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A Stackelberg game spectrum sharing scheme in cognitive radio-based heterogeneous wireless sensor networks

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ABSTRACT

In this paper, we focus on spectrum sharing in heterogeneous wireless sensor networks (HWSNs) and consider Stackelberg game exploiting the cognitive radio (CR) technology to utilize those scarce resources. In the game, the licensed network controls and prices the available spectrum resource which the WSN relay: actor nodes can purchase and use to serve the attached sensor nodes as well as offload some nodes in licensed network. Both kinds of nodes try to maximize their own utility which is consisted of data rates, earning and expenditures on spectrum trading. During the dynamic interaction of the game, the interference coordination features of the heterogeneous sensor network and CR technology are employed so that the change of spectrum allocation can be fully exploited. According to simulation result, we evaluate the impact on throughput performance after implementing proposed game strategy in HWSN. And we prove that the proposed approach can significantly improve the throughput of victim licensed nodes with slightly decreasing network total throughput.

1. Introduction

Wireless sensor network (WSN) is one of the most compelling technologies for performing monitoring and surveillance tasks. It is a self-organizing ad hoc network comprised of a large number of sensor nodes that are systematically or randomly deployed [1]. The development of Wireless Sensor Network was first motivated by military applications such as battlefield surveillance; today, with the development of internet of things (IoT), the WSN technology have been widely used in many industrial and consumer applications, such as industrial process monitoring and control, and machine health monitoring.

Although the many outstanding researches on WSNs have been done, there are still little considerations on a communication scheme among sensor nodes. Generally, a wide range of WSN applications utilize the unlicensed spectrum bands such as industrial, scientific and medical (ISM) and unlicensed national information infrastructure (UNII). As shown in Table 1, the precious and limited unlicensed radio spectrum are shared by many wireless applications. However, these unlicensed bands are getting more crowded as the number of wireless mobile communication devices between end-users dramatically increases due to growth of the smart phone or mobile internet devices, etc. In [2], the research shows that the interference from the IEEE 802.11 network increases the interruption and retransmission rate of Zigbee 802.15.4 network and also decreases its lifetime. Therefore, the interference and coexistence issues of wireless systems restrict the development of Wireless Sensor Network.

As a way to escape from getting crowded spectrum, the dynamic spectrum access (DSA) technique, i.e., cognitive radio (CR) system can be adopted to improve the efficiency of WSN communications [4]. Aided by CR technology,

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Table 1
Operating spectrum bands of commercial WSN transceivers and overlapping wireless systems [3].

Sensor node platforms	Radio chip	Operating bands	Overlapping wireless systems
Bean, BTnode, Mica2	Chipcon (TI Norway) CC1000	315, 433, 868, 915 MHz	Fixed, mobile, amateur, satellite, radiolocation, broadcasting, telemetry, ZigBee
IMote, MicaZ, SenseNode, XYZ	Chipcon (TI Norway) CC2420	2.4 GHz	Fixed, mobile, amateur radio as secondary, 802.11b/g/n, telemetry, Bluetooth, ZigBee
Mica, weC	RF Monolithics TR1000	916.3916.7 MHz	Fixed, mobile, broadcasting, telemetry, ZigBee
ANT	Nordic nRF24AP1	2.4 GHz	Fixed, mobile, amateur radio as secondary, telemetry, 802.11b/g/n, Bluetooth, ZigBee
Iris	Atmel AT86RF230	2.4 GHz	Fixed, mobile, amateur radio as secondary, telemetry, 802.11b/g/n, Bluetooth, ZigBee

cognitive radio sensor network (CRSN) is recognized as a promising architecture whose spectrum efficiency and self-adaptive ability is further improved than traditional wireless sensor network (WSN), although the explicit algorithm is an open issue and attracts lots of academic study. In this paper, we will propose a Game Theory based spectrum sharing algorithm exploiting CR technology for WSN. By dynamically changing the strategies in bandwidth selling and purchasing as well as user offloading, the equilibrium of the game can be achieved and both licensed network and HWSN can profit.

In CRSN, dynamic spectrum sharing is a challenging problem due to the requirement of peaceful coexistence of both licensed and unlicensed users as well as the wide range of available radio spectrum. In the context of cognitive technology, tools such as artificial learning algorithms provide a viable approach, especially the unsupervised learning algorithms such as Games Theory ([5,6] etc.).

In this paper, the system we shall considered consists of one licensed network and a number of Heterogeneous CRSN relays: actor nodes. Each actor node have the ability of spectrum sensing, it can catch the changes of the licensed user spectrum environment and adjust its working frequency to a free licensed band and serve its own network.

In previous works, static games, such as Bertrand game, are employed to address the spectrum sharing issue in CR networks [7]. These games often assume that the players act simultaneously according to some complex strategies for optimizing the setting of various resources of the network. However, with respect to CRSN, cognitive base station can communicate with CRSN actor nodes and thus the topology matches a hierarchical game with the licensed network being leader and the CRSN actor nodes being the followers. With this understanding, the dynamic game is introduced to address this kind of problem ([8,9] etc.), but there are only a few attempts to optimize the spectrum sharing between licensed network and CRSN.

For the above scenarios, we formulated a Stackelberg game where licensed network is the leader followed by a number of non-cooperative CRSN actor nodes. In our game, the licensed user impose a price on the shared frequency band and the CRSN nodes have to buy the band to serve their own networks. The more bandwidth the node demands, the higher expenditure node has to pay. Meanwhile, the base station sets up the initial spectrum hole ratio and the actor nodes can make bandwidth purchasing decision based on it, and decide the number of licensed nodes to offload, and then the licensed network performs a backward induction and so on. As the dynamic game continues, equilibrium can be achieved with the optimal parameters.The introduction of the Stackelberg game enables the licensed network and actor nodes act dynamically and intelligently to handle the frequency allocation issue, and makes the underlying HWSN work in a self-organized fashion.

Our work introduces WSN relay: actor node in system model, which becomes a follower of base station in licensed network. We consider a Heterogeneous and Hierarchical CRSN architecture, to make the overall licensed network throughput achieve its maximal, the spectrum sharing mechanism between licensed network and CRSN need to be optimized. This mechanism of encouragement is formulated by the Stackelberg game, where the base station, the radio resource controller of a licensed network, will take the lead and the actor node will follow with correspondent strategies. The Stackelberg game based spectrum sharing strategy can help the system achieve better leader–follower excitation and significantly improve the throughput of victim nodes.

The rest of this paper is organized as follows. Two important concept of Cognitive radio techniques are briefly introduced in Section 2 and the system model is described in Section 3. The spectrum sharing problem is solved in Section 4 by use of Stackelberg game with deduction of the utility functions and the solution of backward induction process. In Section 5, Numerical results are shown with evaluation the performance of the proposed scheme, and the final conclusions are drawn in Section 6.

2. Related background

In this section, we will briefly introduce two important concepts in CR technology: Spectrum sensing and Cognitive cycle. With the help of these two concepts, the traditional wireless sensor networks become more efficient and intelligent in communication.

2.1. Spectrum sensing

Spectrum sensing is one of the major functionalities in CR technology. It is also one of the main differences that distinguish CRSNs from traditional WSNs. The major aim of spectrum sensing is to detect the white space in licensed