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Novel Hybrid Spectrum Handoff for Cognitive Radio Networks

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Abstract

Cognitive radio (CR) is projected as a technology (or solution) that will raise the spectrum utilization considerably by allowing low-priority or secondary user (SU) to utilize the spectrum of high-priority or primary user (PU) opportunistically. Spectrum handoff is a different type of handoff necessitated by the reappearance of the primary user on the frequency channels occupied by the secondary user at that time and location. In this paper, a hybrid type of spectrum handoff algorithm is proposed where proactive decision and reactive decision approaches are combined. Depending on the arrival rate of primary user (i.e. PU activity), the algorithm switches from reactive decision mode to proactive decision mode and vice versa. The switching from one mode to another mode depends on threshold value of PU activity and we evaluated the threshold value through analysis for switching of the algorithm to be 0.37. Simulated results show that the proposed hybrid spectrum handoff algorithm reduces the total service time of secondary user considerably compared to conventional proactive decision or reactive decision handoff approaches.

Index Terms: Cognitive radio; spectrum handoff; proactive decision handoff; reactivedecision handoff; queueing theory.

1. Introduction

The spectrum is a precious natural resource and is presently regulated by governmental agencies to avoidinterference among users and is allocated by fixed spectrum allocation policy. The fast growth of new wireless applications and services has resulted in increased demand of radio spectrum access. But most of the radio spectrum stands already allocated by fixed allocation policy and it becomes difficult to find unallocated spectrum for these new upcoming applications and services. As per the survey of Federal Communications Commission (FCC) [1], up to 85% of the assigned spectrum is underutilized. This allocation policy has

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created a situation where there appears an artificial scarcity of the spectrum. This ever increasing demand of spectrum for new applications cannot be fulfilled unless an alternate scheme to regulate the scarce spectrum is not found. Therefore, FCC has suggested a new communication paradigm for accessing the assigned spectrum dynamically [2] known as cognitive radio (CR). CR is a key technology that will make the dynamic spectrum access (DSA) a reality. DSA allows the SU to dynamically adjust its operating parameters (such as transmit power, modulation, operating frequency) in order to adapt to time varying radio environment and utilize the idle spectrum opportunistically [3-6], not used by the primary user at that time and location.In addition to spectrum sensing and management, another important function a CR should perform is spectrum mobility and gives rise to a different type of handoff in cognitive radio networks known as spectrum handoff.The aim of spectrum handoff is to help the SU to release the occupied channels instantlyin order to avoid interference to the primary user and find suitable idle channels to restart the interrupted transmission. The handoff to new channels should be seamless so that an application running on the SU perceives minimum quality of service (QoS) degradation [7]. The CR technology allows SUs to sense the environment to find spectrumholes (or idle channel) and utilize these spectrum holes for transmission opportunity with the constraint of non-interference to the primary user. In cognitive radio, the PU has the priority to access the spectrum.

Depending on the decision method used for selecting the idle channels for future handoffs, the spectrum handoff process is classified as the proactive decision and reactive decision handoff approaches.

- In case of proactive decision handoff [8-12], the channels to be used for future handoffs are decided before actual data transmission takes place. The SU senses the wideband spectrum periodically for detection of idle channels so that expected usage pattern of the wideband spectrum over longer period is generated. Then the CR predicts the channels having highest probability of appearing idle at the time of actual handoff.
- In case of the reactive decision handoff [13-14], idle channels are detected through instantaneous sensing of the wideband spectrum after arrival of the PU.

There have been many studies applying queueing theory to study spectrum handoff in cognitive radio networks. Theauthors of [15], proposed the comparative analysis of two approaches namely proactive decision and reactive decision. The analysis of total service time of proactive decision handoff algorithm with multiple interruptions was proposed in [16] while analysis of extended data delivery time of reactive decision was proposed in [17]. The authors of [18] proposed spectrum management techniques in cognitive radio networks with main focus on QoS provisioning.

In this paper, we focus on the performance analysis of the proposed hybrid spectrum handoff algorithm against the conventional proactive decision or reactive decision handoff approaches. The total service time of the algorithm with multiple interruptions is evaluated using pre-emptive resume priority M/G/1 queueing network model.

The rest of the paper is organized as follows. Section 2 introduces a PRP M/G/1 queueing network model used to evaluate total service time. Section 3 presents proactive decision spectrum handoff. Section 4 presents reactive decision spectrum handoff. Section 5 proposes the hybrid spectrum handoff algorithm. Section 6 presents the simulated results of the hybrid spectrum handoff algorithm and the conclusion is provided in section 7.

2. PRP M/G/1 Queueing Network

A PRP M/G/1 queueing network model [19-25] is used for the characterization of the spectrum usage interactions between primary users and secondary users. The transmission of the SU can be interrupted multiple times by the arrival of PU. Therefore, this model is used to calculate the total service time of the two

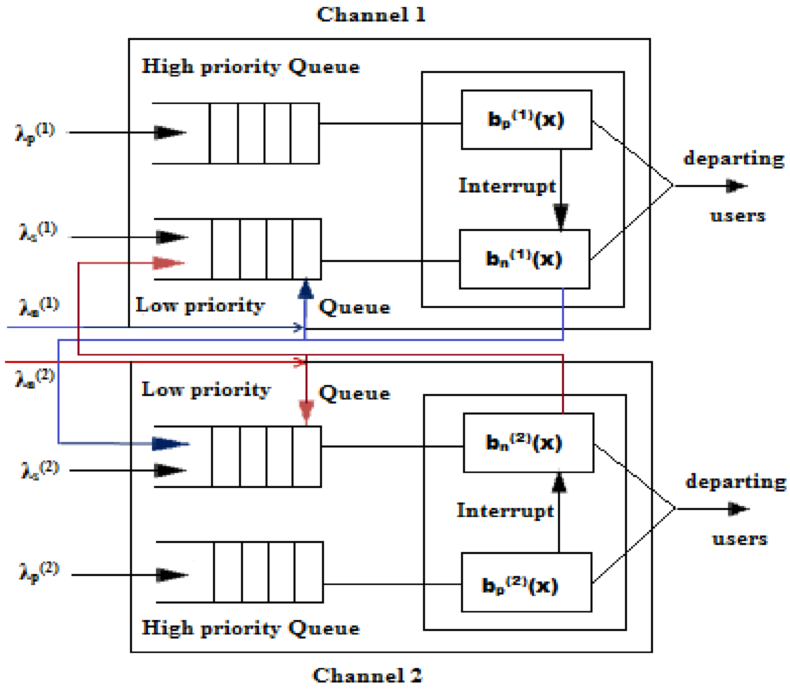

Fig. 1. The PRP M/G/1 queueing network for two channel system where n ≥ 1 (Reproduced from [15])

approaches namely proactive decision and reactive decision.Important featuresof PRP M/G/1 queueing network model are given below:

- The transmissions of secondary users have low priority; therefore, can be interrupted by the arrival of PUs.
- When PU arrives back on the channels presently occupied by SU, the transmission of the SU is paused instantly in order to avoid interference.
- The interruptedSU has a choice to transmit either on the same channels or on other idle channels.
- In case of many secondary users contending for channel access, the access to channels is allowed as on first come first served basis.

Fig.1 shows an example of the PRP M/G/1 queueing network with two channels.The PUs are put into the high priority queue while theSUs are put into the low priority queue. The interrupted SU has two options, either to stay on the current channels or change the operating channels. In case of staying on the same channels, the unfinished transmission is put into the head of low-priority queue while in case of changing the operating channels, the unfinished transmission is put into the tail of low-priority queue. In both cases, the interrupted transmission is resumed as soon as the channels become idle. The parameter of importance in this model is the effective packet length and is defined as the duration of the transmission of the packet until PU arrives back on those channels.

3. Proactive Decision Spectrum Handoff

In case of proactive decision handoff, the decision for channel switching is taken prior to actual handoff. When PU arrives back, the SU pause its transmission and quickly handoff to the predetermined target channel. In this case, the total service time of SU may be reduced as there is no need of instantaneous spectrum sensing and handshaking between the transmitting and receiving SUs. But at the time of actual handoff, the predetermined channels may be busy. Therefore, the SU has to wait in the queue till all the PUs and SUs complete their service. As a consequence of this, there could be an increase in actual handoff delay.

Let λp (arrivals/slot), λs (arrivals/slot) be the initial arrival rates of the primary users' and secondary users' connection at each channel and Xp (slots/arrival) and Xs (slots/arrival) be their corresponding service time. It is assumed that Xp and Xs are exponentially distributed with service rates μp and μs. In this paper, we have decided to change the channels when spectrum handoff takes place. Ifpredetermined channel is idle then the transmission of secondary user is restarted on this new channel and the handoff delay happens to be the switching delay. If the predetermined channel happens to be busy then secondary user has to wait till all primary users and the secondary users in the queue complete their transmission. The handoff delay in this case is switching delay and waiting time on that channel.

Let Tproactive be the average total service time, ts be channel switching time and Ws be waiting time of secondary user on another channel until all primary users and other secondary users finish their transmission. The closed form expression for proactive decision spectrum handoff is derived in [16], we have

$$T_{proactive} = E[X_s] + E[N](W_s + t_s) \tag{1}$$

where E[N] is the average number of interruptions, $E[X_s]$ is the average secondary service time.
The average number of interruptions for a secondary user within a period of $E[X_s]$ can be obtained as

$$E[N] = \lambda_p E[X_s] \tag{2}$$

since the transmission of the secondary users will depend on the primary arrival rate.
The total service time of the proactive handoff scheme comes out as

$$T_{proactive} = E[X_s] + (\lambda_p E[X_s] (\frac{\lambda_p (E[X_p])^2 + \frac{\lambda_s}{(\lambda_p + \mu_s)\mu_s} + \frac{\rho_p{}^2}{1-\rho_p} E[X_p]}{1-\rho_p-\rho_s} + t_s) \tag{3}$$

where t_s is the channel switching time, $E[X_p]$ is the average primary service time, ρ_p is primary utilization is equal to $\rho_p = \lambda_p E[X_p]$ and ρ_s is secondary utilization is equal to $\rho_s = \lambda_s E[X_s]$.

4. Reactive Decision Spectrum Handoff

In case of reactive decision handoff, idle channels are found through instantaneous sensing of the wideband spectrum at the time of the actual handoff. The unfinished transmission of the interrupted SU will be restarted on these idle channels. In this approach, the handoff delay may be short as the target idle channels are found reliably through instantaneous sensing of the spectrum and the handoff delay is the sensing time plus the handshaking time necessary for consensus of the target idle channels between the transmitting and receiving SUs. Hence, time duration of spectrum sensing and handshaking is an important factor for assessing the performance of this approach.

The closed form expression is derived in [17] for total service time for reactive decision spectrum handoff as

$$T_{reactive} = E[X_s] + E[D] \tag{4}$$

where $E[X_s]$ is the average service time of secondary users and E[D] is the average cumulative handoff delay.
Then total service of reactive decision handoff ($T_{reactive}$) comes out as

$$T_{reactive} = E[X_s] + \frac{\lambda_p\,[t_p\,\mu_s + (E[X_p])^2 \lambda_p \mu_s + E[X_p](\lambda_s - t_p\,\lambda_p \mu_s)]}{(1-\lambda_p E[X_p])(\mu_s)^2} \quad (5)$$

where t_p is the processing time and is given as $t_p = t_s + t_f$, t_s is channel switching time, t_f channel sensing time and μ_s is the secondary service rate equal to $\mu_s = 1/E[X_s]$ and μ_p is the primary service rate equal to $\mu_p = 1/E[X_p]$.

5. Proposed Hybrid Spectrum Handoff Algorithm

A hybrid type of spectrum handoff is proposed in this section,which is the combination of proactive decision and reactive decision approaches. Depending on the PUactivity, the algorithm switches from proactive decision mode to reactive decision mode and vice versa. Equation (3) determines total service time of proactive decision (i.e. Tproactive) approach, while equation (5) determines total service time of reactive decision (Treactive) approach. As can be seen from equations (3) and (5), the total service time of both decision approaches depend on average secondary service rate (μs), average primary service rate (μp), secondary arrival rate (λs) and mean sensing time (tp).For different arrival rates of PU, the total service time of both decision approaches change due to change in number of perceived handoffs. In order to simplify the analysis of the proposed algorithm, it is assumed that each channel has identical traffic patterns and the hybrid handoff algorithm is simulated for two channel scenario. It is also assumed that channel switching time (ts) is equal to zero so that channel processing time (tp) is equal to the sensing time only.

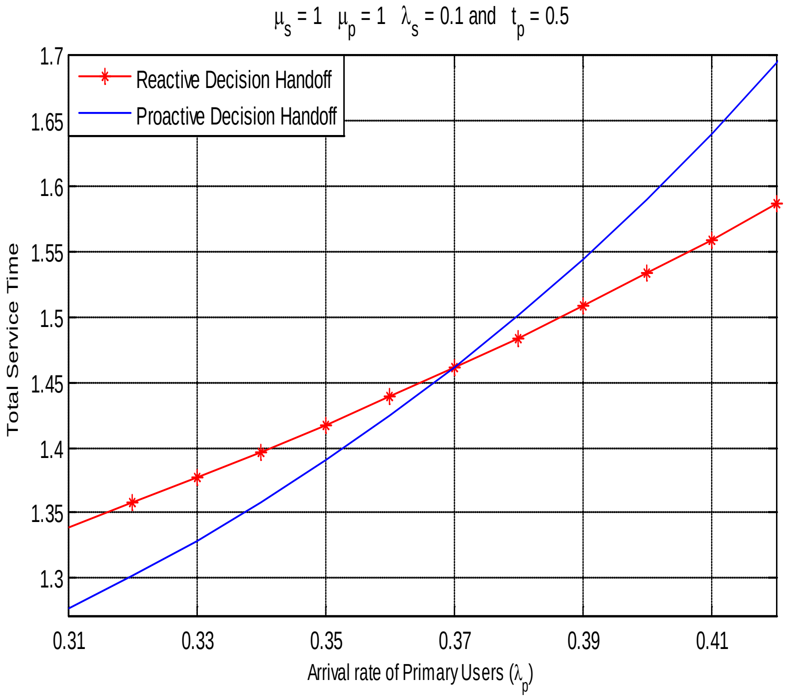

Fig.2. Comparison of reactive decisionand proactive decisionhandoff approaches for threshold evaluation

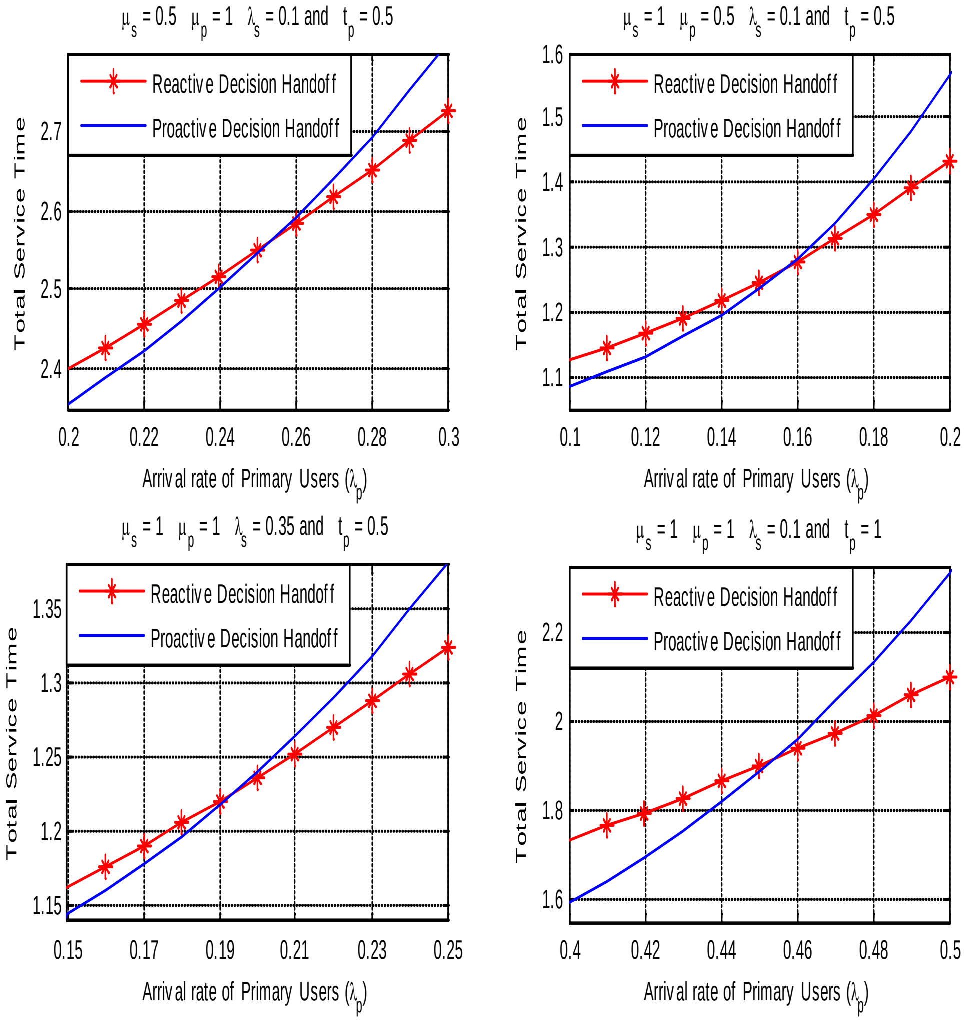

Fig.3. Sensitivity of μs, μp, λs and tp parameters on threshold value of λp

6. Simulated Results

In this section, we presented the simulated results of the proposed hybrid handoff algorithm to support our analysis and the analysis of the algorithm is performed in Matlab 7.6. The first step for the analysis is to determine the value of threshold to be used for switching between proactive decision and reactive decision approaches and vice versa. In Fig. 2, we plot the total service time of proactive decision and reactive decision approaches as a function of primary arrival rate (λp). As can be seen from Fig. 2, for parameter values such as μs=1, μp=1, λs=0.1 and tp=0.5, the threshold value of primary arrival rate (λp) comes out to be 0.37. We have analysed, the sensitivity of threshold value to these parameters, such as average secondary service rate (μs),

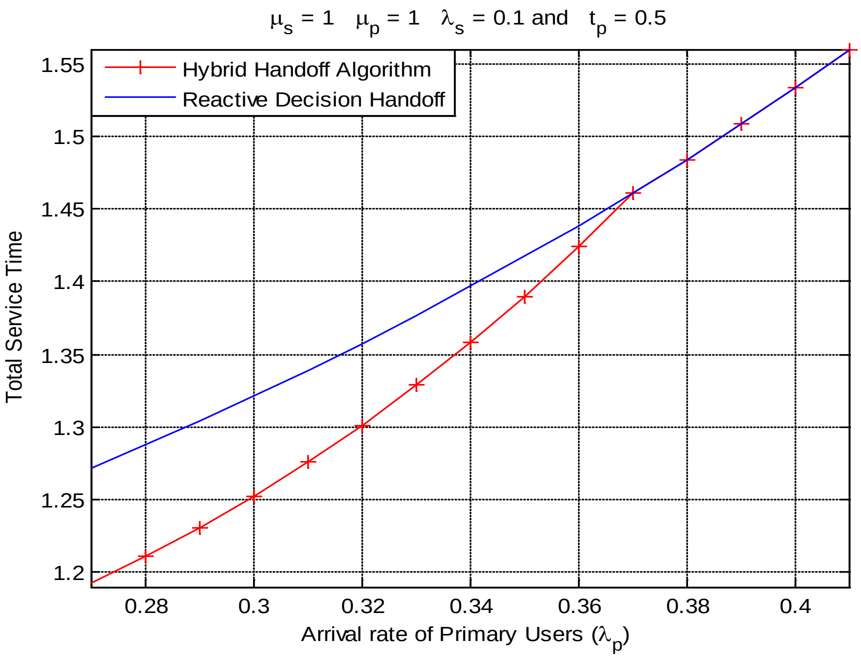

Fig. 4. Comparison of total service time of hybrid handoff and reactive decision handoff algorithms

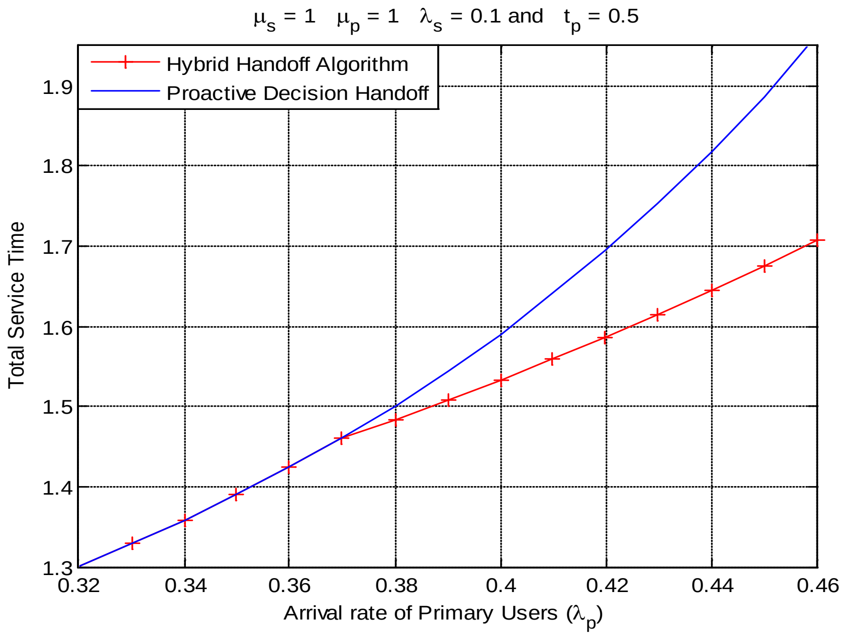

Fig. 5. Comparison of total service time of hybrid handoff and proactive decision handoff algorithms

average primary service rate (μ_p), secondary arrival rate (λ_s) and mean sensing time (t_p) with reference values of parameters such as μ_s=1, μ_p=1, λ_s=0.1 and t_p=0.5. Fig. 3 presents the impact analysis of varying one parameter at a time to threshold value in comparison to reference values. As can be seen from Fig. 3, for parameter values of μ_s=0.5, μ_p=1, λ_s=0.1 and t_p=0.5, the threshold value λ_p = 0.252, for parameter values μ_s=1, μ_p=0.5, λ_s=0.1 and t_p=0.5, the threshold value λ_p=0.155, for parameter values of μ_s=1, μ_p=1, λ_s=0.35 and t_p=0.5, the threshold value λ_p = 0.192 and for parameter values of μ_s=1, μ_p=1, λ_s=0.1 and t_p=1, the threshold value λ_p=0.453.

Fig. 4 presents the comparison of the proposed hybrid algorithm with reactive decision handoff approach. As can be seen from Fig. 4, the service time of the hybrid algorithm is lower until $\lambda p < 0.37$. For $\lambda p \geq 0.37$, the service time of both the algorithms is same. At lower values of λp (i.e. $\lambda p < 0.37$), there is highest probability that the predetermined channels will appear to be idle at the time of actual handoff. In this case, handoff delay is only the switching delay and our hybrid algorithm experiences lesser number of handoffs which results in reduction of total service time of the SU.

Fig. 5 presents the comparison between the proposed hybrid algorithm with proactive decision handoff algorithm. As can be seen from Fig. 5, the service time of the of both algorithms is equal until $\lambda p \leq 0.37$. For $\lambda p > 0.37$, the service time of the hybrid algorithm is lower than the proactive decision algorithm. At higher values of λp (i.e. $\lambda p > 0.37$), there is highest probability that the predetermined channels appear busy at the time of actual handoff. Therefore, SU will spend most of the time waiting in queue for service while reactive decision handoff approach will find idle channels reliably by instantaneous sensing. The total delay in this case is sensing and switching delay which is considerably lower than the waiting time in a queue.

Therefore, the proposed hybrid handoff algorithm will intelligently operate in proactive decision handoff mode when $\lambda p < 0.37$, will switch to reactive decision handoff mode when $\lambda p = 0.37$ and remains in this mode until $\lambda p > 0.37$. The results demonstrate that there is considerable reduction in total service time of the secondary users.

7. Conclusion

We have proposed and analysed a hybrid spectrum handoff algorithm for total service time of the secondary user. The proposed hybrid algorithm switches from proactive decision mode to reactive decision mode and vice versa, depending on the threshold value of the primary arrival rate. We have analyzed the sensitivity of selected parameters such as μs, μp, λs and tp on threshold value used for switching of the hybrid algorithm. The resultsdemonstrate that for the parameter values μs = 1, μp = 1, λs= 0.1, and tp = 0.5, the threshold value of arrival rate of primary users (λp) comes out to be λp = 0.37. The simulated results show that the proposed hybrid handoff algorithm reduces the total service time of SUs considerably as compared to conventional proactive decision or reactive decision handoff algorithms. The reduction in total service time results in increased throughput and will support higher quality of service (QoS) for SUs.

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