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Cognitive Radio Wireless sensor Network and its Efficient Spectrum Utilization

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Abstract: Cognitive radio has been considered as a key technology for future wireless communications and mobile computing. We note the cognitive radios can form cognitive radio networks (CRN) by extending the radio link features to network layer functions and above. A cognitive radio wireless sensor network is one of the candidate areas where cognitive techniques can be used for opportunistic spectrum access. Research in this area is still in its infancy, but it is progressing rapidly. The aim of this study is to classify the existing literature of this fast emerging application area of cognitive radio wireless sensor networks, highlight the key research that has already been undertaken, and indicate open problems. This paper describes the advantages of cognitive radio wireless sensor networks, the difference between ad hoc cognitive radio networks, wireless sensor networks, and cognitive radio wireless sensor networks, and its efficient spectrum utilization.

Keywords: Cognitive Radio, Cognitive Radio Network, Ubiquitous Computing, Wireless Networks, Heterogeneous Wireless Networks

I. INTRODUCTION

Among diverse wireless technology supporting Internet access and other stream traffic services[1] , a different vision is to integrate different wireless systems/networks and to appropriately use one of them based on the communication environments and the application requirements, based on reconfigurable communication and networking. Cognitive radio pioneered by J. Mitola[8] III from software defined radio (SDR) was originally considered to improve spectrum utilization and FCC endorsed such an idea shortly . Upon to this scenario, cognitive radio is primarily a link-level technology for dynamic access of radio spectrum for physical layer radio transmission, as a sort of configurable wireless communication technology[2]. However, cognitive radio provides not only spectrum advantages but also networking "macro-scale diversity" above link-layer to bridge our integrated re-configurable system/networking vision. Communications in wireless sensor networks (WSNs) are event driven. Whenever an event triggers wireless sensor (WS) nodes generate bursty traffic. In a dense network environment, wireless sensor nodes deployed in the same area might try to access a channel whenever an event occurs. Recently, many sensitive and critical activities are being monitored and observed increasingly using WSNs. Several heterogeneous WSNs can exist, which causes a long waiting time for the delay sensitive data. Current WSNs operate in the ISM band, which is shared by many other successful communication technologies.

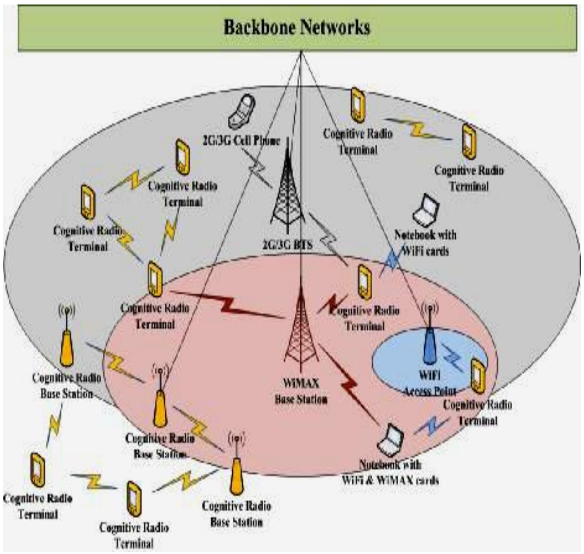

Fig.1 Backbone Network

Research has shown that this coexistence in the ISM band can degrade the performance of the WSNs. The wide deployments, large transmit power, and large coverage range of IEEE 802.11 devices and other proprietary devices can degrade the performance of WSNs significantly when operating in overlapping frequency bands. The coexistence of wireless personal area networks (WPAN) with other wireless devices operating in an unlicensed frequency band is addressed in reference [3].

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II. ARCHITECTURE OF COGNITIVE RADIO NETWORK

In addition to spectrum sensing to effective improve spectrum utilization, a cognitive radio in CRN can sense available networks and communication systems around it. A Cognitive Radio Network (CRN) is thus not just another network to interconnect cognitive radios. The CRNs are composed of various kinds of communication systems and networks, and can be viewed as s sort of heterogeneous networks. The heterogeneity exists in wireless access technologies, networks, user terminals, applications, and service providers[4] . The design of cognitive radio network architecture is toward the objective of improving the entire network utilization, rather than just link spectral efficiency. From the users' perspective, the network utilization means that they can always fulfill their demands anytime and anywhere through accessing CRNs. From the operators' perspective, they can provide better services to mobile users, and allocate radio and network resources to deliver more packets per unit bandwidth in a more efficient way.

A. NETWORK ARCHITECTURE

The CRNs can be deployed in network-centric, distributed, ad hoc, and mesh architectures, and serve the needs of both licensed and unlicensed applications. The basic components of CRNs are mobile station (MS), base station/access point (BSs/APs) and backbone/core networks. These three basic components compose three kinds of network architectures in the CRNs: Infrastructure, Ad-hoc and Mesh architectures, which are introduced as follows.

1. Infrastructure Architecture:

In the Infrastructure architecture, a MS can only access a BS/AP in the one-hop manner. MSs under the transmission range of the same BS/AP shall communicate with each other through the BS/AP. Communications between different cells are routed through backbone/core networks.

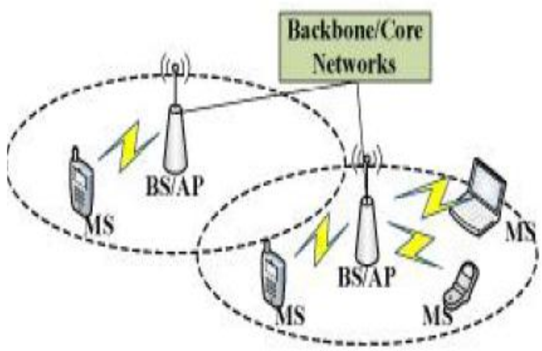

Fig.2 Infrastructure Architecture

The BS/AP may be able to execute one or multiple communication standards/protocols to fulfill different demands from MSs. A cognitive radio terminal can also access different kinds of communication systems through their BS or AP.

2. Ad-Hoc Architecture

There is no infrastructure support (or defined) in ad-hoc architecture. If an MS recognizes that there are some other MS nearby and are connectable through certain communication standards/protocols, they can set up a link and thus form an ad hoc network. Note that links between nodes may be set up by different communication technology[6]. Two cognitive radio terminals can either communicate with each other by using existing communication protocols (e.g. WiFi, Bluetooth) or dynamically using spectrum holes.

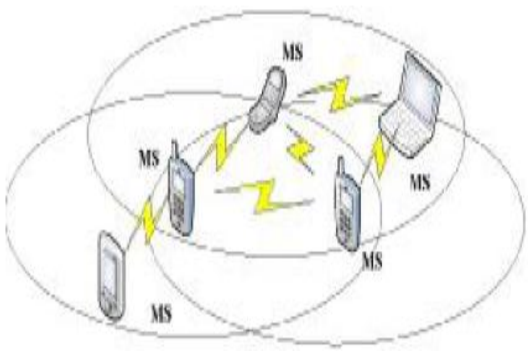

Fig.3 Ad-hoc Architecture

B. MESH ARCHITECTURE

This architecture is a combination of Infrastructure and Ad Hoc architectures by enabling the wireless connections between BSs/APs, which is similar to the Hybrid Wireless Mesh Networks . BSs/APs work as wireless routers and form wireless backbones[5] . MSs can either access the BSs/APs directly or use other MSs as multi-hop relay nodes.

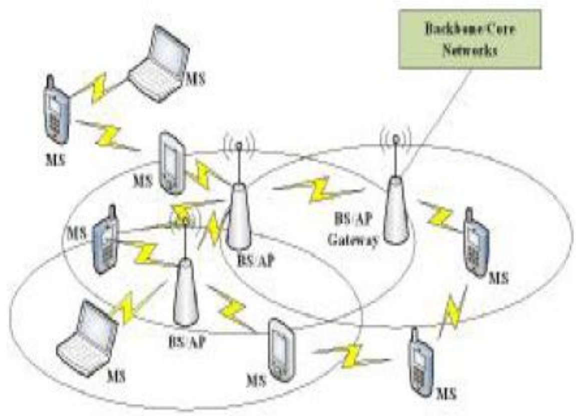

Fig4. Mesh Architecture Network

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Some BSs/APs may connect to the wired backbone/core networks and function as gateways. Since BSs/APs can be deployed without necessarily connecting to wired backbone or core networks, it is more flexible and less costly in planning the locations of BSs/APs. For BSs/APs having cognitive radio capabilities, they may use spectrum holes to communicate each other. Due to potentially lots of spectrum holes available, the capacity of wireless communication links among cognitive radio BSs/APs may be enough to serve as wireless backbone.

III. COGNITIVE RADIO HARDWARE STRUCTURE

Hardware structure of cognitive radio-based sensor network is typically composed of the power unit, sensing unit, processing unit, the cognitive radio platform and the RF unit. This is shown in figure 5. Two new unit i.e. location finding unit and mobilize unit are required for application specific network[13]. There is an extra unit in Cognitive radio sensor network related to traditional wireless sensor node which is the RF unit of the cognitive radio sensor nodes. The cognitive engine is responsible for cognitive cycle which enables CR sensor nodes to dynamically adapt their communication parameters is done by even though this hardware architecture looking promising in terms of dynamic spectrum access for sensor nodes, there are noticeable challenges posed to a resource-constrained wireless sensor networks.

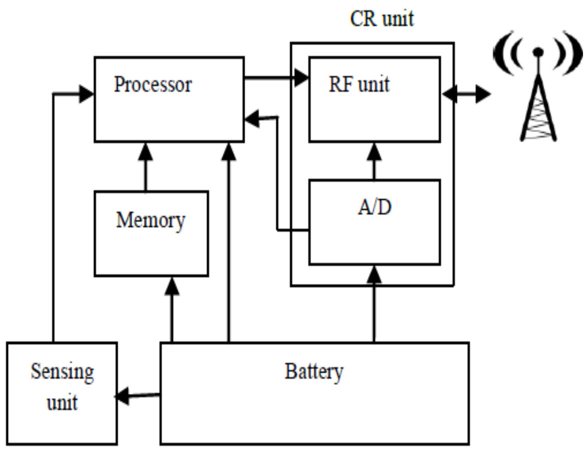

Fig. 5 Hardware Structure of a Cognitive Radio Sensor node

Wireless sensor networks are constrained by resources such as power, low complexity processing device, communication and memory. As a result of these limitations, the cognitive radio capability is also affected. For instance, to increase the network lifetime there should be necessary to consider low energy consumption spectrum sensing design and energy saving protocols.

For better system architecture for CRWSN, there should be adaptive, dynamic MAC protocol using reinforcement learning technique. Also, there should be cross-layer energy management protocol integrating the physical and the MAC layer.

IV. PRIMARY SYSTEM AND COGNITIVE RADIO SYSTEM

There are two kinds of wireless communication systems in CRNs: Primary System and Cognitive Radio System, which are classified by their priorities on frequency bands. A primary system is referred to an existing system which operates in one or many fixed frequency bands. Various kinds of primary systems work either in licensed or unlicensed bands and are explained asfollows.[7]

1. Primary System In Licensed Bands

A primary system operated in the licensed band has the highest priority to use that frequency band (e.g. 2G/3G cellular, digital TV broadcast). Other unlicensed users/systems can neither interfere with the primary system in an intolerable way nor occupy the license band.

2. Primary System In Unlicensed Bands

A primary system operating in the unlicensed band (e.g. ISM band) called unlicensed band primary system. Various primary systems should use the band compatibly. Specifically, primary systems operating in the same unlicensed band shall coexist with each other while considering that the interference to each other.

These primary systems may have different levels of priorities which may depend on some regulations. A cognitive radio system neither has a fixed operating frequency band nor has privilege to access that band. Entities of this system communicate with each other by dynamically using spectrum holes. There are two components in CR systems: Cognitive Radio Base Station (CR-BS) and Cognitive Radio Mobile Station (CRMS).

3. Cognitive Radio Base Station (Cr-Bs)

A CR-BS is a fixed component in the cognitive radio system and has cognitive radio capabilities. It represents the infrastructure side of the CR system and provides supports (e.g. spectrum holes management, mobility management, security management) to CR-MSs. It provides a gateway for CR-MSs to access the backbone networks (e.g. Internet).

CR-BSs can also form a mesh wireless backbone network by enabling wireless communications between them, and some of them act as gateway routers if they are connected with wired backbone networks. If a CR-BS can run PR system protocols, it can provide access network services to PR-MSs.

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4. Cognitive Radio Mobile Station (Cr-Ms)

A CR-MS is a portable device with cognitive radio capabilities. It can reconfigure itself in order to connect to different communication systems. It can sense spectrum holes and dynamically use them to communicate with CR-MS or CR-BS.

5. Coexistence With Ieee 802.22 (Wran) And Other Cr Networks:

Research on the use of various CR devices in ISM and incumbent bands has been performed, but more research on the coexistence of CR devices operating in the same location will be necessary. Widely deployed CR wireless sensors use lower transmission power than other wireless network devices. Therefore, the coexistence issue between themselves and other non-CR-WSNs should be considered. In addition to interference, there could be opportunities to utilize the spectrum information with the cooperation of IEEE 802.22 CPEs. Although there are no reports on the possibilities of the coexistence of CR-WSNs with IEEE 802.22 RAN, it may be possible to obtain information from the CPEs and/or WRAN BS and use the spectrum information. The CPE can work as a coordinator or gateway between the CR-WSNs and WRANs.

V. SPECTRUM MANAGEMENT IN CRSN

An efficient spectrum management framework is primarily required to realize the cognitive radio sensor networks. In this section, some major challenges and major issues regarding such dynamic spectrum management framework is discussed in this section.

Among these, spectrum sensing is one of the key functionalities distinguishing CRSN from traditional WSN. Several techniques for channel sensing in the physical layer have been proposed in this literature Matched filter, Energy detection, feature detection, interference temperature are the most common spectrum sensing techniques. Available channels are assigned to cognitive users opportunistically by resource allocation. There may be multiple cognitive users trying to access the spectrum. SUs should coordinate their access to the available spectrum channel. Now, we will discuss some of the well known spectrum sensing techniques and examine in terms of how they can apply to CRSN.

A. Matched Filter:

It has been shown that the optimal spectrum sensing method for the cognitive radio with the presence of Gaussian noise is the matched filter method. However, this approach requires a priori knowledge about the transmission of the primary user. Since it is a coherent detection method, it requires synchronization with the primary user.

B. Energy Detection:

CRSN nodes needs for a simpler spectrum sensing technique such as energy detection method. This method is popular even in cognitive radio networks, where nodes are typically less power constrained and have more computational power. It measures the received energy on the specific portion of the spectrum, i.e., channel, for acertain period of time.

C. Feature Detection:

When certain features of the primary user transmission such as Carrier frequency and cyclic prefixes are known, t his method can be used. Feature detection method takes advantage of the cyclo-stationary features of the PU signal. Unlike noise, the PU signal has spectrum correlation due to its inherent cyclo-stationarity.

D. Interference Temperature:

The sensing method introduced by the FCC is the interference temperature measurement method. An interference temperature level above the noise floor is determined. CRSN nodes calculate how much interference they would cause at the primary user receiver.[13]

There is enough amount of work on spectrum sensing methods. Clearly, most of these methods are not suitable for CRSN as they are designed by without considering the unique challenges posed by the resource constraints of wireless sensor nodes. Spectrum sharing is employed to prevent multiple users colliding. Due to limitation of the cognitive radio sensor nodes, techniques developed for cognitive radio networks can not directly applied to CRSN. [14]

TABLE 1 OVERVIEW OF SPECTRUM SENSING METHODS

Spectrum sensing Method	Disadvantages	Advantages
Matched filter	Requires a priori info on PU transmissions, and extra hardware on nodes for synchronization with PUs.	Best in Gaussian noise. Needs shorter sensing duration (less power consumption).
Energy detection	Requires longer sensing duration (high power consumption). Accuracy	Requires the least amount of computational power on nodes.

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	highly depends on noise level variations.	
Feature detection	Requires a priori knowledge about PU transmissions. Requires high computational capability on nodes.	Most resilient to variation in noise levels.
Interference Temperature	Requires knowledge of location PU and imposes polynomial calculations based on these locations.	Recommended by FCC. Guarantees a predetermined interference to PU is not exceeded.

Therefore, additional research must be conducted on spectrum sensing for CRSN. However, none of these works consider the challenges posed by the inherent limitations of CRSN. Therefore, minimizing the effect of spectrum handoff is very important issue to increase the communication reliability

VI. CONCLUSION

In this paper, we introduce the cognitive radio network (CRN) architecture to extend networking efficiency from cognitive radios' spectral efficiency. CRN can be considered as infrastructured, ad hoc, and mesh structure in terms of network topology. We also identified possible "uni-directional" links among these network structures, while such uni-directional links are resulted from the special nature of CRN operation. We hope this effort to pave the way for future CRN systematic research. CR wireless sensor networks are still in their infancy. Several areas remain to be explored and improved. For the success of CR-WSNs, massive research is required in several aspects. Substantial developments in hardware, software and algorithms are needed to make smart CR wireless sensors.

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