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Ontology of Dynamic Spectrum Sharing through Cognitive Radio Nodes in Wireless Networks

J. Suji Priya, T. Padma

Abstract - Cognitive radio (CR) can effectively deal with the growing demand and scarcity of the wireless spectrum. To exploit limited spectrum efficiently, CR technology allows unlicensed users to access licensed spectrum bands. Since licensed users have priorities to use the bands, the unlicensed users need to continuously monitor the licensed users' activities to avoid interference and collisions. In traditional method spectrum sharing between licensed and unlicensed users are done by static method which is inefficient. In this method spectrum bands are wasted. Since spectrum bands are scarce resource it can be effectively used by dynamic spectrum sharing method. Recent research discovered various dynamic spectrum sharing methods. In this paper technique of spectrum sharing among service providers to share the licensed spectrum of licensed service providers in a dynamic manner is considered. The performance of the wireless network with opportunistic spectrum sharing techniques is analyzed with the help of cognitive radio has been investigated. This paper suggests the best method for sharing spectrum in which, the spectral utilization and efficiency is increased, the interference is minimized.

Index Terms - Cognitive radio, dynamic spectrum, interference, efficiency, spectrum sharing, licensed user, primary user

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1 INTRODUCTION

Cognitive radio is a new research area in wireless communications systems which aim to enhance the utilization of the radio frequency (RF) spectrum. The motivation behind cognitive radio is the scarcity of the available frequency spectrum, increasing demand, caused by the emerging wireless applications for mobile users. Most of the available radio spectrum has already been allocated to existing wireless systems; however, the only small parts of it can be licensed to the wireless applications. The study by the Spectrum Policy Task Force (SPTF) of the Federal Communications Commission (FCC) has showed that some frequency bands are heavily used by licensed systems in particular locations and at particular times, but that there are also many frequency bands which are only partly occupied or largely unoccupied[1]. For example, spectrum bands allocated to cellular and TV channels utilizes the highest spectrum band width during working hours, but remain largely unoccupied from midnight until early morning.

The major factor that leads to inefficient use of the radio spectrum is due to spectrum licensing scheme itself. In the traditional spectrum allocation the static allocation method is followed based on the command-and control model, where the radio spectrum allocated to licensed users or otherwise known as primary users (PUs) is not used or underutilized. It cannot be utilized by unlicensed users or otherwise known as secondary users (SUs) and applications.

The unused spectrum band is called white space. It can be shared by the secondary users when the primary users are not using it. In the traditional method the spectrum bands are shared in static method which is inefficient. Since the white space can't be allocated to the secondary users in this method. Hence the spectrum bands are wasted. This problem can be overcome by dynamic spectrum sharing technique using cognitive radio.

The paper is organized as follows; section 2 defines cognitive radio, section 3 describes spectrum management functions, section 4 methods of spectrum access are investigated to improve spectrum efficiency and finally conclusions are presented in section 5.

2 COGNITTIVE RADIO

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. The term, cognitive radio, can formally be defined as follows : [2]

A "Cognitive Radio" is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. The cognitive radio has two main characteristics; they are cognitive capability and reconfigurability [2].

2.1 Cognitive capability

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The capabilities of cognitive radios as nodes of CRN can be classified according to their functionalities. A cognitive radio shall sense the environment (cognitive capability), analyze and learn sensed information (self-organized capability) and adapt to the environment (reconfigurable capabilities). [2][3]

2.2 Reconfigurability

The cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment [2][3].

3 SPECTRUM MANAGEMENT FUNCTIONS

A Cognitive Radio can able to sense the spectral environment over a wide frequency band and exploit this information to opportunistically provide wireless links that best meet the user communications requirements. CR provides the real time interaction with its environment. This provides the way to dynamically adapt to the dynamic radio environment and the radio analyzes the spectrum characteristics and changes the parameters among the users that share the available spectrum. With the approach to solve the issue of scarcity of available radio spectrum, the Cognitive radio technology is getting a significant attention [4][5][6].

The cognitive radio has capability to optimize the relevant communication parameters given in a dynamic wireless channel environment. Since the unused spectrum bands are allocated to the secondary users while it is not used by the primary users, a fundamental requirement is to avoid interference to potential primary users in their vicinity [7]. On the other hand, primary user networks have no requirement to change their infrastructure for spectrum sharing with cognitive networks.

The Cognitive radio techniques have the capability to use or share the spectrum in an opportunistic manner. Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. More specifically, the cognitive radio technology will enable the following function to the users.

- ***Spectrum sensing*** - determine which portions of the spectrum is avail-able and detect the presence of licensed users when a user operates in a licensed band
- ***Spectrum decision*** - select the best available channel
- ***Spectrum sharing*** - coordinate access to this channel with other users, and
- ***Spectrum mobility*** - vacate the channel when a licensed user is detected.

The spectrum management of a CR includes spectrum sensing, spectrum decision; spectrum sharing and spectrum mobility is shown in the Fig.1.

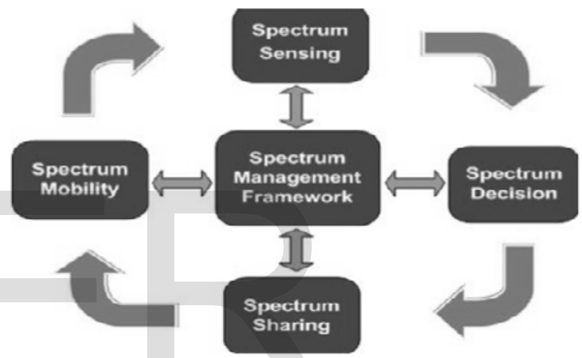

Fig.1 Spectrum management

3.1 Spectrum sensing

Spectrum sensing detects the unused spectrum and shares it without harmful interference with other users. It is an important requirement of the CR network to sense the spectrum holes otherwise known as white space. The spectrum holes are shown in the Fig. 2. Primary users' detection is found to be the most efficient way to detect the spectrum holes [8].

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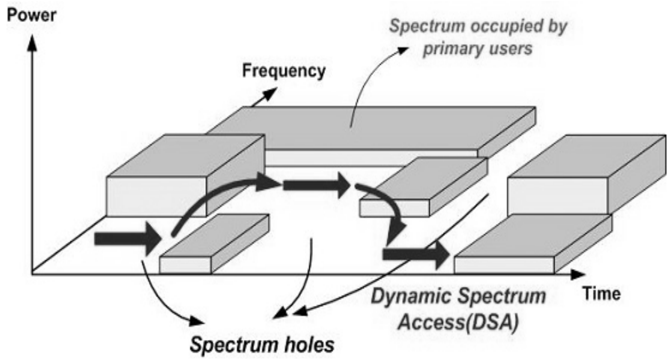

Fig. 2 Spectrum hole concept

The spectrum sensing can categorized as follows. The cognitive radio spectrum sensing can be fall 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 pre-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.

The secondary users will detect the spectrum holes vacated by the primary users by signals. it is difficult for the SUs to differentiate the PU signals from other pre-existing SU transmitter signals. Therefore, we treat them all as one received signal, s(t). The received signal at the SU, x(t), can be expressed as [9].

$$x(t) = \begin{cases} n(t) & H0, \\ s(t) + n(t) & H1, \end{cases} \quad (1)$$

where n(t) is the additive white Gaussian noise (AWGN). $H0$ and $H1$ denote the hypotheses of the absence and presence of the PU signals, respectively. The objective for spectrum sensing is to decide between $H0$ and $H1$ based on the observation x(t).

3.2 Spectrum Decision

Spectrum decision is the task that captures the best available spectrum to meet the user requirements. CR should decide on the best spectrum band from available spectrum bands, therefore spectrum management functions are required for CRs. This concept is called spectrum decision and constitutes rather important but unexplored topic. Spectrum decision is closely related to the channel characteristics and the operations of primary users.
Spectrum decision usually consists of two steps namely

1. Each spectrum band is characterized based on not only local observations of CR users but also statistical information of primary networks.

2. Based on this characterization, the most appropriate spectrum band can be chosen.

This category can be classified as spectrum analysis, spectrum selection and reconfiguration.

Spectrum Analysis – In this category spectrum hole should be considered with respect to time and primary user activity.

Spectrum Selection – After the necessary analysis of spectrum band is done suitable spectrum band should be selected for the current transmission. In the spectrum selection QoS requirements and spectrum characteristics are considered. Based on the user requirement the data rate and the bandwidth is determined and then according to decision rule appropriate spectrum band is chosen.

Reconfiguration -The CR users reconfigure communication protocol as well as communication hardware and RF front end according to the radio environment and user QoS requirements.
CR users require spectrum decision in the beginning of the transmission. CR users characterize available spectrum bands by considering the received signal strength, interference and the number of users currently residing in the spectrum which are also used for resource allocation in classical wireless networks [10].

3.3 Spectrum Sharing

The spectrum access and sharing among licensed and unlicensed users is regulated in a way that the unlicensed or

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secondary user accesses the spectrum. It should not affect the degree of satisfaction of the licensed users requirements.

It refers to providing the fair spectrum scheduling method, one of the major challenges in the open spectrum usage is the spectrum sharing. CRs have the capability to sense the surrounding environments and allow intended secondary user to increase QoS by opportunistically using the unutilized spectrum holes. If a secondary user senses the available spectrum, it can use this spectrum after the primary licensed user vacates it. Spectrum sharing mainly focuses on resource management within the same spectrum with the following functionalities [7][11].

Resource Allocation- Based on the QoS monitoring results, CR users select the proper channels [12,13,14] and adjust their transmission power [15,16,17] to achieve QoS requirements as well as resource fairness. Especially in power control, sensing results need to be considered as not to violate the interference constraints. Fig. 3 shows the spectrum sharing model.

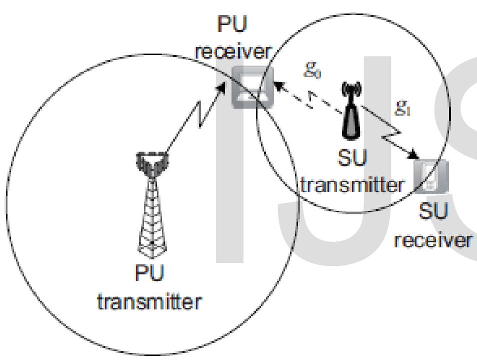

Fig. 3 Spectrum sharing model

- ***Spectrum Access*** - Spectrum access enables multiple spectrum users to share spectrum bands by determining who will access the channel or when a user may access the channel. Once a proper spectrum band is selected in spectrum decision, communication channels in that spectrum need to be assigned to a CR user while determining its transmission power to avoid the interference to the primary network. Then, the CR user decides when the spectrum should be accessed to avoid collisions with other CR users.

The infrastructure based network can provide sophisticated spectrum sharing method with support of the Base Station (BS). Thus, it can exploit time slot based scheduling and dynamic channel allocation to maximize the total network capacity as well as achieve fair resource allocation over CR users. Furthermore, through the synchronization in sensing operation the transmission of CR users and primary users can be detected separately. This decouples sensing operation with spectrum sharing

3.4. Spectrum Mobility

CR users are generally regarded as 'visitors' to the spectrum. Hence, if the specific portion of the spectrum in use is required by a PU, the communication needs to be continued in another vacant portion of the spectrum. This notion is called spectrum mobility. Spectrum mobility gives rise to a new type of handoff in CR networks, the so called spectrum handoff, in which, the users transfer their connections to an unused spectrum band. In CRAHNs, spectrum handoff occurs: (1) when PU is detected, (2) the CR user loses its connection due to the mobility of users involved in an on-going communication, or (3) with a current spectrum band cannot provide the QoS requirements. Spectrum mobility is a process when the CR user exchanges its frequency of operation. CR networks target to use the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during the transition to better spectrum at the same time reduced interference [11].

4. DYNAMIC SPECTRUM ACCESS

Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. Since the vast growth in the wireless communication, Radio spectrum is considered as a scarce resource with the growing demand for spectrum-based services because a major portion of the spectrum has been allocated for licensed wireless applications. The primary job in dynamic spectrum access is the detection of unused spectral bands. However, to determine whether the channel is idle or not, CR device is used for measuring the RF energy. But, this approach has a problem in that wireless devices can only sense the presence of a primary user (PU) if and only if the energy detected is above a certain threshold. Taxonomy of dynamic spectrum access has been depicted in the Fig. 4.

Generally, dynamic spectrum access can be categorized into three models, namely[18]–[21]:

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1) Dynamic exclusive use model;
2) Open sharing model;
3) Hierarchical access model.

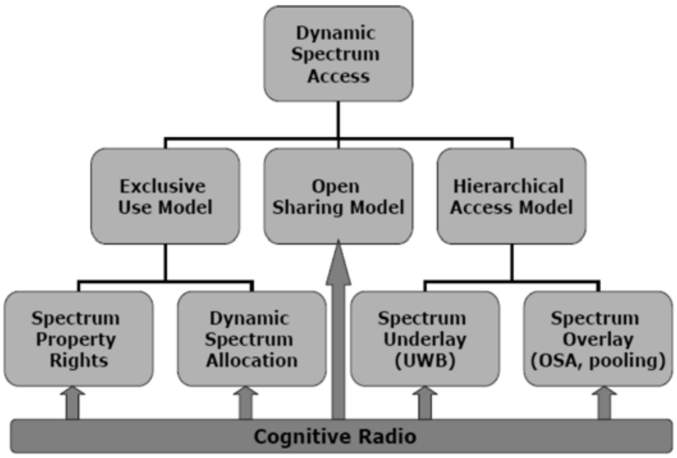

Fig. 4 Taxonomy of Dynamic spectrum access

4.1 Dynamic Exclusive Use Model

This model maintains the basic structure for exclusive use for the licensed users. It manages spectrum in the finer scale of time, space, frequency and use dimensions so at any given point in space and time, only one operator has exclusive right to the spectrum but the identity of the owner and type of use can change. This model maintains the basic structure of the current spectrum regulation policy. Spectrum bands are licensed to services for exclusive use. The main idea is to introduce flexibility to improve spectrum efficiency. Two approaches have been proposed under this model: spectrum property rights and dynamic spectrum allocation. The former approach allows licensees to sell and trade spectrum and freely choose technology.

The other approach, dynamic spectrum allocation, aims to improve spectrum efficiency through dynamic spectrum assignment by exploiting the spatial and temporal traffic statistics of different services. Similar to the current static spectrum allotment policy, such strategies allocate, at a given time and region, a portion of the spectrum to a radio access network for its exclusive use. Based on an exclusive-use model, these approaches cannot eliminate white space in the spectrum resulting from the bursty nature of wireless traffic.

4.2 Open Sharing Model

This model is called as spectrum commons. This model employs open sharing among peer users as the basis for managing a spectral region. Centralized and distributed spectrum sharing strategies have been initially investigated to address technological challenges under this model.

4.3 Hierarchical Access Model

This model adopts a hierarchical access structure with primary and secondary users. The basic idea is to open licensed spectrum to secondary users while limiting the interference perceived by primary users (licensees). Two approaches to spectrum sharing between primary and secondary users have been considered: *Spectrum underlay and spectrum overlay.*

The underlay approach imposes severe constraints on the transmission power of secondary users so that they operate below the noise floor of primary users. By spreading transmitted signals over a wide frequency band (UWB), secondary users can potentially achieve short-range high data rate with extremely low transmission power. Based on a worst-case assumption that primary users transmit all the time, this approach does not rely on detection and exploitation of spectrum white space.

Spectrum overlay was first envisioned by Mitola [22] under the term spectrum pooling and then investigated by the DARPA Next Generation (XG) program under the term opportunistic spectrum access. Differing from spectrum underlay, this approach does not necessarily impose severe restrictions on the transmission power of secondary users, but rather on when and where they may transmit. It directly targets at spatial and temporal spectrum white space by allowing secondary users to identify and exploit local and instantaneous spectrum availability in a nonintrusive manner.

5. CONCLUSION

Cognitive radio is a paradigm for wireless communication where transmission or reception parameters are changed by a network or a wireless node to communicate efficiently and avoid interference between licensed or unlicensed users. The discussions provided in this survey strongly advocate spectrum-access methods and the spectrum management functionalities. After the investigation we conclude that the overlay approach in hierarchical model best suits for the secondary users with less interference. Many researchers are currently engaged in developing the spectrum sharing technologies. However, to ensure efficient spectrum sharing, more research is needed along the lines introduced in this survey.

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