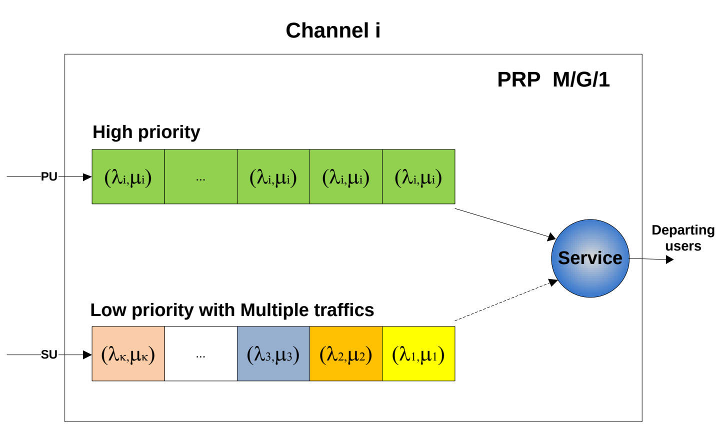

Fig 2. The preemptive resume priority (PRP) M/G/1 queuing network model for the channel.

5. Proposed Spectrum Handoff Scheme

When a SU is interrupted by a high priority PU, the main issue for him is whether he go to another available channel or stay in current channel for the completion of a PU data transmitting. Note that when SU is interrupted, selecting the appropriate channel can improve the performance of handoff process significantly and prevent unnecessary handoff in future. In proposed Scheme there are two important parameters should be considered for selecting an appropriate channel at handoff time:

- **Waiting time:** To decline the service time and overall delay, it is obvious that the secondary user should select a channel with the minimum waiting time to improve its QOS.
- **Idle Probability of a channel:** A user should select a channel with the maximum probability of being idle in the future. Therefore, providing that the idle probability of a channel is less, the user has to wait more in the channel queue. Hence, it may increase the service time. In addition, in a case that the idle probability of a channel is low, in the future, the user has to handoff to another channel with the greater probability.

5.1 Channel selection algorithm

5.1.1 Computing waiting time

Since a channel is modeled as a preemptive M/G/1 and primary users have the most priority than other users, we define average waiting time for priority class k as:

$$W_k = \frac{E[X_k](1-\rho_1-\cdots-\rho_k)+R_k}{(1-\rho_1-\cdots-\rho_{k-1})(1-\rho_1-\cdots-\rho_k)} \tag{1}$$

Where ρ_{k} is the utility factor of priority k and R_k is defined as the average residual service time for current entity in the channel. In the proposed approach, we define k = 2 as it demonstrates that there are two priority classes. Therefore, it is given that: $W_k = R_k + T_Q + \frac{1}{\mu}$, where T_Q is waiting time in queue and $\frac{1}{\mu}$ shows the service time of an entity in the system. We can calculate R_k as:

$$R_k = \frac{1}{2}\sum_{i=1}^{k} \lambda_i E[X_i^2] \tag{2}$$

While in the proposed scheme it is assumed that k = 2 then average waiting time in second priority class which is corresponded to secondary users queue is equal to:

$$W_2 = \frac{E[X_2](1-\rho_1-\rho_2)+R_2}{(1-\rho_1)(1-\rho_1-\rho_2)} \tag{3}$$

Since it is assumed that there are M traffic classes, total arrival rate can be given by:

$$\lambda_t = \sum_{i=1}^{M} \lambda_i \tag{4}$$

Also, the total utility factor can be considered as:

$$\rho_t = \sum_{i=1}^{M} \rho_i = \sum_{i=1}^{M} \frac{\lambda_i}{\mu_i} \tag{5}$$

It is not necessary to mention that for stability condition in a queue, the following condition should be satisfied: $\rho_t < 1$ and $\rho_i < 1$. Moreover, the average service time and its variance can be computed as:

$$E_t[X] = \sum_{i=1}^{M} \frac{\lambda_i}{\lambda_t} E[X_i] \tag{6}$$

$$E_t[X^2] = \sum_{i=1}^{M} \frac{\lambda_i}{\lambda_t} E[X_i^2] \tag{7}$$

Regarding Eq. (4-4) to (4-7), the average waiting time in second priority class of an M/G/1 system can be obtained as:

$$W_2 = \frac{\sum_{i=1}^{M} \frac{\lambda_i}{\lambda_t} E[X_i] \times \left(1 - \frac{\lambda_1}{\mu_1} - \sum_{i=1}^{M} \frac{\lambda_i}{\mu_i}\right) + \frac{1}{2}(\lambda_1 E[X_1^2] + \lambda_t \sum_{i=1}^{M} \frac{\lambda_i}{\lambda_t} E[X_i^2])}{\left(1 - \frac{\lambda_1}{\mu_1}\right)\left(1 - \frac{\lambda_1}{\mu_1} - \sum_{i=1}^{M} \frac{\lambda_i}{\mu_i}\right)} \tag{8}$$

5.1.2 Computing idle probability of a channel

The idle probability is measured as the ratio of the idle time-slots in the channel to all time-slots in a given time period. Once a user decides on the channel with the high idle probability, the need of other handoff ratio will be reduced. Therefore, we define the idle probability as:

$$P_I = 1 - P_B \tag{9}$$

Where P_I and P_B are the idle probability and busy probability respectively. Since the utility factor a channel is equal to busy probability, it can be driven that:

$$P_I = 1 - \rho = \frac{\mu - \lambda}{\mu} \tag{10}$$

While it may be a channel being at the idle state by primary users, other secondary users may involve in transmitting in this period and also considering the proposed system model, the channel will be regarded as busy. In result, the idle probability of a channel can be obtained as the probability of not present any primary and secondary users in the given time-slot:

$$P_I = \left(1 - P_p\right) \times (1 - P_s) = \left(1 - \rho_p\right) \times (1 - \rho_s) \;=\; \frac{\mu - \lambda}{\mu} \times (1 - \sum_{i=1}^{M} \frac{\lambda_i}{\mu_i}) \qquad (11)$$

Where P_p , P_s , ρ_p and ρ_s are indicated as busy probability for primary users, busy probability for secondary users, utility factor for primary users and utility factor for secondary users respectively.

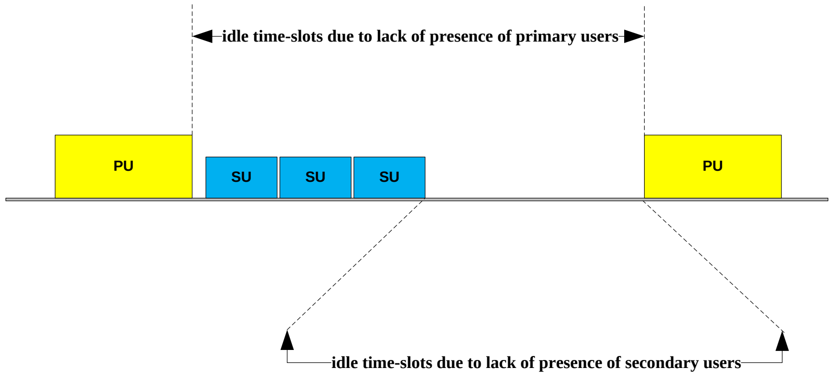

Fig 3. Channel is idle if there are no PU and SUs in it.

In the proposed scheme, a payoff for a channel is calculated based on idle probability of a channel and average waiting time. Hence, a channel can be determined as an appropriate among others with higher idle probability and lower average waiting time. Consequently, a channel payoff is defined as:

$$V_k(t) = \alpha P_I^k(t) + \frac{(1-\alpha)}{W_2^k(t)} \quad \alpha \in (0,1) \;\; , \;\; k \in \{1, \dots, N\} \qquad (12)$$

As a result, a channel is measured as the target for handoff, as long as, the corresponding amount of its V_k is higher than other channels. Also, α as a coefficient is applied for adapting in various channel situations.

5.2. Handoff procedure

Each secondary user i, has a channel payoff vector $V_i = \{V_1, V_2, \dots, V_c\}$ where the vector size is identical to maximum number of channels which secondary user can select as the candidate channels. With the aim of this vector in a given time-slot, the user can determine which channel can be suitable as target for handoff. The initial value for all channels in the vector is set to zero. At commence, every secondary user select channel i as a default channel for transmitting packets. Once a secondary user needs to handoff, the value of payoff available channels is calculated based on eq. (12) and finally regarding the highest payoff value, the corresponding channel will be selected as the target channel for handoff. To be more precise, to prevent the unnecessary handoff, a threshold as the hysteresis value will be used.

$$\begin{cases} V_j - h > V_i & Handoff \\ V_j - h \le V_i & Stay \end{cases} \qquad (13)$$

Where V_i and V_j are the payoff value for current channel and candidate channel respectively. Also, h is regarded as hysteresis value.

5.2.1 Hysteresis Value

The concept of hysteresis is used in cellular network to reduce the ping-pong effect as well as the number of unnecessary handoff in the channel selection procedure. Applying Hysteresis value to the network in handoff procedure, the user accomplishes handoff in a case that the different received signal is greater than a predefined or dynamic threshold. It is extremely difficult to allocate a constant value for hysteresis. Providing that the hysteresis value is diminutive, the handoff rate may be increased dramatically and also on a condition that the value is considered enormous, it leads to raise the overall delay and service time and it is reduced the QOS. For this reason, deciding on adaptive and dynamic value for hysteresis can improve the handoff scheme and it prevents the unnecessary forced delay on the network.

In the proposed scheme, it is employed an adaptive hysteresis value to establish a strict procedure to accomplishing handoff in order to declining the superfluous handoff. The hysteresis value consists of the probability of performing a handoff all over again from the target channel to another dynamically. Therefore, we can obtain the hysteresis value h as the probability of being busy operated channel and the probability of having greater payoff value than the target channel:

$$h = P_{Busy}^{target} \times \frac{|\{i|\ V_i \geq V_{target}\}|}{N} \quad , \quad i \in 1, \dots N \tag{14}$$

and in other form, it can be given by:

$$h = \left[\frac{\lambda_{target}}{\mu_{target}} \times \sum_{k=1}^{M} \frac{\lambda_k}{\mu_k}\right] \times \frac{|\{i|\ V_i \geq V_{target}\}|}{N} \quad , \quad i \in 1, \dots N \tag{15}$$

In the eq. (4-14), we use the target channel busy probability for two reasons: firstly, the busy probability of a given channel can indicate the channel load. Therefore, if the channel load is very high, it is required to amplify the threshold value to prevent accomplishing the handoff. Secondly, by considering the busy probability, the initial users' arrival rate is taken into account where demonstrates the number of handoff events in a given channel.

5.3 Fairness

To improve the functionality of proposed handoff scheme, it is required to establish fairness when users want to accomplish handoff to a specific channel. To be more exact, imagine a scenario where at a given time, a quantity of users discovers a specific channel is appropriate for performing handoff. In result, once all users immigrate to the target channel, it makes to increase the queue length as well as service time. To avoid this situation, a user maintains a set of candidate channels with greater payoff value than others. Followed by, with the aim of geometric probability, it selects a channel from the set randomly. Consequently, the channels will be distributed in fair manner between all users. Eq. (4-16) figures the selection probability P_{ch} where V_{ch} is payoff value for a specific channel among c channels.

$$P_{ch} = \frac{V_{ch}}{\sum_{i=1}^{c} V_i} \tag{16}$$

6. Simulation Results

In this section, the proposed scheme is compared with random and also greedy schemes [21] in terms of handoff rate and packet delivery ratio as well as average service time. While random scheme is applied, the user selects the next channel randomly from the available channels when an interruption occurred, in greedy method, the user selects the next channel regarding minimizing the secondary users' service time. The simulation parameters are summarized in Table (1).

Table 1: Simulation parameters

Parameter	**Value**
Total Channels	10
PU	2-10
SU	2-10
Candidate channels	2-10
PU's average arrival rate	$\lambda_p = 0.01 - 0.2$ (arrivals/slot)
DU's average arrival rate	$\lambda_s = 0.05 - 0.1$ (arrivals/slot)
PU's average packet length	$\mu_p = 0.5 - \ 0.7$ (slots/arrival)
SU's average packet length	$\mu_s = 0.55 - 0.95$ (slots/arrival)
Hand-shaking time	$t_h = 0.0$ (slots)
Switching time	$t_s = 0.05$ (slots)
α	0.4
Simulation time	1000 time slots

6.1 Average service time

As the figure (4) illustrates, while the greedy approach has the minimum service time in comparison with the other schemes for the reason that the only metric for QOS is average service time, the proposed approach consider average service time in addition to handoff rate as the metrics. Furthermore, due to the fact that in proposed approach, the status of channel is considered precisely, by increasing the PU's traffic rate, the secondary users prefer to stay at their operating channel until it turns to be idle instead of deciding for hand-off. Consequently, in a heavy loaded network situation, the average service time will be reduced in proposed approach.

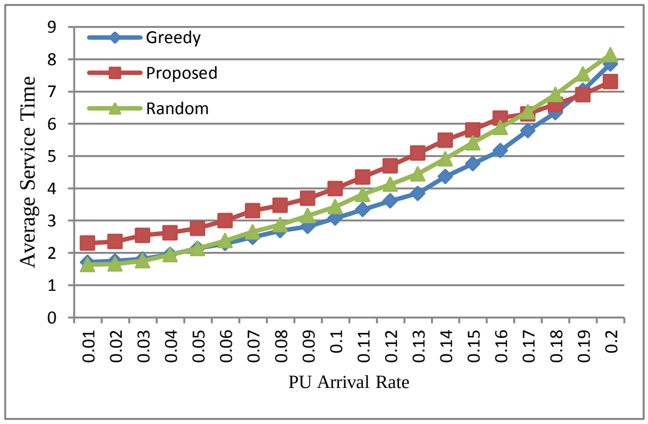

Fig. 4: Comparing average service time V.S. PU's arrival rate

6.2 Hand-off rate

Figure (5) depicts the secondary users' average hand-off rate. As it can be extracted, in the greedy method for all time, it decides on the optimum channel from its view point. In result, due to dynamic nature of cognitive radio networks, user has to migrate to the new channel. Consequently, it raises the hand-off rate. Nevertheless, applying proposed algorithm, by increasing the traffic load, hand-off operation will be accomplished in a stricter manner. Hence, staying in operating channel will be preferred and as a result hand-off rate will be reduced significantly. It is obvious that in the random approach, hand-off process is accomplished without considering any network conditions and it can leads to increase hand-off rate.

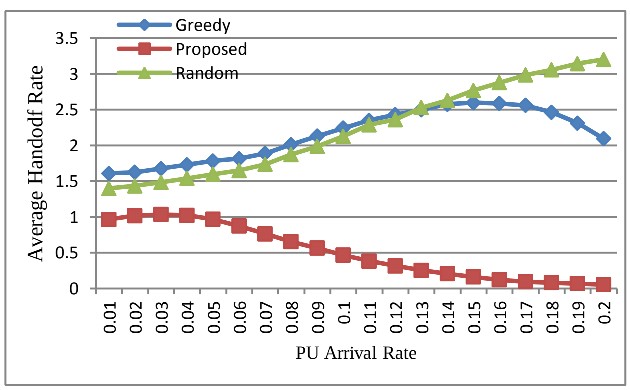

Fig. 5: Comparing average hand-off rate V.S. PU's arrival rate

6.3 Packet delivery ratio

Once channel selection and hand-off procedure are performed randomly without any knowledge of network, by frequent migrating among the channels, packet delivery ratio may be changed depending on the network situations. Due to strict hand-off procedure in proposed scheme, delivery ratio is close to the greedy method despite of increasing service time. Figure (6) demonstrates this scenario. Regarding figure (4) – (6), with diminishing hand-off, average service time in heavy loaded network can be reduced, also it can aim to increase delivery ratio in comparison with other schemes.

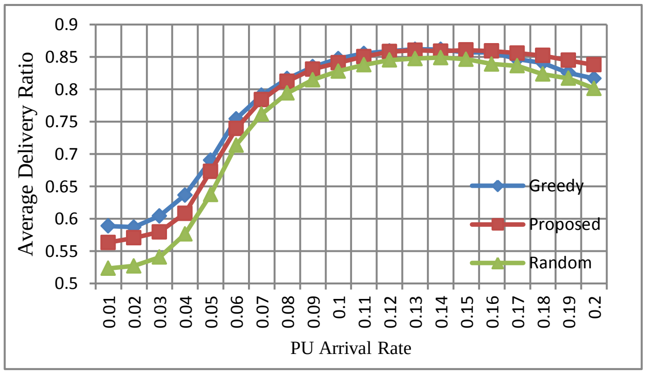

Fig. 6: comparing packet delivery ratio for all schemes

6.4 Impact of α on the other metrics performance

In Eq. (10), changing the value of α has the impact on the channel value. Consequently, it leads to alter hand-off rate and service time as well as delivery ratio. In figure (7), the effect of altering value of α is pointed up. As it can be demonstrated, by raising value of α can cause reducing average service time. Since there is a tradeoff between idle probability of a channel and service time in Eq. (10), as a result by increasing the value of α, the influence of average service time will be declined and finally a channel will be selected with a lower service time.

In figure (8) the effect of α on hand-off rate is demonstrated, the influence of growing value of α can result in declining hand-off rate. This diagram shows that it is not appropriate considering average service time as the only metric for deciding on hand-off. However, taking into account average service time as the metric can cause to reduce overall service time, nevertheless it forces the extra overhead in terms of increasing hand-off rate, wasting bandwidth for communicating control messages and increasing energy consumption as well as additional delay caused by accomplishing hand-off process on the network. In [21] the single metric for performing hand-off is the minimum service time. Therefore as it is expressed, it is very important to take into consideration other network parameter for immigrating from operating channel to others. As the figure (9) depicts, the impact of α on the delivery ratio has not any significant influence. In result, by adjusting the weighting factor $\alpha = 0.4$, it can be obtained to reduce hand-off rate as well as delay caused by service time efficiently.

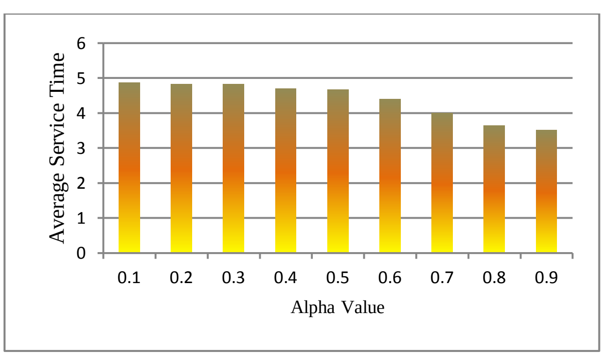

Fig. 7: Comparing average service time under varying α

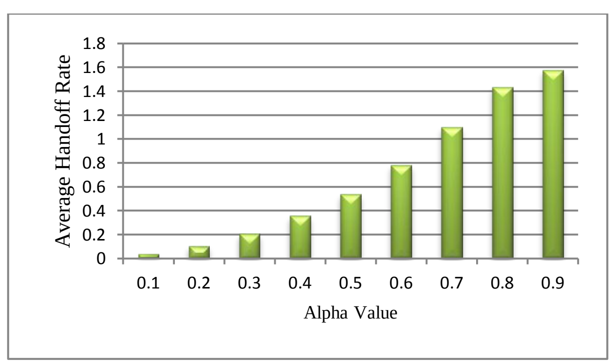

Fig. 8: Comparing average handoff ratio under varying α

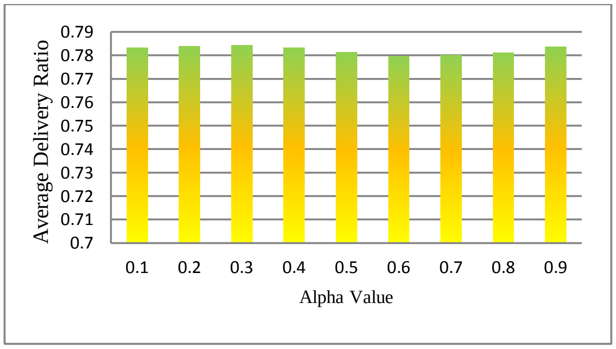

Fig. 9: Comparing packet delivery ratio under varying α

7. Conclusions

In this paper, we studied the hand-off spectrum in cognitive radio networks. Due to extra overhead caused by hand-off procedure in terms of delay and collision as well as packet dropping, a hand-off scheme can be appropriate in a case of lower rate. Based on the preemptive resume priority (PRP) M/G/1 queuing network model, a payoff value as the metric for hand-off procedure for each channel computed. To be stricter performing hand-off, we used a dynamic threshold as hysteresis to prevent unnecessary hand-off. Simulation results demonstrated that the proposed scheme is more efficient than greedy and random schemes regarding hand-off rate and packet delivery ratio despite of insignificant overhead as service time in light loaded traffics.

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