Cognitive Radio Networks and Security: A Survey

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***Abstract*—In cognitive radio networks (CRNs), cognitive radio (CR) nodes adaptively access the spectrum aiming to maximize the utilization of the scarce resource. Crucial to the successful deployment of CRNs, security issues have begun to receive research interests recently. This article surveys the research advances in CRNs. First, the fundamentals of CRNs including the basic components (*i.e.*, characteristics, opportunistic links, and network architectures), opportunistic spectrum access (OSA), and the inherent issues in CRNs are reviewed. Then, we present the current issues in security for CRNs. The current works on attacks in different layers of CRNs along with the state-of-the-art counter-strategies are investigated in detail.**

***Index Terms*—Cognitive radio networks, security, dynamic spectrum allocation, opportunistic spectrum access.**

I. Introduction

Communication and networking, both of the deepest needs of the human being, is essential to forming social unions, to expressing a myriad of emotions and needs, and it is central to a civilized society. Digital communication [1] and computer networking [2] in engineering have the purpose of providing technological aids to human communication. Recent increases in demand for high quality of service (QoS) ubiquitous digital communication have driven researchers to rethink the implications of the traditional engineering (more bandwidth, more resource, and more of everything, *etc.*) designs and approaches to communications and networking. As a novel communication paradigm, cognitive radio (CR) [3][4] is a key technology that enables dynamic spectrum access networks to utilize the spectrum more efficiently in an opportunistic fashion [5][6][7], and offers a revolutionary perspective in the designs of modern intelligent communication networks [8][9][10]. In a cognitive radio network (CRN), secondary users (SUs), *i.e.*, unlicensed users, are envisioned to be able to sense and analyze their environment, learn from the environment variations, and access the licensed bands to achieve highly reliable communications without interference with the primary users (PUs), *i.e.*, licensed users. Specifically, the main functions of CR technology in CRNs include: (1) *spectrum sensing*, *i.e.*, to determine the available spectrum and detect the presence of PUs; (2) *spectrum management*, *i.e.*, to select the best available channel spectrum sensing to meet users' communication requirements; (3) *spectrum sharing*, *i.e.*, to coordinate access to this channel with other users; and (4) *spectrum mobility*, *i.e.*, to vacate the channel when a PU is detected.

In the past decade, CR and CRNs have been receiving growing attention and extensive research interests. The authors in [11] surveyed the fundamental capacity limits and associated transmission techniques for different wireless network design paradigms based on CR. Spectrum sensing, a first fundamental element in CRNs, was recently surveyed in [12]; Cooperative spectrum sensing in CRNs to enhance the reliability of detecting PUs was reviewed in [13]. The opportunistic spectrum access (OSA) strategies were discussed in [6][7][14]-[15] for CRNs. Recently proposed dynamic spectrum sharing, access, and management schemes have been presented in [16], such as medium access control and scheduling, spectrum handoff, cross-layer design, power control, routing, and cooperation enforcement, *etc.*

Since users in CRNs are intelligent and have the ability to observe, learn, and act to optimize their performance adaptively, *graph theory* and *game theory* are two well-developed tools underpin extensive investigations of networking and users' behaviors [17]. Graph theory is the study of network structure, while game theory provides models of individual behaviors in strategic interaction, such as cooperation and competition. In CRNs, to address the interactions of the dynamics among conditions, resources, environments, and users, A game theoretic modeling is presented that analyzes the behaviors of PUs and SUs. Mechanism design is proposed to suppress the cheating behavior of SUs in open spectrum sharing and accessing by introducing cost functions of users utility.

Because of the interaction and cooperation in CRNs, ensuring security becomes a major and crucial issue. Some users who are attackers are assumed to be malicious, *i.e.*, their goal is to damage the system's functionality, instead of maximizing their own interest. In fact, CRNs are extremely vulnerable to malicious attacks compared to the traditional networks, partly due to SUs' opportunistic access cannot be protected from adversaries. Also, highly dynamic spectrum availability and mobility make it difficult to implement effective security countermeasures. In addition, as CRNs benefit from the technology to adaptively utilize spectrum, the same technology can also be adopted by malicious attackers to launch more complicated and unpredictable attacks. Authors in [10] presented three main themes in the security of CRNs: trust modeling and evaluation, defense mechanism and strategies, and game-theoretically analysis of security. In [18], security threats - *primary emulation* and *spectrum sensing data falsificatin* which destroy the CRNs in distributed spectrum sensing are discussed. An information secrecy game was developed in [19] to foster collaboration between PUs and SUs against eavesdroppers. [20] proposed a channel hopping defense strategy based on the Markov decision process to combat the jamming attacks in CRNs. The authors in [21] gave an overview of the security threats and challenges that CRNs face, along with the current state-of-the-art to detect the

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corresponding attacks.

This article surveys the current advances in CRNs and security for CRNs. In Section II, the fundamentals of CRNs are presented in detail, including basic components in CRNs, opportunistic spectrum access, and several inherent reliability issues in CRNs. Section III overviews the challenges and strategies for the security CRNs. The conclusions are drawn in Section IV.

II. Fundamentals in CRNs

In this section, the fundamentals of CRNs, such as basic components, opportunistic spectrum access, and several inherent reliability issues in CRNs, are reviewed in detail.

A. Basic Components in Cognitive Radio

The main motivation behind CR is to increase the limited-spectrum utilization by allowing SUs to opportunistic access the frequency band actually owned by PUs. CR, built on a software radio platform, is a context-aware intelligent radio potentially capable of autonomous reconfiguration by learning from and adopting to the radio environment [3][4]. CR is a link level technology requiring: reliable sensing information for spectrum utilization, dynamic spectrum access, and possible programmable radio to support, *etc*. So SUs could adjust their transmission to fill in the spectral void, as shown in Figure 1. Authors in [5] presented two main characteristics of CR: *cognitive capability* and *configurability*. The ability to capture or sense the information from its radio environment is referred to as *cognitive capability* of CR; *reconfigurability* of CR is the capability of dynamically adjust operating parameters for the transmitter or/and the receiver without any modifications on the hardware component. Therefore, the cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment.

CR represents a much broader paradigm where many aspects of communication systems can be improved via cognition and networking. When multiple CR devices are interconnected, CRNs are formed along with the existing networks. CRNs open up exciting opportunities to enable and support a variety of emerging applications, ranging from smart grid, public safety and broadband cellular, to medical applications [22], *etc*. Figure 2 gives a simplifed CRN model, which is filled with PUs, SUs, relay nodes, and base stations. Figure 3 shows one opportunistic link window in CRNs. There are two types of (CRN) are being deployed [8] in practice: *centralized* and *distributed*. The centralized network is an infrastructure-based network, where the SUs are managed by secondary base stations which are in turn connected by a wired backbone. In a distributed architecture, SUs communicate with each other in an ad hoc manner. Two SUs who are within communication range can exchange information directly, while the SUs who are not within direct communication range can exchange information over multiple hops. Spectrum sensing operation in distributed architecture is usually performed collaboratively. Collaborative sensing techniques [13] highlight the fact that is the SUs share their relative sensing information, then the

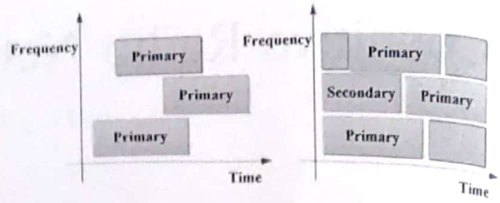

Fig. 1. One of the simplest instance of cognition: a cognitive user senses the time/frequency white spaces and opportunistically transmits over these detected spaces.

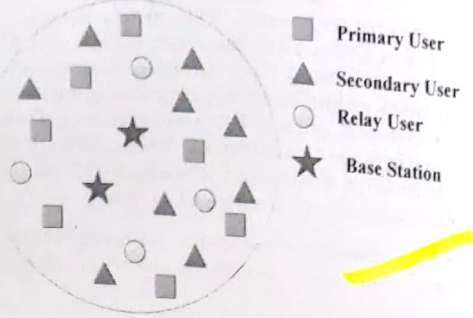

Fig. 2. A simplified cognitive radio network model

overall primary user detection for the cognitive network can be improved. However, these protocols do not consider malicious users in the network.

Figure 4 shows the CRN terminal architecture. Medium access control (MAC) refers to the policy that controls how a SU should access a licensed spectrum band. Due to the new features of CR networks, such as the collision avoidance with a PU and dynamics in spectrum availability, new medium access protocols need to be designed to address the new challenges in CRNs. A cognitive medium access protocol with stochastic modeling is proposed [23], which enhances the coexistence of CR with WLAN systems based on sensing and prediction. A primary-prioritized Markov approach for dynamic spectrum access is proposed in [15][24], which models the interactions between the PUs and the SUs as continuous-time Markov chains. In order to manage the interference among SUs, or avoid harmful interference to PUs due to secondary spectrum usage, various power control schemes are considered in CRNs to coordinate spectrum sharing [7][12][15].

B. Opportunistic Spectrum Access

Opportunistic spectrum access (OSA) is certainly an important application of CRNs, which include spectrum opportunity

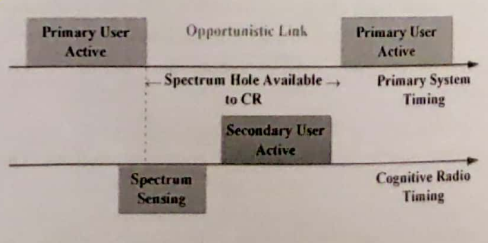

Fig. 3. Opportunistic link in cognitive radio networks

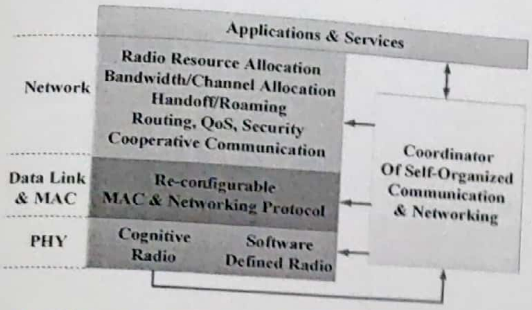

Fig. 4. Cognitive radio network terminal architecture.

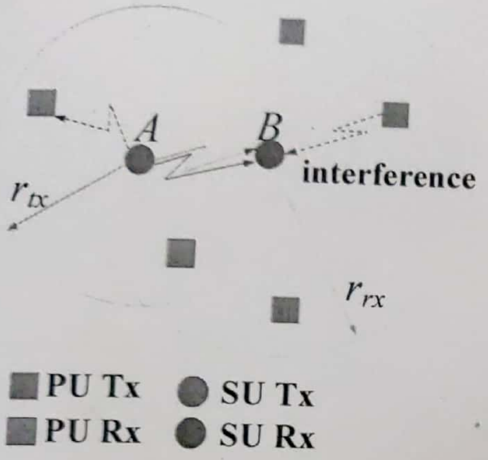

Fig. 5. Illustration of spectrum opportunity (SU A wishes to transmit to SU B, where A should watch for nearby primary receivers and B nearby primary transmitters.)

identification, spectrum opportunity exploitation, and regulatory policy [6]. The overall design objective of OSA is to provide sufficient benefit to SUs while protecting spectrum licensees from interference [7].

Consider a pair of SUs where A is the transmitter and B its intended receiver in Figure. 5. One *channel*[1] is opportunity to A and B if they can communication successfully over this channel while limiting the interference to primary users below a prescribed level determined by the regulatory policy. This means that receiver B will not be affected by primary transmitters, and transmitter A will not interfere with primary receivers. Consider monotonic and uniform signal attenuation and omnidirectional antennas, a channel is an opportunity to A and B if no primary users within a distance of r_{tx} from A are receiving and no primary users within a distance of r_{rx} from B are transmitting over this channel. Clearly, r_{tx} is determined by the secondary users' transmission power and the maximum allowable interference to primary users, while r_{rx} is determined by the primary users' transmission power and the secondary users' interference tolerance. Four classical signal detection techniques [7][12][16] can be employed for

[1]Here the term *channel* is defined in a broad way, *i.e.*, a channel can be a frequency band with certain bandwidth, a collection of spreading codes in a code division multiple access (CDMA) network, or a set of tones in an orthogonal frequency division multiplexing (OFDM) system..

spectrum sensing as follows.

1) Energy Detector: Energy detection is the most common type of spectrum sensing because it is easy to implement and requires no priories knowledge about the primary signal. A good detector should ensure a high detection probability P_D and a low false alarm P_F, or it should optimize the spectrum usage efficiency while guaranteeing a certain level of primary user protection. There also exist some challenges in designing a good energy detector. First, the detection threshold depends on the noise power, which may change over time and hence is difficult to measure precisely in real time. Moreover, an energy detector can only decide the primary user's presence by comparing the received signal energy with a threshold; thus, it cannot differentiate the primary user from other unknown signal source.

2) Feature Detector: There are specific features associated with the information transmission of a primary user. In a more general sense, features can refer to any intrinsic characteristics associated with a primary user's transmission, as well as the cyclostationary features. For example, center frequencies and bandwidths extracted from energy detection can also be used as reference features for classification and determining a primary user's presentence. Different from an energy detector which uses time-domain signal energy as test statistics, a cyclostationary feature detector performs a transformation from the time-domain into the frequency-domaiin and then conducts a hypothesis test in the new domain. Specifically, define the cyclic autocorrelation function (CAF of the received signal $y(t)$ by

$$R_y^{\alpha}(\tau) = E[y(t+\tau)y^*(t-\tau)e^{j2\pi\alpha t}], \qquad (1)$$

where $E[.]$ is the exprction operation, $*$ denotes complex conjugation, and α is the cyclic frequency. Since periodicity is a common property of wireless modulated signals, while noise is WSS, the CAF of the received signal also demonstrates periodicity when the primary signal is present. Thus, we can represent the CAF using its Fourier series expansion, called the cyclic spectrum density (CSD) function, expressed as

$$S(f,a) = \sum_{\tau=-\infty}^{\infty} R_y^{\alpha} e^{-j2\pi f\tau}. \qquad (2)$$

The CSD function have peaks when the cyclic frequency α equals to the fundamental frequencies of the transmitted signal $x(t)$, *i.e.*, $\alpha = (k/T_x)$ with T_x being the period of $x(t)$.

3) Matched Filtering and Coherent Detection: If secondary users know information about a primary user' signal a priori, then the optimal detection method is the matched filtering, such a matched filter can correlate the already known primary signal with received signal to detect the presence of the primary user and thus maximize the SNR in the presence of additice stochastic noise. Matched filtering requires perfect knowledge of the primary user's signal, such as the operating frequency, bandwidth, modulation type and order, pulse shape, packer format, *etc*.

4) Collaborative Spectrum Sensing: It is known that wireless channels are subject to fading and shadowing. When secondary uses experience multipath fading or happen to be

AN OVERVIEW OF COGNITIVE RADIO NETWORKS

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Table 1. Existing Frequency Assignment for Different Services

Service	Frequency
E-GSM-900 (Mobile)	880–915, 925–960 MHz
DCS (Mobile)	1710–1785, 1805–1880 MHz
FM radio (Broadcasting)	88–108 MHz
Standard C Band (Satellite communication)	5.850–6.425, 3.625–4.200 GHz
Nondirectional radio beacon (Navigation)	190–1535 kHz

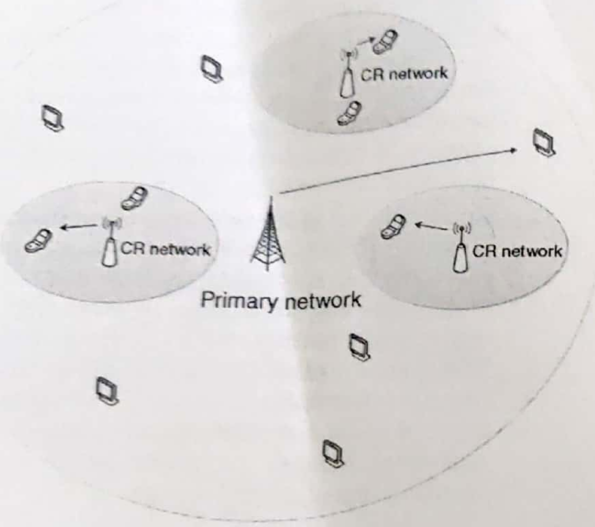

Figure 1. Cognitive radio (CR) networks existing within a primary network.

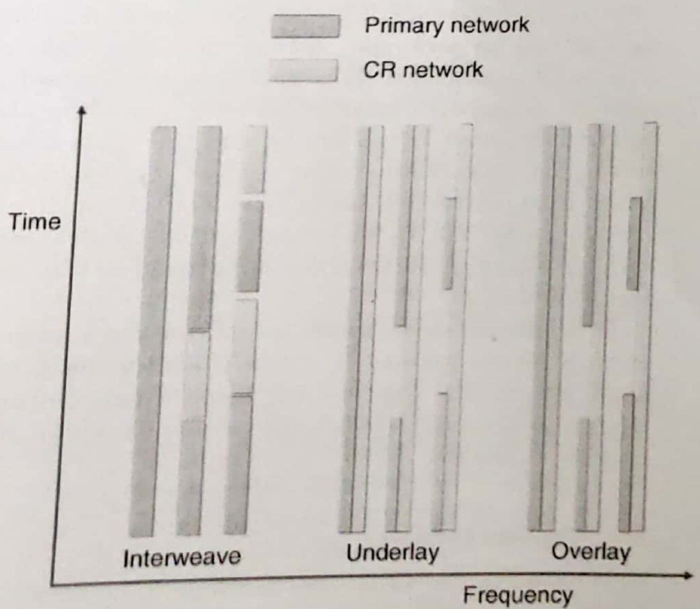

Figure 2. Interweave, underlay, and overlay modes of cognitive radio.

(e.g., message) encoding methods (code book) (17,19). This information can be utilized in two different ways. First, it can be used to cancel the PU interference on SU receivers, using canceling techniques such as dirty paper coding (DPC) that precodes transmitted data to negate the effects of interference (31). Second, it can be used by SU nodes to cooperate with the primary network by relaying PU messages.

2. COGNITIVE RADIO FUNCTIONALITIES

To enable opportunistic spectrum access, the key functions of CR networks are (1) spectrum sensing, (2) spectrum management and decision, (3) spectrum sharing, and (4) spectrum mobility (15). These are briefly described next.

2.1. Spectrum Sensing

This refers to detecting spectrum holes accurately. Furthermore, it must be ongoing and continuous such that whenever the PU reaccesses the spectrum, it indicates to CR nodes to cease transmission immediately. It can be implemented via in-band sensing, out-of-band-sensing, and geolocation databases (Section 3). It also helps to adjust additional parameters such as power levels, codes, and frequencies in order to limit unwanted interference (15).

2.2. Spectrum Management and Decision

When multiple spectrum holes are distributed over a wide frequency range (15), spectrum management involves selecting the best possible one. The choice is made by considering transmit power, bandwidth, modulation schemes, coding schemes, and scheduling (15). The choice also depends on Quality of Service (QoS) criteria for the needs of CR communication, such as packet error rate, latency, and throughput, and these can be based either on the optimality for a single pair of communicating nodes or for a whole set of CR devices. In the latter case, a central entity makes the decisions and disseminates those to the participating nodes.

Before a spectrum decision can be made, the available spectrum holes must be characterized based on the following factors (10,15):

(a) Interference on the primary network: The potential interference on primary network when using a spectrum hole depends on several factors. For a given spectrum hole within a specific geographical area, there may be adjacent PUs, which also could be subject to interference. Furthermore, underlay nodes can transmit even with PU activity. In addition, even if a nearby PU transmitter is silent, it may reaccess the spectrum hole at any moment. If multiple spectrum holes exist that are otherwise equal apart from potential interference to the PUs, the one with the lowest potential interference must be chosen.

(b) Mutual CR interference: This occurs when multiple CR nodes access the same spectrum hole. Thus, the level of their mutual interference is a factor in choosing the spectrum hole. Low potential interference levels permit the use of higher transmit powers, and thus higher order constellations such as 256 QAM (quadrature amplitude modulation) may be used instead of lower order QPSK (quadrature phase shift keying).

However, in a CR network, the available channels change in a dynamic manner, and thus the hopping sequences must adapt accordingly. Rendezvous-based control channels and ultrawideband control channels (13).

5.3. Spectrum Sharing

Spectrum sharing can be accomplished for CR networks using several criteria (13). These are the protection of PUs and fairness among SUs. Several of these methods are described below.

CSMA (Carrier Sense Multiple Access). CSMA is a multiple access protocol where a device senses a shared channel before transmitting. It is well suited to the dynamics of CR networks due to its adaptability and robustness. Furthermore, it can be implemented without any global controller or a control channel. Moreover, CSMA-based schemes may also provide PU protection due to power control features (13). However, before any CSMA scheme is applied to a CR network, it needs to be adapted keeping in mind the PU activities and QoS requirements of the SUs (19).

By applying PTS/RTS/CTS mechanisms, Chen et al. (121) tweaked the traditional CSMA/CA protocol to adapt it to the CR context. Asynchronous spectrum sensing is accomplished by sending a prepare to sense (PTS) frame to neighbouring SUs, requesting these devices to cease transmission in a following time duration. Only then would the original CR device sense the spectrum. Furthermore, a blocking mechanism may be implemented when PUs are active, which temporarily halts the back-off timer.

Dynamic Frequency Hopping. In this spectrum sharing technique, the available spectral blocks are shared among CR devices by assigning each a specific hopping sequence. In order to be robust to dynamic channel availabilities, a constant monitoring process is needed, and the hopping sequences need to be changed dynamically. To achieve this, ideally a central controller and a control channel are needed.

TDMA (Time Division Multiple Access)/FDMA (Frequency Division Multiple Access). The available time–frequency blocks are shared between participating SU nodes. For this scheme to work, the underlying primary network must also use this as a multiple access scheme (13). One disadvantage with this scheme is that some time frequency blocks may need to be released due to PU activity sooner than others, and SUs accessing those blocks may be at a temporary disadvantage.

CDMA (Code Division Multiple Access). This approach is most attractive for underlay CR (13) because SUs can use orthogonal codes to access spectrum irrespective of whether PUs are active. The interference from CR signals will be added to the noise floor of the PUs and other CR devices. Therefore, stringent transmission power limits have to be enforced such that the interference power experienced by PUs is less than an acceptable limit. Disadvantages of CDMA include the requirement of a wide bandwidth and the need for significant control information.

Stochastic Approaches. These use probabilistic objectives to reduce PU interference (122), and are most attractive when there is no common control channel. The channel selection procedure is treated as an optimization problem providing the highest probability to access a potential channel, and can be solved according to a Markov chain Monte Carlo method (122). The primary prioritized Markov approach can also be used for dynamic spectrum access in a stochastic manner where the interactions between PUs and CR devices are modeled as continuous time Markov chains (123).

Several other more specialized protocols such as dynamic open spectrum sharing (DOSS), single radio adaptive channel (SRAC), opportunistic spectrum medium access control (OS MAC), cognitive medium access control (C MAC), cognitive mesh network (COMNET), hardware constrained medium access control (H MAC), and others have also been proposed (43,120). As a final note, any MAC spectrum access strategy must consider the fluidity of available channels, the disparity of channels that may be separated by vast swathes of frequency, and the presence or absence of a control channel.

5.4. Routing

When CR devices relay data/packets from an originating CR to a destination, efficient routing protocols are needed (15,43). Routing in CR networks is a critical issue because available spectrum holes are spread far and wide (19). Furthermore, the spectrum availability for a particular node changes with time, and neighbouring nodes may not identify the same frequency band for opportunistic access. Therefore, the routing algorithms should be able to handle the dynamics of the CR environment, and deploying legacy routing algorithms designed for general ad hoc networks may not be suitable (124).

The issues with routing in a CR networks include the unavailability of a control channel to share link information needed for dynamic routing protocols among neighbours, reachability of CR devices being hampered due to channel dynamics, the necessity of having rerouting algorithms to alter the route when one or more CR devices become unavailable due to interruptions from the primary system, the inadequacy of traditional routing metrics, and managing queues of different packets in a dynamic spectral environment (15,124). For example, packets may arrive at a particular CR device when it had identified spectrum holes for communication. However, these may become unavailable. A question arises on what to do with the received packets. Furthermore, similar to ad hoc networks, most of the opportunistic links in a CR network may be unidirectional, and thus need to be identified as such. Moreover, instead of the traditional single-path routing schemes, multipath routing where multiple redundant paths exist to the destination are more attractive for the dynamic spectral environment CR nodes operating in Reference 124. However, additional metrics such as route sta-

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Cognitive Radio Networks: A Survey

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***Abstract*— Cognitive Radio (CR) technology is developed to overcome the spectrum scarcity due to rapid development in wireless networks. Both licensed and unlicensed users can utilize the spectrum using this technology. Spectrum is allocated dynamically in cognitive radio networks thus it increases the spectrum utilization. The unlicensed users can transmit in the vacant spectrum already assigned to licensed users with minimum level of interference. It senses the spectrum to find the vacant spectrum and choose the best spectrum which meets the required QoS of the unlicensed users. The unlicensed users leave the spectrum whenever the licensed users return. This paper tries to give a comprehensive description of cognitive radio and its functions such as spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility.**

***Index Terms*—Cognitive radio, spectrum sensing, spectrum decision, spectrum sharing, spectrum mobility.**

I. INTRODUCTION

With the rapid development in communication applications the spectrum becomes more congested and also the need for data rate increased. Radio spectrum is a limited resource and the service is allocated by fixed spectrum assignment. So some frequencies are heavily used and other bands are weakly used. The number of devices utilizing the unlicensed spectrum is growing, which indicates the increase in spectrum demand. So spectrum scarcity is a major issue faced by wireless networks. In order to overcome this issue Dynamic spectrum access (DSA) is introduced, which improves the spectrum efficiency. In DSA the unlicensed systems are allowed to use the licensed bands without interfering the existing user. So the weakly used spectrum can be used by other users. Cognitive Radio (CR) uses dynamics spectrum allocation which provides higher bandwidth and efficient spectrum usage. CR enables to reuse the licensed spectrum in unlicensed manner i.e., it open the licensed bands to unlicensed users to use them without causing any interference to the licensed user. Radio sensing, self-adaptation and dynamic spectrum sharing are the abilities of CR. Spectrum underutilization and spectrum scarcity can be mitigated by an efficient spectrum usage of CR.

CR network contains two types of users: primary user (PU) and secondary user (SU). Licensed users are PU. They have the higher priority to access the channel. SU are unlicensed user. They can access the spectrum only in the absence of the PU. The SU can use the channel without causing any interference to the PU. SU wants to leave the channel when the PU reappears. SU is also called as Cognitive Radio (CR) user. CR users choose the vacant portion of the spectrum which can meet its QoS.

Paper is organized as follows: background concepts and functions of cognitive radio are overviewed in section II. In section III, various spectrum sensing techniques are explained and compared. Spectrum decision is briefed in section IV. Spectrum sharing classifications are described in section V and in section VI various spectrum mobility strategies are compared. Finally, the paper is concluded.

II.COGNITIVE RADIO

Cognitive radio is a radio which alters its transmission parameters according to the environment in which it operates. Cognitive radio is dynamic in nature. The main objective of CR is to choose the best spectrum. The CR user senses the spectrum in order to find the vacant one. The vacant spectrum is called as the spectrum holes or white space. CR user continues its transmission until the PU reappears otherwise it leaves the spectrum as illustrated in Fig. 1 [8]. The CR user should be aware about the interference level with the PU. For seamless transmission it moves to new vacant spectrum.

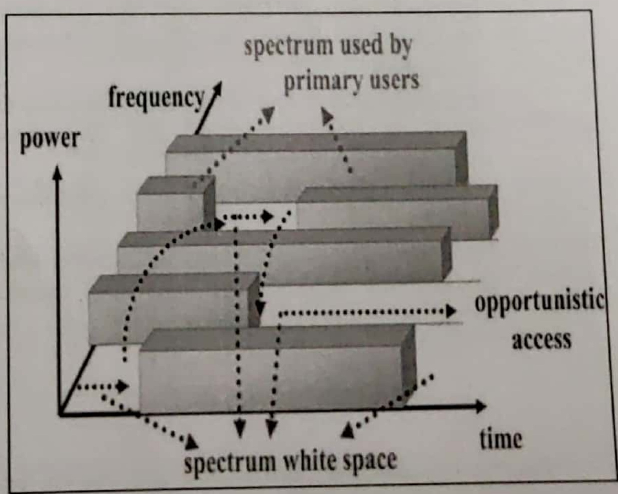

Fig.1. Spectrum hole concept

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The CR transceiver contains a Radio Frequency (RF) unit, analog to digital converter and baseband processing unit. RF and analog to digital converter together called as the RF front end. General CR transceiver is shows in Fig. 2 [2]. The RF front end amplifies the received signal and it converted to digital signal. Then the signal is modulated/demodulated and encoded /decoded at the base processing unit.

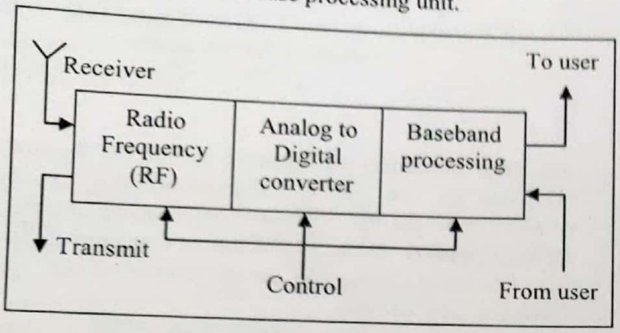

Fig.2. Cognitive radio transceiver

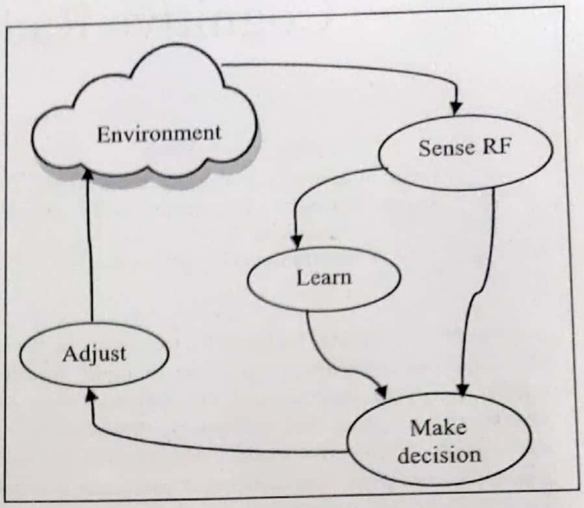

Fig.3. Cognitive cycle

The main characteristics of cognitive radio are:

- Cognitive capability: It refers to the ability of CR node to sense and gather the information such as transmission frequency, bandwidth, power, modulation, etc from its environment. By appropriate sensing the SU can choose the best spectrum by adjusting the parameters.
- Reconfigurability: It adjusts the parameters such as operating frequency, modulation, transmission power, etc. based on the gathered information without any modification in hardware components [13].

The main functions of CR are illustrated in Fig. 3. The CR senses the environment and collects the information. Based on this it make a decision and adjust the parameters. These functions are named as spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility.

- Spectrum sensing: CR senses the spectrum and determines the spectrum holes. Also it captures their information.
- Spectrum decision: Out of the sensed spectrum the CR selects the best spectrum and determines the transmission parameters.
- Spectrum sharing: It coordinates the spectrum access with other users.
- Spectrum mobility: SU vacate the channel when the licensed user reappears. For continuous transmission the CR user moves to another spectrum hole.

III. SPECTRUM SENSING

Channel selection and spectrum hole detection are the main functions of spectrum sensing. CR should be aware of the surroundings. Normally, CR senses the spectrum in order to find the presence of PU. More the sensing time, the gathered information will be more accurate. But it decreases the transmission time. In cooperative sensing, the sensing time can be decreased due to the cooperation between the users. Spectrum sensing can be classified into:

A. Primary transmitter detection

Primary transmitter detection detects the weak signal from primary transmitter [11]. It is also called as non-cooperative detection. The CR user configures itself based on the information sensed. Different non-cooperative sensing techniques are:

- Energy detection: *CR* user sense the presence of PU by analyzing the energy of the received signal. If the energy of the signal is greater than the threshold then PU is present otherwise PU is absent [14]. Threshold value is calculated based on the channel condition.
- Matched filter detection: It gives optimal detection in AWGN channel and maximizes the SNR. Prior knowledge of signal is required in matched filter feature detection. The received signals are compared with the primary user signals. Main advantage of matched filter is it needs less time to attain high processing gain [9]. If the prior knowledge such as modulation type, pulse shape, packet format are incorrect then it performs poorly.
- Cyclostationary feature detection: In cyclostationary detection, the PU transmissions can be detected by analyzing the cyclostationary features of received signals [3]. The cyclostationary features can be periodicity in signal, mean, autocorrelation. It has the ability to differentiate the noise from PU signal. If the autocorrelation of the received signal is calculated as