Hindawi
Journal of Electrical and Computer Engineering
Volume 2019, Article ID 7692630, 12 pages
https://doi.org/10.1155/2019/7692630

Research Article

Intelligent Process of Spectrum Handoff/Mobility in Cognitive Radio Networks

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Received 20 November 2018; Revised 30 January 2019; Accepted 25 February 2019; Published 13 March 2019

Academic Editor: Vinod Sharma

Cognitive radio is an innovative technology in the field of wireless communication systems, aimed at significantly improving the use of the radio spectrum while allowing secondary users to access the spectral band opportunistically. Spectrum management mechanism ensures the transmission of data by controlling the efficiency of operation between the primary and secondary networks. The main task of spectrum management is to ensure that secondary users benefit from the spectrum without interfering with primary users. This paper deals with some of the important characteristics of spectrum mobility in the cognitive radio networks. The new management approaches of the mobility and the connection are designed to reduce the latency and loss of information during spectrum handoff, a list of channel safeguard is maintained in this effect, but the maintenance and update are a challenge. In this paper, we describe the reasons and mechanisms of spectrum handoff. Protocols have been developed to illustrate this handoff mechanism. We also make a comparison between the different methods of spectrum handoff. The simulation results obtained confirm that the protocols developed and the proposed method performed better than the pure reactive handoff method.

1. Introduction

Since some tens of years, the field of wireless telecommunications tends to take a more and more important in the current companies, both in economic terms and in terms of technological advances. Unfortunately, this spectacular development of wireless technologies is threatened as the majority of the spectrum, which represents the physical media for wireless transmission, has already been allocated to existing systems. In 2002, the body of regulation and spectrum management in the United States, the Federal Communications Commission (FCC), established a spectrum control and management system to ensure the availability of communications services [1]. The preliminary measures carried out by this group highlighted the need for more flexibility in the spectrum management. Indeed, some frequency bands are used intensively, and others are barely or not at all used. At a time and place given, by browsing through the full spectrum, it is quite possible to find a band of frequencies not used by its owner. It is therefore clear that the shortage of frequencies is only artificial and can be regulated by a new policy of more flexible access.

The objective of the cognitive radio (CR) is to enable terminals, using different standards of communications, to coexist on the same frequency bands. On the one hand, bands of fixed frequencies are assigned to primary users (PU). This allows the PUs to communicate in priority. On the other hand, secondary users (SUs) are allowed to communicate on the frequency bands of the PU in a nonpriority. In effect, the SU must interfere with the least possible communications of PUs. There are several methods available for an SU to access the radio frequency (RF) spectrum. These can be classified into three different techniques of access to the spectrum of the PU: the interweave, the overlay, and the underlay techniques [2]. The interweave technique is to operate during a given time and at a given location the frequency bands not used by the PU. The overlay and underlay techniques allow, with respect to them, to SU to use a frequency band occupied by a PU. In this context, the SU must guarantee a level of minimum interference on the signal of the PU.

The mobility aspect is very important in cognitive radio networks (CRNs), and it takes into account various requirements: (1) to adapt the mechanisms of anticipation of the handoff to the context of the CR and (2) to propose specific solutions to this new type of networks. The change of the operating frequency band of the SUs is a task related to the management of the spectrum mobility which makes it possible to guarantee the continuity of transmission of SU without interruption. When a PU decides to resume its licensed radio channel in use by the SU, the SU must switch to another frequency band deemed inactive over a given period to guarantee the quality of service (QoS) of one or the other. The mechanism of this change in the frequency band is known as spectrum handoff (SH). The SH process for the secondary system is much more based on the PU and SU action models. Therefore, the probabilistic SH study that takes into account that both the PU and SU elements are fundamental to the performance evaluation of the CRN.

During SH, temporary communication interruptions are unavoidable due to the search for new available spectrum bands. CR users may need to modify their frequencies. This process causes latency in the transfer delay, reduces the transmission throughput, and creates the interference between the PU and the SU, the significant losses in the quality of the current communication and the collisions between the users during the transmission. This paper provides proactive multilevel SH schemes to avoid collisions and reduce total service time.

The channel maintenance time by the PU is a key element in analyzing the performance of SH mechanism in a CRN. The accessibility of the channels for the SU depends on the appearance of PU, which can be characterized by the residual time of the holes of the spectrum. In general, there are three distinct conditions for SH: (1) when an SU fails connection because of mobility, (2) when the available spectrum does not support the prior requirements, and (3) when the PU activity on the licensed spectrum is detected. There are different techniques for SH in CRNs. These techniques allow SUs to switch to other channels without interrupting their transmission. These techniques are as follows: pure proactive handoff, pure reactive handoff, hybrid handoff, and nonhandoff, but our study is focused on the technique of proactive handoff. Table 1 shows the comparison of different spectrum handoff techniques in CRNs [3, 4]. It is important to underline that the proactive handoff technique considerably reduces the detection time, and this is due to the fact that the instant broadband detection is not feasible in this type of handoff. This has the advantage of significantly reducing the total service time and the delay of handoff in the network. However, the problem is that the channels targeted or preselected cannot be accessed when the interrupt event occurs. Unlike other SH techniques, the proactive handoff is considered the most accurate and reliable in terms of delay reduction, collision reduction, and to increase the average throughput of SUs [3, 4]. The hybrid handoff technique combines both a pure reactive technique and pure proactive technique while using a reactive handoff action and proactive spectrum detection. Hybrid handoff is a sensible tradeoff between pure proactive and pure reactive. The handoff time of spectrum more rapid can be achieved because the time of spectrum detection is not performed during the course of the handoff procedure [5]. However, the target channel may remain old as this is done in a pure proactive approach. For the nonhandoff method, the SU continues to remain on the channel of origin and is inactive until the channel is released again. Once the potential channel is released by the PU, the SU resumes data transmission on the same channel. The main drawback of this method is that it creates a latency of significant waiting to SU and that the latency period is also long when the PU remains in the active state on the channel [6]. In practice, this approach does not correspond to the QoS requirement. The reactive spectrum is generally used for the presence of PUs, while the proactive spectrum is used for user mobility. These events do not require a sudden SH and can be easily predicted. SH delay is the most important criterion for determining spectrum mobility performance. This delay is due to the completion of certain processes in the CRNs [3]. The main function of this SH scheme is to make the decision regarding the selection of inactive channels. Concerning the proactive handoff technique, PU activities are periodically detected by SUs before deciding whether to handoff the data to the idle channel. Afterward, the SUs have the ability to choose which channel has the highest probability of inactivity for a period of time. Therefore, this handoff technique achieves a slow handoff delay that responds to the PU traffic pattern. The multiple handoff processes result in a degradation of the QoS of the SUs while increasing the total service time the handoff delay.

The question concerning the mobility management in CRNs is not very advanced although this problem was evoked at the time of the onset of the CR. Indeed, most of the research works on the CR have concentrated primarily on the spectrum detection and the dynamic allocation of frequencies between users without taking into account the mobility and of the handoff. The process of SH related to mobility management remains a problem in CRNs.

The main contribution of this paper is summarized as follows:

(i) The paper gives an in-depth description and more precise description of the problems related to spectrum handoff in CRNs. The work starts with a brief overview of the CRNs, followed by the general idea of the concept of SH and its technical aspects; the comparative analysis of all SH techniques is presented, and also a detailed classification of the mechanisms of SH is discussed.

(ii) This paper makes a significant contribution by proposing a very effective method that reduces information loss and latency of SH between a primary and secondary user. Reducing unnecessary and multiple handoffs of SUs improves the communication system stability of cognitive users. For this purpose, protocols have also been initiated to promote the smooth operation of the proposed scheme. The proposed scheme is implemented through simulation and compared to

Table 1: Comparison of spectrum handoff techniques.

Techniques	Strong point	Weak point	Handoff latency	Principal characteristics
Pure proactive handoff	(i) Predicts the arrival of PU on the channel (ii) Fastest response collision rate reduction	(i) Obsolete target channel selection (ii) Poor PU traffic detection leads to poor handoff results	Very weak handoff time	(i) Appropriate for large detection data (ii) Exploitable in a well-modeled PU network
Pure reactive handoff	(i) Target channel selected accurately	Slow response	Medium handoff time	(i) Appropriate for short detection time data (ii) Exploitable for normal CRNs
Hybrid handoff	(i) Fastest response (ii) Intelligent target selection	(i) Selection of the obsolete target channel (ii) Poor proactive spectrum detection results in poor spectrum handoff	Very weak handoff time	(i) Appropriate for short detection time data
Nonhandoff schemes	(i) Very low interference level of PU	Very high interference level of SU	Incredibly high latency	

other handoff schemes following serious simulation experiments.

(iii) To fill the gap that until now has caused a real problem to the functioning of the CRNs by giving a targeted investigation on the mechanisms of SH. It is also a reference topic for research on spectrum handoff in CRNs.

To deal with the problems mentioned above, we retain the following plan: the related work is presented in Section 2. The system model is presented in Section 3. Section 4 describes the scenarios explaining the mechanism of spectrum handoff. In Section 5, we discuss the proactive spectrum handoff technique. Spectrum handoff protocols are presented in Section 6. Section 7 presents the simulation results and finally the conclusion in Section 8.

2. Related Work

In the literature, various studies have been conducted on SH in CRNs. In [7], the authors proposed a priority and proactive decision-making mechanism for SH in order to reduce the latency of the SH and the total duration of the service. The proposed mechanism was modeled using a queue. The performance of the proposed SH mechanism was evaluated and compared to the available SH mechanisms. The results show that the improved mechanism was better than the existing mechanisms in terms of average handover time and total service time for different traffic arrival rates and different service rates. But this work does not take into account any preference giving SUs the possibility of resuming their unfinished transmission on a well-defined target channel.

In [8], the authors proposed a new technique for SH aimed at reducing unnecessary handoff by taking into account the time limit requirement. First, the expected delay of application packets is calculated based on the queue associated with the channel. Secondly, the anticipated delays were used to estimate the rate of SH offenses and the selection decision in order to avoid unnecessary handoff. To avoid unnecessary handoff, the secondary user must remain on the same channel unless the estimate of the cumulative probability exceeds a certain limit. However, it may not respond to real PU behaviors during sudden decisions, even if effective predictive models are used. In [9], the authors proposed an M/G/1 queue model with mixed/unstructured and nonpreemptive recovery priority for priority transmission in CRNs. The traffic-based SH technique has been developed based on the tail model proposed for delay-sensitive applications. This SH technique reduces the service time of delay-sensitive applications for SUs. In addition, the total network performance is guaranteed by avoiding SH between SUs. In this approach, the emergence of PU is predicted on the basis of preavailable spectral information but does not specify the possible risk of collision between the PU and the SU.

In [10], the authors examined the SH techniques used in CRNs. In their study, two important SH techniques, pure reactive handoff and pure proactive handoff, were compared. The advantage of pure reactive SH is the accuracy of the selected target channels, but the detection time is long. On the other hand, the pure proactive SH technique has no cost in terms of detection time, but the predetermined target channels may not be suitable. The M/G/1 recovery priority queue network was used to analyze. In this case, the reactive or proactive SH technique would be used, depending on the detection time. But in this paper, the authors did not make the comparison in terms of flow and capacity between these two handoff methods. In [3], the authors made a comparative study on different SH techniques that highlight the advantages and disadvantages of each technique. The results presented in this paper show that the proactive handoff can improve channel utilization by 6% and reduce the perturbation rate by 40% compared to the reactive handoff. This paper does an analysis on the SH classification but does not have a particular focus on the consequences of multiple handoffs that may degrade the QoS of the system.

In [11, 12], the authors proposed a proactive SH technique focused on statistical measurements of observed channel usage. Issues related to the rendezvous and network coordination have been solved in this SH scheme without using a common control channel. The collision between the

SUs was avoided through a distributed channel determination scheme. But the authors did not suggest an effective protocol to avoid this collision. In [13], the author presented the appropriate solutions and needs for spectrum mobility in CRNs. In [14], the authors proposed an SH procedure in which the ideal spectral band was chosen on the basis of multiplexing criteria, taking into account the probability of the presence of PU, time of spectrum availability, and time of transmission. But the probability relative to the arrival of PU on the channel was not mentioned. In [15], a spectrum detection scheme in cooperative mode was used to predict channel inactivity. A geolocation technique has been used to characterize a model of SH in the spatial domain. The numerical results that were presented in this SH scheme give the best performance compared to that of the conventional technique in terms of handoff delay. However, parameters related to channel heterogeneity were not considered in SH. In [16], the authors focused their research on proactive flow handoff in existing mobile ad hoc networks. The schema proposed in this work had the main contribution of maintaining end-to-end connectivity after establishing a flow. This scheme presented the idea of location information and user mobility. But, this paper did not mention the questions concerning the mechanism of mobility management.

A comparison of proactive and reactive SH has been proposed in [17] where the authors have specified a fundamental difference between these handoff methods. But, the authors did not show the different steps of transfer jump. In [18], a proactive SH scheme was used by the SUs to select a channel and this scheme was based on the greedy channel selection technique. In this scheme, the selection of the channel is a function of the prediction of the service time and the channel usage information. The disadvantage of this scheme is that it takes into account only one pair of SUs on the network and that in a multiuser network system, this scheme may create collisions between SUs. In [19], a proactive SH mechanism based on a time estimate was discussed. The scheme proposed by the authors was aimed at improving the use of channels and reducing communication disturbances. The scheme was presented in the case of a network with a single SU pair, which is a simple case that is not usable in real networks. The authors of this paper have not developed an effective protocol or algorithm that confirms the performance of this handoff technique. In [20], the authors examined and introduced the criteria for proactive SH in the common jump coordination scheme in a multiuser CRN. They associated this scheme with another distributed channel selection scheme. These two schemes work together to improve the performance of the SH mechanism. The points related to the probability of inactivity of PU on the channel were not suggested, and the conditions relating to the waiting time of SU was not so mentioned.

3. System Model

We consider an SH model where SUs will perform SH by the emergence of PUs. As SUs predict the emergence of PUs using channel utilization data, it is likely to avoid collision between PUs and SUs. The operating mode of channel i is characterized by the active process (ON) and inactive (OFF). The transmission of PU data packets on the channel indicates active PU process, and the transmission of PU data packets on the channel indicates the inactive PU process. We assume SUs are competing to access the channels.

Figure 1 illustrates the process of performing spectrum handoff in CRNs. Channels 1 and 2 belong, respectively, to the first and second main users. In the figure, we see that the SU uses mainly the channel of the first PU which is inactive. The reason the SU initially chose this channel is that the second PU channel is active. The SU is obliged to release the channel because the SU is considered as a guest. In the next step, the SU is passed on channel 2 due to the activity of the PU. During this transition, a spectrum handoff delay is experienced for a period of time. Therefore, if the frequency channels used by the SU are to be used by the PU, they must continue to communicate on another channel that is deemed available.

A better channel selection system is taken into account in this modeling to facilitate SH and increase the throughput of SUs. The PUs and SUs are the M/G/1 systems, and the arrival of the data packets on the channel i are related to the Poisson distribution process with an arrival rate γ. $P_k(\tau)$ denotes the probability of having k arrivals in a time slot τ as equation (1) shows (Table 2). To simplify the model, we consider that the PUs and SUs use the same channels; this means that all SUs have the same information on the availability of the channels. To perform an SH, SUs must select the best channel based on two criteria: first, the maximum channel vacancy time, and second, the minimum service time. This reduces the service time.

$$P_k(\tau) = \frac{(\gamma\tau)^k}{k!}e^{-\gamma\tau}. \tag{1}$$

4. Scenarios Illustrating the Mechanism of Spectrum Mobility

As in CRN systems, secondary users do not own the frequency band and the appearance of the owner (the primary user) on a frequency band forces the CU to cede that band. The SU will attempt by another means to access another available frequency band in order to continue transmission in accordance with one of the following three actions. (1) Until the PU finishes its transmission, the SU will remain in the original channel and set its transmission, (2) selects a channel from a list of previously detected channels (predetermined SH), or (3) it switches to a certain channel immediately (detection-based SH), and if the SU fails to regain the spectrum, it is obliged to terminate its session. In Figure 2(a), the SU1 and SU2 transmit on channel 1, and when the PU makes its appearance on the channel, the SUs are obliged to stop their communications as described in Figure 2(b). In this condition, two possibilities present at SU1: (1) the secondary users (SU2 and SU1) can restart the transmitting on the chosen target channel as appeared in Figure 2(c) or (2) channel and restart transmission after the

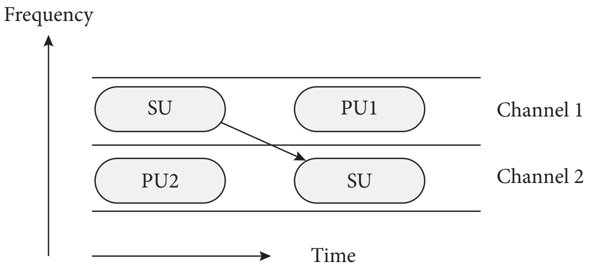

Figure 1: The process of spectrum handoff.

Table 2: The symbols in the equations used.

Symbol	Definition
$P_k(\tau)$	The probability of having k arrivals in a time slot τ
γ	Arrival rate
P_b	Probability for that channel i to be inactive or active for a certain time τ
P_i^k	The time of arrival of the kth data packet on the channel
H_i^k	The kth information packet dimension of the PU on the channel i
M	The state of the channel, which is a random variable in binary form (0 and 1), indicating the inactive state and the active state
τ	Time
i	The number of channels
$g_{H_i}(h)$	The probability density function
τ_{off}	The time of waiting
τ_{H}	The probability limit below which a channel is considered active
t_{L}	The probability limit that the channel should be considered inactive
φ	Probability limit that the channel is considered inactive
μ	The length of a frame plus a time slot ($\mu = \zeta + \alpha$)

PU activity is completed as shown in Figure 2(d). This latter possibility is preferred when the PU does not have much activity led on the channel, as it will promote the handoff number reduction. A frame can be stopped several times during transmission so that the SH procedure can be performed several times.

5. Proactive Spectrum Handoff

The SU has the ability to make a channel accessibility prediction while utilizing the parameter information about the channel utilization state before the data packets being transmitted are terminated. Then, the SU must make a decision to stay on the same channel or change channels or even stop the transmission of the current data packets. Under these conditions, we considered two main criteria concerning SH [21]:

(i) Predicted probability: this is the probability when the candidate channel is in the active or inactive state; in other words, the candidate channel is the channel that can be chosen to continue the transmission of the information in progress

(ii) The period of inactivity of the expected channel: this is the moment for the channel to remain in the inactive state

Figure 3 represents the channel i on which the PU handoff mechanism is carried out. The time between the arrivals of two data packets is designated by U_i^k, and P_i^k denotes the time of arrival of the kth data packet on the channel. U_i^k is distributed exponentially with the average arrival rate γ_i packets per second, as indicated by the hypothesis that PUs packets arrive in a form of Poisson flow [22]. The data packet dimension of PUs is the probability density function (PDF) $g_{H_i}(h)$. To determine the probability of a channel being inactive, it is important to know the time intervals related to the inactive and active states of the random transmission times. Based on Figure 3, the probability (P_{b}) for that channel i to be inactive or active for a certain time τ can be formulated as follows [21].

$$\begin{aligned} &P_b(M_i(\tau)=1)^{\cdot}\cdot ., \quad P_i^k > t, P_i^k + H_i^k \geq \tau, k \geq 1,\\ &P_b(M_i(\tau)=0), \quad P_i^k + H_i^k < \tau, P_i^{k+1} \geq \tau, k \geq 1,\\ &\qquad P_i^k \geq \tau, \quad k=0, \end{aligned} \tag{2}$$

where H_i^k denotes the kth information packet dimension of the PU on the channel i. Thus, the probability at any point interval of time τ where the channel i is inactive is formulated by [21, 23]

$$\begin{aligned} P_{\text{b}}(M_i(\tau)=1) &= \int_0^\infty \left[\sum_{k=1}^\infty P_{\text{b}}\left(P_i^k + H_i < \frac{\tau}{k}\right)P_{\text{b}}(k) + P_{\text{b}}\left(P_i^1 < \tau\right)P_{\text{b}}(k=0)\right]\cdot g_{H_i}(h)dh,\\ P_{\text{b}}(M_i(\tau)=1) &= \int_0^\infty \left\{\sum_{k=1}^\infty \left[\frac{(\gamma(\tau-H_i))^k}{k!}e^{-\gamma_i(\tau-H_i)}\right]\left[\frac{(\gamma_i\tau)^k}{k!}e^{-\gamma_i\tau}\right]\cdot\frac{(\gamma_i\tau)}{k!}e^{-\gamma_i\tau} + e^{-2\gamma_i\tau}\right\}g_{H_i}(h)dh, \end{aligned} \tag{3}$$

where τ_{off} represents the time of waiting. The cumulative distribution function (CDF) related to the waiting time for the ith channel is formulated as follows:

$$\begin{aligned} P_{\text{b}}(\tau_{\text{off}} < y) &= \int_0^\infty \int_0^{1+y} \gamma_i e^{-\gamma_i\tau} g_{H_i}(h)d\tau\, dh\\ &= \int_0^\infty \left(1 - e^{-\gamma_i(1+y)}\right)g_{H_i}(h)d\tau\, dl. \end{aligned} \tag{4}$$

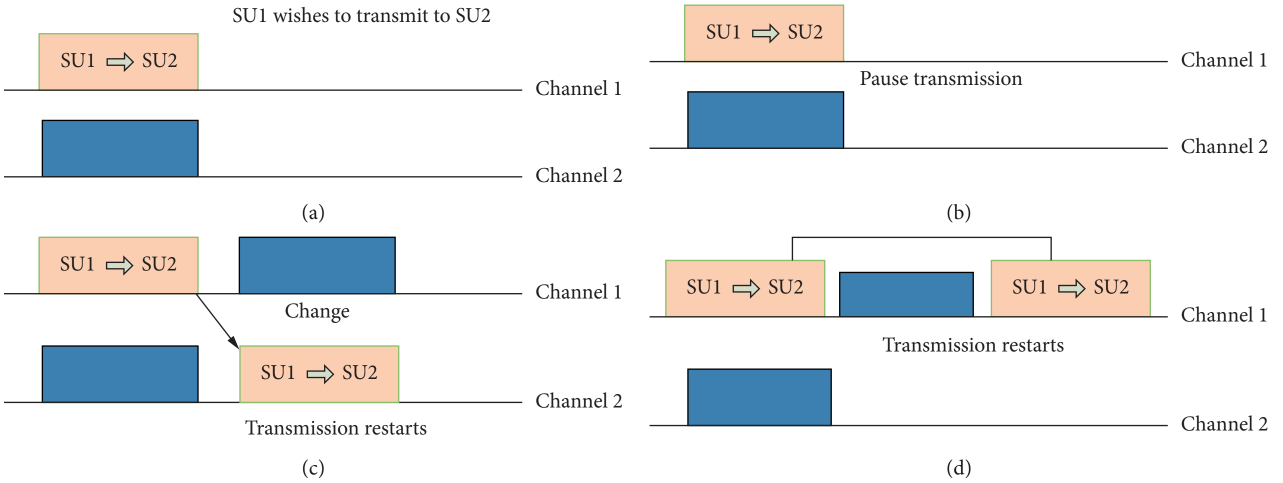

Figure 2: Illustration of spectrum mobility mechanism. (a) Transmission between secondary users (SUs). (b) The appearance of the primary user (PU). (c) Restart transmission on the selected channel. (d) Transmission restart on the same channel.

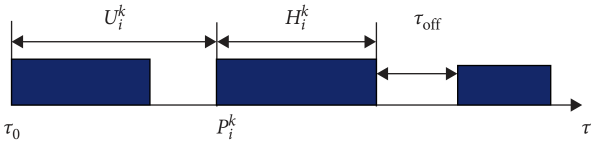

Figure 3: Illustration the handoff mechanism of PU on the channel.

Using the previous predictions, the condition giving the possibility for an SU to pass on another channel is

$$P_{\mathrm{b}}\left(M_i(\tau)=0\right)<\tau_{\mathrm{H}}, \tag{5}$$

where τ_H represents the probability limit below which a channel is considered active and the SU must perform an SH, for the current channel cannot be considered active at the end of the transmission of information packets. Moreover, the measures by which a potential channel j can become a promising channel at the next time τ are [21]

$$\begin{cases} P_{\mathrm{b}}\left(M_j(\tau)=0\right)\geq t_{\mathrm{L}}, \\ P_{\mathrm{b}}\left(\tau_{j,\text{off}}>\mu\right)\geq\varphi, \end{cases} \tag{6}$$

where t_{L} is the probability limit that the channel should be considered inactive, $\mu=\zeta+\alpha$ is considered as the period of an information packet and a time interval; and φ is the probability limit that the channel is considered inactive.

6. Spectrum Mobility Protocols

In this section, protocols relating to the mechanism of SH in the mobility management framework in CRNs are proposed. The protocols are designed to make the mechanisms of SH effective as a function of the channel activities of the PUs. Therefore, the protocols developed should have a positive effect on the performance of the proposed scheme compared to other SH protocols. The SH process proposed here is focused on the handoff techniques developed above. The operating mode consists of two parts, the first part (protocol 1) shows the initial handoff stage and the second part (protocol 2) shows the complete handoff chain.

Protocol 1. Figure 4 shows how an SU pair starts a new transmission of data packets on a channel [24]. Regardless of the patterns used in the SH, if a data packet arrives at an SU, it predicts the availability of the next hop channel at the outset of the next time slot. After knowing the results of the forecast, if the channel obeys the conditions (equation (6)), a send demand is sent to the receptor via the same channel at the outset of the next time slot. Once the sending request packet is received by the receiver, the intended SU destination responds to an acceptance message through the same time slot. Then, if the packet is successfully received by the transmitter SU, the two SUs pause the channel and start transmitting data on the same channel.

R_{r} indicates the flag regarding the request for the information packet transmission, R_{ds} denotes the issuance of the information packet, k represents the next jump channel, and τ indicates the beginning of the next interval.

Protocol 2. Figure 5 describes the complete sequences of the pure proactive SH mechanism, and this relates to the handoff at the time of SU transmission. The most interesting part of this process is to determine if the emitting pair of SU has to start an SH and then move on to another channel. By applying the new proposed protocol scheme, the transmitting SU pair can escape a likely SH failure when a PU appears on the channel.

Through the information obtained concerning the use of the channel, a transmitter SU examines the SH technique (equation (5)) of the current channel while determining in advance the accessibility of the channel at the end of the frame. When the SH technique does not obey, this proves that the channel is always in an idle state and can be used for the next data transmission. Therefore, the emitting pair of SU does not carry out SH and stays on the same channel. If the SH strategy obeys, a channel swap flag is defined; in other words, the current state of the channel is considered to be occupied for the next data transmission and that the SUs can carry out an SH

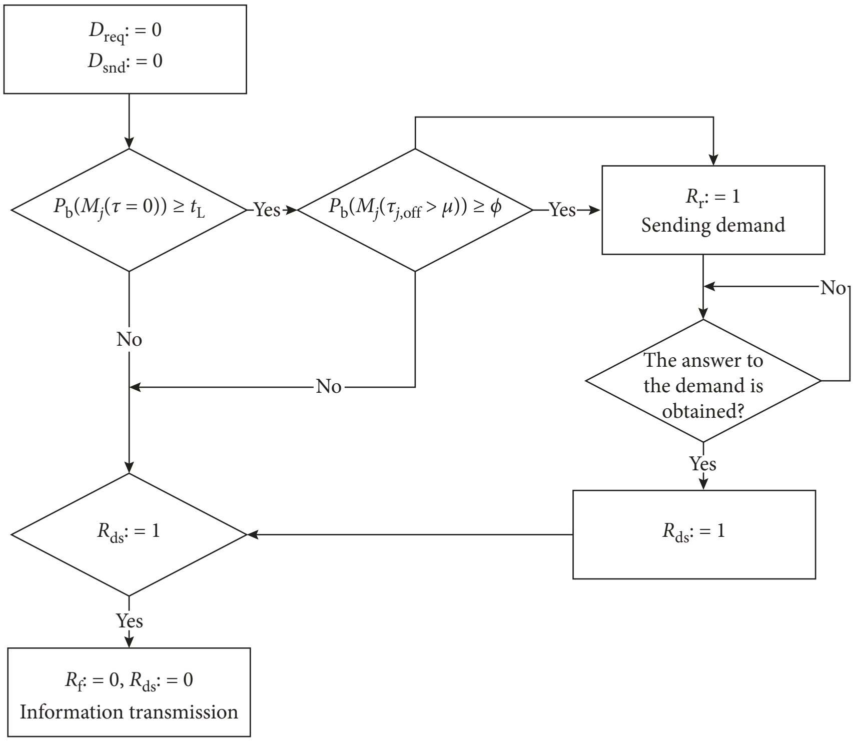

Figure 4: Protocol illustrating the initial handoff.

only at the end of the transmission in order to allow a PU to escape a possible interference that may be caused by an SU. Once the channel swap flag is defined, both SUs join the channel hop later in the next slot only after the previous data transmission. It is important to note that when the channel permutation flag is defined, the SUs that must carry out an SH stop the current transmission and restart the channel hopping with the same concatenation so that they pass to the same channel. To exchange of information regarding the availability of channels between SUs on the same channel, according to our proposed scheme, secondary users are required to conform to the same rate of jump at the time of execution of the SH. And also, the SU issuer verifies the conditions (equation (6)) regarding the availability of candidate channels for SH. If all the channels are not accessible, the transmission in progress is temporarily stopped at the end of the transmission.

SUs that need to perform SHs simultaneously need to update the channel accessibility data provided to other SUs. Therefore, secondary users must have access to the same channel to inform neighboring SUs. It is important to specify that in the case of a diagram focused on coordination with a single appointment, secondary users who do not have the ability to transmit information follow the same sequence of jumps. On the other hand, in the case of a diagram focused on the coordination with multiple appointments, the sequence of jumps by default of each SU cannot be identical to the sequence of the other jumps. To be able to share information about the availability of channels between SUs on the same channel, secondary users are forced to follow the same sequence of jumps only at the moment of performing SHs. The two SUs jump into the other channel during a supplementary time slot and check the channel's accessibility according to the requirements of (equation (6)) at the beginning of next time slot for multiple appointment and single appointment coordination schemes. On the other hand, if the set of the target channels to the handoff is not free, the transmitter SU triggers a distributed channel selection process (which will be studied in detail in another paper) and sends a demand packet of permutation of channel grouping the new selected channel information into the next time slot. When the channel swap demand packet is received, a confirmation message must be sent by the receiver SU. This proves that the channel swap authorization between the two nodes of the SU is made and that the two nodes can swap over the new selected channel to continue the transmission. It is also necessary to specify that the prediction may be incorrect and that there is a PU on the channel to which the SUs switch. Therefore, at the beginning of the frame, the transmitter pair SU restarts the radio scan to ensure that the selected target channel is inactive. When the detected channel is busy, both SUs immediately resume the channel handoff.

The problem of channel selection requires very special attention and needs to be analyzed with much more caution to avoid collisions between SUs. In addition, it is crucial to make the SH scenario efficient than general channel assignment scenarios in order to avoid SU collisions. Collisions between SUs make the data transmission system fail and cause latency on network applications. Therefore, the channel selection protocol must be executed with reasonable speed, and the channel selection protocol must be applied in a distributed manner to achieve a short handoff delay and avoid collisions [25].

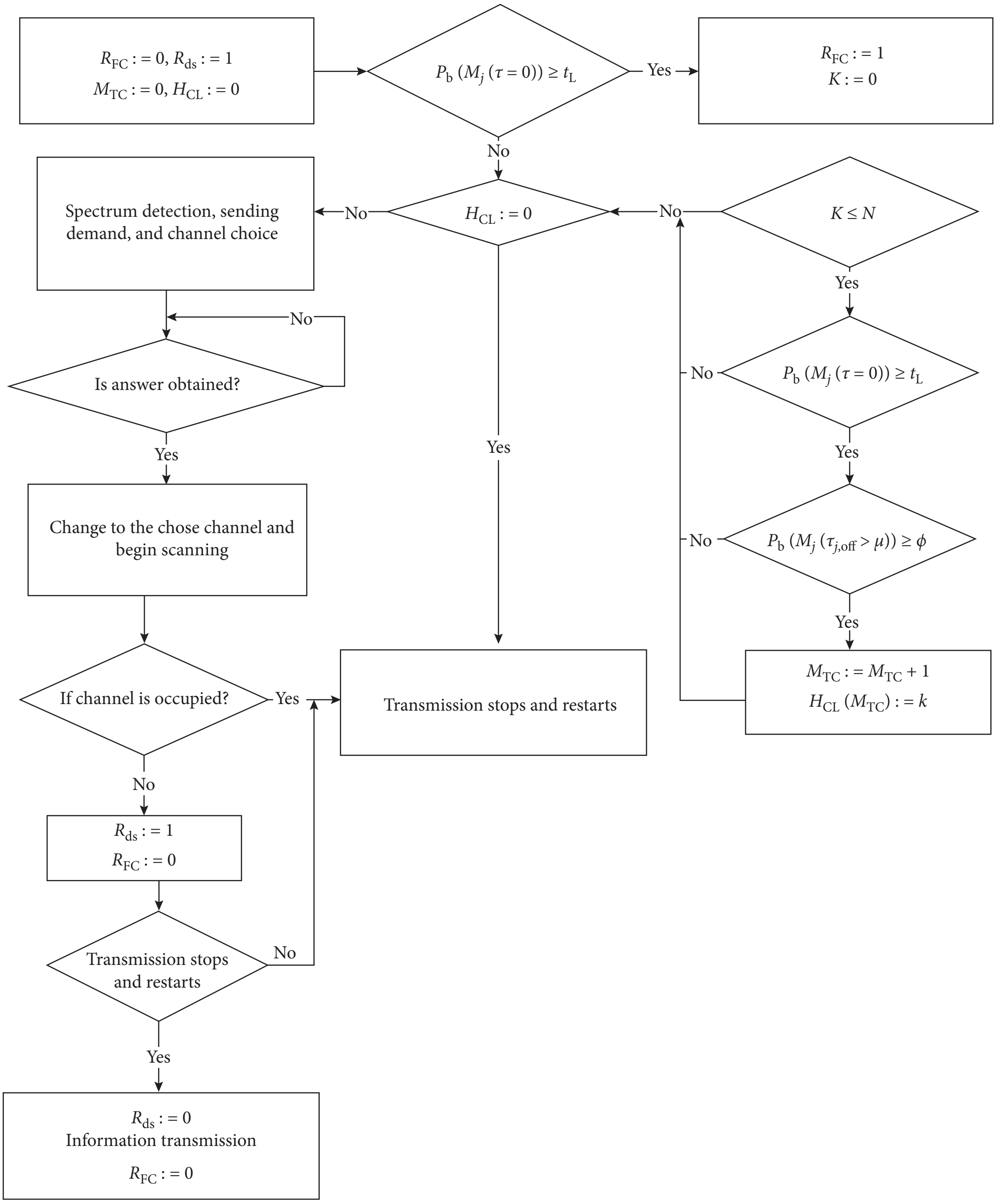

Figure 5: Protocol illustrating the steps of proactive spectrum handoff.

The objective is to realize a scheme for an SH scenario that can make CRNs effective. According to our described protocols, there are two situations that arise. The first situation is that at the time of the channel hop phase, several secondary users desire to simultaneously start new transmissions of data on the same channel, and this can lead to a collision. The second situation is that if several pairs of secondary users wish to perform simultaneous SH on the same channel, this can also lead to a collision. Once the collision occurs, all relevant data packets are lost and must be retransmitted again [26]. In terms of sensitivity, the SH delay of transmission is very sensitive as the waiting time of the data packets of a new transmission. Therefore, the collision must be prevented with higher priority in order to guarantee the QoS of the network. We have been motivated by the use of this method because it has significant advantages.

R_{FC} indicates the channel switching flag, M_{TC} characterizes the number of information packet transmission channels, and H_{CL} represents the list of information packet transmission channels. Table 3 presents the abbreviations used in the protocol.

Table 3: Summary of abbreviations used in the protocol.

Symbol	Definition
R_r	The flag regarding the request for the information packet transmission
R_{ds}	The issuance of the information packet
R_{FC}	The channel switching flag
H_{CL}	The list of information packet transmission channels
k	The next jump channel and indicates the beginning of the next slot
M_{TC}	The number of information packet transmission channels

7. Performance Evaluation

This section presents numerical results using the MATLAB platform (discrete event simulator) program to analyze the effectiveness of each SH technique on mobility management in cognitive radio networks. We compare these different handoff techniques. We select the collision rate (the number of SUs and PUs collisions in the transmission), the handoff delay, and the average throughput (SU's successfully transmitted data packets per unit of time) as a means of analysis of performance. To make a reasonable comparison, we consider that the channel forecast is a secondary user capability; in other words, the SUs must select candidate channels based on the strategy presented in (6). In addition, to analyze the performance of SH techniques, we adopt a random channel selection system, that is, an SU randomly selects a channel from among its candidate channels in the systems. The main parameters selected for the simulations are listed in Table 4.

Figure 6 shows the comparison of different SH techniques in terms of capacity versus a number of primary users. We note through this figure that the average load of the bandwidth of the primary network per user concerning the pure proactive handoff technique is significantly higher than 50% to 55% compared to other SH techniques. This proves that the pure proactive handoff technique gives better performance in the context of spectrum mobility management in CRNs.

Figure 7 presents the performance of different SH techniques regarding the potential collision rate relative to the number of PUs in the network. We find that the collision rate is reduced by 40% when the pure proactive technique of SH is used. Indeed, when the PU traffic is less on the channel, the probability of collisions between the SU and the PU is better than when the PU traffic on the channel is much more intense. This collision reduction is explained by the fact that the proactive technique predicts the next hop channel as explained by the protocol 2, and this will prevent the collision or loss of data. Therefore, the pure proactive technique of SH has a better performance compared to SH techniques.

Figure 8 compares the different SH techniques in terms of delay (latency) of handoff and based on the arrival of the main users on the channel. We see in this figure that the handoff delay for the pure proactive technique of SH is very small (10%), which proves that the pure proactive technique of handoff gives a better performance than the other handoff techniques as studied in [3]. The nonhandoff technique has a very high latency because this technique allows the secondary user to remain on the target channel until the channel is available again before continuing to retransmit the information packets.

Figure 9 shows the performance of proactive SH in terms of delay but this time depending on the density of PU traffic. We find on the graph that the proactive handoff gives a better performance compared to the others even if the traffic density of PU is long on the channel, because everything is programmed in advance and the multiple SHs are minimized by taking into account the future use of the target channels while selecting the safeguard target channel as presented in [27]. The reduction of handoff time is very significant and can be estimated at 18%.

Table 4: Simulation parameters.

Parameters	Values
Simulation time	12000 sec
Channel bit rate	3 Mbps
Switching delay	(0.005–0.03) sec
PU packet length	$2 * 10^5$ bits
PU arrival rate	0.03–0.3
SU packet length	$13 * 10^5$ bits
Number of channels	100
Number of SUs in CRNs	20
Maximum transmission power	1 W
Channel bandwidth	120 kHz
Packet transmission rate of SU	(100–400) pkt/s
Packet transmission rate of PU	(10–80) pkt/s
Number of primary users	15

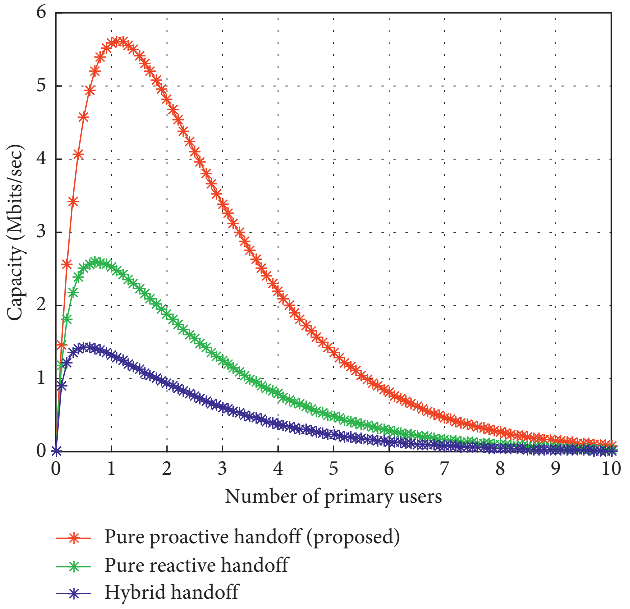

Figure 6: Capacity comparison in the different modes of spectrum handoff.

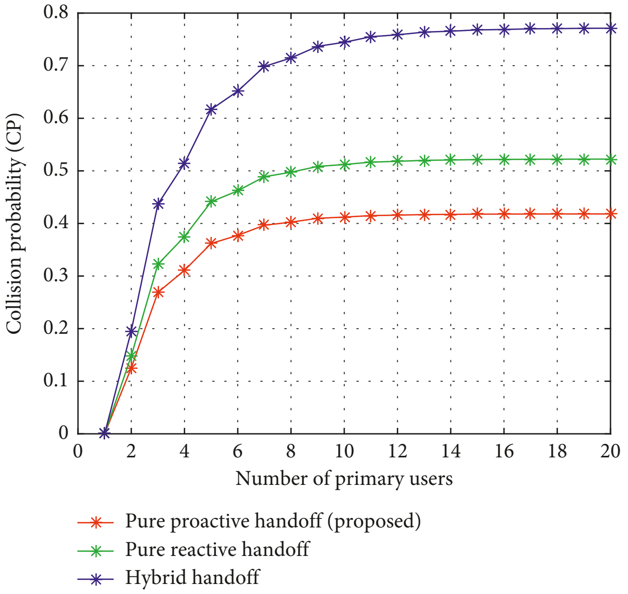

Figure 7: Performance of different spectrum handoff techniques regarding the potential collision rate.

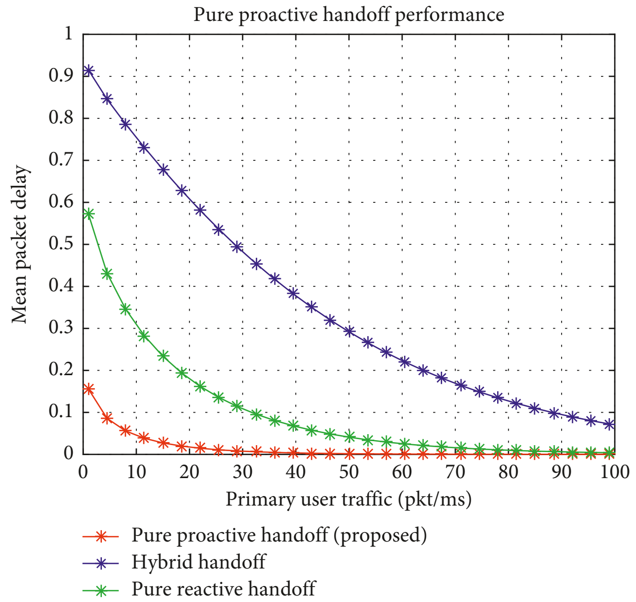

Figure 9: Performance of different spectrum handoff techniques according to the density of PU traffic.

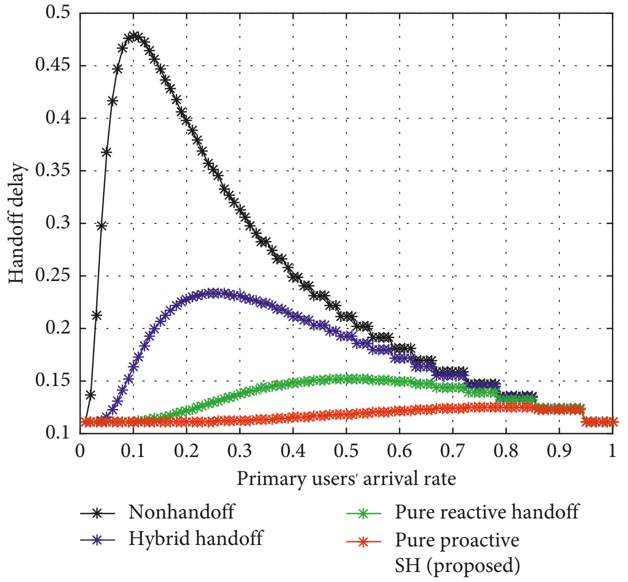

Figure 8: Performance of different spectrum handoff techniques in terms of delay (latency).

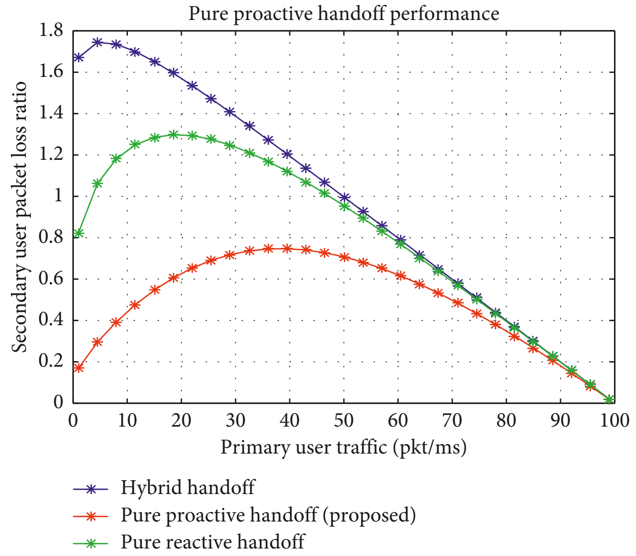

Figure 10: Performance of different spectrum handoff techniques in terms of the lost packet.

Figure 10 illustrates the performance of proactively transferring spectrum in terms of packets lost during handoff as a function of the density of the PU traffic. We notice the best performance of this method even if the duration of the PU packet transmission is long. Because the SU is able to predict the arrival of PU on the channel, this gives the possibility to the SU to release the channel in advance. In other terms, the choice of the handoff and the target channel handoff activities are done taking into account the proactivity before the event is triggered. In summary, the data packet loss rate for the proactive handoff technique is minimal and is 6%.

Figure 11 shows the average throughput of SUs as a function of the number of channels in the network. It is estimated that the transmission rate of SU packets varies between (50–200) pkt/s and that of PUs vary between (10–80) pkt/s and that the number of SUs in the network is 20. Note that when the number of channels increases, the average rate of SUs also increases; this is due to the increase in the number of available channels in the network. The average throughput of SUs can be reduced when the number of channels decreases; it does not allow SUs to have a channel available for transmission. It can be seen that the proposed method (pure proactive handoff) has a better

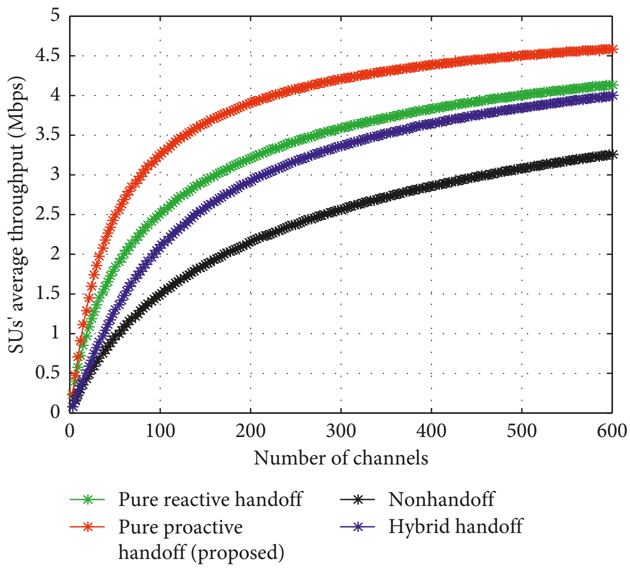

Figure 11: Illustration of performance in terms of throughput versus a number of channels spectrum handoff techniques.

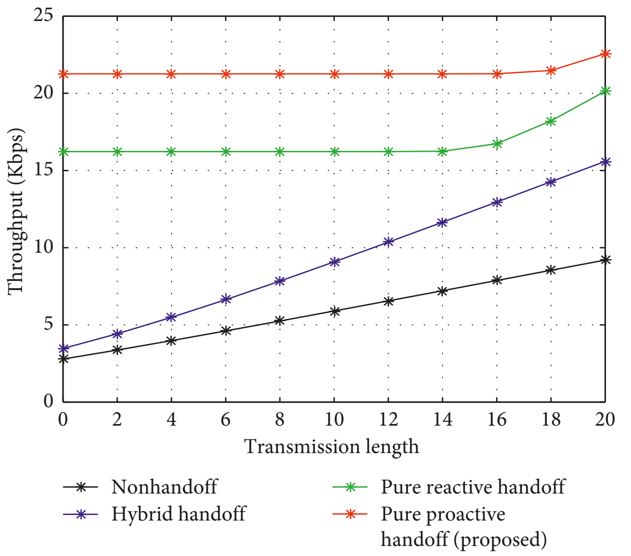

Figure 12: Illustration of performance in terms of throughput versus length of a transmission.

performance of 40.5% in terms of average throughput compared to other SH methods.

Figure 12 discusses the impact of the transmission length of PUs on the throughput of SUs. It can be seen that as the transmission length of the PUs increases, there is a reduction of 4.5% to 12% of throughput in the level of SU. This reduction is due to the increased use of PU channels, leading to fewer channels available for SUs. When the SU transmission length and the PU transmission length are less on the channel, the SU flow rate is almost similar in the case of hybrid handoff technique and nonhandoff technique. However, when the SU transmission length and the PU transmission length are important, the proactive SH technique exceeds that of the reactive technique in terms of higher throughput. Thus, the proactive handoff technique gives better performance (17% to 25%) in terms of throughput despite the increase in the transmission length of the PUs.

8. Conclusion

Cognitive radio is a promising technology for next-generation wireless communication networks, which significantly improves the efficiency of spectrum use. SH is a crucial point in CRNs. The multiple SHs can cause degradation of the secondary system by increasing the total service time and the handoff time. In this paper, the proposed proactive handoff scheme is based on a probabilistic and predictive approach, which is somewhat unavoidable due to the uncertain behavior of PUs. The proactive handoff method gives a great possibility to the SUs who had stopped their transmissions process due to the appearance of PU on the channel to continue their incomplete transmission on the target channel. This mobility management is characterized by two main criteria, namely, the period of inactivity and predicted probability. The new management approaches of the mobility and the connection are designed to help reduce information loss and latency at the time of SH. The numerical results confirm that the proposed scheme has a significant reduction of up to 60%; the collision rate between SUs and between PU and SU during handoff reduces the handoff latency and improves the throughput of SUs.

The future research topic will focus on a new algorithm for selecting the best channel in cognitive radio networks.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the University of Science and Technology Beijing.

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