ISBN 978-981-11-0008-6
Proceedings of 2016 6th International Workshop on Computer Science and Engineering (WCSE 2016)
Tokyo, Japan, 17-19 June, 2016, pp. 719-723
doi: 10.18178/wcse.2016.06.128

Energy-Efficient Sensing and Transmission for Real-Time Traffic in Cognitive Radio Networks

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Abstract. Cognitive radio networks significantly increase the utilization of radio spectrum. Most previous literatures related cognitive networks attempt to increase the throughput in cognitive networks. However, energy efficiency is a major consideration for battery-powered devices or green wireless networks. It is critical for cognitive users to opportunistically use idle spectrum to send real-time data such that energy reduction and quality-of-service provision of real-time data transmission are available at the same time. In this paper, we propose cross-layer sensing and transmission with energy efficiency schemes for real-time traffic in cognitive radio networks. In the proposed schemes, we use the information of packets in a queue to save energy. Extensive simulation results show that the proposed schemes appropriately use the queueing information to reduce energy consumption while provide different levels of quality-of-service of real-time packets (in terms of packet loss ratio).

Keywords: cognitive networks, real-time traffic, sensing and transmission, energy efficiency.

1. Introduction

Cognitive radio networks aim to alleviate the under-utilized radio spectrum in most wireless systems [1]-[2]. The concept of cognitive radio has been applied and studied in various wireless networks [3]-[5]. The main idea of cognitive radio is to provide an opportunity for mobile users (called cognitive users herein) to use the idle spectrum of licensed spectrum band to send a message. Energy efficiency is an important consideration for battery-powered devices or green cellular networks. A number of papers study the energy efficiency of sensing and transmission in cognitive networks [6]-[9]. In [6], authors consider the energy efficiency as a constraint in the optimization of sensing and transmission problems. In [7], an optimal sensing strategy is designed to maximize an expected reward which is increased with the increasing of throughput and is decreased with the increasing of sensing and transmission energy. In [8], a utility function, which includes sensing parameters and power allocation, is designed to be maximized. In [9], a concept of the number of data bits transmitted per unit of energy consumption, is defined to find an optimal sensing strategy, transmission time and power.

All of the above papers do not consider the quality-of-service of real-time traffic, such as voice and multimedia, and energy efficiency simultaneously. However, it is critical for cognitive users to opportunistically use idle spectrum to send real-time data such that energy reduction and quality-of-service provision of data transmission are available at the same time. In this paper, we propose an energy-efficient sensing and transmission scheme for real-time traffic in cognitive radio networks. In the proposed scheme, we use the information of packets in a queue to save energy. In addition, we further utilize the information of the number of packets in a queue in order to increase the energy efficiency of sensing and transmission. We

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also propose a threshold based sensing and transmission scheme which is a generalization of the proposed sensing and transmission scheme. Extensive simulation results show that the proposed sensing and transmission schemes appropriately uses the queueing information to reduce energy consumption while provide the different levels of quality-of-service of real-time packets (in terms of packet loss ratio).

The rest of this paper is organized as follows. Section 2 describes the system model considered herein, and then proposes cross-layer sensing and transmission with energy efficiency mechanism. Subsequently, performance evaluation and numerical results are described in Section 3. Finally, some concluding remarks are presented in Section 4.

2. System Model and the Proposed Sensing and Transmission Schemes

2.1. System model

The radio environment considered in this paper is as follows. Radio spectrum is divided into spectrum bands and each radio band is further divided into time slots. Primary users (or called licensed users), who are authorized to access radio spectrum at any time, send data in time slots. We assume that merely one data packet is sent in a time slot. When a primary user sends a data packet in a time slot, we call that the slot is busy slot; otherwise, the slot is idle slot. The structure of time slots in a radio spectrum band k is shown in Fig. 1. In Fig. 1, idle slots could be utilized by cognitive users who are opportunistically access idle time slots. A cognitive user could use energy detection [10] to sense a time slot in a physical layer. Then, if the sensing result shows that the time slot is idle, the cognitive user can send data in the idle slot.

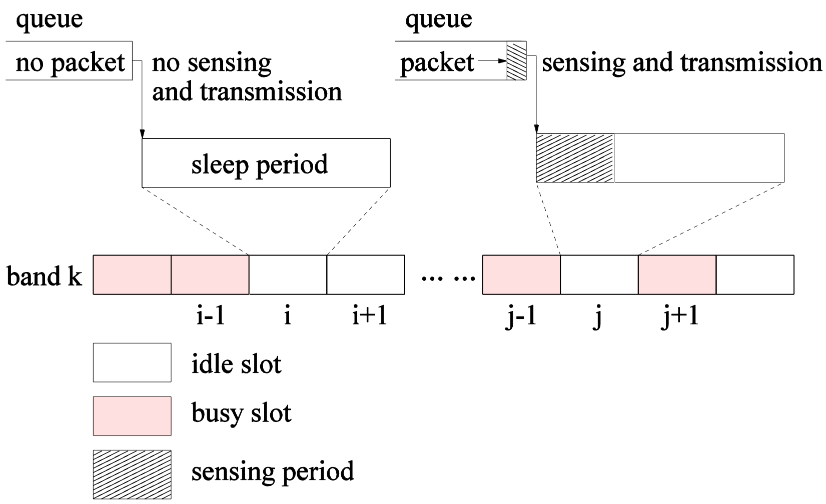

Fig. 1: System model.

2.2. The proposed sensing and transmission scheme

In the proposed sensing and transmission scheme, a cognitive user does not always sense whether a time slot is idle or not. On the contrary, a cognitive user first checks its queue in which arrival packets temporarily stay. If there is no packet in a queue, the cognitive user does not enable its sensing mechanism; then, the cognitive user enters a sleep mode to reduce energy consumption. If there is at least one packet in a queue, the cognitive user starts its sense operation at the beginning of a time slot. If the sensing result is that the time slot is idle, the cognitive user sends a data packet; otherwise, the cognitive user waits the next time slot. In summary, the proposed scheme utilizes the information of packets in a medium access control (MAC) layer to determine to enter a sleep mode or to perform a sensing mechanism in a physical layer.

2.3. Generalization of the proposed sensing and transmission scheme

We further utilize the information of packets in a queue in order to increase the energy efficiency of sensing and transmission. We propose a threshold based sensing and transmission scheme which is a generalization of the proposed scheme in Section 2.2. In the threshold-based scheme, a cognitive user first checks its queue in which arrival packets temporarily stay. If the number of packets in a queue is less than or equal to a pre-defined threshold value, the cognitive user does not enable its sensing mechanism and enters a sleep mode to reduce energy consumption. Otherwise, the cognitive user starts its sense operation at the beginning of a time slot. If the sensing result is that the time slot is idle, the cognitive user sends a data packet; otherwise, the cognitive user waits the next time slot. Figs. 2a and 2b illustrate the threshold-based scheme. Fig. 2a shows a scenario that the number of packets in a queue is greater than a pre-defined threshold. Under such a scenario (scenario I herein), if a sensing result is idle, a cognitive user sends data; if a sensing result is busy, a cognitive user enters a sleep mode. Fig. 2b shows a scenario that the number of packets in a queue is less than or equal to a pre-defined threshold. Under such a scenario (scenario II herein), a cognitive user enters to sleep mode.

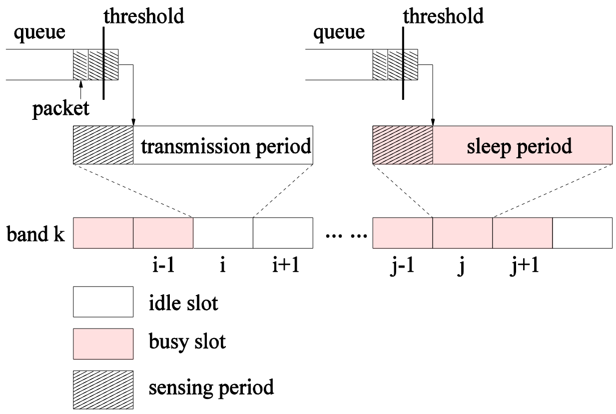

Fig. 2a: Threshold-based system model: scenario I.

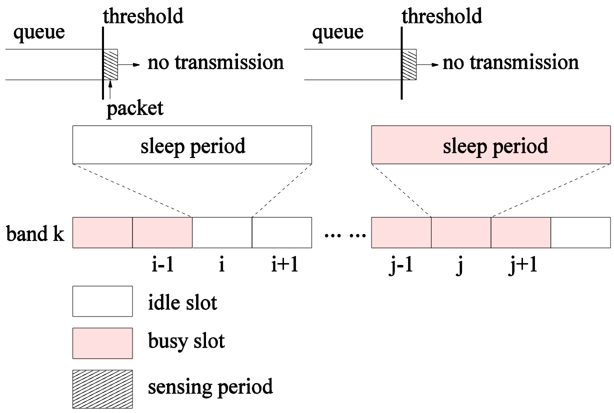

Fig. 2b: Threshold-based system model: scenario II.

3. Simulation results and discussion

Table 1 shows the system parameters used in simulation results. Two performance metrics are used in our simulation results. One is the sleep ratio, which is the percentage that cognitive devices are in a sleep mode. The other is the packet loss ratio, which is the percentage that packets are dropped.

Table 1: Simulation Parameters

Definition	Value
Idle probability of a spectrum band	0.8
Detection probability	0.90
False-alarm probability	1.6×10^{-2}
Sensing time	3.2×10^{-3} sec.
Slot time	1.5×10^{-2} sec.
Transmission rate	1 Mbps
Packet length	600 bits
Packet delay deadline	5×10^{-2} sec.

3.1. Performance of the proposed sensing and transmission scheme

Fig. 3 shows the sleep ratio of the systems with and without the proposed sensing and transmission scheme. From the figure, we can observe two phenomena. First, the system with the proposed scheme produces higher sleep ratio (about 3%-47%) than that without the proposed scheme, especially in the light and middle traffic load, because the proposed scheme enables the sensing mechanism only when at least one packet is in a queue. Second, with the increasing load, the sleep ratio of the proposed scheme is decreasing because the probability of at least one packet in a queue is increasing in a queue.

Fig. 4 shows the packet loss ratio of the systems with and without the proposed sensing and transmission scheme. From the figure, we can observe two phenomena. First, when the load is less than or equal to 0.8, the packet loss ratios of the system with and without the proposed scheme are kept below 2% which is acceptable in the transmission of real-time packets. Second, the system with the proposed scheme produces slightly higher packet loss ratio (about 0.2%-0.5%) than that without the proposed scheme. This is because cognitive users in the proposed scheme enter a sleep mode which will delay packet transmission and then delayed packets may be dropped.

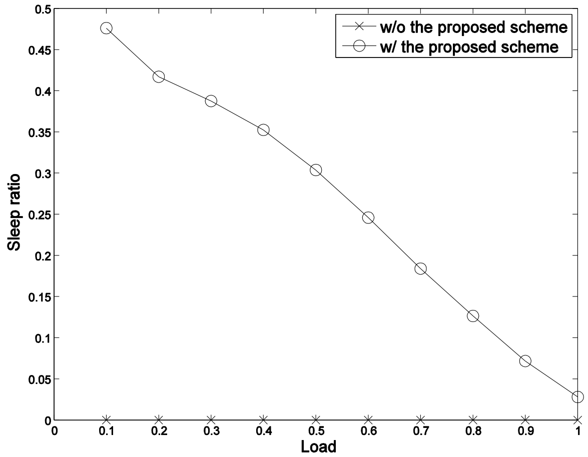

Fig. 3: Sleep ratio.

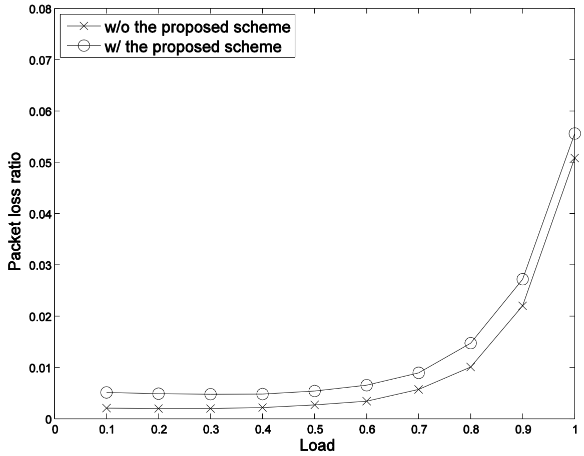

Fig. 4: Packet loss ratio.

3.2. Performances of the threshold based system

Fig. 5 shows the sleep ratio of the threshold based system at different thresholds. From the figure, we can observe two phenomena. First, when traffic load is light or middle, the sleep ratio is increasing with the increasing of the threshold value. The reason is as follows. A cognitive user does not enable sensing operation when the number of packets in a queue is less than or equal to a pre-defined threshold value. Larger threshold value implies that a cognitive user has higher opportunity to stay in a sleep mode, which produces higher sleep ratio. Second, when traffic load is heavy, the systems with different thresholds produce similar low sleep ratio. The reason is as follows. Heavy traffic load implies that the number of packets in a queue is usually greater than the thresholds in the figure, which means that a cognitive user would perform sensing operation in most situations instead of entering a sleep mode.

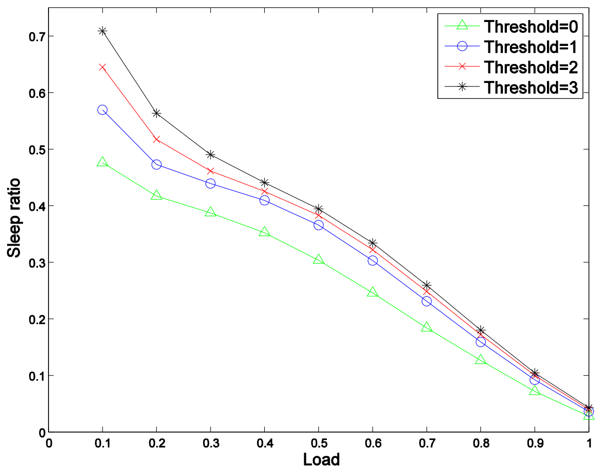

Fig. 5: Sleep ratio at different thresholds.

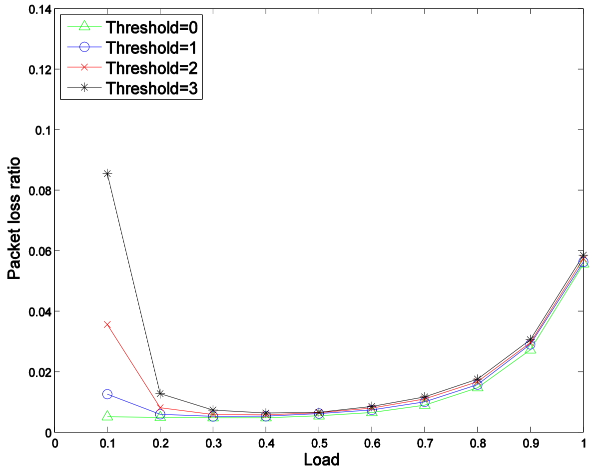

Fig. 6: Packet loss ratio at different thresholds.

Fig. 6 shows the packet loss ratio of the threshold based system at different thresholds. From the figure, we can observe four phenomena. First, when traffic load is less than 0.3, the system with higher threshold value yields higher packet loss ratio. The reason is as follows. When traffic load is light, the system with larger threshold has higher opportunity to enter a sleep mode because the number of packets in a queue is less than or equal to the threshold. Once a cognitive user enters a sleep mode, the packets in a queue would be delayed to be sent. If the delay time exceeds packet delay deadline, the packet will be dropped. Second, when load is less than 0.3, the packet loss ratios in the systems with non-zero threshold value are decreasing with the increasing traffic load. This is because when traffic load is light, a cognitive user may often stay in a sleep mode due to low number of packets in a queue, which leads to that packets are delayed and dropped. With the increasing load, the number of packets in a queue is also increasing, which implies that a cognitive user has lower opportunity to enter a sleep mode due to low number of packets, which leads to that fewer packets are delayed and dropped. Third, when load is greater than 0.4, the systems with different thresholds produce similar packet loss ratio. This is because when traffic load is middle or high, the number of packets in a queue is usually greater than the thresholds. The effect of the different thresholds is small in heavy load which is relative to that in light load. Thus, the systems with different thresholds yield similar packet loss ratio in heavy load. Fourth, when load is greater than 0.4, the packet loss ratio is increasing with the increasing load. This is because more traffic load means more packets are required to be sent, which usually prolongs the waiting time of packets in a queue. Thus, packets have higher probability to be dropped because the waiting time exceeds the packet delay deadline.

4. Conclusions

We first propose an energy-efficient sensing and transmission scheme for real-time traffic in cognitive radio networks. In the proposed scheme, we use the information of packets in a queue to determine whether or not to enter into a sleep mode in order to save energy. Furthermore, we extend the proposed scheme to a threshold based sensing and transmission scheme. Extensive simulation results show that the proposed sensing and transmission schemes appropriately use the queueing information such that cognitive users enter a sleep mode and reduce energy consumption while different levels of quality-of-service of real-time packets are provided.

5. Acknowledgements

This research was supported by the Ministry of Science and Technology, Taiwan, under grant MOST 103-2221-E-017-004-and MOST 104-2221-E-017-003-.

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