Performance Analysis of Channel Switching with Various Bandwidths in Cognitive Radio

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Abstract—**Dynamic spectrum access is a key technique in cognitive radio. Whenever primary users appear, secondary users must evacuate the primary channel rapidly, and switch the appropriate channel to primary users. There are two types of channel access methods, namely reactive and proactive channel access. In reactive method, cognitive radio does not need to switch channel until primary users appear, while in proactive method, secondary users predict future channel traffic by using channel history and switch channel before primary users appear. Most of the previous researches assume that all primary users possess the same channel bandwidth. In this paper, we take various channel bandwidths into consideration to make spectrum handoff decision with the method proposed before under real cognitive radio environment, and use this method to analyze the performance. Channel utilization rate in both methods is enhanced while considering various bandwidths.**

Keywords- ***reactive channel access; proactive channel access; Bandwidth.***

I. Introduction

Spectrum is a precious and limited natural resource, and most portions of it have been authorized. With the development of network techniques, the demand for spectrum is increasing. “The biggest problem of spectrum application is not scarcity but ineffective,” according to [1]. Not only do we have to solve the ineffective problem, but we also need to make good use of the spectrum. With "spectrum sensing capability”, cognitive radio technology has been proposed [2], hoping that through time and space configuration, full use of those unused spectrum resources can effectively solve the problem of the spectrum congestion or the unequal distribution.

The first step of developing cognitive radio is dynamic spectrum access [3]. Cognitive radio users must monitor the idle spectrum periodically, analyze the surrounding wireless messages at the same time to adapt themselves to the environment, and use these messages to learn and adjust the transmission state and parameters in radio. As soon as the primary users appear, cognitive radio users can seamlessly switch to other idle channels, making transmission continue in spite of the appearance of the primary users.

Liu, *et al.* [4] discusses the concept of spectrum mobility, and develops the probability models of spectrum holes and spectrum handoff according to the characteristics when primary users appear. The probability of handoff is an important indicator to affect spectrum mobility, and it is also an important part of spectrum management.

There are two types of channel access methods, namely proactive channel access and reactive channel access. It is still unclear under what condition we shall use which of these handoff methods. Wang, *et al.* [5] introduces these two methods, and uses a PRP M/G/1 model to derive the formula to analyze which of the two spectrum handoff methods can achieve the best efficiency with the variation of spectrum sensing time.

Without interference to primary users, secondary users are allowed to temporarily use the channel for transmission. Aravinda, *et al.* [6] uses proactive channel access method without interference under TV broadcast condition. Secondary users can use the information of channel history to build a prediction model, and use it to make the spectrum handoff decision. Not only can it enhance the channel utilization, but it can also reduce the interfering time produced by primary users.

Höyhtyä, *et al.* [7] proposes a simple method to classify the channels to either periodic or stochastic patterns, which may in turn help the secondary users to schedule the channel. Yang, *et al.* [8] sets the period when primary users appear as an alternative exponential ON/OFF model, and predicts future primary channel state according to previous primary users’ traffic. Secondary users can try not to interfere with the primary users by quickly switching to another unused primary channel to continue its transmission. Xue, *et al.* [9] emphasizes the importance of handoff delay in real life so that the secondary users can take it into consideration to make the spectrum handoff decision.

Most of the previous researches assume that all primary users possess the same channel bandwidth. In reality, however, cognitive radio needs to adapt to the heterogeneous network architecture in which not all primary users possess the same channel bandwidths. According to IEEE 802.22 standard [10], cognitive radio is applied for 54 ~ 862 MHz UHF/VHF TV bands and must adapt to 6MHz, 7MHz, and 8MHz TV bands. This will lead us to make different spectrum handoff decision. Hence, we take various channel bandwidths into consideration to make spectrum handoff decision with the method proposed before under real cognitive radio environment, and use this method to analyze the performance.

The rest of the paper is organized as follows: In Section II, we introduce the system model. In Section III, we discuss the strategy of handoff decision. In Section IV, we show our simulation results. In Section V, we provide our conclusion.

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II. SYSTEM MODEL

A. System prediction model

At the beginning of channel prediction model shown in Fig. 1, secondary users will perform spectrum sensing, and then save the sensing information into channel history database. Primary users channel's traffic information can be obtained from the historical database. Cognitive radio can use spectrum sensing results and channel history to predict channels idle time in the next slot. If it needs spectrum handoff, the channels idle time in the next slot subtracts channel switch cost and spectrum sensing time to get the channels remaining time. The packet capacity can be derived from the product of channels remaining time and the channel bandwidth. Finally, in the handoff decision section, cognitive radio will look for the channel that has the maximum packet capacity to be the handoff channel, and use it to transmit data.

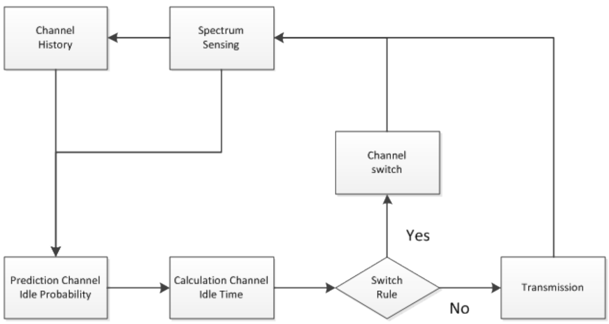

Figure 1. Flowchart of proactive spectrum access

B. Channel model

We use the common alternative exponential ON-OFF model to be our channel model as shown in Fig. 2. The difference with previous research is that our bandwidth is variable. At first, all primary channels will be random in ON or OFF state. When the channel is in the "ON" state, which means that the channel is "BUSY", the secondary users cannot access the channel; when the channel is in the "OFF" state, which means that the channel is "IDLE", the secondary users can access the channel for transmission. The durations that the primary user passage shows ON (BUSY) and OFF (IDLE) are independently exponentially distributed. For channel n, the period of ON, B_n, follows an exponential distribution with mean $1/\lambda_{B_n}$. On the other hand, the period of OFF, I_n, also follows an exponential distribution with mean $1/\lambda_{I_n}$.

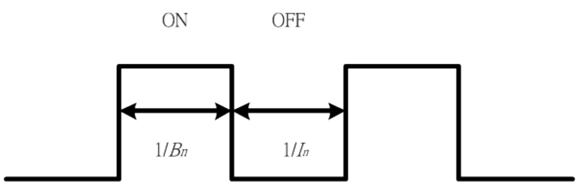

Figure 2. The alternative exponential ON/OFF channel model

$$f(B_n)=\begin{cases}\lambda_{B_n} e^{-B_n\lambda_{B_n}}, & B_n \geq 0\\ 0 & , B_n < 0\end{cases} \quad (1)$$

In our simulation environment, we assume that cognitive radio is operated in a slotted model, and has N primary channels for access as shown in Fig. 3. At the period of spectrum sensing, cognitive radio will use the spectrum sensing result and the information from channel history database to predict the probability of channel idle time in next slot.

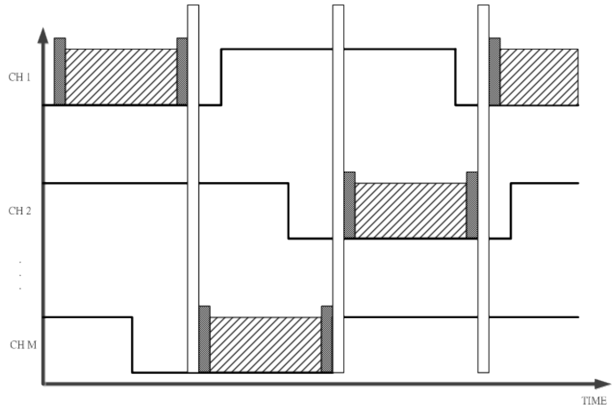

Figure 3. The slotted structure of the secondary user

III. THE STRATEGY OF HANDOFF DECISION

A. Reactive v.s. Proactive channel access

Spectrum handoff occurs when the primary user appears in the licensed channel that is temporarily used by the secondary users. The main significance of the spectrum handoff is to help the secondary users switch to the suitable idle channels to resume transmissions. The types of spectrum handoff are divided into two types:

Reactive channel access: Whenever a primary user occurs, secondary users have to handoff by following steps: first, after detecting any primary user, secondary users interrupt transmission and do spectrum sensing. Second, according to the real-time spectrum sensing, find idle channels and switch to the idle channel to resume transmissions. Not only does it have to spend real time spectrum sensing, some real time applications (for example, watching movies online) will also cause great harm. This is shown in Fig. 4.

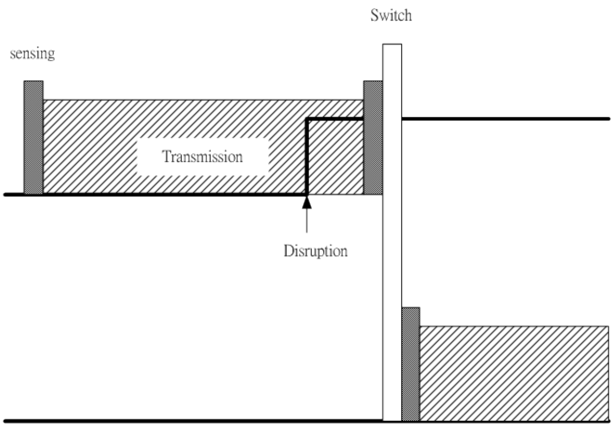

Figure 4. The reactive channel access model

Proactive channel access: Secondary users use channel history to predict future channel traffic, and schedule the channel access intelligently. They may use the predicable method with the result of spectrum sensing to predict future channel traffic before primary users appear in order to avoid disruption by primary users, and to maintain reliable communication. The advantage of using proactive channel access is the reduction of communication disruption by primary user, for secondary users can switch to other channels before primary users appear and resume transmission faster. This is shown in Fig. 5.

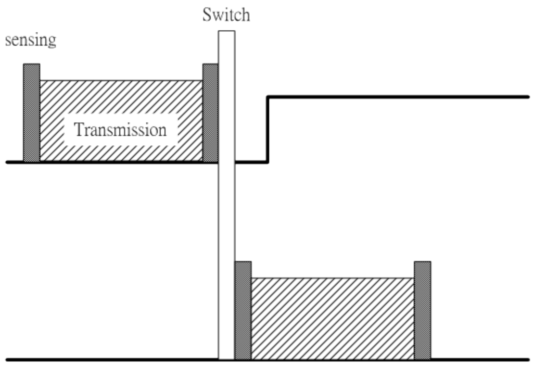

Figure 5. The proactive channel access model

B. Channel prediction

We assume that the primary channels are a series of ON/OFF model; when the channel is in ON state, the channel is being used; when the channel is in OFF state, the channel is IDLE and secondary users can access this channel. The frequency of primary users' appearance can be built in an alternative exponent ON/OFF model. The average channel IDLE time can be set as $E[T^n_{IDLE}]={}^1/_{\lambda_{I_n}}$, and the average channel IDLE time can be set as $E[T^n_{ON}]={}^1/_{\lambda_{B_n}}$. We can use the built model to predict future channel traffic. We assume that the idle probability of channel N in next slot is P_n which can be derived based on renewal theory [11]:

$$Pn = \begin{cases} \frac{\lambda_{B_n}}{\lambda_{B_n}+\lambda_{I_n}} + \frac{\lambda_{I_n}}{\lambda_{B_n}+\lambda_{I_n}} e^{-(\lambda_{B_n}+\lambda_{I_n})\Delta t} & , s = 0 \\ \frac{\lambda_{B_n}}{\lambda_{B_n}+\lambda_{I_n}} - \frac{\lambda_{B_n}}{\lambda_{B_n}+\lambda_{I_n}} e^{-(\lambda_{B_n}+\lambda_{I_n})\Delta t} & , s = 1 \end{cases} \quad (2)$$

We can use the following formula to predict the channel idle time in next slot:

$$T^n_{IDLE} = {}^{Pn}/_{\lambda_{I_n}} \quad (3)$$

C. Intelligence channel switching

When we make the spectrum switch channel decision, we consider [9] which mentioned switching cost to achieve more realistic simulation. In real life, spectrum switch decision making must consider more situations such as packet-loss-ratio, synchronization and delay. It must produce non-negligible handoff delay. The handoff delay needs to be taken into consideration, and it must affect the handoff decision as follows:

$$CH = \arg\max[\,(T_{IDLE} - \Gamma T_{switch})] \quad (4)$$

$$\Gamma = \begin{cases} 1 & , \text{if CH(Prev)} \cong \text{CH(Current)} \\ 0 & , \text{else} \end{cases}$$

D. Bandwidth consideration

When we make a switch decision in the process of proactive channel access, we take the channel bandwidth into consideration to achieve the best QoS.

$$PACKET^n = T^n_{remain} * BW^n \quad (5)$$

$$T^n_{remain} = T^n_{IDLE} - \alpha\,(\,Tswitch - Tsense\,) \quad (6)$$

$$\alpha = \begin{cases} 1 & , \text{if CH(Prev)} \cong \text{CH(Current)} \\ 0 & , \text{else} \end{cases}$$

$$CH = \arg\max_n(\,PACKET^n) \quad (7)$$

$PACKET^n$ means the packet capacity of the channel which performs transmission once and is equal to the product of channel remaining idle time and channel bandwidth. T^n_{remain} means the channel remaining idle time, and BW^n means channel bandwidth. If it needs to do channel switch, channel idle time has to subtract switch cost and spectrum sensing to calculate the channel remaining idle time. Finally, we will find the channel which has the maximum packet capacity to be our spectrum switch channel. The flowchart of this proactive channel access model is shown in Fig. 6.

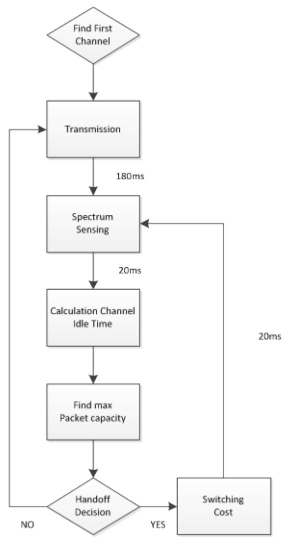

Figure 6. The flowchart of proactive channel access model

The available amount of the bandwidth is the key to determine the channel switch. When the remaining channel idle time is the same, the channel with bigger bandwidth possesses higher data transmission rate so that secondary users can finish their transmission faster.

Example: In Fig. 7, the channel remaining idle time of CH Y is larger than that of CH X. It is the best choice to switch to CH X according to conventional channel switch method which does not consider the channel bandwidth. After taking it into consideration, even if the channel remaining idle time of CH Y is larger than that of CH X, CH X can achieve faster data transmission since the channel bandwidth of CH X is twice that of CH Y. Selecting CH X not only reduces the cost of channel switch and the slots needed for further spectrum sensing so that more slots can be used for data transmission, but also requires less time to finish transmission.

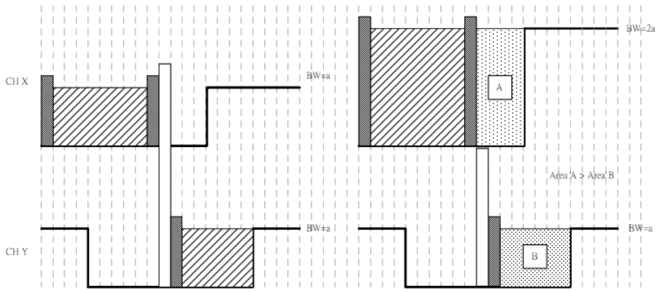

Figure 7. Channel selection with bandwidth consideration

As for the process of reactive channel access shown in Fig. 8, cognitive radio will first select a channel which is in IDLE state with maximum bandwidth to be “the First channel”, and start data transmission for 180ms. After finishing data transmission for 180ms, cognitive radio will perform spectrum sensing for 20ms periodically. Once primary user appears, cognitive radio will switch to the channel which has maximum bandwidth to resume communication if idle channels exist; otherwise, cognitive radio will keep spectrum sensing until the first idle channel appears.

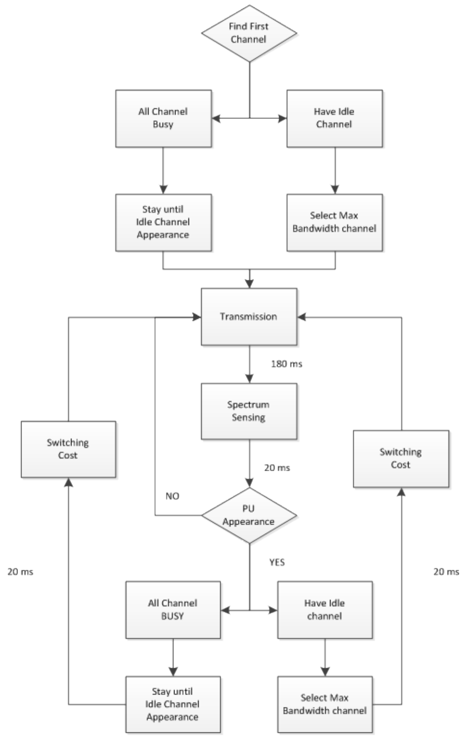

Figure 8. The flowchart of reactive channel access model

IV. SIMULATION RESULTS

We take various channel bandwidths into consideration to make spectrum handoff decision with the method proposed before under real cognitive radio environment, and use this method to analyze the performance. In our simulation environment, there are a secondary user and ten primary users. The bandwidths of ten primary channels are uniformly distributed from 1 to 10 MHz and the mean idle and busy periods are also uniformly distributed in min=0.5 and max=0.6~2.0. Sensing period and switch cost is 20ms. The period of data transmission is 180ms. Simulation time is set to 10000 sec.

Fig. 9 shows the number of channel switch in proactive and reactive methods. Note that proactive channel access method will process channel switch before primary users appear in order not to interfere with the primary users. On the other hand, reactive method just switch after primary users appear. Therefore, the number of channel switch in proactive method will be larger than that in reactive method.

Fig. 10 illustrates the number of interruption by primary users in these two methods. We find that the number of interruption by primary users in proactive method is always smaller than that in reactive method since proactive method predicts future primary channel state according to previous primary users’ traffic.

Channel utilization rate in both methods is shown in Fig.11. Instead of choosing the longest transmission time, proactive method always chooses the channel with maximum data transmission rate to switch. Comparing with reactive method which switches to the first channel with the idle state, the channel utilization rate of proactive method is lower than that of reactive method.

Proactive method can derive channel remaining time according to channel prediction model, and use the product of channel remaining idle time and the channel bandwidth to switch to channel with maximum data transmission rate, while in reactive method, cognitive radio will switch to the channel which has the maximum bandwidth without considering the probability of appearance of primary users, as shown in Fig. 12.

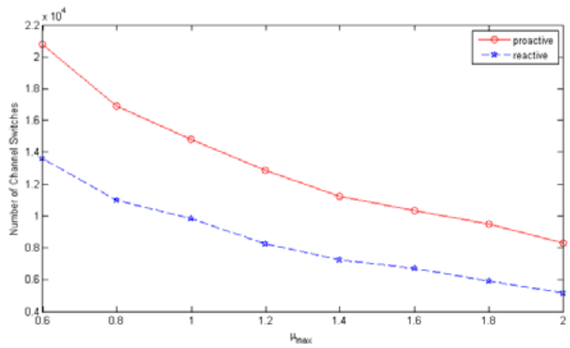

Figure 9. Number of channel switches

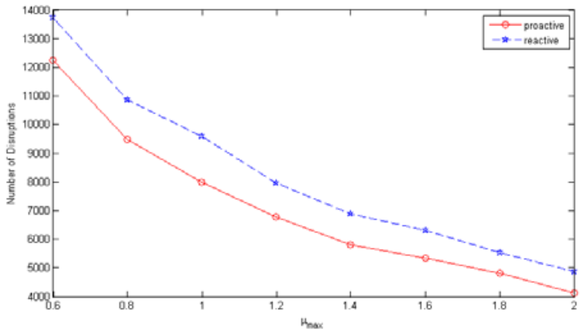

Figure 10. Number of disruptions by primary users

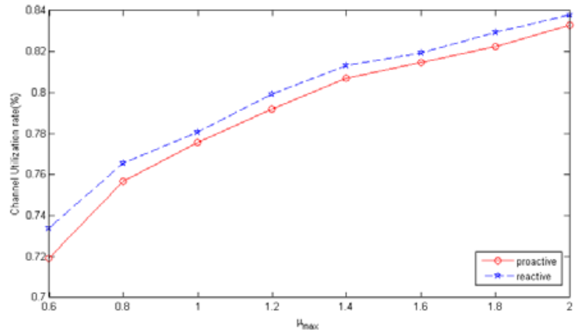

Figure 11. Channel utilization rate

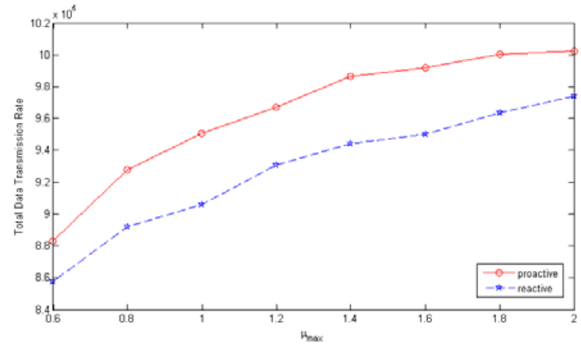

Figure 12. Total data transmission rate

V. CONCLUSION

Previous methods of channel switch just apply to channels with the same bandwidth. In this paper, we take different bandwidths into consideration for that purpose. Under these circumstances, the rule of channel switch should be changed in order to find the channel which meets the requirements of the users. By comparing the Proactive with the Reactive methods, we conclude that the former has better performance in terms of total transmission data rate and the number of disruptions by primary users, while the latter enjoys less channel switches and higher channel utilization rate.

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