International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in

Vol.4., Issue.2., 2016 (Mar-Apr)

REVIEW ARTICLE

ISSN: 2321-7758

COGNITIVE RADIO: A NOVEL SOLUTION TO SPECTRUM SCARCITY

AVNEET KAUR

2nd year M.Tech, Dept. Of Electronics & Communication, Guru Nanak Dev Engineering College, Ludhiana

ABSTRACT

In the wireless communication, the radio spectrum is allocated to multiple users . But the spectrum occupied by the various wireless applications is not distributed in a uniform manner. Some part of spectrum is rarely used while other is used extensively leading to unbalanced usage of frequency spectrum. So the cognitive radio technology is used to make maximum utilization of available licensed bandwidth. It is the one of the solutions to solve the spectrum scarcity problem and supports increasing demand of the wireless communications by allowing the unlicensed users to access the licensed frequency band along with the licensed users. The licensed users (primary users) have been assigned the fixed parts of the channel and they can access it at any time. But they are not active for all the time, so cognitive radio technology allows unlicensed users (secondary users) to use unoccupied channels of licensed spectrum.[1] Thus, the secondary users are dynamically allocated to occupy certain parts of spectrum, based on primary users activities.

Keywords : Cognitive Radio (CR) ; Software defined Radio (SDR) ; Primary user (PU); Cognitive radio ad hoc network (CRAHN) ; Spectrum sensing; Cognitive Cycle.

I. **Introduction:** A ''Cognitive Radio'' is an intelligent radio technology built on software defined radio (SDR) that can change its transmitter parameters by awareness of the environment in which it operates.[2]

Two main characteristics of the cognitive radio can be defined as follows:

A. Cognitive capability: Cognitive capability refers to the real-time interaction with radio environment and provides spectrum awareness. This capability requires sophisticated techniques, such as autonomous learning and certain decisions that are required to capture the temporal and

spatial variations in the radio environment and avoid interference to other users. Through Cognitive capability, spectrum holes can be identified at specific time or location. Thus the best spectrum and appropriate operating parameters can be selected. [3]

B. Reconfigurability: This capability is provided by a platform known as software-defined radio, upon which a cognitive radio is built. SDR is a practical reality today, because of the convergence of two technologies: digital radio, and computer software [4]. It is equipped with devices with reprogrammable features (e.g. FPGA or general purpose processors) that can change their physical layer parameters dynamically without any modifications of the hardware components. Thus CR can be programmed on the fly to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design [5] .This capability enables the cognitive radio to adapt easily to the dynamic radio environment. There are several reconfigurable parameters that can be incorporated into the cognitive radio as explained below:

- Operating frequency: On the basis of information about the radio environment, the most suitable operating frequency can be determined and the communication can be dynamically performed on this appropriate operating frequency.'
- Modulation: The modulation scheme adaptive to the user requirements and channel conditions is chosen .e.g., in delay sensitive applications, the data rate is more important than the error rate. Thus, the modulation scheme with higher spectral efficiency should be selected. Similarly for loss-sensitive applications focus is on modulation schemes with low bit error rate.
- Transmission power: If higher power operation is not necessary, the cognitive radio reduces the transmitter power to a lower level to allow more users to share the spectrum and to decrease the interference.
- Communication technology: A cognitive radio can also be used to provide interoperability among different communication systems. The transmission parameters of a cognitive radio can be reconfigured not only at the beginning of a transmission but also during the transmission.

II. Network Architecture

On the basis of network architecture, cognitive radio (CR) networks can be classified as infrastructure-based CR network and the CRAHNs (Cognitive radio adhoc networks).The infrastructure-based CR network has a central network entity, such as a base station in cellular networks. The observations and analysis performed by each CR user feeds the central CR base-station, so that it can make decisions on how to avoid interference with primary networks. As per this decision, each CR user reconfigures its communication parameters, as shown in Fig. 1a. But CRAHN does not have any infrastructure backbone. Thus, a CR user can communicate with other CR users through adhoc connection on both licensed and unlicensed spectrum bands.

Each user needs to have all CR capabilities and is responsible for determining its actions based on the local observation, as shown in Fig. 1b. Since CR user cannot predict the influence of its actions on the entire network with its local observation, cooperation schemes are essential, where the observed information can be exchanged among devices to increase the knowledge of the network [2].

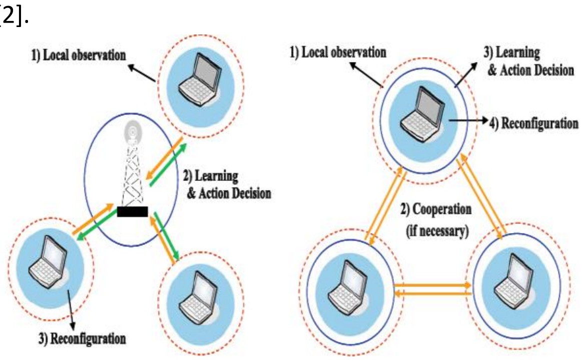

Fig.1: a) infrastructure-based CR networks b) CRAHNs

III. Components of CR Network:

The components of the CRAHN architecture are classified as the primary network and the CR network.

Primary network: It is an existing network infrastructure that has an exclusive right to a certain spectrum band, e.g. cellular and TV broadcast networks. The components of the primary network are as follows:

– Primary user: Primary user (or licensed user) has a license to operate in a certain spectrum band. This access is controlled by the primary base-station and is not affected by the operations of any other unlicensed users. Primary users do not need any modified or additional functionality for coexistence with CR base-stations and CR users.

– Primary base-station: Primary base-station (or licensed base-station) is a fixed component which has a spectrum license e.g., base-station transceiver system (BTS) in a cellular system. This base-station does not have any CR capability for sharing spectrum with CR users.

CR network: CR network (or secondary/ unlicensed network) does not have a license to operate in a desired band. Hence, access to spectrum is allowed only in an opportunistic manner. This network can be deployed as an infrastructure network or an adhoc network as shown in Fig.2. The components of a CR network are:-

– CR user: CR user has no spectrum license. Hence, some additional functions are required to share the licensed spectrum band.

– CR base-station: CR base-station is a fixed infrastructure component with CR capabilities. This station provides single hop connection to unlicensed users. Through this connection, CR user can access other networks.

– Spectrum broker: Spectrum broker (or scheduling server) is a central network entity that plays a role in sharing the spectrum resources among different CR networks. Spectrum broker can be connected to each network and can serve as an information manager to enable coexistence of multiple CR networks.

Flexible spectrum management is needed for wireless devices that operate in either the licensed band or the unlicensed band, or both. Hence, the functionalities required for CR networks vary according to whether the spectrum is licensed or unlicensed:

– Operation in Licensed band: CR users try to exploit the unused spectrum holes in the licensed spectrum band. However, priority is given to primary user (PU), so CR users must be able to detect the presence of a PU as interference avoidance with primary users is the most important issue in this architecture and should vacate the spectrum band immediately if a PU appears in the spectrum band occupied by a CR user .This is called spectrum handoff.

– Operation in Unlicensed band: if no primary user is occupying the spectrum, then CR users have equal right to access the spectrum. . Multiple CR networks coexist in the same area and communicate using the same portion of the spectrum. CR users focus on detecting the transmissions of other CR users and they compete with each other for the same unlicensed band. Intelligent spectrum sharing algorithms can improve the efficiency of spectrum usage and support high QoS.

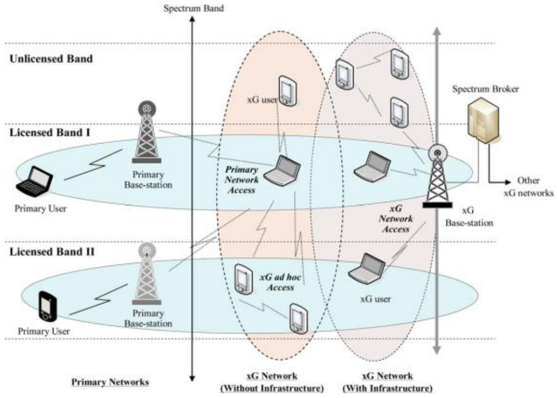

Fig.2 The CRAHN architecture

III. Transceiver Architecture

The architecture of a CR transceiver is shown in Fig 3 .Its main components are the radio front-end and the baseband processing unit. All components can be reconfigured via a control bus in order to adapt to the time-varying RF environment. At the RF front-end, the received signal is first amplified, mixed and then A/D converted. In the baseband processing unit, the signal undergoes modulation/demodulation and encoding/decoding. However, it is the RF front-end that makes CR network distinct. The main characteristic of CR transceiver is a wideband sensing capability of the RF front-end which is possible because of RF hardware technologies such as wideband antenna, power amplifier, and adaptive filter. RF hardware for the cognitive radio should be capable of tuning to any part of a large range of frequency spectrum.

A general wideband front-end architecture for the CR has the following structure as shown in Fig.4.The components of a cognitive radio RF front-end are as follows [3]:

- RF filter: It is a bandpass filter that selects the desired RF signal.
- Low noise amplifier (LNA): The LNA minimizes noise component while amplifying the desired signal simultaneously.
- Mixer: Here, the received signal is mixed with locally generated RF frequency and

converted to the baseband or the intermediate frequency (IF).

- Voltage-controlled oscillator (VCO): It generates a signal at a specific frequency and given voltage so to mix with the incoming signal. This procedure converts the incoming signal to baseband or an intermediate frequency.
- Phase locked loop (PLL): This unit locks the signal on a specific frequency and can also generate precise frequencies with fine resolution.
- Channel selection filter: It is used to select the desired channel and to reject the adjacent channels. The direct conversion receiver uses a low-pass filter for the channel selection. But the superheterodyne receiver adopts a bandpass filter.
- Automatic gain control (AGC): The AGC maintains the gain or output power level of an amplifier constant over a wide range of input signal levels.

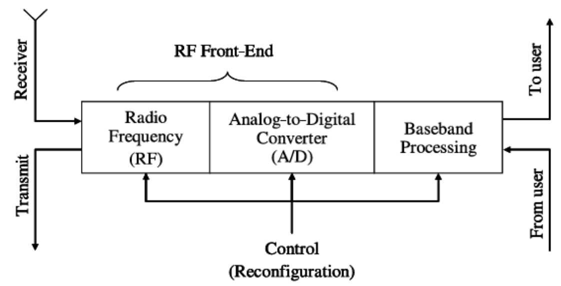

Fig.3 Cognitive radio transceiver

Operation:

A wideband signal received through the RF front-end is sampled by the high speed A-to D converter, and measurements are performed for the signal detection of the licensed user.

The wideband RF antenna receives signals from various transmitters operating at different power levels, bandwidths, and locations. Thus RF frontend should have the capability to detect a weak signal in a large dynamic range. This capability requires a multi-GHz speed A/D converter with high resolution, which might be infeasible. It has necessitated the dynamic range of the signal to be reduced before A/D conversion. This reduction can be achieved by filtering strong signals. Tunable notch filters are required for this purpose as strong signals can be located anywhere in the wide spectrum for spectrum sharing with cognitive networks. Therefore, cognitive radios should be able to independently detect PU presence through continuous spectrum sensing. Spectrum sensing is a general term that involves obtaining the spectrum usage characteristics across multiple dimensions such as time, space, frequency, and code. Generally, the spectrum sensing techniques can be classified as shown in Fig.6

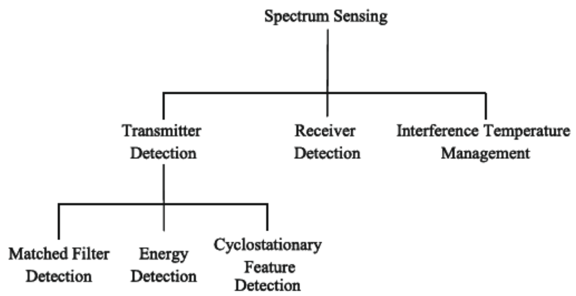

Fig.4 Classification of spectrum sensing.

i) Primary transmitter detection: This approach is based on the detection of the weak signal from a primary transmitter through the local observations of CR users. It includes several techniques such as energy detection, cyclostationary detection, filter matching, etc.

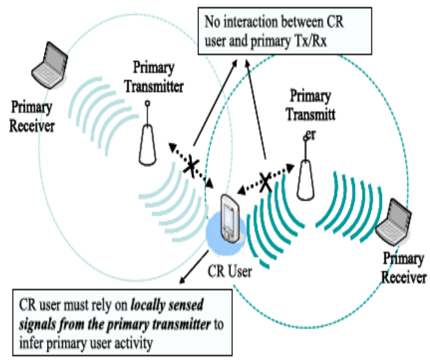

Fig. 5 Transmitter Detection

ii) Primary receiver detection: This aims at finding the PUs that are receiving data within the communication range of a CR user. As shown in Fig.7b, the local oscillator (LO) leakage power emitted by the radio frequency (RF) front-end of the primary receiver is used, which is typically weak. Though it provides the most effective way to find spectrum holes, currently this method is only feasible in the detection of the TV receivers.

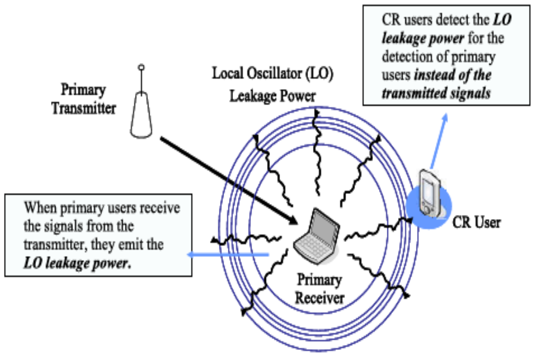

Fig.6 Receiver Detection

iii) Interference temperature based Detection :- The FCC Spectrum Policy Task Force has recommended new metric called the interference temperature. It is a measure of the power and bandwidth occupied by an interferer. Any transmission in a band is considered to be harmful if it would increase the noise floor above the interference temperature limit. Therefore, any unlicensed transmitter using a certain band must guarantee that its transmissions added to the existing interference does not exceed the interference temperature limit at a licensed receiver.

Spectrum decision: The characteristics of the spectrum holes that are detected through spectrum sensing are estimated. When all the available spectrums are identified, it is essential that CR user must select the most appropriate band according to its QoS requirements. New spectrum management functions are required for CR networks, considering the dynamic spectrum characteristics. Each spectrum hole must be characterized on the basis of not only the time-variant radio environment but also the PU activity, spectrum band information such as operating frequency and bandwidth. Hence, certain parameters are specified essentially that can represent the quality of a particular spectrum band such as interference level, channel error rate, path loss, link layer delay, and the holding time which refers to the expected time duration that the CR user can occupy a licensed band before getting interrupted. Channel capacity is the most important factor for spectrum characterization.

Spectrum sharing: Since there may be multiple CR users trying to access the spectrum, their transmissions should be coordinated to prevent collisions in overlapping portions of the spectrum. It provides the capability to share the spectrum resource opportunistically with multiple CR users which includes resource allocation to avoid interference caused to the primary network. Furthermore, this function necessitates a CR medium access control (MAC) protocol, which facilitate the sensing control to distribute the sensing task among the coordinating nodes as well as spectrum access to determine the timing for transmission.

Spectrum mobility: It is the process when a CR user changes its frequency of operation either because the current channel conditions become worse or a primary user appears. This situation gives rise to handoff in CR networks is called, spectrum handoff [6]. If a PU is detected in the specific portion of the spectrum in use, CR users should vacate the spectrum immediately and continue their communications in another vacant portion of the spectrum. Thus, spectrum mobility necessitates switching the current transmission to a new route or a new spectrum band with minimum quality degradation. All this needs co-ordination with spectrum sensing, neighbor discovery in a link layer, and routing protocols. Further, this functionality requires a connection management scheme to sustain the performance of upper layer protocols by mitigating the influence of spectrum switching.

Conclusion

Radio spectrum is a precious resource in wireless communication systems, and it has been the focus of many research efforts over the last several decades. Cognitive radio networks assures to solve current wireless network problems resulting from the limited spectrum and the inefficiency in its usage by introducing the opportunistic usage of frequency bands that are not frequently occupied by licensed users. However, this must be done so that minimum interference is caused to existing users. Luckily, the advances in software defined radio have enabled the development of flexible and powerful radio interfaces for supporting spectral alertness.

Current researcher efforts are directed in developing the protocols required for CR networks.

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