SPECTRUM MANAGEMENT IN COGNITIVE RADIO NETWORKS

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Abstract:

Cognitive radio networks will provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques. However, CR networks impose challenges due to the fluctuating nature of the available spectrum, as well as the diverse Qom requirements of various applications. Spectrum management functions can address these challenges for the realization of this new network paradigm. To provide a better understanding of CR networks, this article presents recent developments and open research issues in spectrum management in CR networks. More specifically, the discussion is focused on the development of CR networks that require no modification of existing networks. First, a brief overview of cognitive radio and the CR network architecture is provided. Then four main challenges of spectrum management are discussed: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

Key words: CR (Cognitive Radio), SDR (Soft Defined Radio), Qom (Quality of Service), spectrum management.

1. Introduction

Current wireless networks are characterized by a static spectrum allocation policy, where governmental agencies assign wireless spectrum to license holders on a longterm basis for large geographical regions. Recently, because of the increase in spectrum demand, this policy faces spectrum scarcity in particular spectrum bands. In contrast, a large portion of the assigned spectrum is used sporadically, leading to underutilization of a significant amount of spectrum **[1]**. Hence, dynamic spectrum access techniques were recently proposed to solve these spectrum inefficiency problems. The key enabling technology of dynamic spectrum access techniques is cognitive radio (CR) technology, which provides the capability to share the wireless channel with licensed users in an opportunistic manner. CR networks are envisioned to provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques. This goal can be realized only through dynamic and efficient spectrum management techniques.

CR networks, however, impose unique challenges due to the high fluctuation in the available spectrum, as well as the diverse quality of service (Qom) requirements of various applications.

In order to address these challenges, each CR user in the CR network must:

- Determine which portions of the spectrum are available;
- Select the best available channel ;
- Coordinate access to this channel with other users;
- Vacate the channel when a licensed user is detected **[2].**

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These capabilities can be realized through spectrum management functions that address four main challenges: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

This article presents a definition, the functions, and the current research challenges of spectrum management in CR networks. More specifically, we focus our discussion on the development of CR networks that require no modification in existing networks. An overview of CR technology is provided, and the CR net work architecture is presented. We explain the concept of spectrum management and the required functionalities. Then we describe spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility concepts.

2. Cognitive Radio Technology

The key enabling technologies of CR networks are the cognitive radio techniques that provide the capability to share the spectrum in an opportunistic manner. Formally, a CR is defined as a radio that can change its transmitter parameters based on interaction with its environment [1].

From this definition, two main characteristics of cognitive radio can be defined [3]:

• *Cognitive capability*: Through real-time interaction with the radio environment, the portions of the spectrum that are unused at a specific time or location can be identified. CR enables the usage of temporally unused spectrum, referred to as spectrum hole or white space. Consequently, the best spectrum can be selected, shared with other users, and exploited without interference with the licensed user.

• *Reconfigurability*: A CR can be programmed to transmit and receive on a variety of frequencies, and use different access technologies supported by its hardware design [4]. Through this capability, the best spectrum band and the most appropriate operating parameters can be selected and reconfigured.

In order to provide these capabilities, CR requires a novel radio frequency (RF) transceiver architecture. The main components of a CR transceiver are the radio front-end and the baseband processing unit that were originally proposed for software-defined radio (SDR). In the RF front-end the received signal is amplified, mixed, and analog-to-digital (A/D) converted. In the baseband processing unit, the signal is modulated/ demodulated. Each component can be reconfigured via a control bus to adapt to the time-varying RF environment. The novel characteristic of the CR transceiver is the wide band RF front-end that is capable of simultaneous sensing over a wide frequency range. This functionality is related mainly to the RF hardware technologies, such as wide band antenna, power amplifier, and adaptive filter. RF hardware for the CR should be capable of being tuned to any part of a large range of spectrum. However, because the CR transceiver receives signals from various transmitters operating at different power levels, bandwidths, and locations; the RF front-end should have the capability to detect a weak signal in a large dynamic range, which is a major challenge in CR transceiver design [5].

3. Cognitive radio network architecture

A comprehensive description of the CR network architecture is essential for the development of communication protocols that address the dynamic spectrum challenges. The CR network architecture is presented in this section.
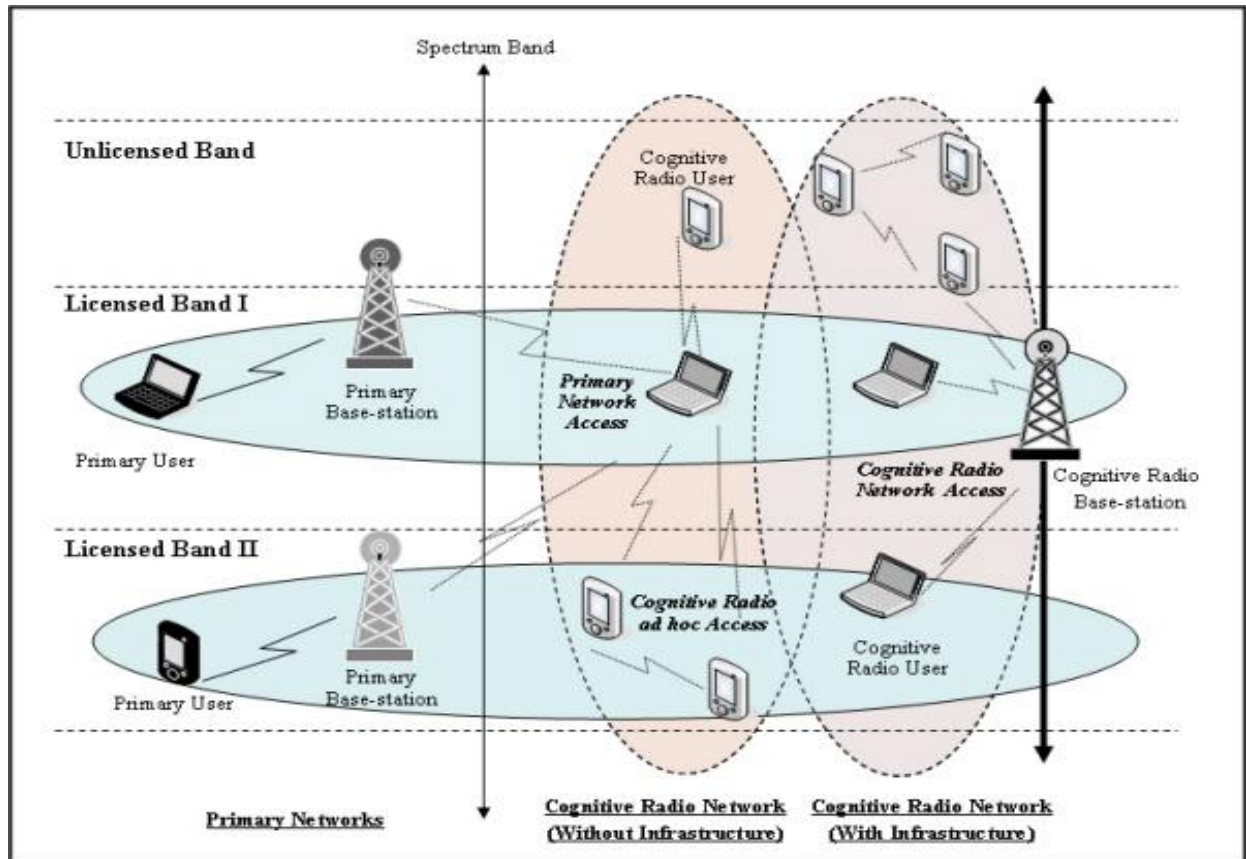
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Fig.1 A CR network architecture **[9]**

4. Network components

The components of the CR network architecture, as shown in Fig. 1, can be classified as two groups: the primary network and the CR network.

The primary network (or licensed network) is referred to as an existing network, where the primary users have a license to operate in a certain spectrum band. If primary networks have an infrastructure, primary user activities are controlled through primary base stations. Due to their priority in spectrum access, the operations of primary users should not be affected by unlicensed users.

The CR network (also called the dynamic spectrum access network, secondary network, or unlicensed network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users to share the licensed spectrum band. CR networks also can be equipped with CR base stations that provide single-hop connection to CR users. Finally, CR networks may include spectrum brokers that play a role in distributing the spectrum resources among different CR networks **[6]**.

5. *Spectrum sensing in cognitive radio networks*

With Cognitive Radio being used in a number of applications, the area of spectrum sensing has become increasingly important. As Cognitive Radio technology is being used to provide a method of using the spectrum more efficiently, spectrum sensing is key to this application.

The ability of Cognitive Radio systems to access spare sections of the radio spectrum, and to keep monitoring the spectrum to ensure that the Cognitive Radio system does not cause any undue interference relies totally on the spectrum sensing elements of the system.

For the overall system to operate effectively and to provide the required improvement in spectrum efficiency, the Cognitive Radio spectrum sensing system must be able to

effectively detect any other transmissions, identify what they are and inform the central processing unit within the Cognitive Radio so that the required action can be taken.

5.1 Cognitive Radio Spectrum Sensing basics

In many areas cognitive radio systems coexist with other radio systems, using the same spectrum but without causing undue interference. When sensing the spectrum occupancy, the cognitive radio system must accommodate a variety of considerations:

- *Continuous spectrum sensing:* It is necessary for the cognitive radio system to continuously sense the spectrum occupancy. Typically a cognitive radio system will utilize the spectrum on a non-interference basis to the primary user. Accordingly it is necessary for the Cognitive radio system to continuously sense the spectrum in case the primary user returns.
- *Monitor for alternative empty spectrum:* In case the primary user returns to the spectrum being used, the cognitive radio system must have alternative spectrum available to which it can switch should the need arise.
- *Monitor type of transmission:* It is necessary for the cognitive radio to sense the type of transmission being received. The cognitive radio system should be able to determine the type of transmission used by the primary user so that spurious transmissions and interference are ignored as well as transmissions made by the cognitive radio system itself.

5.2 Types of cognitive radio spectrum sensing

There are a number of ways in which cognitive radios are able to perform spectrum sensing. The ways in which cognitive radio spectrum sensing can be performed falls into one of two categories:

- *Non-cooperative spectrum sensing:* This form of spectrum sensing, occurs when a cognitive radio acts on its own. The cognitive radio will configure itself according to the signals it can detect and the information with which it is per-loaded.
- *Cooperative spectrum sensing :* Within a cooperative cognitive radio spectrum sensing system, sensing will be undertaken by a number of different radios within a cognitive radio network. Typically a central station will receive reports of signals from a variety of radios in the network and adjust the overall cognitive radio network to suit.

5.3 Cognitive radio spectrum sensing methodologies

There are a number of attributes that must be incorporated into any cognitive radio spectrum sensing scheme. These ensure that the spectrum sensing is undertaken to meet the requirements for the particular applications. The methodology and attributes assigned to the spectrum sensing ensure that the cognitive radio system is able to avoid interference to other users while maintaining its own performance.

- **Spectrum sensing bandwidth:** There are a number of issues associated with the spectrum sensing bandwidth. The first is effectively the number of channels on which the system will sense whether they are occupied. By sensing channels apart from the one currently in use, the system will be able to build up a picture of alternative channels that can be used should the current one become occupied. Secondly the actual reception bandwidth needs to be determined. A narrow bandwidth will reduce the system noise floor and thereby improve the sensitivity, but it must also have a sufficiently wide bandwidth to detect the likely transmissions on the channel.
- **Transmission type sensing:** The system must be capable of identifying the transmission of the primary user for the channel. It must also identify transmissions of

other units in the same system as itself. It should also be able to identify other types of transmission that may be spurious signals, etc.

- ***Spectrum sensing accuracy:*** The cognitive radio spectrum sensing mechanism must be able to detect any other signal levels accurately so that the number of false alarms is minimized.
- ***Spectrum sensing timing windows:*** It is necessary that the cognitive radio spectrum sensing methodology allows time slots when it does not transmit to enable the system to detect other signals. These must be accommodated within the frame format for the overall system.

6. Spectrum decision

Based on information of spectrum sensing, a spectrum band is analyzed and best available spectrum is selected for transmission. This allocation is focused mainly on spectrum availability, cost of communication and quality of service requirements. CR networks require the capability to decide This notion is called spectrum decision and constitutes a rather important but as yet unexplored topic in CR networks. Spectrum decision is closely related to the channel characteristics and operations of primary users. Furthermore, spectrum decision is affected by the activities of other CR users in the network. Spectrum decision usually consists of two steps: first, each spectrum band is characterized, based on not only local observations of CR users but also statistical information of primary networks. Then, based on this characterization, the most appropriate spectrum band can be chosen.

7. Spectrum sharing

Cognitive radio has to access and share the spectrum with multiple other secondary or cognitive users. Spectrum sharing is to distribute the spectrum among all cognitive and non-cognitive users such that there should be no collisions among them.

8. Spectrum mobility

The fourth step in spectrum management and one of the most prominent features of cognitive radio networks will be the ability to switch to different portions of radio spectrum as soon as spectrum left over or spectrum holes are detected. Spectrum mobility is the technique that will enable cognitive radio networks to achieve this goal. As licensed users or primary users have the right to their spectrum slice thus cannot accept any interference thus in this direction the most important and challenging issue of spectrum mobility is to avoid interference to primary users and obtain a seamless communication.

9. Conclusion

CR networks are being developed to solve current wireless network problems resulting from the limited available spectrum and the inefficiency in spectrum usage. CR networks, equipped with the intrinsic capabilities of cognitive radio, will provide an ultimate spectrum-aware communication paradigm in wireless communications. In this paper intrinsic properties and current research challenges of spectrum management in CR networks are presented. In particular, we investigate novel spectrum management functionalities such as spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. However, to ensure efficient spectrum-aware communication, more research is required along the lines introduced in this paper.

References

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[1] FCC, *ET Docket No 03-322 Notice of Proposed Rule Making and Order*, Dec 2003.

[2] I. F. Akyildiz et al., *"NeXt Generation/Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey,"* Comp. Networks J., vol. 50, Sept. 2006, pp. 2127–59.

[3] S. Haykin, *"Cognitive Radio: Brain-Empowered Wireless Communications,"* IEEE JSAC, vol. 23, no. 2, Feb. 2005,pp. 201–20.

[4] F. K. Jondral, *"Software-Defined Radio — Basic and Evolution to Cognitive Radio,"* EURASIP J. Wireless Commun. and Networking, 2005.

[5] D. Cabric, S. M. Mishra, and R. W. Brodersen, *"Implementation Issues in Spectrum Sensing for Cognitive Radios,"* Proc. 38th Asilomar Conf. Sig., Sys. and Comp. 2004, Nov. 2004, pp. 772–76.

[6] O. Ileri, D. Samardzija, and N. B. Mandayam, *"Demand Responsive Pricing and Competitive Spectrum Allocation via Spectrum Server,"* Proc. IEEE DySPAN 2005, Nov. 2005, pp. 194–202.

[7] Steenkiste P, Sicker D, Minden G and Raychaudhuri D. 2009. *"Future directions in cognitive radio network research".* NSF Workshop; Arlington, Virginia, USA. pp 1-40.

[8] Akyildiz IF, Lee WY, Vuran MC and Mohanty S. " A Survey on Spectrum Management in Cognitive Radio Networks." IEEE Communications Magazine 2008; pp.40-48.

[9]http://www.researchcritique.com/intelligent-spectrum-sensing-cognitive-radio-network-using-median-filtering.