

Decentralized Spectrum Selection Algorithm to Consider Hardware Constraints in Cognitive Radio Ad-hoc Networks

Bosung Kim*, Nguyen Manh Tuan*, Byeong-hee Roh*, Dae-Young Kim**, and Soo Bum Park**

* Graduate School of Information and Communication, Ajou University,
San 5 Wonchon-dong, Youngtong-gu, Suwon-si, 443-749, Korea

** LIG Nex1 Corporation,
Pangyo Techno Valley, Sampyeong-dong, Bundang-gu, Seongnam-si, 463-400, Korea,
{kbs8354, nmtuan, bhroh}@ajou.ac.kr, {daeyoung.kim81, sbpark93}@lignex1.com

Abstract— The Cognitive Radio (CR) is considered as a solution to increase in wireless devices and traffic in existing networks where inefficient spectrum utilization occurs. Common Control Channel (CCC) of CR helps unlicensed devices to make a decision for availability of spectrum resources in CR Ad Hoc Networks (CRAHNs). Actually, it is not easy to adopt CCC to the network in which supports applications such as military units penetrating deep in unknown and/or hostile territories, wireless networks established for particular social events, or sensor networks deployed for specific tasks. Therefore, various kinds of decentralized MAC protocols are developed recently to consider hardware constraints. However, these protocols also have limitations that they did not consider various operation environments and parameters to enhance the performance. In this paper, we propose a memoryless access based spectrum selection algorithm to overcome the hardware constraints and enhance the spectrum utilization. To evaluate the network performance, simulations are conducted in terms of throughput.

Keywords— Cognitive Radio, Decentralized MAC, Periodic Sensing, Spectrum Selection, Memoryless Access, OPNET

I. INTRODUCTION

The spectrum resources of today's wireless networks are allocated to licensed users on a long-term basis over vast geographical regions by the spectrum allocation policy governed by the Federal Communication Commission (FCC) [1]. However, the wireless networks undergo spectrum resource shortage problems due to the development of wireless communication technology and increased demands for application services [2]. In order to address the critical problem of spectrum scarcity, the FCC has recently approved the use of unlicensed devices (also called cognitive radio users or secondary users) in licensed bands. Consequently, Dynamic Spectrum Access (DSA) techniques are proposed to solve these current spectrum inefficiency problems. This new area of research foresees the development of Cognitive Radio (CR) networks to further improve spectrum efficiency [2].

The CR networks can be classified into infrastructure-based and infrastructure-less CR networks. In other word, the infra-

structure-less can be called Cognitive Radio Ad Hoc Networks (CRAHNs). Because CRAHNs have no coordinator or base station and they need to utilize the cooperative sensing to make decisions with their local observation of wireless nodes with the cognitive capability [2]. However, the provision of Common Control Channel (CCC) used in CRAHNs is not easy to support the device's portability, mobility, and hardware cost, but there are difficulties to operate the cooperative sensing scheme [3].

In [3], they proposed the decentralized cognitive MAC (DC-MAC) to consider hardware constraints in CRAHNs which the CR nodes can make decision individually. Since then, they proposed spectrum selection algorithm based on DC-MAC for Multi-Channel Single-User (MCSU) [5][6] and Multi-Channel Multi-User (MCMU) [7] cases. In [7], since they only consider the case that the number of Secondary Users (SUs) is equal to the number of channels, there is room for additional improvement of spectrum selection algorithm in the case that the number of SUs increases.

In this paper, we propose an efficient spectrum selection algorithm with memoryless access which is operated with DC-MAC in CRAHNs. In the network, the SU with the proposed scheme selects the spectrum band without any control message with consideration of the various performance parameters, such as the number of SUs and traffic specification.

The rest of the paper is organized as follows. In Section 2, we overview the CRAHNs and the DC-MAC based spectrum selection algorithms. The description of the proposed scheme is given in Section 3. The performance of the proposed scheme is examined through the simulation in Section 4. Finally, Section 5 draws the conclusions and lists the future direction for research on DC-MAC based spectrum selection.

II. BACKGROUNDS

A. Cognitive Radio Ad Hoc Networks (CRAHNs)

As shown in Figure 2, in Cognitive Radio Ad Hoc Networks (CRAHNs) SU cannot predict the influence of its actions on the entire network with its local observation, so that

the cooperation schemes are essential, which the observed information can be exchanged among devices to broaden the knowledge on the network. To support the cooperation schemes between the SUs, the Common Control Channel (CCC) is used. However, applying the CCC into the CRAHNs is not easy, because there are hardware constraints considering portability, mobility, and hardware cost. That's why decentralized cognitive MAC to compensate this limitation is necessary.

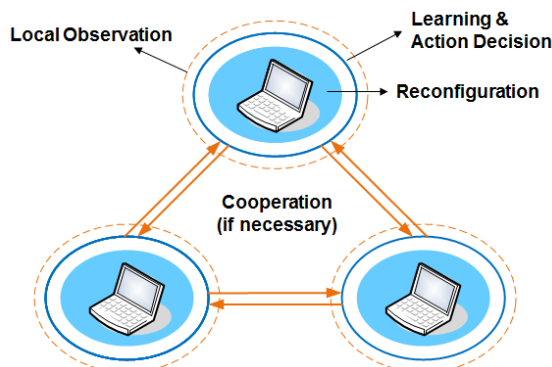


Figure 2. CRAHNs, Cognitive Radio Ad-hoc Networks

B. Hardware Constrained Spectrum Selection Algorithms

For CRAHNs which have no coordinator or base station, it is desirable to have Decentralized Cognitive MAC (DC-MAC) [3] where each node decides individually how to sense the spectrum and how to gain access. Because SUs cannot exchange local information on channel availability before agreeing on a communication channel such a protocol should no rely on cooperation among SUs. The network state is partially observable since a more practical and more general sensing model that allows a SU to sense, not all channels, but a subset of channels. For above mentioned problem, Partially Observable Markov Decision Process (POMDP) [3] is used to maximize the overall network throughput.

The author continued to find the way to enhance the spectrum efficiency, and had been studying Memoryless Access (MA) based Periodic Sensing (PS), which is heuristic spectrum selection algorithm. PS-MA [5] and IS-MA [6] were proposed for Multi-Channel Single-User (MCSU), and OPS-MA [7] was proposed for Multi-Channel Multi-User (MCMU).

The sensing and transmission in Periodic Sensing with Memoryless Access (PS-MA) [5] can be described as follows. The SU senses the channels in an increasing order at the beginning of each slot, starting from an arbitrary channel. If the i -th channel status is idle. The SU transmits in the sensed channel with transmission probability. Orthogonalized Periodic Sensing with Memoryless Access (OPS-MA) [7] implements PS-MA for each SU in an orthogonal manner. The K SUs periodically sense the channels by using different sensing phases.

As shown in Figure 1, when all SUs follow a slotted transmission structure, two cases of problems can occur. First one is depicted as Case-1 which timeslots are concentrated in cer-

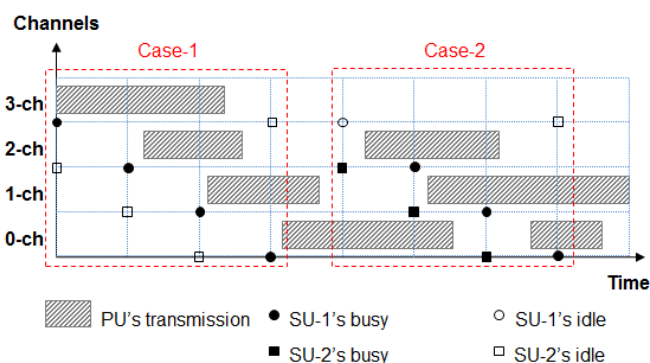


Figure 1. The operation and problems of OPS-MA

tain SU (in Figure 1, SU-2) and other SUs (in Figure 1, SU-1) are starved. Second one is depicted as Case-2 which on account of the nature caused by periodic sensing, certain SUs (in Figure 1, both SU-1 and SU-2) cannot find available timeslots (in 3-ch of Figure 1) to transmit a data, even though they exist at the periodic sensing period. Additionally, there is a limitation that the number of SUs should be no more than the number of channels.

In Indexed Periodic Sensing with Memoryless Access (IS-MA) [6], the SU first fixes an ordered list of the N channel in the list. If it is idle, the SU transmit with transmission probability. The SU then keeps sensing the first channel on the list until first busy sensing result after the SU switches to the next channel in the list and transmits probabilistically. The SU moves down along the list as described above until reaching the last channel. After the first busy sensing results from the channel, the SU goes back to the first channel again. Equivalently, the SU stays in the same channel and transmit probabilistically, if the channel status is idle, and moves down along the ordered list otherwise. In this way, IS-MA achieves the closer throughput to ideal case than PS-MA.

In this paper, we propose an efficient spectrum selection algorithm based on IS-MA's sensing pattern for MCMU. IS-MA, of course, supplements the drawbacks of PS-MA, but if IS-MA is just employed in MCMU, it can cause severe problems. For example, when IS-MA is operated in MCMU as shown in Figure 3, except for the collision with Primary Users (PUs), the collision with SUs can happen. There are three white triangle points, which mean SU-1 and SU-2 can collide

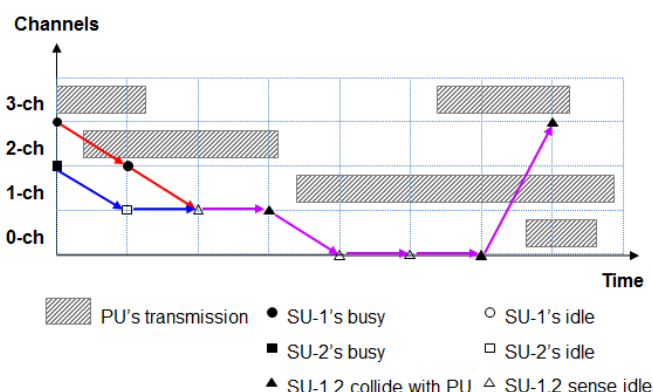


Figure 3. The operation and problems of IS-MA

with each other although there is no collision with PUs. Because after first white triangle point, the sensing pattern of both SU-1 and SU-2 is converged into one channel, the spectrum efficiency decreases drastically.

III. PROPOSED SCHEME

A. System Model

The system variables for the proposed scheme are as follows.

N	The number of channels
K	The number of secondary users
T_f	The length of a frame
T_s	The length of a timeslot
T_c	The length of a mini-slot
I_j	The initial channel number assigned to j -th SU
C_j	The channel number under sensing of j -th SU
X_i	The status of i -th channel

Assume that there are N parallel channels (indexing from 0 to $N-1$) available for transmissions by the PUs. The occupancy of the N channels is modelled by N independent continuous-time Markov chains. The holding times are exponentially distributed. As shown in Figure 4, unlike PU's activity, SUs are operated in slotted transmission structure and they have one transceiver each, so that they can sense one channel every timeslot. Each channel consists of a series of timeslots, which are a composition of transmission delay and propagation delay. These timeslots are divided into several mini-slots to initialize a network. Then, T_f , T_s , T_c are the length of a frame, the length of a timeslot, and the length of a mini-slot, respectively. In network initialization, j -th ($j=0,1,\dots,K-1$) SU receives the channel number I_j to sense the channel at first. With I_j and our proposed scheme each SU changes the channel number C_j to next sense according to the channel status. The channel status X_i is obtained by sensing i -th channel ($i=0,1,\dots,N-1$). Then, each channel has two states with idle ($X_i=0$) and busy state ($X_i=1$), respectively. If the

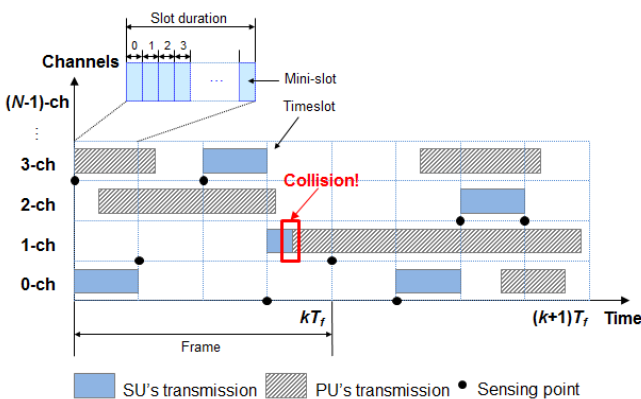


Figure 4. The slot structure

channel status is idle, the SU try to transmit a data, otherwise, the SU counteracts according to our proposed scheme. As shown in Figure 4, the collision with PU can occur since it use different spectrum access protocol from SUs which use random access protocol in slotted transmission structure.

B. OIS-MA: Orthogonal IS-MA

Initially, in the formation of the CR network, the first SU that joins the network divides one or more timeslot into N mini-slot intervals corresponding to N channels. It sends a beacon message in each channel during the channel's corresponding mini-slot. The other joining SUs randomly choose a channel and listen to the channel until they receive the beacon message and synchronize with the first SU. If a SU cannot sense the beacon message within N mini-slots, it is supposed to be the first SU and will send the beacon message. After synchronization, each SU is required to choose a channel to form a fixed sensing pair and exchange this pair information with other SUs. The reason why we designate such sensing pairs is that a SU can specially sense and record the PU activity in the channel. After network initialization, all SUs get synchronized and will perform the periodic sensing and transmission defined by our proposed scheme.

Figure 5 shows the algorithm of OIS-MA simulated during time T and k indicates the current index of timeslot.

Algorithm – OIS-MA

-
- T – The total simulation time
 k – The current index of timeslot
- 1: Get an initial j -th SU's channel index C_j from (1).
 - 2:
 - 3: **while** ($k \leq \lceil T/T_s \rceil$) {
 - 4: Get a sensing result of i -th channel, i.e., X_i .
 - 5: **if** ($X_i \equiv 0$) {
 - 6: Transmit a data probabilistically in i -th channel.
 - 7: } **end if**
 - 8: Update the j -th SU's channel index C_j from (1).
 - 9: $k = k + 1$;
 - 10: } **end while**
 - 11:
 - 12: Get the simulation result.
-

Figure 5. The algorithm of OIS-MA

The channel number C_j to sense the channel status in CR network is determined by (1).

$$C_j = \begin{cases} I_j & \text{If (SU- } j \text{ starts sensing initially)} \\ C_j & \text{Else if } (X_i \equiv 0) \\ C_j + 1 & \text{Else if } (X_i \equiv 1) \\ 0 & \text{Else if } ((C_j \bmod N) \equiv 0) \\ I_j & \text{Else if } ((T \bmod T_f) \equiv 0) \end{cases} \quad (1)$$

When j -th SU enjoys the CR network initially, the channel number I_j is allocated. If the current sensing channel

number i equals C_j , X_i means the channel status of j -th SU. Each SU obtains X_i every timeslot, and if $X_i \equiv 0$, it maintain C_j as before, otherwise it increments C_j by one. After the first busy sensing result from the last channel, the SU goes back to the first channel again. Final option is that SU goes back to I_j every frame length T_f during simulation time T .

j -th SU with C_j by (1) moves to corresponding channel and senses the channel status. As you can see from (1), the pattern of channel change for spectrum sensing is similar to IS-MA. However, there is a difference between IS-MA and our proposed scheme. That is when T_f elapses, corresponding SU goes back to I_j and restarts the spectrum sensing. This is the effort for trying to reduce the collision with SUs.

Figure 6 depicts the how OIS-MA select the channel, performs the spectrum sensing, and transmit a data. As show in Figure 6, there are four channels and two SUs (SU-1 and SU-2), and OIS-MA is operated in CR networks. SU-1 and SU-2 with I_j start to sense the channel status, and at the third timeslot they confront a situation that they see each other in the same channel, which means that both SUs can collide with each other. In order to reduce such a situation, each SU goes back to I_j every T_f and restarts to sense the corresponding channel. By doing this, each SU can reduce collisions and attempts to sense the channel, and then we can expect to reduce the end-to-end delay as well.

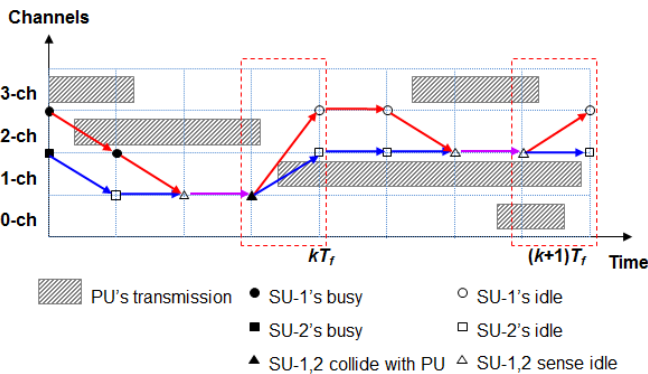


Figure 6. The illustration of OIS-MA

IV. PERFORMANCE EVALUATION

A. Simulation Environments

The simulation parameters for experiment environment are shown in Table 1. OPNET simulator was used as a simulation tool for performance evaluation of our proposed scheme. Every simulation takes 1-hour each and each scenario was simulated ten times to support reliable measurement. To construct the CRAHN, the number of licensed channels was fixed to five with 1 Mbps, and each channel has the one PU's activity. The number of SUs in this network was one, five, and ten to consider MCSU and MCMU cases. When the number of channels is five, MCSU with one SU is for $K < N$, MCMU with five SUs is for $K = N$, and MCMU with ten SUs is for

$K > N$. For the slotted transmission structure, we need to consider the length of timeslot. In this case, the data slot length was 2.5 msec. each SU generated the traffic with exponential distribution in range from 0.01 to 0.08 second, and the packet size was constant 1250 bytes. OIS-MA was compared with OPS-MA varying these simulation parameters.

TABLE 1. SIMULATION PARAMETERS

Simulation time	3,600 sec
The number of CHs	5
The number of SUs	1, 5, 10
Data rate	1 Mbps
Data slot length	0.0025 sec
Packet arrival rate	Exponential {0.01, 0.02, 0.04, 0.08} sec
Packet length	Constant 10,000 bits
Scheme	OIS-MA, OPS-MA

B. Simulation Results

Figure 7 shows the simulation results for varying the number of SUs and PU's occupancy in the same channel.

Figure 7(a) shows the throughput for $K = 1$ varying PU's occupancy. Prior to simulation for MCMU cases, the reason why this simulation has done first was to identify the safety of our proposed scheme changed by IS-MA which is operated in MCSU case. As with IS-MA, OIS-MA showed better performance than OPS-MA and in some case, OIS-MA preceded OPS-MA more than double.

Figure 7(b) shows the throughput for $K = 5$ varying PU's occupancy. In this case, OPS-MA performed well opposite to OIS-MA because OPS-MA is based on PS-MA with round-robin manner in $K = N$ case which means that each SU occupies different channel so that they could achieve the maximum throughput. However, due to the nature of channel changing pattern of each SU with OIS-MA, it could collide with each other and the throughput is decreased.

Figure 7(c) shows the throughput for $K = 10$ varying PU's occupancy. When $\lambda = 0.01$, both OIS-MA and OPS-MA showed the performance close to zero. This is because SUs generated packets more than SU's transmission capability and collisions are increased drastically. When $\lambda = 0.02$, we could see the throughput is increased gradually, and OIS-MA outperformed OPS-MA.

Let's examine the interrelationship between PU's occupancy and packet arrival rate. As shown in Figure 7(d)-(f), when $\lambda = 0.08$, because the packets generated by each SU are relatively small, OPS-MA showed better performance than OIS-MA, but when $\lambda = 0.04$ and PU's occupancy is 60%, OIS-MA intersected and surpassed OPS-MA. When $\lambda = 0.02$, OIS-MA also had good performance continuously. Notable here is we can identify that the packet arrival rate and PU's occupancy were interrelated.

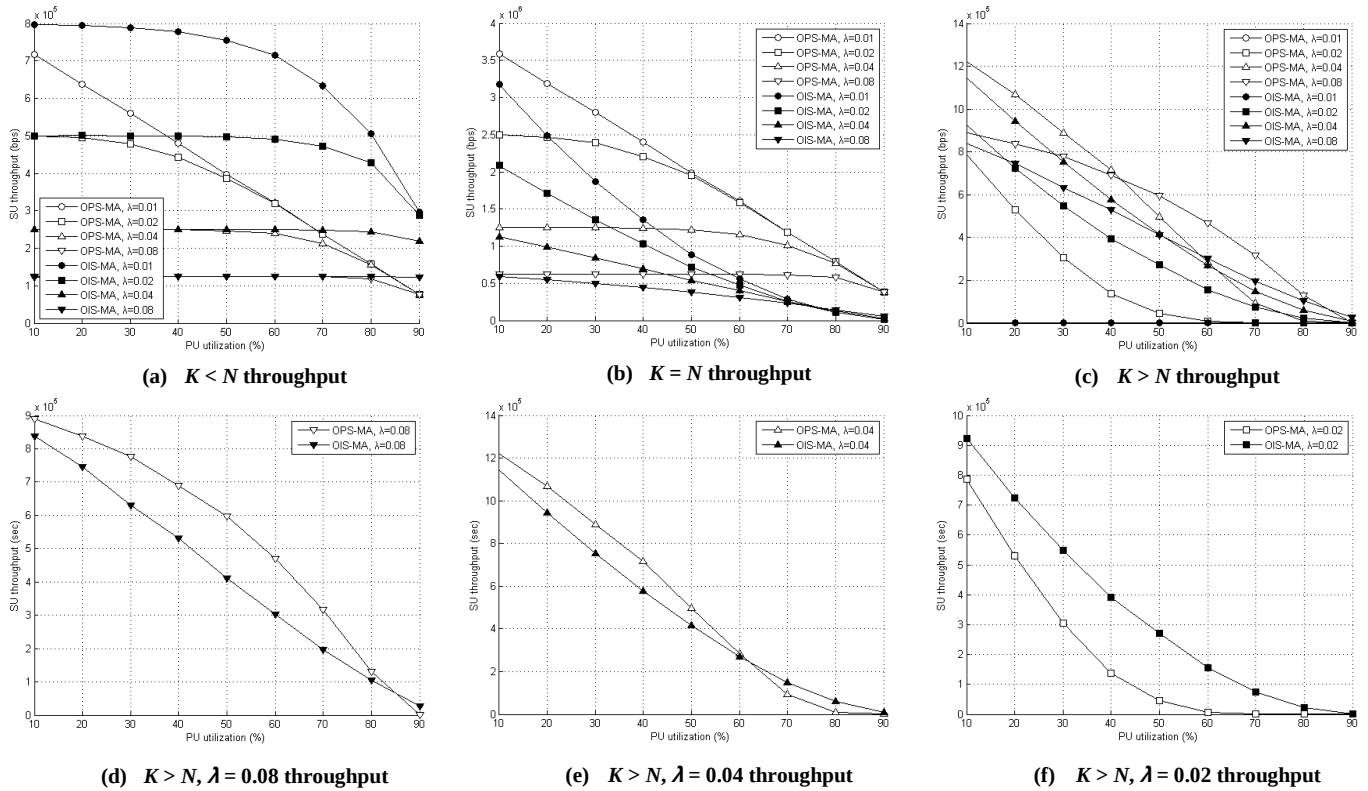


Figure 7. Throughput varying the number of SUs in the same channel environment

V. CONCLUSIONS

In this paper, we proposed the efficient spectrum selection, called OIS-MA considering hardware constraints. As a simulation results, since OIS-MA is based on IS-MA, it was superior to OPS-MA based on PS-MA in terms of throughput. Especially, the more the number of SUs and the packet arrival rate, the better performance OIS-MA had. Possible issues of future study in this area could be the collision resolution protocols and retransmission techniques.

ACKNOWLEDGMENT

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency" (NIPA-2012-(H0301-12-2003)), and also supported by the network protocol technology research for the next TMMR through the LIG Nex1 corporation (Y11-026).

REFERENCES

- [1] I. F. Akyildiz, W. Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *ELSEVIER Computer Networks*, vol. 50, pp. 2127-2159, May 2006.
- [2] I. F. Akyildiz, W. Y. Lee, and K. R. Chowdhury, "CRAHNS: Cognitive radio ad hoc networks," *ELSEVIER Ad Hoc Networks*, vol. 7, pp. 810-836, January 2009.
- [3] Q. Zhao, L. Tong, and A. Swami, "Decentralized Cognitive MAC for Dynamic Spectrum Access," *IEEE DySPAN*, pp. 224-232, November 2005.
- [4] Q. Zhao, L. Tong, A. Swami, and Y. Chen, "Decentralized Cognitive MAC for Opportunistic Spectrum Access in Ad Hoc Networks: A POMDP Framework," *IEEE JSAC*, vol. 25, no. 3, pp. 589-600, April 2007.
- [5] Q. Zhao, S. Geirhofer, L. Tong, and B. M. Sadler, "Opportunistic Spectrum Access via Periodic Channel Sensing," *IEEE TSP*, pp. 785-796, February 2008.
- [6] Q. Zhao, B. Krishnamachari, and K. Liu, "On Myopic Sensing for Multi-channel Opportunistic Access: Structure, Optimality, and Performance," *IEEE T-WC*, pp. 5431-5440, December 2008.
- [7] X. Li, Q. Zhao, X. Guan, and L. Tong, "Optimal Cognitive Access of Markovian Channels under Tight Collision Constraints," *IEEE JSAC*, pp. 746-756, April 2011.
- [8] J. Jia, Q. Zhang, and X. Shen, "HC-MAC: A Hardware-Constrained Cognitive MAC for Efficient Spectrum Management," *IEEE JSAC*, vol. 26, no. 1, January 2008.
- [9] L. F. Huang, S. L. Zhou, D. Guo, and H. C. Chao, "MHC-MAC: Cognitive MAC with asynchronous-assembly line mode for improving utilization and network capacity," *ELSEVIER Mathematical and Computer Modelling*, November 2011.