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Issues in Realization of Cognitive Capability in Wireless Sensor Networks

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Abstract:Recently, significant growth in the applications of the wireless sensor networks (WSNs) operating in unlicensed spectrum bands has been made. In the meantime, existing unlicensed bands are becoming congested and overcrowded. On the other hand, Cognitive Radio (CR) technology has been proposed as the key technology for future wireless communication that exploits dynamic spectrum access strategies. Since this offers more flexible way to utilize the wireless spectrum than traditional radio technology based on a fixed spectrum access policy, it is thought that the key feature of cognitive radio i.e. dynamic spectrum access can be applied in WSNs to access the underutilized spectrum bands to transmit their readings in an opportunistic manner to the next hops and finally to the sink. In this paper, we discuss the basic responsibilities of MAC layer and its functionalities in cognitive radio sensor networks (CRSN). We mainly focus on investigating the MAC layer issues while realizing the cognitive capability into wireless sensor networks.

Keywords: wireless sensor networks (WSN), cognitive radio (CR), medium access control (MAC)

1 Introduction

A wireless sensor network is composed of a large number of sensor nodes, which are densely deployed. They are able to observe a wide variety of ambient conditions which include temperature, humidity, vehicular movement, lighting conditions, pressure, the presence or absence of certain kinds of objects etc. [1]. For current WSN solutions, a key feature is operation in unlicensed frequency band i.e. the worldwide available 2.4 GHz band. However, other popular wireless applications such as Bluetooth, WiFi and other proprietary technologies also share the same band. As a result, the unlicensed band is becoming overcrowded and eventually one network may

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degrade the performance of the other. That is why; coexistence in unlicensed band is one of the key issues in research.

On the contrary, frequency spectrum is statically allocated to licensed users i.e., primary users (PUs) only, in a traditional wireless communication system. Since licensed users may not always occupy the allocated radio spectrum, this static spectrum allocation results in spectrum underutilization. Thus, new spectrum allocation policies were introduced to allow unlicensed users i.e., secondary users (SUs) to access radio spectrum when it is not occupied by PUs. However, when PU comes back into operation, the SU should vacate the spectrum instantly to avoid interference with the primary one. These new spectrum allocation policies are expected to improve spectrum utilization while satisfying the increasing spectrum demand for emerging wireless applications [2]. In the past few years, even though significant progress has been made in the field of cognitive radio, this research area is still at immature stage because various research challenges have to be addressed and solved.

A WSN composed of sensor nodes equipped with cognitive radio is called CRSN. In general, a cognitive radio sensor network (CRSN) can be defined as a distributed network of wireless cognitive radio sensor nodes, which sense event signals and collaboratively communicate their readings dynamically over available spectrum bands in a multihop manner to ultimately satisfy the application-specific requirements [3]. However, it is a great challenge to adopt the CR principle to sense the underutilized spectrum dynamically. Moreover, applying the existing protocols and algorithms for CRNs and WSNs in CRSNs is the key issue raised in research.

Medium Access Control has an important role in several cognitive radio functions: spectrum mobility, channel sensing, resource allocation, and spectrum sharing. When a primary user is detected, spectrum mobility allows a SU to vacate its channel and to access an idle band [4]. Channel sensing is the process of collecting the information about spectrum usage and maintaining the information of available channels dynamically. Several techniques for channel sensing in the physical layer have been proposed in this literature. This sensing is abstracted in the MAC layer to identify whether the channel is occupied by PUs or not.

Recently, number of studies associated to CR MAC protocols and WSN have been proposed and a few publications have already been made reviewing the CRSN. In [3], advantages and limitations for the realizations of CRSN have been discussed. Furthermore, using multiple channel availability provided by CR capabilities to overcome the problems caused by the dense deployment and bursty communication nature of sensor networks has also been discussed. Performance of a CR-based WSN with standard Zigbee/802.15.4 has been compared in [5]. In [6], infrastructure based and ad-hoc cognitive MAC protocols are classified according to the exploited medium access scheme. In [7], a general review in CRN spectrum management has been provided.

It is promising and challenging for WSNs to adopt the CR technology to sense spectrum hole and utilize the vacant frequencies to improve the spectrum utilization. The existing protocols and algorithms devised for CRNs and WSNs are not perfectly fit for CRSN. In this study, we discuss the major cause of extra energy expenditure in section 2 and later the major MAC layer issues and some open research issues in incorporating CR capabilities into CRSN in section 3. Finally section 4 draws the conclusion.

2 Extra Energy Expenditure

In WSN, neighbor nodes may be close to each other. One of the most important constraints on sensor is the low power consumption requirement. Sensor nodes carry limited power sources. Hence, multihop communication in sensor networks is expected to consume less power than the traditional single hop communication. Multihop communication can also effectively overcome some of the signal propagation effects experienced in long-distance wireless communication [1].

Typically, a large number of sensor nodes are deployed in a specific monitor area. In [8], it has been assumed a base station which provides broadcasting service for the primary users, and most of the sensor nodes are within its coverage region. The nodes organize themselves into local clusters, with one node acting as the cluster head. All non-cluster-head nodes in a cluster transmit their data to the cluster head at given time slots according to TDMA scheme, while the cluster head receives data from its members, performs signal processing functions on the data, and transmits the data to the dedicated sink. The sensor nodes cooperatively detect potentially vacant bands and transmit the detection results to the sink. The spectrum decision is ultimately determined by the sink. Depending on the spectrum availability, sensor nodes transmit their readings in an opportunistic manner to the next hops and finally to the sink. Here, we summarize some important cause of extra energy expenditure:

(i) *Spectrum sensing*: Spectrum sensing is the one of the major functionalities that differentiates CRSN with the traditional WSN. There are various sensing methods proposed in this literature and they have been summarized in [9]. This sensing is abstracted in the MAC layer to identify whether the channel is occupied by PUs or not. However, due to limitations of the cognitive radio sensor node, techniques developed for cognitive radio networks cannot be directly applied to CRSN. Therefore, additional research must be conducted on spectrum sensing for CRSN.

(ii) *Bursty traffic*: If there is large number of sensor nodes, the generated packet traffic is high. So it may increase the probability of collision, decrease the communication reliability, excessive power consumption and packet delay. So this opportunistic spectrum access to multiple choice channels, this challenge may be overcome.

(iii) When nodes have no data to send, they will remain idle listening to the radio channel. This excessive idle listening will cause waste of energy.

(iv) If there will be multiple nodes that want to access or participate in competition for the same channel, and consequently lead to data collision. There will be the packet data lost and it will incur extra energy consumption in retransmission.

(v) *Spectrum handoff*: CRSN node must detect the primary user activity and they should immediately vacate the channel even if they have ongoing transmission. However, they should move to another available channel decided by an effective spectrum decision mechanism. This fundamental mechanism of cognitive radio is called spectrum handoff. For handoff, it takes long delays and hence, buffer overflows which may lead to packet losses, degradation in reliability and ultimately resource waste in CRSN. Thus, unnecessary spectrum handoff should be eliminated. In [10], a central spectrum allocation scheme, which tries to minimize spectrum handoff, has been proposed for CRSN.

3 Discussion and Open Research Issues

While designing CR MAC protocol for dynamic spectrum access, we must have to consider some communication challenges. While deploying cognitive networks, there will be both PUs and SUs. Each CR MAC protocol should maintain the coexistence between them in order to avoid interference. It is one of the important functions of a CR MAC protocol. Also, coexistence among SUs is important to avoid collisions due to simultaneous channel access. Since the channel occupancy time of PUs is varying, CR MAC protocol must be able to detect time-varying activity of PUs and adjust the channel access strategies dynamically. Also, the hidden and exposed terminal problems have to be solved to avoid collision and underutilization of the available channels.

In CRSN also, MAC protocols provides the sensor nodes the means to access the medium in fair and efficient manner. The existing MAC solutions for WSN are not designed for dynamic spectrum access, and simply they cannot address the requirement for CRSN. This is a challenging task by considering the resource limitation, dense deployment of sensor nodes. In CRSN, handshaking mechanism may require to negotiate the channel by exchanging some control packets. Thus, MAC layer of CRSN has to handle additional challenges as compared to the traditional WSN. On-demand negotiation is one of the channel reservation mechanisms. In this reservation approach, a channel i.e. control channel is used to exchange the information about the channel reservation on demand and the nodes switch to the negotiated channel for transmission. The main problem with this approach is that if large number of nodes attempt to transmit in a short amount of time, it cannot handle the cases. It will get congested very quickly. It is due to the bursty traffic due to the dense deployment of sensor networks. Having multiple control channels can also improve the performance of the cases such that the other control channels can be used until a new vacant band is found. On the other hand, those approaches which have multiple transceiver assumption are also not so practical for CRSN. Another approach is based on the use of time division techniques which divides the time into frame and nodes transmit their data in a round-robin fashion [11]. Channel reservation is made at the beginning of each frame and nodes perform their transmission in their reserved slots. Due to the network wide strict synchronization requirement, this approach is also cannot be directly implemented in CRSN. Moreover, as the number of nodes increase, the reservation time at the beginning of each frame increases, leading to overall performance degradation. Thus, none of these existing approaches can be directly employed in CRSN.

In MAC layer, the means of lessening energy dissipation mainly include reducing traffic, prolonging sleep time of RF module and taking collision avoidance mechanism etc. Among them, reducing traffic is a fundamental method, and is achieved generally by adding a data fusion layer over the MAC layer or network layer [8]. However, the mature research results about data fusion in MAC layer have not been reported.

Clearly none of the existing approaches can be directly employed in CRSN. Here, we discuss the main open research issues. If the channel condition is degraded, forward error correction (FEC) schemes with more redundancy may be used to decrease the error rate. Therefore, dynamic spectrum FEC schemes with minimum energy consumption must be developed. Moreover, impact of packet size on transmission efficiency is one of the crucial factors and hence, optimal packet size for CRSN must be analyzed under varying channel characteristics [3]. New MAC solutions must be developed that can make full use of the multiple alternative channel availability.

4 Conclusion

Dynamically spectrum access in cognitive radio networks is still in its infancy. Many important and complex issues need to be addressed. In this paper, we discussed cognitive radio sensor network which is a new paradigm formed by incorporating the cognitive capability into wireless sensor networks i.e. CRSN. We discussed the importance of CRSN and the basic functionalities and role of CR MAC layer. Even though cognitive radio and wireless sensor networks have individually been studied extensively, it is obvious that it is promising and challenging for WSNs to incorporate the CR principle to sense the vacant spectrum bands and utilize to improve spectrum utilization. We must have to modify and enhance to the existing CR MAC protocols and algorithms since there exists no complete MAC solution which can address the requirements of CRSN. As we know that the energy is the most important constraint while realization of CRSN, we tried to exploit some important cause of extra energy expenditure and discussed some open research issues.

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