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Brief Overview of the Cognitive Radio Technologies

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Abstract - In an effort to improve radio spectrum management and promote a more efficient use of it, regulatory bodies are currently trying to adopt a new spectrum access model. At the same time, cognitive radio technology has received a lot of interest as possible enabling technologies. This article, provide a brief overview of the cognitive radio technology and the xG network architecture. The presentation of Dynamic spectrum access techniques under four models: dynamic exclusive use model, open sharing model, hierarchical access model. The technical challenges and recent advances under each model are considered. Finally, the technique to avoid of hidden terminal for Cognitive Radio by using sensing devices was provided.

Keywords - Cognitive radio, dynamic spectrum access, hidden Terminal

I. INTRODUCTION

Due to the rapid advance of wireless communications, a tremendous number of different communication systems existed in licensed and unlicensed bands, suitable for different demands and applications such as GSM/GPRS, IEEE 802.11, Bluetooth, UWB, Zigbee, 3G (CDMA series), HSPA, 3G LTE, IEEE 802.16, etc.

In the past, spectrum allocation was based on the specific band assignments designated for a particular service. The spectrum allocation chart used by the Federal Communications Commission (FCC) is shown in Figure1 [1]. This spectrum allocation chart seems to indicate a high degree of utilization. However, the FCC Spectrum Policy Task Force [2] reported vast temporal and geographic variations in the usage of the allocated spectrum with use ranging from 15% to 85% in the bands below 3 GHz that are favored in non-line-of-sight radio propagation. The spectrum utilization is even tighter in the range above 3 GHz. In other words, a large portion of the assigned spectrum is used sporadically, leading to under utilization of a significant amount of spectrum.

Although the fixed spectrum assignment policy generally worked well in the past, there has been a dramatic increase in the access to limited spectrum for mobile services and applications in the recent years. This increase is straining the effectiveness of the traditional spectrum polices.

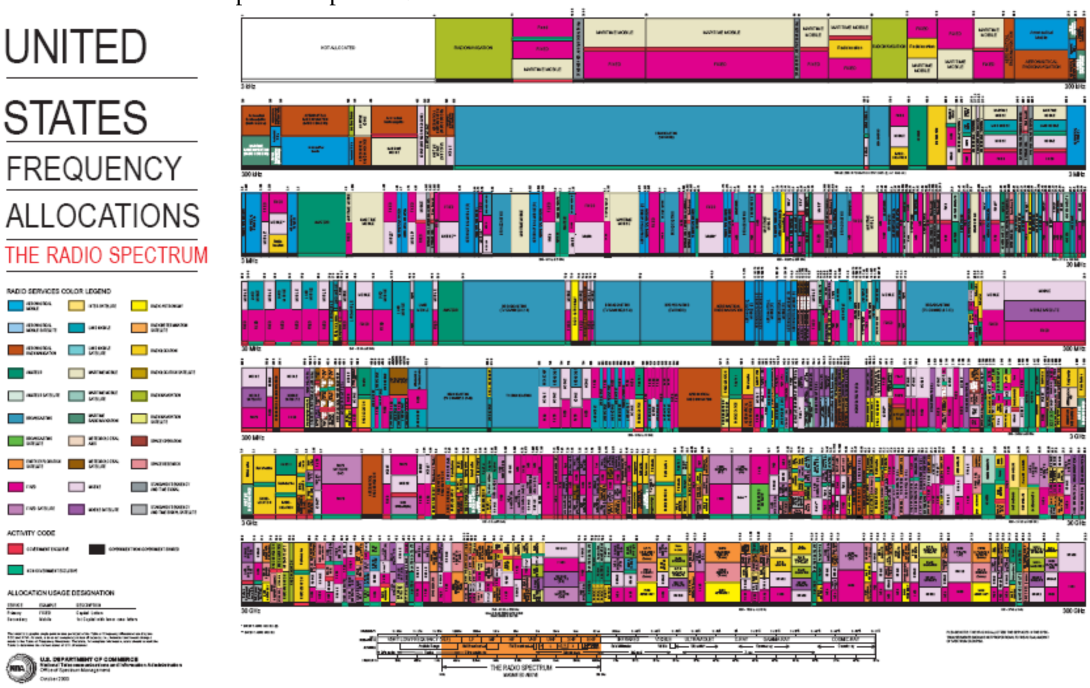


Figure1. Federal Communications Commission (FCC)

The limited available spectrum due to the nature of radio propagation and the need for more efficiency in the spectrum usage necessitates a new communication paradigm to exploit the existing spectrum opportunistically. Inspired by the successful global use of multi-radio co-existing at 2.4 GHz unlicensed ISM bands and others, dynamic spectrum access is proposed as a solution to these problems of current inefficient spectrum usage. The inefficient usage of the existing spectrum can be improved through opportunistic access to the licensed bands by existing users (primary users).

The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. Dynamic spectrum access is proposed to solve these current spectrum inefficiency problems. DARPAs approach on a Dynamic Spectrum Access network, the so-called NeXt Generation (xG) program aims to implement the policy based intelligent radios known as cognitive radios.

NeXt Generation (xG) communication networks, also known as Dynamic Spectrum Access Networks (DSANs) as well as cognitive radio networks will provide high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques.

The key enabling technology of dynamic spectrum access is cognitive radio (CR) technology, which provides the capacity to share the wireless channel with the licensed users in an opportunistic way. CRs are envisioned to be able to provide the high bandwidth to mobile users via heterogeneous wireless architectures and dynamic spectrum access techniques. The networked CRs also impose several challenges due to the broad range of available spectrum as well as diverse QoS requirements of applications. In order to share the spectrum with licensed users without disturbing them, and meet the diverse quality of service requirement of applications, each CR user in a CRN must:

- Determine the portion of spectrum that is available, which is known as Spectrum sensing.
- Select the best available channel, which is called A Spectrum decision.
- Coordinate access to this channel with another user, which is known as Spectrum sharing.
- Vacate the channel when a licensed user is detected, which is referred as Spectrum mobility.

Each CR has the capability of being cognitive, reconfigurable and self-organized to fulfill the functions of spectrum sensing, a spectrum decision, and spectrum sharing and spectrum mobility that each CR must require. An overview of different spectrum sharing models, namely open sharing, hierarchical access and dynamic exclusive usage models, was proposed in [3]. Spectrum management is an important functionality in cognitive radio networks, which involves dynamic spectrum access/sharing and pricing, and it aims to satisfy the requirements of both primary and secondary users.

- ***Paper Outline:*** This paper is structured as follows. In Sect. II, we describe the Cognitive Radio technology and the xG network architecture is introduced. In Sect. III, we discuss Dynamic Spectrum Access. In Sect. IV, we describe the new Cognitive Radio Cycle. In Sect. V we conclude.

II. COGNITIVE RADIO

Cognitive radio technology is the key technology that enables a xG network to use a spectrum in a dynamic manner. The term, cognitive radio, can formally be defined as follows:

A ''Cognitive Radio'' is a radio that can change its transmitter parameters based on interaction with the environment in which it operates.

From this definition, two main characteristics of the cognitive radio can be defined:

Cognitive capability: Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. This capability cannot simply be realized by monitoring the power in some frequency band of interest but more sophisticated techniques are required in order to capture the temporal and spatial variations in the radio environment and avoid interference to other users. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.

Re-configurability: The cognitive capability provides spectrum awareness, whereas Re-configurability enables the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design.

Since most of the spectrum is already assigned, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users as illustrated in Figure2. The cognitive radio enables the usage of temporally unused spectrum, which is referred to as *a spectrum hole or white space*. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference as shown in Figure 2.

The main feature of cognitive radios is their ability to recognize their communication environment and independently adapt the parameters of their communication scheme to maximize the quality of service for the secondary users while minimizing the interference to the primary users [4]. Figure.3 [5] and figure.4 illustrate a cognition radio cycle and cognitive radio scenario respectively. In a cognitive radio cycle, a cognitive radio monitors spectrum bands, captures their information, and then detects the spectrum spaces .The characteristics of the spectrum spaces that are detected through spectrum sensing are estimated. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements. Once the operating spectrum band is determined, the communication can be performed over this spectrum band.

A cognitive radio scenario consists of two-user cognitive radio are shown in figure4 , we assume that each user knows only his channel and the unused spectrum through adequate sensing, The cognitive user will listen to the channel and, if sensed idle, will transmit during the voids.

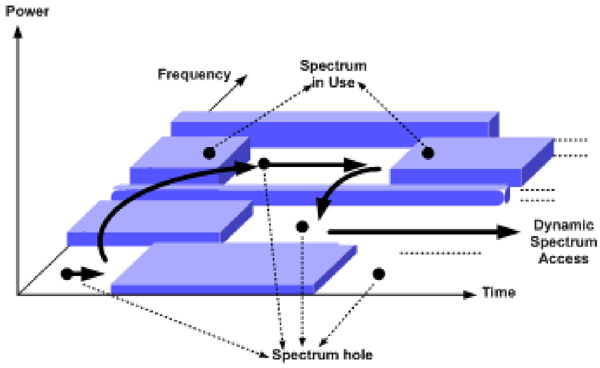


Figure2. Spectrum hole concept

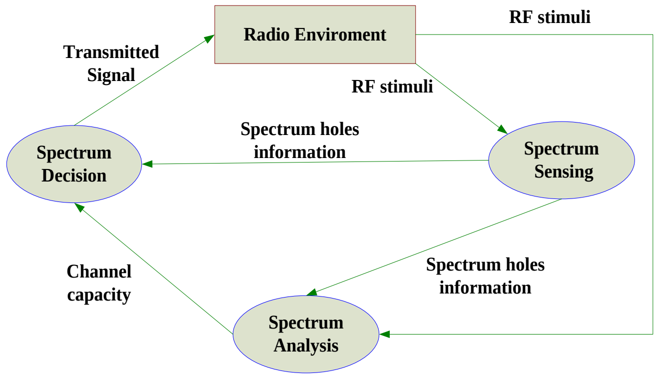


Figure3. Cognitive radio cycle

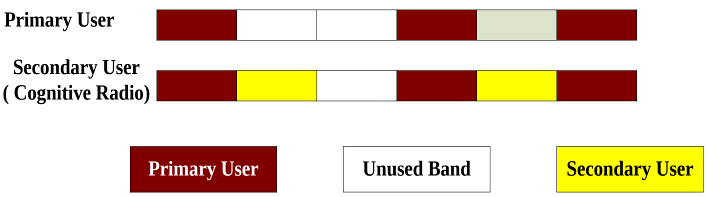


Figure4. Cognitive radio scenario

Firstly, sensing the current radio frequency spectrum environment this includes measuring which frequencies are being used, when they are used, estimating the location of transmitters and receivers, and determining signal modulation [6]. Results from sensing the environment would be used to determine radio settings.

A. The xG network architecture

The components of the infrastructure-based (or centralized) CR network architecture, as shown in Figure 5, can be classified in two groups as the primary network and the CR network. The primary network is referred to as the legacy network that has an exclusive right to a certain spectrum band. Examples include the common cellular and TV broadcast networks. In contrast the CR network does not have a license to operate in the desired band. Hence, the spectrum access is allowed only in an opportunistic manner. The following is the basic components of primary networks:

Primary user: A primary user has a license to operate in a certain spectrum band. This access can only be controlled by the primary base station and should not be affected by the operations of any other CR users. Primary users do not need any modification or additional functions for coexistence with CR base stations and CR users.

Primary base station: A primary base station is a fixed infrastructure network component that has a spectrum license, such as a base station transceiver system (BTS) in a cellular system. In principle, the primary base station does not have any CR capability for sharing spectrum with CR users.

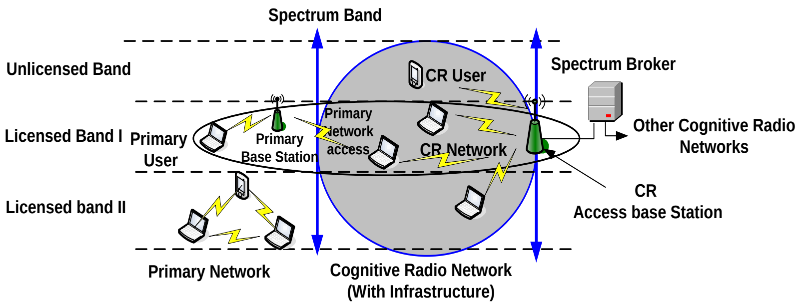


Figure5. Infrastructure-based CR network architecture

The basic elements of the CR network are defined as follows:

- *CR user*: A CR user has no spectrum license. Hence, additional functionalities are required to share the licensed spectrum band. In infrastructure-based networks, the CR users may be able to only sense a certain portion of the spectrum band through local observations. They do not decide on spectrum availability and just report their sensing results to the CR base station.

- *CR base station*: A CR base station is a fixed infrastructure component with CR capabilities. It provides single-hop connection without spectrum access licenses to CR users within its transmission range and exerts to control over them. Through this connection, a CR user can access other networks. It also helps in synchronizing the sensing operations performed by the different CR users. The observations and analysis performed by the latter are fed to the central CR base station so that the decision on the spectrum availability can be made.

- *Spectrum broker*: A spectrum broker (or scheduling server) is a central network entity that plays a role in sharing the spectrum resources among different CR networks. It is not directly engaged in a spectrum sensing. It just manages the spectrum allocation among different networks according to the sensing information collected by each network [5, 7]

B. Networking the Cognitive Radios:

Recent research suggests that it is not enough to establish a CR link (from CR-Tx to CR-Rx), and we shall develop ways to the network the CRs, which is known as CR network (CRN). The CRNs can be deployed in network-centric, distributed, ad-hoc and mesh architectures, and serve the needs of both licensed and unlicensed applications. Also, CRN users can either communicate with each other in a multi-hop manner or access the base station. Thus, CRNs have three different access types as It follows:

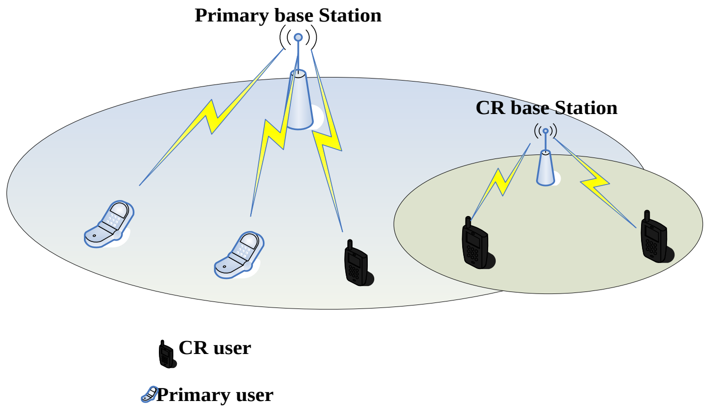
CR network access: CR users can access their own base station on licensed and unlicensed bands.

CR ad-hoc access: CR users can communicate with each other through ad-hoc communication on licensed and unlicensed bands.

Primary network access: CR users can also access the primary base station through a licensed band.

As mentioned above, CR users can operate in both licensed and unlicensed bands. However, the functionality required for CRN is based on whether the spectrum is licensed or unlicensed. And some properties and constraints of CRN will also differ in spectrums that are licensed or unlicensed. We may categories the CR application of spectrum into three possible scenarios, which are depicted in Figure 6: (i) CRN on a licensed band; (ii) CRN on an unlicensed band; and (iii) CRN on both a licensed band and unlicensed band.

(a)



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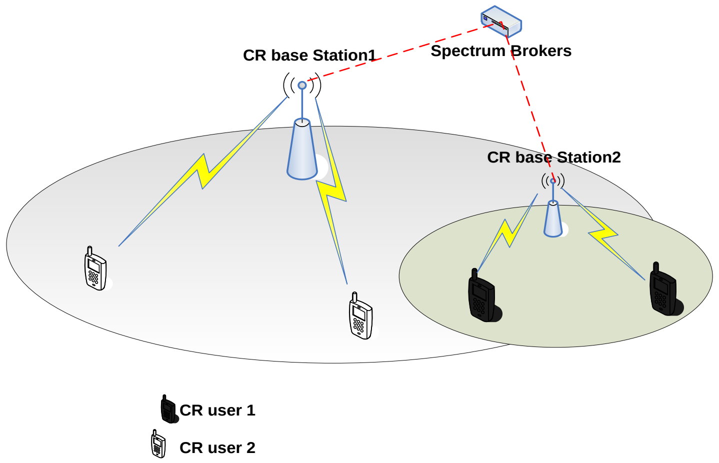

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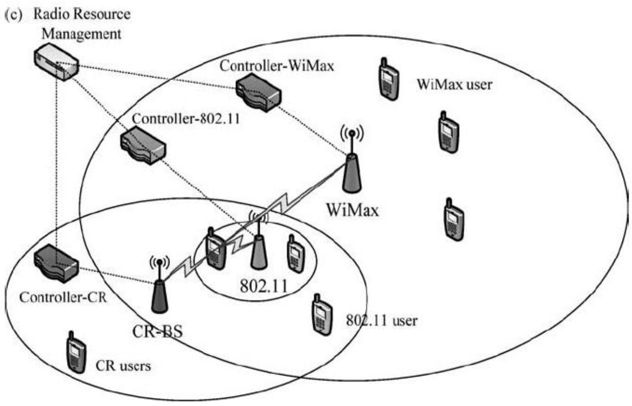

Figure6. (a) CRN on licensed band (b) CRN on Unlicensed band; and CRN on both licensed and unlicensed band

C. Cognitive Radio Issues:

The cognitive radio issues as mention in [11], Advance spectrum management, Unlicensed spectrum usage, Spectrum sharing strategies, Hidden node and sharing issues, Trusted access and security, Complexity issue, Cross-layer design and Hardware and software architecture

III. DYNAMIC SPECTRUM ACCESS

The term "dynamic spectrum access" has broad connotations that encompass various approaches to spectrum reform. The diverse ideas presented at the first *IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN)* suggest the extent of this term. As illustrated in Figure 7, dynamic spectrum access strategies can be generally categorized under three models.

i. Dynamic Exclusive Use Model 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 a spectrum and to freely choose technology. Economy and market will thus play a more important role in driving toward the most profitable use of this limited resource. Note that even though licensees have the right to lease or share the spectrum for profit, such as sharing is not mandated by the regulation policy. The other approach, dynamic spectrum allocation, was brought forth by the European DRiVE project. It 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 as strategies allocate, at a given time and region, a portion of the spectrum to a radio access network for its exclusive use. This allocation, however, varies at a much faster scale than the current policy.

Based on an exclusive-use model, these approaches cannot eliminate white space in the spectrum resulting from the bursty nature of wireless traffic.

ii. Open Sharing Model also referred to as spectrum commons this model employs open sharing among peer users as the basis for managing a spectral region. Advocates of this model draw support from the phenomenal success of wireless services operating in the unlicensed ISM band (e.g., WiFi). It centralized and distributed spectrum sharing strategies have been initially investigated to address technological challenges under this model. [8, 9]

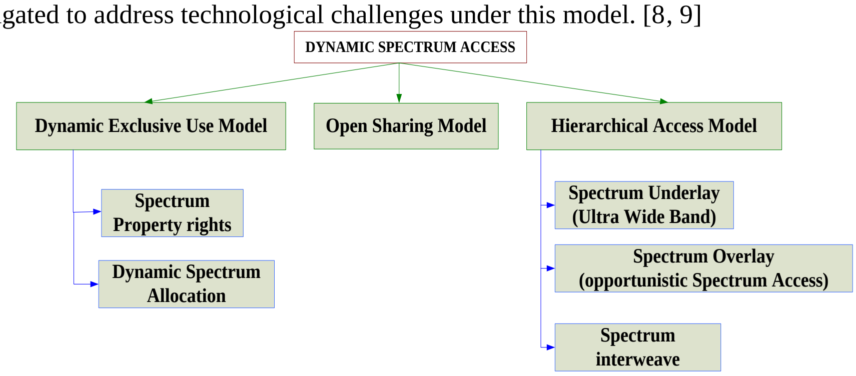

Figure7. Taxonomy of dynamic spectrum access

iii. **Hierarchical Access Model**: In order to allow cognitive radio (CR) to take advantage of the opportunity of spectrum hole (or availability) to transmit, which implies the CR system simultaneously operating in the same frequency bands without affecting the primary system (PS), we need to consider possibilities such as underlay, overlay and interweave.

The underlay approach allows concurrent primary and secondary transmissions by enforcing a spectral mask on the secondary signals so that the interference generated by the secondary users/ nodes is below the acceptable level of primary users. The secondary signal can be typically spread and is usually confined to short-range communications such as ultra wideband (UWB) systems.

The overlay approach allows concurrent primary and secondary transmissions. The secondary nodes/ users can use part of their power for secondary transmissions and the remaining power to assist primary transmissions, as a sort of cooperative relay. Through appropriate splitting power, the increase of the primary user's SNR due to cooperative relay can offset the decrease of the primary user's SNR due to the interference generated by the secondary user(s). Contingent on available side information and sophisticated coding such as dirty paper, codes are commonly used to mitigate interference by secondary nodes/users.

The interweave approach is based on the opportunistic communication, derived from J. Mitola's original idea. There exist temporary frequency voids in a frequency band, which are referred to as spectrum holes, not used by the licensed/primary users. Such spectrum holes pop up according to changes in time and geographical locations. Therefore, CRs must constantly monitor the spectrum typically via physical layer spectrum sensing and then adopt certain medium access strategies to use the spectrum holes as transmission opportunities for secondary transmissions, with minimum (preferably no) interference to nodes/users in PS.

IV. NOVEL COGNITIVE CYCLE

In the traditional cognitive cycle, three tasks interact with each other to handle the outside worlds so that the best strategy can be calculated and it implemented. As aforementioned, the sensing components can. be expensive for the secondary users. Moreover, the hidden terminal problem should be solved so that the primary users' performances are not impaired by the hidden secondary users. In the sequel, we first develop a new cognitive network structure to overcome these challenges, then a low-temperature handshake mechanism is constructed, and finally the proposed protocols are explained [11].

J. Mitola and Haykins Have developed different but similar cognitive cycle concepts. Since we generalize to the cognitive radio 'network' along with the rate-distance concept, novel features are primarily distinguished here. Cognitive radio functions not only sense the spectrum and fitting spectrum resource but also the networking environment, and adapt into cognitive routing in the network level [9]

A. Cognitive Network with Separate Sensing Devices

We propose a new cognitive network structure in which the sensing mechanism is not implemented by the secondary users. Instead, the service provider deploys separate sensing devices in the networks. Those sensing devices are able to detect the primary users' activities and provide the admission control to the second users for spectrum access. In Figure 8, we show the new cognitive cycle in the proposed networks.

Compared with the traditional cognitive cycle, within the secondary user, the soft radio part is still maintained. In other words, the cognitive radio devices can still estimate a channel state, adjust their transmit power, and manage the spectrum access. The difference is that the sensing part is moved to the sensing devices. It is the sensing devices' role for admission control of secondary users. After admission, it is the secondary user's responsibility to combat the hostile wireless channel and maintain the link quality. The expensive sensing devices are moved out of the secondary user which requests cheap implementation cost for consumers.

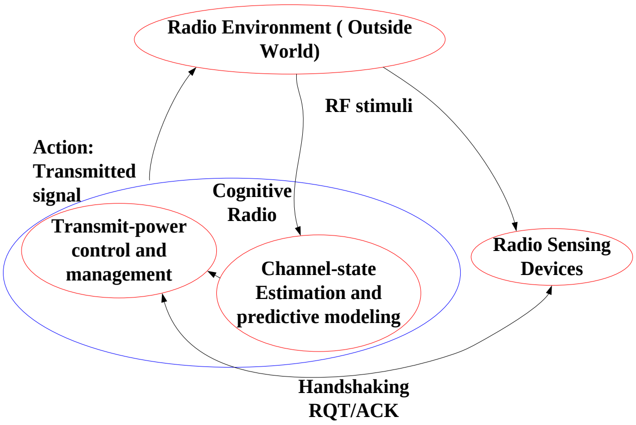

Figure8. Proposed a cognitive cycle

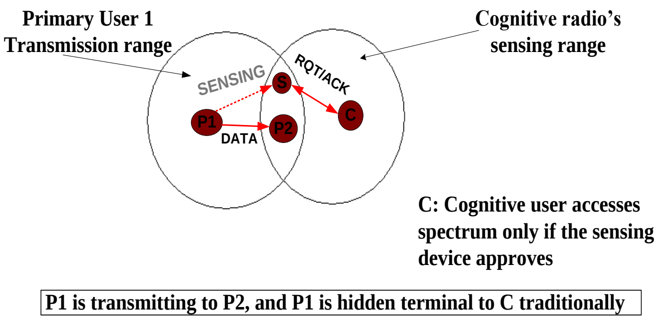

Figure9. Solution of Hidden Terminal Problem by Proposed Sensing Devices

Next, we investigate how the proposed scheme can overcome the hidden terminal problem. In the traditional sensing mechanism, a secondary sender senses the activities (of the primary users) in spectrum prior to its transmission. However, when a secondary sender is close to a primary receiver but far away to the primary sender, it cannot sense the transmission of the primary sender, (*out of range*) and thus transits its packet. The hidden secondary user's transmission then corrupts the desired reception at the primary receiver. It is worthy mentioning that in wireless LAN, the hidden terminal problem can be solved by four-way handshake using Request-To-Send/Clear-To-Send. However, it is impossible to implement the handshake in cognitive radio, since the primary users will not add additional equipments for handshake.

This problem can be solved by the sensing devices. Consider the networks as shown in Figure 9. Primary user P1 transmits to primary user P2. If the secondary user C is equipped with sensing ability, it still cannot realize the existence of primary user P1 due to the hidden terminal problem. Instead, we propose a sensing device S located in the network. Before secondary user C tries to access the primary users' spectrum, it sends requests to the nearby sensing device that senses whether any primary user is utilizing the spectrum. If there is any active primary user, the sensing device sends back a veto message to the secondary user to deny the spectrum access. Otherwise, an acknowledge message is sent to secondary user C to grant the spectrum access. By employing enough number of sensing devices in the networks, the hidden terminal problem is solved and no extra sensing ability is needed for the secondary users.

Moreover, the proposed solution can even improve the expose terminal problem, because the sensing devices can be placed close to the prime receivers and have better correct-sensing-probability than that of cognitive radios with sensing devices.

B. Handshake between Sensing Devices and Secondary Nodes

In the preceding subsection, the licensed (to the primary users) the frequency band is referred to as a data band. The handshake between the sensing devices and the secondary users should not use the data band because the secondary user is not allowed to transmit (its request) until it gets permission. So the handshake is traditionally performed at a separate frequency channel, referred to as a handshake band. As long as a sensing device detects activity of primary users, it will deny any transmission request received in the handshake band from the secondary users. However, there are several challenges in the handshake procedure.

The data transmissions and handshakes are performed at different frequency bands, with probably different channel gains. It is possible that the sensing device may not be able to detect the transmission request from a secondary user due to deep fading at the handshake band. (Unlike data band, handshake band is usually narrow band.) • When there are a number of secondary users, the handshake band may become the bottleneck. In addition, the handshake messages may collide with each other when the secondary users are hidden from each other. • It is very likely that there are a number of sensing devices in the network. When a secondary user sends a request, more than one sensing devices may receive it. Then the feedbacks from the sensing devices will collide at the secondary user.

The first challenge implies that the handshake should be carried out at the data band. And the second and third challenges suggest that the traditional request/feedback at the handshake band may not work well. In the following, a low-temperature handshake is proposed to address the above challenges.

The handshake consists of two portions: a request from the secondary user and a potential veto from the sensing device, both at the data band with low interference temperature. If a secondary user has traffic to send, it first sends a request (at the data band) that has a low transmit power level (much lower than power for its normal data transmission) and is spread by a common request code which is known in advance to the sensing devices and the secondary network. No bit-information is carried by the request. The low temperature of the request is to guarantee that the tolerable interference temperatures of primary users are not exceeded by the extra interference from the request signal.

The spreading code is to get enough gain such that the sensing devices are able to detect the request. Each sensing device continuously detects the received power (from primary users) at the data band. It also scans the common request code for the low-temperature request. If the sensing device detects activity of primary users and also detects a transmission with the common request code, it sends a veto that has a low transmit power level and is spread by a common veto code, to notify the secondary user of the rejection of its transmission request. No bit-information is carried by the veto. After the secondary user sends the low-temperature request, it scans the common veto code. If no veto is detected, the secondary user is allowed to transmit at the data band. It can be seen that, by the low-temperature request and veto, the three challenges (as mentioned at the beginning of this subsection) in the traditional handshake procedure can be solved effectively.

The request is sent at the data band. So the different channel gain problem does not exist anymore. • No bit-information is carried in the request. So when there are a number of secondary users, and they send requests at the same time, the sensing device can detect the energy from all the secondary users by a RAKE receiver. Therefore, the bottleneck effect and collisions of requests are avoided. • When multiple sensing devices send veto messages, the secondary user can use a RAKE receiver to collect all the energy from the veto messages, since no bit-information is carried by the veto. Thus the secondary user can still be notified not to transmit.

C. Protocols for Secondary User and Sensing Device

Finally, based on the discussions in the previous two subsections, we construct the protocol for the secondary user and the sensing device. The secondary user selects the most preferred channel from the set of channels that it can adapt to, and then sends the request to the sensing device for spectrum admission. The sensing device decides if the secondary user can utilize the channel. If the channel is occupied by the primary user, the sensing device sends the veto to prevent the secondary user transmission. Even the access is granted, the sensing device keeps track of admission. If the primary user regains the channel, the sensing device sends the veto to stop all secondary users from transmission in this channel [11]

V. CONCLUSION

In this work, a survey on dynamic spectrum access and cognitive radio techniques is done with intensive details about the traditional cognitive cycle problems. A new cognitive cycle with separate sensing device mechanism is proposed to; It enhances spectrum management, obtains fairness between secondary users, solves the hidden and exposed terminal problems and reduces the cost of adding sensing devices to each cognitive node, which keep the constrains to the legacy network devices. Analysis and comparison with the previous work demonstrate that the new protocol will significantly improve network performance and solve the hidden terminal problem. In the future work simulation will be done to confirm the result with different number of sensing devices in different locations.

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