Cognitive Learning-Based Spectrum Handoff for Cognitive Radio Network

Chong Feng, Wenbo Wang, and Xiao Jiang

***Abstract*—In cognitive radio network, spectrum handoff occurs when primary user appears in the licensed band which is occupied by the cognitive user. Spectrum handoff aims to help cognitive user find suitable channel to resume the unfinished transmission as quickly as possible. In this paper, we propose a cognitive learning algorithm which can be used to decide the order of channel-sensing when the cognitive user needs to carry on spectrum handoff. Both theoretical analysis and simulation results show that using the cognitive learning algorithm to predict the channel status can reduce the average spectrum handoff time compared with the random access algorithm.**

***Index Terms*—Spectrum-handoff, average handoff time, cognitive learning algorithm.**

I. Introduction

The demand for wireless communication is growing very rapidly, but the spectrum resources are non-renewable. It has led to intense research and efforts toward finding an efficient way to improve the spectrum utilization to satisfy this growing demand. Cognitive radio technology can allow a cognitive user use the idle spectrum resources temporarily on the condition that it does not interfere with the communication of the licensed user during this process. In order to complete above process successfully, the cognitive user must have the ability of spectrum sensing, spectrum access and spectrum handoff. When the primary users appear in the licensed band which is occupied by the cognitive user [1], in order to avoid affecting primary users, the cognitive user has to vacate the spectrum and reestablish a communication link on some other vacant spectrum to avoid interrupting the transmission, this process is described as spectrum handoff.

In recent years, some of research is devoted to the study of spectrum handoff. In the work [2], the author proposes a preemptive resume priority (PRP) M/G/1 queueing network model to evaluate total service time for various target channels selections. He analyzes some parameters such as total service time in that model. In another study, the author develops a Markov transition model integrating with the (PRP) M/G/1 queueing network to characterize the multiple handoff delay which is composed by sensing time, handshaking time, channel switching time and waiting time [3]. In the study [4], author compares the advantage and disadvantage of reactive-sensing and proactive-sensing spectrum handoff schemes then he proposes an algorithm which can automatically switch between two strategies. In the work [5], author proposes a time relationship model of spectrum handoff, he also analyzes the service duration of cognitive user with the change of spectrum handoff probability. Author of [6] proposes a partial observation of Markov model (POMDP), the partially observable channel state information will be used to find the optimal target channel for spectrum handoff. By adopting the POSH algorithm for target channels selection, minimal waiting time at each occurrence of spectrum handoff can be achieved.

In this paper, the major work consists of two parts.

1) We focus on modeling the real process of spectrum handoff, even though there are already some research about spectrum handoff in previous studies, they didn't describe the process accurately. Many of the studies just consider the time of spectrum-sensing when cognitive user needs to switch to another channel, but the real process is cognitive user must sense the channel which is occupied by him at the start of every time slot, in order to make sure the channel is not occupied by the primary user. So the process of spectrum handoff must be analyzed at every time slot. Each time slot includes three parts, the spectrum sensing time, transmission time and handoff time. We will analyze the relationship between the several time parameters in spectrum handoff and get the numerical solution of average spectrum handoff time.
2) We propose a cognitive learning algorithm to decide the order of spectrum-sensing, the cognitive user records the data of all the channel and senses the channel by the order of idle probability when the cognitive user needs to switch to another channel. We compare the algorithm with the random access algorithm, then we analyze the average handoff time of the two algorithm. The results show the cognitive learning algorithm can reduce the average handoff time of cognitive user obviously.

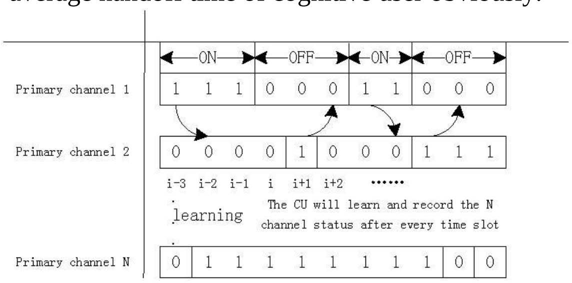

Fig. 1. Process of spectrum handoff duing a period of time.

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The rest of this paper is organized as follows: In Section II, we introduce the system model which can describe the process of spectrum handoff accurately. In Section III, we derive the numerical result of average handoff time by using the model of Section II, then we describe the process of cognitive learning algorithm and compare it with the random access algorithm. All the numerical results and simulation results are given in Section IV. Finally, our conclusions are summarized in Section V.

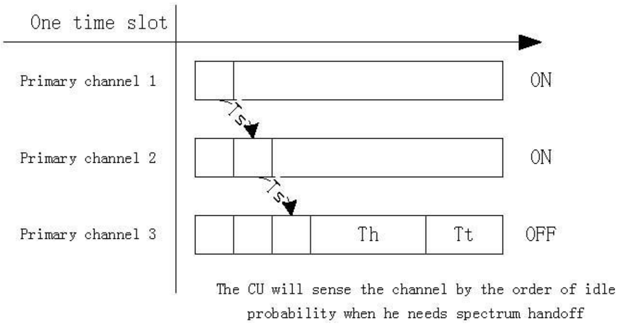

Fig. 2. The composition of one time slot.

II. System Model

In cognitive radio network, in order to avoid interfering the primary user, when the cognitive users use the licensed band temporarily, they must sense the licensed band at the beginning of each time slot, if they find the spectrum is occupied by the primary user, they have to find the other idle channel, then switch to the target channel to resume the transmission [7].

In the cognitive system, there are N primary channels which are indexed as 1, 2 . . . N.(Fig.1) The cognitive user can access any of these channels without having to inform the primary user beforehand. Each i represents the different time slot. 1 represents the channel is occupied by the primary user at this time slot. 0 represents the channel is idle, the cognitive user can use it in this time slot [8]. In order to get the information about the channel, the cognitive user has to sense the channel at the start of each time slot, we define Ts as the length of time cognitive user senses one channel, Tt as the time cognitive user can transmit information, Th as the handoff time of cognitive user. The cognitive user will learn and record the data of every time slot for the next spectrum handoff [9].

The process of spectrum handoff can be described by fig.2. In one time slot, the channel status is unchanging, it will be always ON or OFF, when cognitive user needs to switch to another channel, he has to use one Ts to sense the channel which he wants to use, if the channel is occupied by the primary user, he has to sense another channel with another Ts, the cognitive user will repeat this process until he finds an idle channel, then he spends the time of Th to reestablish the connection and switch to the idle channel [10] [11]. During the process, the cognitive user will use the data which is obtained from the previous learning, he will sense the channel by the order of idle probability which he calculates at the end of every time slot. After the process of spectrum handoff, the cognitive user can use the rest of time slot to transmit the data, so we define the Tt as the length of the time cognitive user can transmit the data.

Through the analysis of above process, we can speculate there will be three situations in spectrum handoff. In situation A, cognitive user uses one Ts to sense the channel which he is using now, if there is not any primary user who wants to use the channel, the cognitive user will use the channel for the rest of the time slot. In situation B, the cognitive user uses one Ts to sense the channel, but finds the primary user want to use the channel, so he spends another Ts to find idle channel, if this process is successful, he can switch to the target channel with the time of Th, then he can transport the information on the new channel in the rest of the time slot. In situation C, the cognitive user uses one Ts to sense the channel, but finds the primary user want to use the channel, then he spends another Ts to sense, this procedure is repeated until an idle channel is found. As a result, when he finds the idle channel, there is not enough time for spectrum handoff, so the cognitive user wastes all of this time slot [12].

In channel n, the primary user's arriving rate is λ_n and leaving rate is μ_n , They all follow the exponential distribution, the channel status is a two-state birth-death process [13]. If we denote Pn as the idle probability of the nth primary channel in one time slot, the Pn can be expressed as:

$$P_n = \frac{1/\lambda_n}{1/\lambda_n + 1/\mu_n} \tag{1}$$

III. Performance Analysis

In the previous sections, we understand the reason and process of spectrum handoff in cognitive radio network, then we introduce the channel model and define the different parameters which can affect the status of each channel. In this section, in order to compare the two algorithms, we derive the average handoff time as an important parameter to analyze the difference between two algorithms. So we divide this section into two parts. Firstly, we drive the numerical solution of average handoff time in different channel conditions. Secondly, we compare the average spectrum handoff time of cognitive learning algorithm with random access algorithm at the same channel status.

A. Average Handoff Time

We define the K represents the max times cognitive user can sense the channel and the T is the total length of one time slot. when the cognitive user needs to switch to another channel, there are two situations: (a) The cognitive user senses the channel, finds the idle channel and switches to the target channel successfully when $KTs + Th < T$. (b) The cognitive user senses the channel so many times that the cognitive user doesn't have enough time switch to the target channel when $KTs + Th > T$. When the number of idle channels is n , the probability of cognitive user fails to find an idle channel can be represented as:

$$P_f = \prod_{m=1}^{K} \left(1 - \frac{n}{N-m+1}\right) \tag{2}$$

The average handoff time can be given:

$$T_a^n = \sum_{k=1}^{K}(kT_s \frac{n}{N+1-k}\prod_{m=1}^{k-1}(1-\frac{n}{N-m+1}) + T\prod_{m=1}^{k}(1-\frac{n}{N-m+1})) \tag{3}$$

When all the channel status is same, the idle probability of each channel is P, the probability that there are n idle channels in the system can be expressed as:

$$P_n = \binom{n}{N} P^n (1-P)^{N-n} \tag{4}$$

The average handoff time can be given:

$$T_a = \sum_{n=1}^{N} P_n T_a^n \tag{5}$$

Then, substituting (3) and (4) into (5)

$$T_a = \sum_{n=1}^{N} \binom{n}{N} P^n (1-P)^{N-n} (\sum_{k=1}^{K}(kT_s \frac{n}{N+1-k} \prod_{m=1}^{k-1}(1-\frac{n}{N-m+1}) + T\prod_{m=1}^{k}(1-\frac{n}{N-m+1}))) \tag{6}$$

B. Cognitive Learning Algorithm

When the channel status is different, if the cognitive user senses the channel with the random order when he needs to conduct spectrum handoff. The average handoff time can be expressed as:

$$T_{case1} = \sum_{n=1}^{N}(\prod_{i\in N} P_i \prod_{j\in N-I}(1-P_j))(\sum_{k=1}^{K}(kT_s \frac{n}{N+1-k} \prod_{m=1}^{k-1}(1-\frac{n}{N-m+1}) + T\prod_{m=1}^{k}(1-\frac{n}{N-m+1}))) \tag{7}$$

The I represents all the combinations of idle channels.

We assume that the status of all channels can be represented as a vector $S=[s_1^i, s_2^i ... s_N^i]$, s_N^i is the status of channel n in time slot i. During the cognitive learning process, the cognitive user records the information of the status before the current time slot i, then cognitive system will predict the primary channel status for time slot i, after time slot i the cognitive user will get the channel data according to the channel states of i time slot. After this process, the cognitive user will update the parameters to make sure the accuracy of next prediction. At the i time slot, if the cognitive user needs to switch to another channel, the cognitive user senses the channel in descending order of idle probability by the S vector. P_k represents the idle probability of all the channels in i time slot. The average handoff time of cognitive user with cognitive learning algorithm can be expressed as:

$$T_{case2} = \sum_{n=1}^{N}\max(P_k)\prod_{k=1}^{K} kT_s(1-\max(P_k)) \tag{8}$$

IV. Numerical and Simulation Results Analysis

In the previous sections, we introduce the model of spectrum handoff and we derive the average handoff time of cognitive user. We also propose the cognitive learning algorithm to reduce the average handoff time of cognitive user. In this section, both the simulation results and the numerical results will be analyzed.

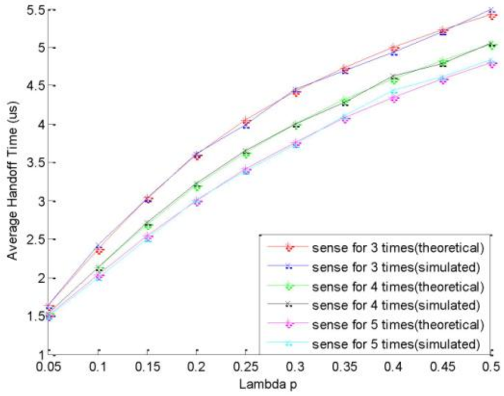

Fig. 3. Compare the average handoff time when the K is different with the λ_p change

A. Average Handoff Time

In this section, we assume there are 10 channels in the system, all of the channels can be used by the primary users at anytime. The primary user's arriving rate and leaving rate are both exponential distribution. The length of one time slot in the system is T, we assume T=8us, the length of time for cognitive users sense a channel is Ts=1us. K is the max times cognitive users can sense the channel which will be determined by the time of Ts and Th.

In Fig.3, we analyze three situations which have different K with the change of λ_p . The three curves represent different K. We can see when the λ_p increases, the idle probability of channel decreases, the cognitive user has lower probability to find idle channel in a time slot when he needs to conduct spectrum handoff, so the result consistent with the expectation that the average handoff time becomes longer when λ_p increases. We can also see that the more times cognitive users can sense in one time slot, the more chance he will succeed in finding an idle channel, the average handoff time will be reduce, but the gap between different curves becomes smaller when K becomes bigger.

In Fig.4, we analyze three situations which have different K with the change of μ_p , the three curves represent different K. We can see when the μ_p increases, the idle probability of channel increases, the cognitive user has more chance to find idle channel when their current channel is occupied by the primary user. The result shows that the average handoff time becomes shorter when μ_p increases which is consistent with our expectation. We can also see that the more times cognitive users can sense in one time slot, the more chance he will succeed in finding an idle channel. The average handoff time decreases when the K increases and the difference becomes very small when μ_p is greater than 0.3.

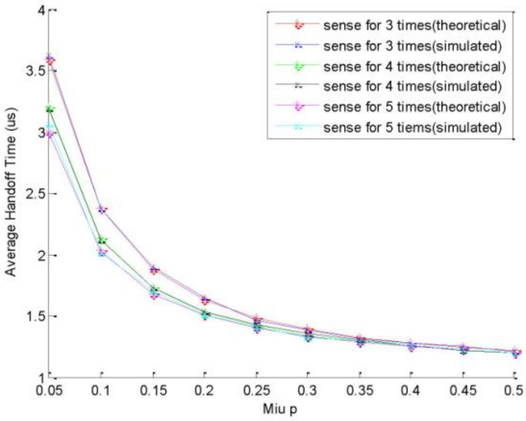

Fig. 4. Compare the average handoff time when the K is different with the λ_p change

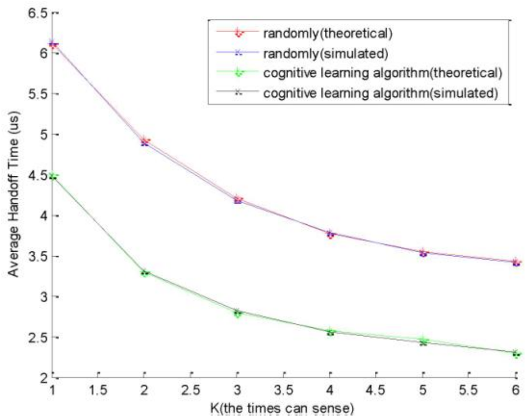

Fig. 5. Compare the cognitive learning algorithm and the randomly schemes

B. *Cognitive Learning Algorithm*

In this section, we compare two strategies under the condition that other parameters are the same. The first strategy is using the random access algorithm, when the cognitive user finds the channel will be occupied by the primary user, he will sense the idle channel in the rest of time slot by the random order. The second strategy is using the cognitive learning algorithm, when the cognitive user needs to switch to another channel, he will sense the idle channel in the descending order of idle probability, the cognitive user gets the data by recording the status of each channel at the end of every time slot.

We can see that when K increases, the cognitive user has more chance to sense and switch to an idle channel, the average handoff time will be reduced. Through the cognitive learning algorithm, the cognitive user can learn the status of channel, predict the next time slot status of all channels, and sense the channel by the order of idle probability, so the cognitive user will have more chance to find the idle channel than the random access algorithm. The results also confirm the idea. We can see the cognitive learning algorithm always has the less average handoff time compares with the random access algorithm in Fig. 5.

V. CONCLUSION

In this paper, we propose a model to analyze the process of spectrum handoff. We derive the average handoff time of cognitive user which is an important parameter to affect the transmission quality. In order to reduce the average spectrum handoff time of cognitive user, we also propose a cognitive learning algorithm, through the cognitive and learning process, the cognitive user can predict the channel status by priori knowledge and select the best order to sense the channel when cognitive user needs to conduct spectrum handoff. Numerical results are derived and the simulation results are in accordance with the numerical results. It is proved that the model is reasonable to analyze the average handoff time and the cognitive learning algorithm can reduce the average handoff time compared with the random access algorithm effectively.

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