International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 3, March 2014

An Optimal Channel Selection Policy Based on POMDP for Maximizing Secondary User Performance in Cognitive Network

Shehana Badar J

Lecturer, Department of Electronics and Communication College of Engineering Kottarakara, Kerala, India

Abstract: ***In the absence of primary users, cognitive radio allows the secondary users to access the "underutilized" primary user band. Whenever the PU need of its bands, SU is interrupted from its data transmission. Periodic Spectrum Sensing (PSS) scheme degrades the QoS of the SU by interrupting its data transmission over the entire PU band. To alleviate this problem, the PU band is divided into two sub bands. One for continuous spectrum sensing and the other for SU data transmission, Based on this band division two schemes are proposed, a delay oriented continuous spectrum sensing (DO-CSS) scheme and throughput oriented continuous spectrum (TO-CSS) scheme. In the DO-CSS scheme, the average SU transmission delay is reduced by proper selection of bandwidth for spectrum sensing within each frame. In the TO-CSS scheme the achievable average throughput of the SU is maximized by choosing the optimal sensing bandwidth within multiple adjacent frames. The throughput is further improved by using an optimal sensing channel selection policy based on partially observable markov decision process.***

Keywords: Periodic spectrum sensing, continuous spectrum sensing, delay oriented, throughput oriented, sensing bandwidth, optimal sensing.

1. Introduction

With the rapid deployments of new wireless systems and services, available wireless spectrum resources are becoming scarce. However, most of the licensed primary user (PU) spectrum bands are underutilized [1]. Cognitive radio (CR) has been proposed to alleviate the problem of spectrum scarcity by accessing the vacant PU bands opportunistically [2].The spectrum sensing problem has gained new aspects with cognitive radio and opportunistic spectrum access concepts. It is one of the most challenging issues in cognitive radio systems [3].

In cognitive radio network, the secondary users are allowed to utilize the frequency bands of primary users when these bands are not currently being used. To support this spectrum reuse functionality, the secondary users are required to sense the radio frequency environment, and once the primary users are found to be active, the secondary users are required to vacate the channel within a certain amount of time. Therefore, spectrum sensing is of significant importance in cognitive radio networks. There are two parameters associated with spectrum sensing: probability of detection and probability of false alarm. The higher the probability of detection, the better the primary users is protected. However, from the secondary users' perspective, the lower the probability of false alarm, the more chances the channel can be reused when it is available, thus the higher the achievable throughput for the secondary network [7].

A Cognitive radio (CR) has been proposed to alleviate the problem of spectrum scarcity by accessing the vacant PU bands opportunistically. The spectrum sensing function provides available spectrum bands for CRs. To provide sufficient protection to the PU, it is required that the probability of detection be no smaller than a prescribed threshold within the sensing interval. Under this protection constraint, when the PU signal strength observed at the secondary user (SU) is extremely weak, the SU experiences high probability of false alarm and thus low spectrum utilization. In the PSS scheme, the SU must interrupt its transmission in the sensing interval since the spectrum sensing is carried out over the entire PU band. Due to the interruption of the SU data transmission, the SU experiences long delay even when the average SU throughput can be effectively optimized [7]. So two schemes are proposed, a delay oriented continuous spectrum sensing (DO-CSS) scheme and throughput oriented continuous spectrum (TO-CSS) scheme. Compared with the PSS scheme these two schemes can achieve better system performance. The proposed delay-oriented continuous spectrum sensing (DOCSS) scheme can adjust the sensing bandwidth. Guaranteeing the required protection for the PU, the scheme derived the optimal sensing bandwidth that maximizes the SU throughput. Compared with the conventional PSS scheme, the SU delay is reduced significantly by using proposed DO-CSS scheme. However, for some throughput-demanding SU services, the achieved maximum throughput of the DO-CSS scheme may still not be satisfactory. Therefore, a new throughput-oriented CSS (TO-CSS) scheme has been proposed by jointly adjusting the sensing time and bandwidth. Provided that the required protection for the PU is guaranteed, the optimal sensing bandwidth that maximizes the SU throughput is also derived for the proposed TO-CSS scheme. In the DO-CSS scheme, the SU makes a decision on the PU activity within each frame, while the TO-CSS scheme only needs to make a decision on the PU activity over multiple consecutive frames.

The throughput of the secondary user is further improved by using an optimal sensing channel selection policy based on partially observable markov decision process (POMDP). Here the full-spectrum is usually divided into multiple channels. However, due to the hardware and energy constraints, a cognitive user may not be able to sense two or more channels simultaneously. As different channels may have different primary user activities and time-varying channel qualities, an important task is to select which channels to sense and access for a given time period so that the available spectrum left by the primary users can be fully utilized by the secondary user. The proposed policy takes the time-varying channel state into consideration and intends to optimally exploit spectrum resources for the secondary user. In addition to selecting optimal channel to sense, the policy derives the optimal sensing time which leads to maximized throughput of the secondary user.

2. System Model

Consider a CR network in which each SU transmits frame-by-frame in the time domain. Conventionally, spectrum sensing is carried out within each frame over the entire PU band periodically [6]. Let W be the PU bandwidth, T be the frame length, and τ be the time interval allocated for spectrum sensing. In each sensing interval τ, the SU must interrupt its data transmission to avoid co-channel interference. Once the sensing result indicates the absence of the PU, the SU accesses the PU band in the rest part of the frame; otherwise, the SU terminates its transmission until it detects a vacant PU band. Here the spectrum sensing and data transmission are carried out simultaneously over two different parts of the PU band. In the frequency domain, the PU band of width W is divided into two parts. One part of bandwidth W_s is allocated for spectrum sensing. In this part of PU band, SU transmission is forbidden to avoid co-channel interference. And the other part of bandwidth $W - W_s$ is allocated for SU data transmission. To implement simultaneous spectrum sensing and data transmission, the SU transmitter needs to be equipped with two radios, one for spectrum sensing and the other for data transmission.

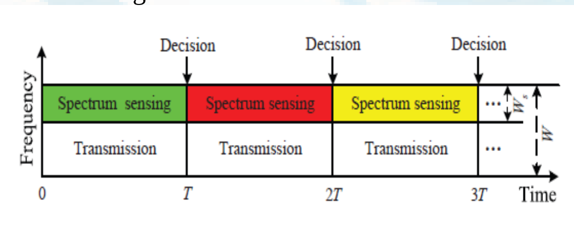

Figure 1: Delay oriented CSS and data transmission.

Assume that here the PU transmits based on orthogonal frequency division multiplexing (OFDM). The PU bit stream is coded, interleaved and then used to modulate OFDM subcarriers using quadrature amplitude modulation (QAM). In the time domain, the SU transmits over its data transmission band of width $W - W_s$. On the one hand, the SU is allowed to transmit only when the result of spectrum sensing in the previous frame indicated that the PU was absent. On the other hand, when the sensing result in the current frame indicates that the PU is present, the SU must terminate its transmission until it detects a vacant PU band. Side-band emission from the SU transmission may have negative effects on the spectrum sensing function at the SU transmitter. To avoid this problem, here assume that 1) the SU uses OFDM signalling for data transmission, and 2) the subcarrier spacing of the SU signal over its transmission band of width $W - W_s$ is the same as that of the PU signal. When the SU senses the PU activity and transmits its own data simultaneously, the out-of-band emission could be ignored, since the subcarriers allocated for sensing are orthogonal with the subcarriers allocated for transmission in the frequency domain.

3. DO-CSS Scheme

For delay sensitive services, a slight increase in the transmission delay will result in degraded QoS. To reduce the SU transmission delay, a new delay oriented CSS (DO-CSS) scheme has been proposed, as shown in Fig. 1.Here the spectrum sensing function is performed by the energy detector and the sensing performance of energy detector is characterized by its receiver operating curve (ROC) or probability of detection versus probability of false alarm. The probability of detection and probability of false alarm are given by,

$$P_f(W_s) = Q\left(\frac{\lambda}{\sqrt{2TW_s}} - \sqrt{2TW_s}\right) \quad (1)$$

$$P_d(W_s) = Q\left(\frac{\lambda}{(1+\gamma)\sqrt{2TW_s}} - \sqrt{2TW_s}\right) \quad (2)$$

Where λ is the sensing threshold and γ is the SNR.

3.1 Secondary User Data Transmission

The result of spectrum sensing is a binary decision on the activity of the PU. Thus, there are four cases to be considered: 1) correct detection of the PU (CDPU), which means that the SU detects the presence of the PU correctly; 2) incorrect detection of the PU (CDPU), which stands for false alarm; 3) correct detection of spectrum opportunity (CDSO), which means that the SU detects the absence of the PU correctly; and 4) incorrect detection of spectrum opportunity (ICDSO), which stands for missed detection. Once a SU decides that the PU is absent, it tries to access the PU band. Therefore, the SU transmits its data in two cases: CDSO and ICDSO.

In the case of CDSO, only the SU transmits its data. The achievable SU throughput is

$$C_1(W_s) = (W - W_s)\ln(1 + \Omega_1(W_s)) \quad (3)$$

where $\Omega 1$ (W_s) is the SNR observed by the SU receiver over its transmission band. In the case of ICDSO, the PU and the SU transmit simultaneously. Thus, the SU receiver is interfered by the PU signal and the achievable SU throughput becomes

$$C_2(W_s) = (W - W_s)\ln(1 + \Omega_2(W_s)) \quad (4)$$

where $\Omega 2$ (W_s) is the signal to noise and interference ratio (SINR) observed by the SU receiver over its transmission band. Let $P(H_0)$ and $P(H_1)$ be the probabilities of the absence and presence of the PU, respectively. By using (3) and (4), the achievable SU throughput can be obtained as

$$C(W_s) = P(H_0)\Pi_1(W_s) + P(H_1)\Pi_2(W_s) \quad (5)$$

where Π1 (*Ws*) and Π2 (*Ws*) are the achievable throughputs under the hypothesis of H_0 and H_1, respectively.

3.2 Achievable Secondary User Throughput

The achievable SU throughput of the proposed DO-CSS scheme is given by

$$C(W_s) = \varphi_1(W_s)U_1 + \varphi_2(W_s)U_2 \quad (6)$$

From the point of view of the SU, it is desirable to maximize *C*(*Ws*) by choosing the proper spectrum sensing bandwidth W_s. While from the point of view of the PU, it is required that the PU be sufficiently protected. To protect the PU, P_d (*Ws*) should not be lower than a prescribed threshold. The larger the P_d(*Ws*), the better the PU is protected. However, P_f(*Ws*) monotonically increases with increase of P_d(*Ws*). Since the increase of P_f (*Ws*) usually leads to low spectrum utilization, it is only necessary to satisfy the basic requirement for protecting the PU, P_d (*Ws*) = P_d^{th} .

Consequently, the optimization problem for the SU can be written as

$$\max_{0\le W_s \le W} C(W_s) = \varphi_1(W_s)U_1 + \varphi_2(W_s)U_2 \quad (7)$$
$$s.t.\ P_d(W_s) = P_d^{th}$$

Therefore, there exists an optimal spectrum sensing bandwidth that maximizes the SU throughput.

3.3 Secondary User Transmission Delay

In the proposed DO-CSS and data transmission scheme, the SU can transmit or retransmit in its transmission band only when the PU is detected to be vacant. Whenever the PU is detected to be present, the SU must stop its transmission to protect the PU. Under the PU protection constraint P_d (Ws) $= P_d^{th}$, the average SU transmission delay can be presented as

$$D(W_s) = T\left[P(H_1)P_d^{th} + P(H_0)Q[f_2(W_s)]\right] \quad (8)$$

Therefore, the SU transmission delay of the DO-CSS is smaller than that of the PSS scheme over a fading channel.

4. TO-CSS Scheme

The DO-CSS scheme utilizes the freedom of adjusting the spectrum sensing bandwidth Ws in the frequency domain to reduce the average SU transmission delay. For some throughput-demanding SU services, the throughput obtained from DO-CSS scheme may still not be satisfactory. To improve the maximum achievable SU throughput, a new throughput-oriented CSS (TO-CSS) scheme is developed. In the spectrum sensing band, *K* adjacent frames are utilized to jointly sense the PU signal. In the transmission band, if the previous sensing result indicated the absence of the PU signal, the SU transmits in the *K* succeeding frames; otherwise, the SU stops its transmission. Consequently, the SU can take advantage of both the freedom in the time domain to adjust the sensing time, and the freedom in the frequency domain to adjust the sensing bandwidth, which is expected to effectively improve the system performance.

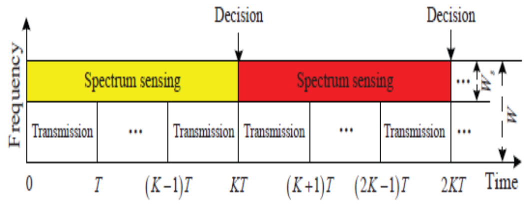

Figure 2: Throughput oriented CSS and data transmission.

4.1 Secondary User Data Transmission

The probability that the SU transmits in the case of CDSO is $P(H_0)(1 - P'_f(Ws))$ and the SU throughput is $C_1(Ws)$, while the probability that the Secondary User transmits in the case of ICDSO is $P(H_1)(1-P'_d(Ws))$ and the SU throughput is $C_2(Ws)$. Thus, the total achievable SU throughput is

$$C'(W_s) = P(H_0)\Pi'_1(W_s) + P(H_1)\Pi'_2(W_s) \quad (9)$$

where $\Pi'_1(W_s)$ and $\Pi'_2(W_s)$ are the achievable throughputs under the hypothesis of H_0 and H_1, respectively.

4.2 Achievable Secondary User Throughput

The total achievable SU throughput can be represented as

$$C'(W_s) = \varphi'_1(W_s)U_1 + \varphi'_2(W_s)U_2 \quad (10)$$

While from the point of view of the SU, it is desirable to maximize the achievable throughput. Therefore, the optimization problem can be formulated as

$$\max_{0\le W_s \le W} C'(W_s) = \varphi'_1(W_s)U_1 + \varphi'_2(W_s)U_2$$
$$s.t.\ P'_d(W_s) = P_d^{th} \quad (11)$$

It can be concluded that the TO-CSS scheme achieves the best transmission throughput among the two schemes.

4.3 Secondary User Transmission Delay

Once the SU claims the presence of the PU, the SU transmission delay of the TO-CSS scheme is KT, instead of T. Under the PU protection constraint given by P'_d(Ws) $= P_d^{th}$, the average SU transmission delay becomes

$$D'(W_s) = KT\left[P(H_1)P_d^{th} + P(H_0)Q[g_2(W_s)]\right] \quad (12)$$

ISSN (Online): 2347-3878
Volume 2 Issue 3, March 2014

This means that the average transmission delay of the TO-CSS scheme is lower than that of the DO-CSS scheme and can be concluded that the TO-CSS scheme shows the best delay performance among the two schemes.

5. Proposed Work

5.1 Optimal Sensing Channel Selection Policy based on POMDP

In the previous works, channel is considered stationary with constant rate. Actually, it is fluctuating all the time due to secondary user mobility and channel fading, etc. Therefore, secondary users not only need to identify primary user activities, but also need to identify the channel condition so that an idle channel with best channel condition can be selected for transmission. In this policy, channel condition is considered as an important criterion in selecting sensing channels. As different channels may have different primary user activities and time-varying channel qualities, an important task is to select which channels to sense and access for a given time period so that the available spectrum left by the primary users can be fully utilized by the secondary user. So an optimal sensing channel selection policy based on partially observable Markov decision process (POMDP) has been proposed.

The proposed policy takes the time-varying channel state into consideration and intends to optimally exploit spectrum resources for the secondary user. In addition to selecting optimal channel to sense, the policy derives the optimal sensing time which leads to maximized throughput of the secondary user. The policy employ finite state Markov channel (FSMC) to model the channel condition transitions and formulate the sensing channel selection problem in POMDP framework. Furthermore, the optimal sensing time is also considered to maximize the secondary user throughput. The optimal policy in each decision stage includes the sensing channel index and optimal sensing time.

The secondary user makes a decision on which channel to sense based on previous observations of the channels. To maximize the secondary user throughput, the proposed policy jointly chooses the optimal sensing channel and sensing time. By taking the time-varying channel state into consideration, the proposed method achieves a better performance than the existing work which does not consider channel state variation. With the optimal sensing time, the channel efficiency is also improved in the proposed method, as compared with the method with fixed sensing time. The policy considered a secondary user and a number of licensed channels. The secondary user can sense one channel at a time. Policy assumes that the channel access of primary users follows a Markov model, besides the channel state transition caused by primary user activity; the secondary user also observes fluctuated channel condition due to fading effect. This channel characteristic can be modelled as finite state Markov channel (FSMC).

6. Result and Discussion

The performance of the Secondary user is evaluated using Network Simulator and are compared with that of the existing system. Wireless channel and two ways ground radio propagation model are studied and Omni antenna is selected. The Routing Protocol used is AODV (Ad hoc On Demand Distance Vector) and the priority queuing method is implemented here. For the simulation purpose number of nodes chosen is 10 and 5 channels per radio is selected. The simulation time is set to be 50ms. At the initialization, CR nodes are located randomly over the distribution area of Primary User. The simulation result shows the throughput, delay and packet delivery ratio comparisons of the existing and the proposed schemes.

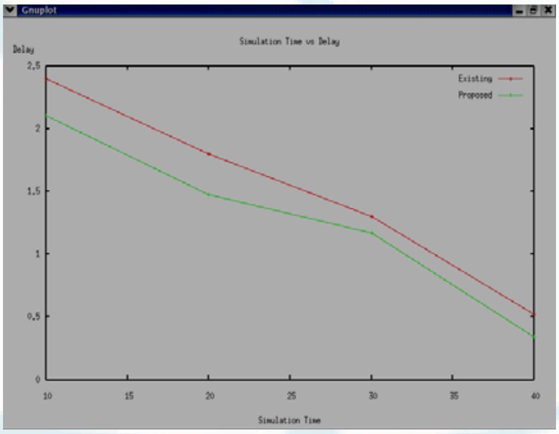

Figure 3: Simulation time Vs delay

Figure 3 shows the simulation time versus delay of existing and the proposed policy. Simulation results reveal that by taking the time-varying channel state into consideration, the proposed method achieves a better performance than the existing work. By using Partially Observable Markov Decision Process the optimal sensing policy reduces the transmission delay of the SU. Figure 4 shows the simulation time versus throughput of the existing schemes and proposed policy. It is used to evaluate how effectively packets are transmitted from source to destination via relays. The simulation result shows the improvement of the SU throughput using partially observable markov decision process. The proposed policy jointly chooses the optimal sensing channel and sensing time to improve the throughput of the secondary user. With the optimal sensing time, the channel efficiency is also improved.

International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 3, March 2014

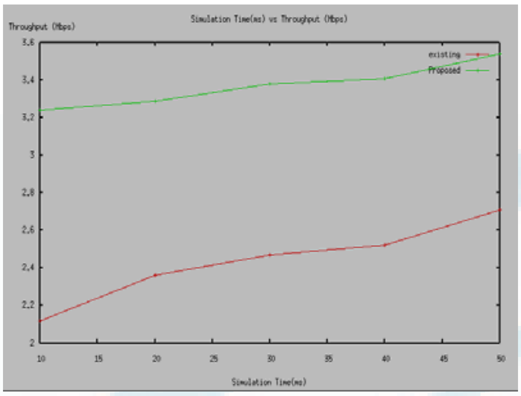

Figure 4: Simulation time Vs throughput

Figure 5 compares the packet delivery ratio of the existing schemes and the proposed policy. By allowing the nodes to transmit multiple packets on the reserved data channel, the proposed policy increases the Packet Delivery Ratio (PDR) than the existing schemes.

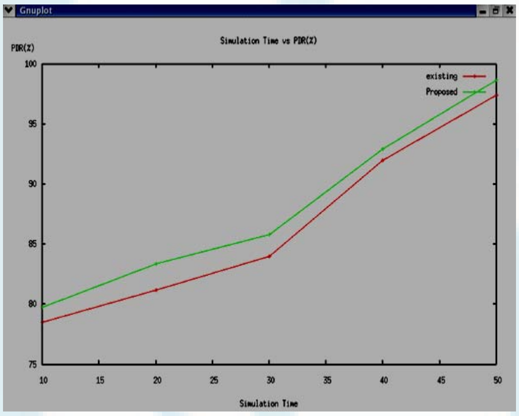

Figure 5: Simulation time Vs packet delivery ratio

7. Conclusion

It is concluded that, Cognitive radio is a paradigm created in an attempt to enhance spectrum utilization. In order to improve the SU performance, two schemes are developed. A Delay Oriented Continuous Spectrum Sensing (DO-CSS) scheme for delay sensitive secondary user services and a Throughput Oriented Continuous Spectrum Sensing (TO-CSS) scheme for throughput demanding SU services. DO-CSS scheme reduces the transmission delay of the SU by selecting proper bandwidth for spectrum sensing within each frame. In the proposed TO-CSS scheme, the maximum SU throughput is improved by sensing continuously in several adjacent frames. The proposed DO-CSS scheme has advantage in the SU transmission delay, and the proposed TO-CSS scheme has advantages both in the SU transmission delay and achievable SU throughput. These schemes cannot takes the time varying channel state into consideration, so an Optimal Sensing Channel Selection policy based on Partially Observable Markov Decision Process (POMDP) is developed. In the proposed policy, the channel condition is considered as an important criterion in selecting sensing channel. The secondary user throughput is improved by jointly choosing the optimal sensing channel and sensing time. By taking the time-varying channel state into consideration, the proposed method achieves a better performance than the existing work which does not consider channel state variation. With the optimal sensing time, the channel efficiency is also improved in the proposed method, as compared with the method with fixed sensing time.

References

[1] Mitola, J. and J. Maguire, G. Q., “Cognitive radio: making software radios more personal,” IEEE Personal Commun. Mag., vol. 6, no. 4, pp. 13–18, Aug. 1999.

[2] Federal Communications Commission, “Notice of proposed rulemaking and order: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies,” ET Docket No. 03-108, Feb. 2005.

[3] J. O. Neel, “Analysis and design of cognitive radio networks and distributed radio resource management algorithms,” Ph.D. dissertation, Virginia Polytechnic Institute and State University, Sept. 2006.

[4] Federal Communications Commission, “Notice of proposed rulemaking: Unlicensed operation in the TV broadcast bands,” ET Docket No. 04-186 (FCC 04-113), May 2004.

[5] M. Marcus, “Unlicensed cognitive sharing of TV spectrum: the controversy at the federal communications commission,” IEEE Commun.Mag., vol. 43, no. 5, pp. 24–25, 2005.

[6] Y. Zhao, L. Morales, J. Gaeddert, K. K. Bae, J.-S. Um, and J. H. Reed, “Applying radio environment maps to cognitive wireless regional area networks,” in Proc. IEEE Int. Symposium on New Frontiers in Dynamic Spectrum Access Networks, Dublin, Ireland, Apr. 2007, pp. 115–118.fiber systems,” J. Lightwave Technol., vol. 28, no. 12, pp. 1811–1820, 2010.

[7] P. Kolodzy et al., “Next generation communications: Kickoff meeting,” in *Proc. DARPA*, Oct. 2001.

[8] R. Matheson, “The electro space model as a frequency management tool,” in *Int. Symposium On Advanced Radio Technologies*, Boulder, Colorado, USA, Mar. 2003, pp. 126–132.

[9] L. Drozd, I. P. Kasperovich, C. E. Carroll, and A. C. Blackburn, “Computational electromagnetic applied to analyzing the efficient utilization of the RF transmission hyperspace,” in *Proc. IEEE/ACES Int. Conf. on Wireless Communications and Applied Computational Electromagnetics*, Honolulu, Hawaii, USA, Apr. 2005, pp. 1077–1085.

[10] W. D. Horne, “Adaptive spectrum access: Using the full spectrum space,” in *Proc. Annual Telecommunications Policy Research Conf.*, Arlington, Virginia, Oct. 2003.

[11] Tonmukayakul and M. B. H. Weiss, “Secondary use of radio spectrum: A feasibility analysis,” in *Proc. Telecommunications Policy Research Conference*, Arlington, VA, USA, Oct. 2005.

[12] S. Geirhofer, L. Tong, and B. Sadler, “Dynamic spectrum access in the time domain: Modelling and exploiting white space,” *IEEE Commun.Mag.*, vol. 45, no. 5, pp. 66–72, May 2007