Challenges in Cognitive Radio Sensor Networks

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Abstract

Current spectrum resources are lack due to inflexible spectrum sharing regulations and underutilization of licensed band for primary users (PUs). Cognitive radio (CR) technology is proposed to address this problem. CR technology enables secondary users (SUs) access temporally unused licensed spectrum in opportunistic manner. Benefit from high spectrum efficiency, CR technology has been widely utilized in various wireless networks. There are many protocols proposed to improve cognitive radio wireless networks performance. However, these works do not consider the requirements of CRSNs, therefore can not apply in CRSNs directly. In this paper, we analyze the features of the existing protocols and discuss the requirement of CRSNs jointly to summarize the challenges must be addressed.

Key words: Cognitive radio sensor network, channel assignment, routing.

1. Introduction

With the development of technology, more and more wireless devices appeared in our life. These devices need large amounts of radio resources. However, the current radio resource is lack due to exclusive spectrum sharing regulations. Large portion of spectrum is the licensed spectrum which occupied by primary users (PUs) exclusively and unlicensed users (SUs) can't utilize it. Moreover, current utilization of the most licensed spectrum is not efficient. It wastes a lot of spectrum resource. Hence the cognitive radio technology is proposed to solve this problem.

Cognitive radio technology enables SUs and PUs coexistence. It can change the parameters depend on interaction with the environment to improve spectrum efficiency. Cognitive radio enables unlicensed users opportunistic access to the licensed bands when the licensed users (PUs) don't use it. However, primary users have higher priority in spectrum access which means secondary users (SUs) must vacate the licensed channel when primary users come back.

Application of the cognitive radio technology in wireless sensor networks (WSNs) can explore new network architecture possibilities and provide human beings better service. In cognitive radio sensor networks (CRSNs), sensor nodes can intelligently use the "spectrum hole" or "white space" to improve spectrum efficiency. However, there are still many challenges in CRSNs. Unlike traditional wireless sensor networks, CRSNs must consider the existence of primary users. Therefore, the existing media access and routing protocols can not guarantee the energy efficiency in CRSNs. In this paper, we compare the various communication protocols for cognitive radio networks and CRSNs. We analyze the features of the existing protocols and discuss whether these protocols can be applied in CRSNs. With the analysis results, we summarize the challenges must be addressed.

In CRSNs, first, due to the PUs' interference, the available channels are variable at any moment. Therefore, how to exactly detect PUs' activity is important for guaranteeing energy efficiency. Second, exposed and hidden node problems may occur if there are large amount of sensor nodes in CRSNs. These problems have to be taken into consideration to avoid collision and transmission delay which may result in additional energy consumption. Third, because assignment of sensing time and transmission time can affect network performance significantly, how to assign them optimally must be addressed. Fourth, since channel assignment and routing are interdependent and interaction, so how to make a cross layer design in energy fairness and energy efficient way are also the challenges we must face. Last, the energy efficiency is the key point. How to cooperate sensor nodes work in energy fairness way is the most important issue to prolong the network lifetime.

The rest of the paper is organized as follows. We discuss CRNs in Section 2. We specifically discuss various protocols in CR based multi-hop wireless network in Section 3. We analyze the challenges in CRSNs in Section 4. Finally Section 5 concludes this paper.

2. Cognitive radio networks

Cognitive radio (CR) is an intelligent technology. CR enables SUs opportunistic access to licensed channels which PUs are not occupying. The key technologies of CR are the technologies which can provide this kind of capacity by cognitive radio to let

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SUs get and share the licensed channels with PUs. Due to this reason, CR has been widely utilized in various kinds of wireless networks to enhance spectrum efficiency. Some protocols can also be utilized in CRSNs. In the following, we discuss the existing communication protocols in CRNs.

Channel assignment: Due to a lot of uncertainties, available licensed channels are changeable at any moment. So how to detect the PUs' activity and how to assign available channels to improve the networks performance are very important. Shengliang Peng *et al.* [1] offer a relay based cooperative spectrum sensing method. In their work, a SU with higher signal-to-noise ratio takes a part of sensing time as a relay to help other SUs enhance the accuracy of spectrum sensing. In this paper, relay technology is utilized to improve the accuracy of PU activity detection. In [2], Ramzi Saifan *et al.* find other available channels which are not aware to enhance the network performance and increase the probability of finding a path from source to destination. This paper considers the expected gain and cost of changing channels to determine whether to change the channels or not. The proposed framework can enhance the routing performance in a certain extent. Consequently, in order to solve the same problems in CRSNs, channel assignment and routing schemes must also be cooperative.

Routing: Relay technology not only can help cooperative spectrum sensing, it is also frequently utilized to address the cooperative communications and achieve cooperating diversity. In [3], Ammar Zafar *et al.* consider a relay assisted cognitive radio network with opportunistic access to licensed band. They propose two optimal resource allocation schemes to improve the throughput and symbol correct rate. The paper shows that there must be optimal values of the sensing time and power to maximize throughput and symbol correct rate. While in [4], authors focus on average transmit power constraint of SUs and average interference power constraint of PUs. They prove that significant improvement in average throughput and minimum of the outage probability of secondary transmission can be achieved with the joint optimization of sensing and power allocation. If we consider assignment of sensing time and power allocation in CRSNs, the network performance must be improved.

3. Cognitive radio based multi-hop networks

In this section, we introduce the CR based multi-hop wireless networks. We aim to explain why some conditions in cognitive radio based wireless mesh networks can not satisfy the requirements of CRSNs in terms of channel assignment and routing.

3.1 Cognitive radio based wireless mesh networks

Channel assignment: The joint channel assignment and routing update (JCAR-update) scheme was proposed in [5]. This paper prefers more stable channels which are not frequently used by PUs. In order to decrease the number of channel assignment updates, the simple recovery algorithm and re-optimization are performed to reduce the signal overhead. This kind of cross layer protocol which combines channel assignment and routing scheme can provide better performance in CRSNs. Moreover, in CRSNs, limited energy resource must be considered as the first issue when we design feasible protocol, while in wireless mesh network, energy is not a restriction in protocol design.

Routing: The work in [6] considers channel heterogeneity and switching latency, and an on-demand multicast routing and channel allocation algorithm is proposed to reduce the end-to-end delay and the degradation of throughput. This paper focuses on end-to-end delay without considering energy efficiency. Hence this on-demand proposed protocol can't be directly utilized in CRSNs.

In [7], S. Parvin *et al.* aim to provide a stable routing scheme for multi-hop CRN. They characterize the PUs' behavior as an on-off process and based on that they propose a novel routing metric which considers delay and PUs' activity jointly. Furthermore, a channel priority list which is locally maintained by each SU is designed to address exposed and hidden node problems. Not only in wireless mesh network, in CRSNs, packet collisions and transmission delay will also occur if exposed and hidden node problems are not taken into our consideration.

3.2 Cognitive radio sensor networks

There are limited works on CRSNs. In CRSNs, the main responsibility of the sensor nodes is to observe the environment and obtain information we want. Sensor nodes with CR technology can improve spectrum efficiency effectively. However, many issues need to be addressed in CRSNs.

Channel assignment: Mehdi Askari *et al*. [8] propose a channel assignment algorithm for cognitive radio wireless sensor networks. The algorithm is based on ordered channel assignment scheme to avoid collisions between PUs and SUs or collisions among SUs. Benefit from reducing the collision possibility, this algorithm can reduce power consumption efficiently. In [9], the authors assume a hierarchical network structure. The channels are managed by cluster head which has rich energy and powerful cognitive radio capability. The cluster head allocates the cognitive channels in energy fairness way to prolong the network life time. According to remaining energy of a sensor node, an optimized channel allocation is performed to guarantee the channel allocation fairness. However, in [8] and [9], routing is not taken into consideration. Usually channel assignment and routing should be jointly considered because they are interdependent and interaction. The cross layer design which combines the channel assignment and routing should be

considered in CRSNs.

Routing: The work in [10] proposes a Q-learning based multi-relay cooperative mechanism to guarantee QoS requirements during data transmission. Relay nodes are selected by Q-learning algorithm. More specifically considering energy consumption, the distance between nodes and SNR, the node with the largest reward value can be taken as a relay node.

There are limited works proposed for CRSNs. Furthermore most of them focus on observation and adaptation and less on the reasoning and learning [11]. Recently more and more researchers focus on the machine learning and game theory to solve the problems in CRNs.

4. The challenges of CRSNs

CRSN faces many challenges in practice due to lots of uncertainties, such as the appearance of PUs, available channels and variable wireless environment.

- **PUs' activity detection**: Due to false alarm and miss detection, the probability that can't detect the existence of PUs will also exist. It is not only conducive to avoid PUs' interference, but also helpful to enhance the network throughput and decrease propagation delay if we exactly know the PUs activity. Hence it is a key point that how to correctly detect PUs' behavior and how to make reaction immediately when PUs come back.
- **Exposed and hidden node problems:** Collision and transmission delay will happen due to exposed and hidden node problems, respectively. Especially when large amounts of data need to be sent among large amounts of sensor nodes in CRSNs, these problems will become more serious. Consequently, these problems have to be taken into consideration.
- **Assignment of sensing time and transmission time:** In CRSNs a time period slot contains the sensing time and transmission time. If increasing the sensing time, accuracy of sensing PUs will be improved, but throughput of CRSNs will be decreased. In contrast, if decreasing the sensing time, the more transmission time will increase the throughput as increasing false alarm and miss detection simultaneously. So how to assign the sensing time and transmission time is also a challenge.
- **Cross layer design:** Channel assignment and routing are interdependent and interaction. So how to jointly cooperate sensor nodes to sense spectrum and select route, how to make a cross layer design in energy fairness and energy efficient way are also the challenges we must face.
- **Energy efficiency:** We must consider energy efficiency first when we design a CRSNs protocol, since it is hard or even impossible to charge the sensor nodes in CRSNs. Network can be considered dead if a certain amount of sensor nodes exhaust energy.

5. Conclusion and future work

In this paper, we give a brief introduction of CR technology and analyze the existing protocols which are based on CR technology in terms of channel assignment and routing. We compare the CRNs and CR based wireless mesh network with CRSNs, respectively. At last we summarize the challenges of CRSNs. We provide a better understanding of CRSNs. Nowadays more and more works focus on machine learning and reasoning. In future, we are aiming to apply machine learning and game theory to solve the summarized challenges in CRSNs.

References

[1] Shengliang Peng, Shuli Shu, Xi Yang, and Xiuying Cao, "Relay based Cooperative Spectrum Sensing in Distributed Cognitive Radio Networks," in *Proc. Wireless Communications and Networking Conference, IEEE*, pp. 1370-1374, April 2012.

[2] Ramzi Saifan, Ahmed E. Kamal, and Yong Guan, "Spectrum Decision for Efficient Routing in Cognitive Radio Network," in *Proc. 2012 Mobile Adhoc and Sensor Systems*, pp.371-379, Oct. 2012.

[3] Ammar Zafar, Yunfei Chen, Mohamed-Slim Alouini, and Redha M.Radaydeh, "Resource Allocation for Relay Assisted Cognitive Radio Networks," in *Proc. Wireless Communications and Networking Conference, 2012 IEEE*, pp. 658- 662, April 2012.

[4] Huogen Yu, Wanbin Tang and Shaoqian Li, "Joint Optimal Sensing and Power Allocation for Cooperative Relay in Cognitive Radio Networks," in *Proc. 2012 IEEE International Conference,* pp. 1635-1640, June 2012.

[5] Dong Heon Lee and Wha Sook Jeon, "Channel Assignment and Routing with Overhead Reduction for Cognitive Radio-Based Wireless Mesh Network," in *Proc. Wireless Communications and Signal Processing, 2011 International Conference*, pp. 1-5, Nov. 2011.

[6] Hisham M. Almasaeid, Tasneem H. Jawadwala, and Ahmed E. Kamal, "On-Demand Multicast Routing in Cognitive Radio Mesh Networks," in *Proc. Global Telecommunications Conference, 2010 IEEE*, pp. 1-5, Dec. 2010.

[7] Shamsad Parvin and Takeo Fujii, "Radio Environment Aware Stable Routing for Multi-hop Cognitive Radio Networks," in *Proc. Personal Indoor and Mobile Radio Communications, 2012 IEEE 23rd International Symposium on*, pp. 944-949, Sept. 2012.

[8] Mehdi Askari, Yousef S. Kavian, Hooman Kaabi, and Habib F. Rashvand, "A Channel Assignment Algorithm for Cognitive Radio Wireless Sensor Networks," in *Proc. Wireless Sensor Systems, IET Conference on*, pp. 1-4, June 2012.

[9] Xiaoyuan Li, Dexiang Wang, Janise McNair, and Jianmin Chen, "Residual Energy Aware Channel Assignment in Cognitive Radio Sensor Networks," in *Proc. Wireless Communications and Networking Conference, 2011 IEEE*, pp. 398-403, March 2011.

[10] Jun Peng, Junbo Li, Shuo Li, and Jing Li, "Multi-relay Cooperative Mechanism with Q-Learning in Cognitive Radio Multimedia Sensor Networks," in *Proc. Trust, Security and Privacy in Computing and Communications, 2011 IEEE 10th International Conference*, pp. 1624-1629, Nov. 2011.

[11] Liljana Gavrilovska, Vladimir Atanasovski, Irene Macaluso, and Luiz A.DaSilva, "Learning and Reasoning in Cognitive Radio Networks," *Communications Surveys & Tutorials*, vol.15, no.4, pp. 1761-1777, 2013.