Channel Selection Statistics for Control Information Sharing within Cognitive Radio Networks

Mai Ohta†, Takamasa Kimura†, Hasan Rajib Imam†,
Sean Rocke‡, Jingkai Su‡, Alexander M. Wyglinski‡ and Takeo Fujii†
†Advanced Wireless Communication Research Center (AWCC), The University of Electro-Communications,
1-5-1, Chofugaoka, Chofu-shi, Tokyo 182-8585 Japan
E-mail: {my, kimura, hasan, fujii}@awcc.uec.ac.jp
‡Wireless Innovation Laboratory, Department of Electrical and Computer Engineering,
Worcester Polytechnic Institute, Worcester, MA 01609-2280, USA
E-mail: {sean.rocke, jksu, alexw}@wpi.edu

***Abstract*—We propose a novel channel selection method for transmitting information that takes into account the amount of communication data and control data generated by the secondary users within a cognitive radio network. In this paper, multiple primary channels are characterized according to a channel occupancy ratio and a state transition ratio (STR), from which the secondary user selects the channel most suitable for transmitting the control information. By obtaining these ratios, the secondary user can estimate the size of a spectral white space for each channel belonging to the primary user. The proposed method is evaluated through computer simulation results and we can confirm the long-term white space can be remained for data transmission.**

Keywords: Cognitive Radio, Information Sharing, Channel Scheduling

I. INTRODUCTION

Recently, wireless spectrum scarcity has increasingly emerged as an important issue being faced by modern society. One potential remedy for this issue is dynamic spectrum access (DSA), where a secondary wireless system accesses unused spectral white spaces (WS) that are exclusively assigned to licensed (primary) systems. To avoid spectral collisions between a primary user (PU) and a secondary user (SU), it is imperative that the SU constantly monitors the surrounding environment. In order to ensure this environmental awareness, several frameworks exist to support SU communications within spectrum allocated to a PU, such as a centralized operator model employing a database [1]-[3] as well as a distributed model where surrounding nodes work together and share control information (CI), (e.g. channel state information or network information). In either case, in order to avoid interference while simultaneously enabling the SUs to temporarily access suitable spectrum, the SUs must be capable of transmitting control information in addition to data information (DI) across the spectral WS frequencies. Consequently, for the realization of more effective spectrum utilization, an appropriate channel selection method is needed, where the SU is required to select one spectral band in order to transmit either the DI or the CI. Thus, it is important to locate sufficient vacant spectrum for accommodating both the requirements of DI and CI (e.g. low occupancy spectrum, which can then be used for both types of data).

Channel selection methods have been extensively researched by the wireless community, and there exists three types of approaches published within the literature, namely: channel selection using spectrum sensing [4, 5], channel selection for communicating with the DI [6]-[9], and channel selection for sharing control information [1, 10, 11]. Whereas the DI represents the actual information, the control data represents the CI that is used for accessing and sharing the wireless spectrum. Moreover, the type of spectrum that is suitable for supporting different types of communication, e.g., DI, CI, also differs based on the specific characteristics of the transmission itself. In general, a channel occupancy ratio (COR) is utilized for statistical characterization of a channel [3, 4, 8, 11, 14, 15]. The COR characterizes the probability that a PU exists within a specific frequency band of interest. As a result, the COR is very useful for selecting the channel and there are many proposed approaches described within the open literature that utilize COR. However, the COR cannot define the duration of a continuous spectral WS, which is very important for an SU transmission in order to assess which frequency channel to utilize in the future for any length of time.

In order to solve this problem, we consider an additional metric called the state transition ratio (STR). The STR defines the probability that the state of the PU changes from a non–active mode to an active mode. In Reference [12], the probability that the channel will be available is derived from the STR, while in Reference [13] the data channel selection is based on the probability that the spectrum is accessed at a specific time slot and the probability that it remains in a non–active state, which is derived from the STR. Moreover, Reference [2] assumes that the PU possesses a periodic transmission characteristic. For situations where the channel is selected for DI transmission, the channel selection index is the length of the continuous WS of a specific channel for a PU. However, as previously mentioned, it is not only important to transmit the DI but also the CI in order to realize cognitive radio networks. The control information channel (CIC) is used for transmitting the CI needed to support the operations of the cognitive radio network within frequency spectrum allocated

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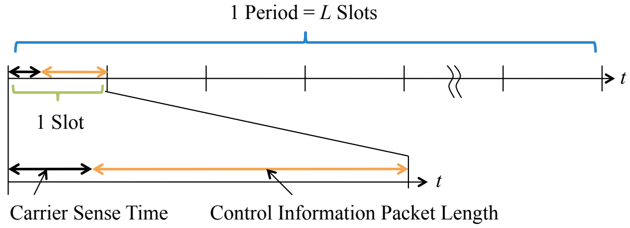


Fig. 1. Structure of slot for secondary user.

to PU transmissions. The CI is shared amongst the local SU nodes and small packets of CI are periodically broadcast to all the SU nodes within the network. However, if the CI is transmitted in the middle of a long WS, this means that another SU will be unable to transmit its own DI in this frequency during that time. Moreover, the resulting fragmented WS will not be suitable for other DI transmissions.

In this paper, we propose a novel channel selection method for assigning spectral WS frequencies to CI generated by SUs within a cognitive radio network in order to remain enough WS toward DI and to improve spectral efficiency. The COR and STR metrics are employed in the proposed channel selection process in order to allocate a suitable channel for a CI transmission, where the CI only requires a spectral WS of short duration while the DI requires a spectral WS of longer duration. Consequently, the resulting CIC that is formed by the SU cognitive radio network will help mitigate the interference experienced by the PU and data information channel (DIC). Moreover, the proposed channel selection method will leave long–term spectral WS for DI transmission by other SUs. This channel selection method for CI considers the occupancy duty cycle of various portions of spectral WS frequency bands. Simulation results are presented showing how the proposed approach operates with respect to evaluating an appropriate channel for DI and CI by using the proposed channel selection based on the COR and the STR.

The rest of this paper is organized as follows: Section II mentions structure of a slot and a channel model of primary system. In Section III, we show a characterization of channel occupancy behavior of the PU and identify five types of the primary channels. Section IV explains the method of making the channel list for the control channel selection. In Section V describes the simulation results by providing the COR and STR. Finally, we conclude our paper in Section VI.

II. Architecture

It is assumed in this work that the cognitive radio network consists of multiple SUs and multiple PUs, where each PU possesses only one licensed channel and the state of the PU channel can change on a per–slot basis. When transmitting the CI, the SU employs carrier sensing on the CIC prior to transmission and observes the entire spectrum of interest in one period. This period consists of L slots, which are constructed from the carrier sense time and the CI packet length as shown in Fig. 1. Since the SUs employ lower transmit power levels relative to the PU transmit power, then SU transceivers possess a more limited communication area.

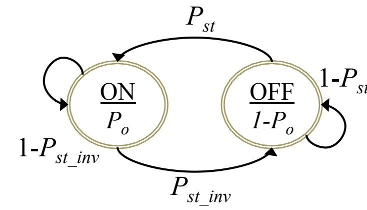


Fig. 2. Two–state Markov chain model. State of the PU is shown as ’OFF’ and ’ON’.

TABLE I
Summary of 5 types of channel behavior.

Type	(COR, STR)	Summary
a	(low, low)	SU obtains very long–term WS because PU does not often communicate.
b	(low, middle)	SU obtains short–term WS because PU often communicates, but for a short time.
c	(high, low)	SU obtains long–term WS because PU stays on state for some time.
d	(high, high)	SU obtains very short–term WS because PU starts communication right after previous communication.
e	(100%, 0%)	SU cannot communicate.

In this study, the primary channel occupancy behaviors are indicated by the COR and STR. The COR is defined by the probability that the PU occupies the channel, thus preventing the SU from utilizing the channel. The STR is defined as the probability that the PU transits to the next state. In this paper in particular, the STR indicates the probability of transitioning from a non–active state (i.e., “OFF”) to an active state (i.e., “ON”). Moreover, we assume that the STR P_{st} and the COR P_o is approximately constant during an M period interval. These are shown in the two–state Markov chain model (see Fig. 2). Consequently:

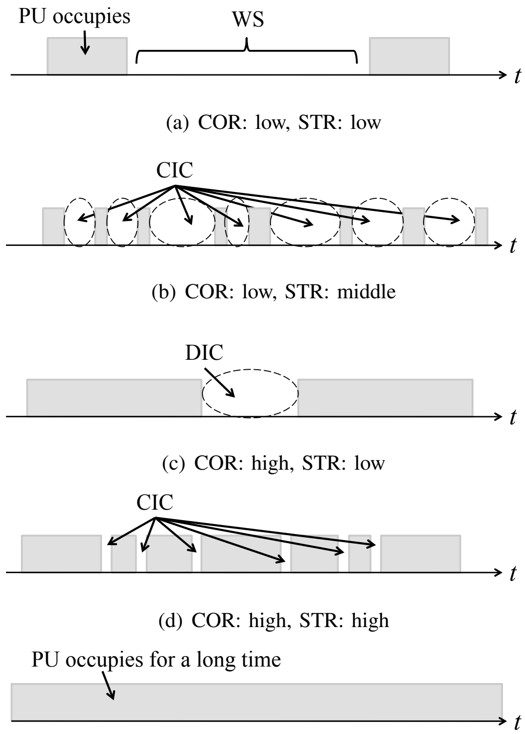
$$\begin{aligned} P_o P_{st\_inv} &= (1-P_o)P_{st} \\ 0 \le P_o &\le 1 \\ 0 \le P_{st} &\le 1 \\ 0 \le P_{st\_inv} &\le 1. \end{aligned} \tag{1}$$

Here, P_{st_inv} is the transittion probability of moving from state “ON” to state “OFF”.

III. Characterization of Channel Occupancy Behavior

Each SU needs to select suitable channels for the transmission of DI and CI . In this study, the channel selection process is based on the COR and the STR, as previously explained. However, most approaches published in the open literature assume that the primary channel characteristic is evaluated by only the COR in terms of channel behavior of the primary user [9, 15]. This method cannot estimate the PU channel state of the next slot. Therefore, the proposed section classifies a channel by using the STR and COR.

The channel behavior can be roughly classified into five types according to the STR and COR, as shown in Table I. Type (a) involves both the COR and the STR being low. In this case, the SU can obtain a long–term WS opportunity. Type (b) occurs when the COR is low and the STR is middle.



(a) COR: low, STR: low

(b) COR: low, STR: middle

(c) COR: high, STR: low

(d) COR: high, STR: high

(e) COR: 100%, STR: 0%

Fig. 3. 5 types of channel behavior for selecting DIC and CIC.

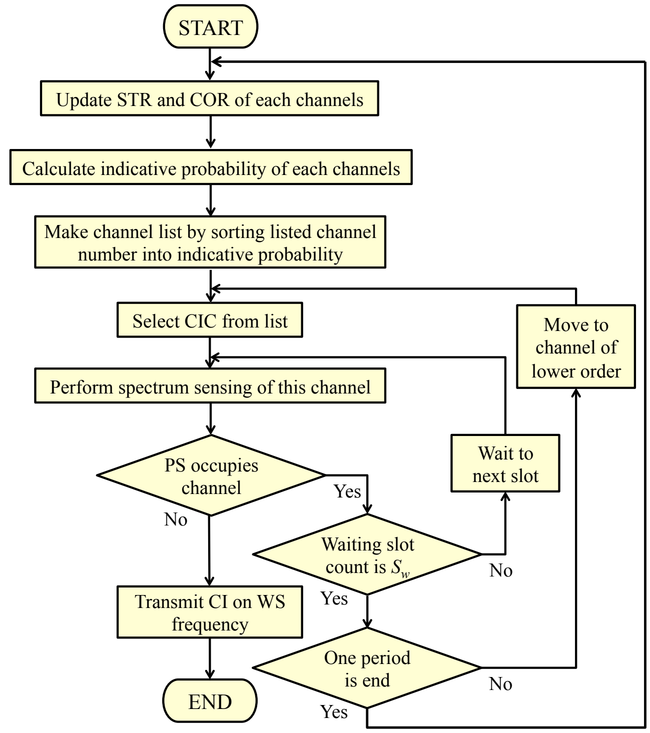


Fig. 4. Flow chart of proposed channel selection method.

In this case, since the PU often utilizes the spectrum, the WS opportunities are fragmented. Here, the STR is limited to middle level because the COR value is depended on the STR occurrence range. From (1), when the COR is high, the STR has obvious limitations. Type (c) involves the COR being high and the STR being low, which means that if the PU starts to use the spectrum, this status will continue for a long period of time. Type (d) involves both the COR and the STR being high. In this case, the PU frequently communicates, and the WS opportunities become very short–term. Finally, type (e) occurs when the COR is 100% and the STR is 0%. In this case, it is obvious that the secondary user cannot use the spectrum. Figs. 3(a)- 3(e) shows the channel occupation status classified by these types. These figures explain examples of the channel characteristic categories and the control channel in this paper is selected according to the channel priority list ordering by indicative metrics shown in the next section.

Note that the SU systems employ a data information channel (DIC) and a control information channel (CIC), where for the former the DI is generally a packet length possessing a long duration. Thus, sufficient bandwidth is needed for this type of channel. In contrast, the packet length of the CI is small, and multiple secondary users transmit CI. Each channel should be selected according to these characters. Our goal is to be clear which channel is best and to optimize these parameters.

IV. Channel Selection and Channel List for Control Information Channel

In order to select the CIC, the SUs make a channel list. In the case of the DIC, the stable and sustainable WS is fitted. From Fig. 3(a), since a WS should be long–term, type (a) is best for DIC. In contrast, in the channel defined by Fig. 3(d), the SUs cannot find a sufficient long–term WS. In this way, appropriate channel for DIC is obvious. Then, CIC list is made from channels unsuitable for DIC. Figure 4 shows a flow chart of our proposed channel selection method.

The procedure for making the channel list and performing the channel selection for the CIC is as follows:

1) Each SU checks both the STR and the COR of all PU channels.
2) The SU calculates the indicative probability for each channel derived from the primary state transitions from “ON” to “OFF”, and from “OFF” to “ON”. Consequently, it is the goal of this approach to find a very short–term WS slot for transmitting the CI, but which may be unsuitable for DI transmission. Then the channel list is constructed in descending order according to this probability, which depends on the STR and the COR. In this study, as previously stated we assume that the primary channel state can change in each slot. In this paper, two indicative metrics are used for making the CIC list. One is the one slot WS probability P_{one} which is given by:

$$\begin{aligned} P_{one} &= P_o P_{st\_inv} P_{st} \\ &= P_o \left(\frac{(1-P_o)P_{st}}{P_o} \right) P_{st} \\ &= (1–P_o)\, P_{st}^2, \end{aligned} \tag{2}$$

where P_{st} and P_{st_inv} is shown as Fig. 2. P_{st_inv} is the transited probability of state from “ON” to “OFF”, P_{st} is the transited probability of state from “OFF” to “ON”.

P_{st_inv} is derived from P_{st} and P_o which indicates the channel occupancy ratio, i.e., the probability that is the PU is active. Here P_{st} indicates the state transition ratio (STR) (i.e. the probability changed from the non–active to active state). P_o and P_{st} can be estimated from measurements, and we assume these probabilities do not during the M period under consideration. The next metric is the probability of being WS in the next slot when PU communicates. This is given by:

$$\begin{aligned} P_{nf} &= P_o P_{st\_inv} \\ &= (1{-}P_o)\, P_{st}. \end{aligned} \tag{3}$$

The SU makes the channel list in descending order according to these indicative probabilities P_{one} and P_{nf}. From these channel lists, the SU can rank the channels based on probabilistic measures of PU occupancy and transition frequency.

3) The SU selects the channel from the upper portion of the channel list, and performs carrier sensing on the selected channel. If there is no PU, the SU transmits the CI on this channel. If the PU is detected, the SU waits until this channel becomes unoccupied for a waiting slot S_w of each channel. The waiting slot is defined as the average number of slots in a single period (i.e. L slots) per candidate CIC (C is the number of candidate CICs), and is given by:

$$S_w = L/C. \tag{4}$$

If the waiting slot finishes, the SU selects the next listed channel and waits the chance of transmitting CI. When the SU can catch the WS during S_w, the SU performs spectrum sensing for the channel during remaining slots in the period.

If the SU cannot transmit CI, even if the period has ended, the SU selects the channel from the top of the channel list again in the next period. In this study, for simplicity we assume that the SU has perfect carrier sensing, and collision among secondary nodes and the PU does not happen.

In this way, the proposed method constructs the channel list for transmitting CI and can select the suitable CIC for efficiently using the spectrum. When the probability of the one slot WS is high, it is likely that the PU is utilizing the channel. In this case, however, it also indicates a high possibility that the PU often transits to non–active state. In the proposed method, the SU waits WS during the waiting slot even if at that time the PU occupies the channel. Thus since the channel list is based on the probability of finding the one slot WS, the proposed method can efficiently use the short–term WS.

V. Simulation Results

We now evaluate the proposed channel selection method through computer simulation. Table II shows the simulation parameters. First simulation evaluates the average number of continuous WS slots counted from the number of rest of vacant slots after the SU utilizes the WS for transmitting CI from the high priority chaneel. In this paper, we focus on the transmission of CI for exchanging the observation information of the surrounding environment. The total number of slots over every PU's channel is derived from a multiplication of the number of slots per one period and the number of periods and the number of channels. The PUs occur according to the Markov chain as previously mentioned, and then the channel slots are utilized from the PUs. At this time, one slot is a unit that the PU communicates, and the utilization slots for each communication of the PU are decided randomly according to STR and COR. The remaining spectrum resources can be utilized by the SUs, and then any remaining slots are evaluated.

TABLE II
Simulation parameters.

Parameters	Values
Number of primary channels	15
Number of slots per L–period	180
Number of averaging periods, F	10
Number of SU, T	30
Number of trials	10000

In this simulation, PU activity is generated based upon the probabilities calculated previously, using the STR and COR of each PU as shown in Fig. 2. Because the SU perfectly performs the carrier sensing, collisions among the secondary users and the PU did not occur in the scenarios considered. Figure 5 compares various proposed methods for channel list construction. The proposed method according to P_{one} means that channel list construction is based on the probability of only one WS slot when the previous slot and the next slot are occupied PU. The proposed method according to P_{nf} means that the channel list is built based on the probability of state transition to OFF when the PU is active state. In the COR–based method the rank of the channels listed depends on only the COR, and the channel list is generated in ascending order of COR. The STR–based method creates the channel list in descending order of STR according to only STR. Finally in then the random method, the channel list is made randomly.

At first, the number of continuous WS slots is evaluated because data transmission is better if the continuous WS is longer. If the number of continuous WS slots is one, the primary channel occupies both of the next slot and the previous slot. In this figure the PU–only result shows the continuous WS resource without the secondary node transmission. From this figure, the COR–based method illustrates that the resource of long–term continuous WS slots is decreased compared with other methods. The reason is that the channel which is high COR has many non–occupied slots and the SU uses the WS whether the WS continues short or long. As a result, the continuous WS slots is fragmented by using the channel which is high COR for transmitting the control packet. Whereas the COR–based method and the random method fragment the continuous WS slots, the proposed methods based on P_{one} and P_{nf} and the STR–based method perform better based on the average length of continuous WS slots. The reason is the COR–based method uses WS slots regardless of the length of WS slots. On the other hand, the methods with considering STR can select the channel which has the short–term WS.

Figure 6 compares the five methods based upon the average

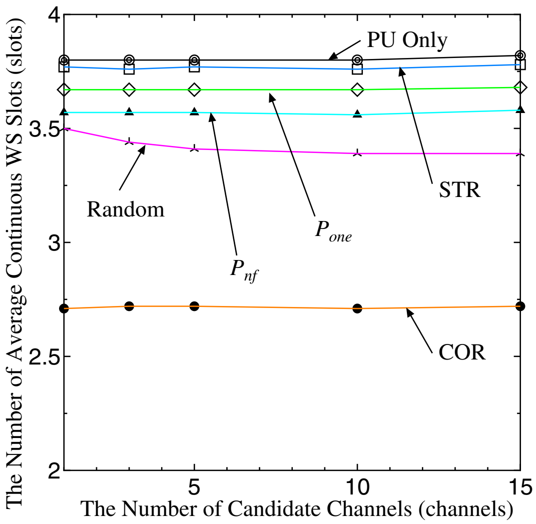


Fig. 5. Average continuous WS slots for transmitting DI compared for the proposed methods.

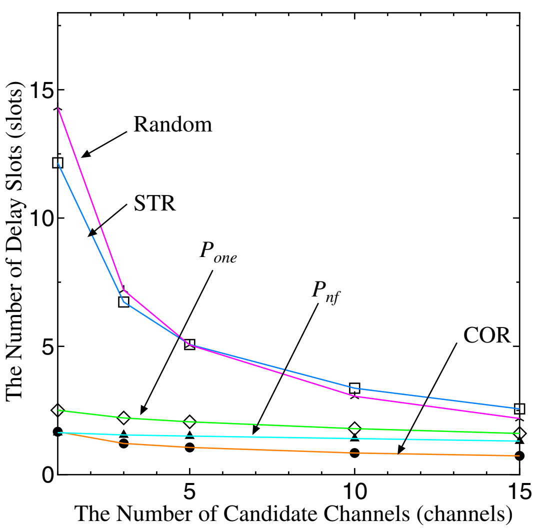


Fig. 6. Average delay slots for transmitting CI compared for the proposed methods.

delay in terms of the number of SUs. In cognitive radio systems, if the selected channel is occupied, the SU cannot transmit CI at this time. Therefore, in this study, the SU waits on one channel for a waiting slot S_w as given by Eq. (4). The average delay is defined by the total waited slots for whole periods. From this figure, it confirms that the random method and STR–based method have large delays compared to the COR–based method. The reason is that the COR–based method selects the channel which has many WS slots. According to the application, this delay becomes the problem: shorter delays may be better. As a result, the proposed methods can use the number of average delay slots and obtain the appropriate channel for transmitting CI without unnecessary white space fragmentation. On this basis, these results show that the proposed methods provide more effective channel selection methods for transmitting CI.

VI. Conclusion

In this paper, we propose a channel selection method for sharing the control information within a cognitive radio network. Specifically, by searching for spectral white space opportunities across a range of frequencies assigned to licensed services, it is possible to allocate control information channels and data information channels based on the occupancy characteristics of each segment of this spectrum. This study confirms the proposed methods can transmit control information on a less–appropriate channel allowing the long–term white spaces to be available to the secondary users for data information transmission. The future work is that the proposed method is evaluated by the results of measurement of real primary systems.

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