International Conference on Emerging Trends in Engineering, Science and Management
Sphoorthy Engineering College, Hyderabad, India (ESM-17)
17th and 18th March 2017 , www.conferenceworld.in ISBN: 978-93-86171-32-0

COGNITIVE RADIO TECHNOLOGY: ARCHITECTURE, SENSING AND APPLICATIONS-A SURVEY

G. Mukesh[1], K. Santhosh Kumar[2]

[1]*Assistant Professor, ECE Dept., Sphoorthy Engineering College, Hyderabad*
[2]*Assistant Professor, ECE Dept., Sphoorthy Engineering College, Hyderabad*

ABSTRACT

There have been rapid advancements in the field of wireless communications and the number of devices which can be accessed in the licensed and unlicensed bands of the electromagnetic spectrum have been increasing by leaps and bounds. In the past, spectrum allocation was based on the specific band assignments designated for a particular service. 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. Moreover, large portions of the licensed spectrum bands are vastly underutilized. The significant underutilization of the licensed spectrum coupled with the heavy overutilization of the unlicensed portion of the wireless spectrum has motivated the need for a new spectrum management paradigm that can be accessed in a dynamic way. This is where the cognitive radio technology comes into picture.

Keywords: Cognitive Radio Networks, Dynamic Access, Spectrum Sensing Algorithms, Spectrum Utilization and Allocation, Efficiency Of Spectrum Utilization.

I INTRODUCTION

The wireless communications technology has recently extended beyond personal communication services to safety monitoring, wearable/embedded health monitoring, disaster relief, traffic control, and broadband access at high mobility. Due to the rapid advance of wireless communications, a tremendous number of different communication systems exist 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.

On the other hand, radio propagation favors the use of spectrums under 3 GHz due to non-line-of-sight propagation. Consequently, many more devices, up to 1 trillion wireless devices by 2020, require radio spectrum allocation in order to respond to the challenge for further advances in wireless communications. The current allocation policy of the wireless spectrum is to statically grant exclusive rights to licensees or services on a long-term basis over vast geographical areas.

Moreover, large portions of the licensed spectrum bands are vastly underutilized. The unlicensed spectrum bands, e.g., the 900MHz, 2.4GHz and 5GHz industrial, scientific and medical (ISM) bands, have become very crowded. More specifically, the measurements showed that the licensed spectrum is underutilized for 15–85% of the time depending on the spatial location. The significant underutilization of the licensed spectrum coupled with the heavy overutilization of the unlicensed portion of the wireless spectrum has motivated the need for a new spectrum management paradigm. This spectrum management paradigm is referred to as Opportunistic Spectrum Access (OSA), Dynamic Spectrum Access (DSA), or Flexible Spectrum Use (FSU).

Opportunistic Spectrum Access (OSA) refers to the communications paradigm in which the communicating parties *dynamically* exploit the spectrum bands that are not utilized by the primary wireless services licensed to operate over such bands. OSA implies that the communicating parties will search for another unutilized spectrum band to exploit during the absence of activities of its licensed users.

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. CR technology aims at providing a solution to the wireless spectrum scarcity problem that tackles new wireless services while improving the efficiency of the utilization of the licensed spectrum bands.

II COGNITIVE RADIO TECHNOLOGY

A cognitive radio is the key technology that allows a cognitive wireless terminal to dynamically access the available spectral opportunities. A cognitive radio was defined by Mitola in his seminal work as “a radio or system that senses, and is aware of, its operational environment and can dynamically and autonomously adjust its radio operating parameters accordingly”

This definition was generalized by the FCC to be “a radio or system that senses its electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets.”

From these definitions, a cognitive radio has two key features that distinguish it from a traditional radio: the cognition capability and the reconfigurability.

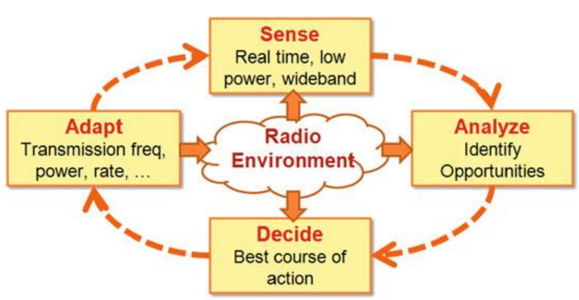

Figure 1: Functional Architecture of Cognitive Radio

The cognition capability of a cognitive radio is defined as the ability of the cognitive radio transceiver to sense the surrounding radio environment, analyze the captured information and accordingly decide the best course of action(s) in terms of which spectrum band(s) to be used and the best transmission strategy to be adopted. Such a cognition capability allows a cognitive radio to continually observe the dynamically changing surrounding radio environment in order to interactively come up with the appropriate transmission plans to be used.

Primary Users (PUs): Users who have higher priority or legacy rights on the usage of a specific part of the spectrum or who are the license holders of the spectrum.

Secondary Users (SUs): Users who have a lower priority and therefore exploit the spectrum in such a way that it does not cause interference to primary users are known as secondary users.

SUs are the unlicensed users of the spectrum.

Cognitive Radio capabilities/Functions:

1. Spectrum Sensing: The primary users have priority in using the spectrum; SUs need to constantly perform real time monitoring of the licensed spectrum which can be used. In doing so the SU should not violate the interference temperature, i.e. the maximum interference tolerable for a particular frequency band between primary and secondary users. The SUs should be aware of the PUs reappearance. The technique used for sensing the PUs presence is called spectrum sensing.

A cognitive radio must make real-time decisions about which bands to sense, when, and for how long. The sensed spectrum information must be sufficient enough for the cognitive radio to reach accurate conclusions regarding the radio environment. Furthermore, spectrum sensing must be fast in order to track the temporal variations of the radio environment. Such requirement of spectrum sensing puts stringent requirements on the hardware implementation of cognitive radios in terms of the sensing bandwidth, the processing power, the radio frequency (RF) circuitry, etc. Existing spectrum sensing techniques depend on detecting the activities of the primary transmitters.

2. Spectrum analysis: It refers to analyze the band of frequencies that are not being used by the primary users of that band at a particular time, in particular geographic area. During the spectrum analysis, the following dimensions of spectrum space may be exploited in one way or the other: frequency, time, space, coding, angle, MIMO (Multiple-Input Multiple-Output), etc.

3. Spectrum Access Decisions: Based on the information gathered regarding spectrum bands, the CR needs to make decisions to define the radio transceiver parameters for the upcoming transmission(s) over such frequency bands. The set of transceiver parameters to be decided depends on the underlying transceiver architecture. Examples of the action set can include which spectrum is more favorable for an upcoming transmission, the time instant a transmission over a certain band should start, the maximum transmission power, the modulation rate, the spread spectrum hopping scheme, the angle of arrival for directional transmissions, and the number and identity of the antennas to be used in MIMO systems, etc. Based on the sensed spectrum information and the transceiver architecture, a cognitive radio defines the values of the parameters to be configured for an upcoming transmission.

4. Spectrum Management: There is a need to capture the best available spectrum to meet the user communication requirements. Spectrum management is to predict how long the spectrum holes (i.e. unused frequency bands) are likely to remain available for use to the unlicensed users or secondary users. CRs should decide on the best spectrum band to meet quality of service requirements over all spectrum bands.

5. Spectrum mobility: Spectrum mobility refers to the process in which a cognitive radio terminal changes its frequency of operation or switches to a new frequency, in order to maintain a seamless wireless connectivity, because of any of the following reasons: the appearance of the primary licensed user(s) of the current band or the deterioration of the channel quality of the currently used channel. In other words, spectrum mobility is the cognitive radio functionality that actually allows the cognitive radio to dynamically explore the available spectral opportunities. Thus, spectrum mobility is associated with a handoff mechanism that guarantees the transition to the new frequency band without breaking (or significantly degrading the quality of the communication between communicating cognitive radio terminals.

6. Spectrum sharing: It is of utmost importance to provide a fair spectrum scheduling policy, keeping in mind the usage costs. It is also one of the most important challenges in open spectrum usage. In the existing systems it corresponds to the existing MAC problems.

In order to be able to share the spectrum with legacy systems, the cognitive radio networks follow policies which deal with controlling the amount of interference that the secondary systems can incur to primary ones.

The interference management can be addressed from two different points of view:

a) Receiver-Centric Interference Management: In the receiver-centric approach, an interference limit at the receiver is calculated and used to determine the restriction on the power of the transmitters around it. This interference limit, called the interference temperature, is chosen to be the worst interference level that can be accepted without disturbing the receiver operation beyond its operating point.

b) Transmitter-Centric Interference Management: In the transmitter-centric approach, the focus is shifted to the source of interference. The transmitter does not know the interference temperature, but by means of sensing, it tries to detect free bandwidth. The sensing procedure allows the transmitter to classify the channel status to decide whether it can transmit and with how much power.

III SPECTRUM SENSING TECHNIQUES

One of the main objectives of embedding a CR in a wireless sensor is to utilize the unused licensed spectrum opportunistically. Here, opportunistically means the SUs should protect the accessing right of the PUs whenever necessary. The interference of SUs to PU depends on the sensing accuracy of SUs. If SUs can sense the channels with high accuracy, interference with the PU decreases. Depending on the sensing technique, there is a tradeoff between the sensing delay and sensing accuracy. The technique that takes a long sensing time has more accuracy with the cost of delays and vice versa.

Basically, there are two types of sensing techniques: (a) signal processing techniques; and (b) cooperative sensing techniques. These are further divided into three more categories: (i) Blind detection, (ii) Noise dependent detection and (iii) feature detection. Blind detection is further classified as (a) Covariance based detection and (b) Eigen value based detection.

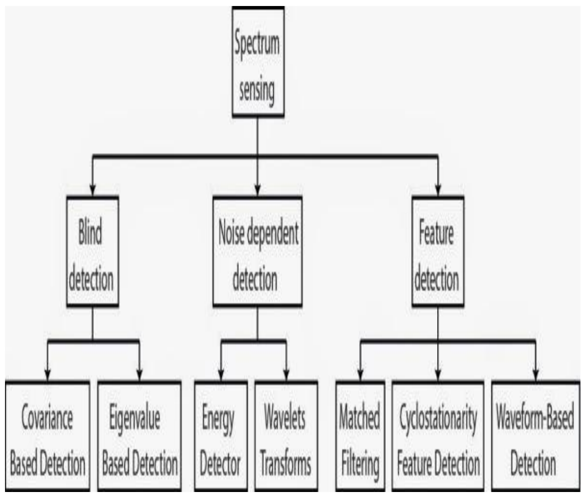

Figure 3: Spectrum Sensing Techniques

Signal processing sensing techniques for CR can be divided further into (a) energy detection and (b) wavelet transforms. Feature detection techniques are classified as Matched filter detection, (b) cyclostationary feature detection and (c) waveform based detection.

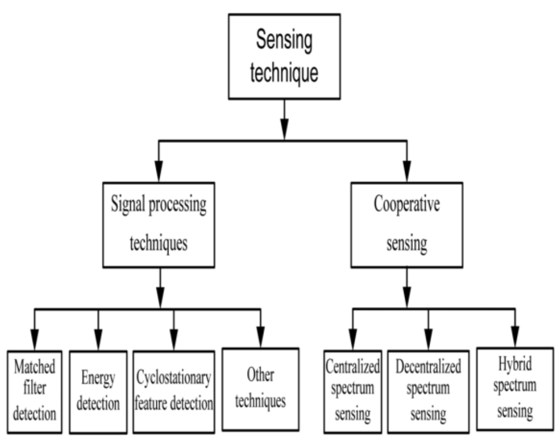

Figure 4: Spectrum Sensing Techniques

Similarly, cooperative sensing can be divided further into centralized spectrum sensing, decentralized spectrum sensing and hybrid spectrum-sensing techniques.

IV ARCHITECTURE

A cognitive radio network consists of primary networks as well as secondary networks. A primary network comprises of one or more PUs and one or more primary base stations. The PUs is licensed to use the spectrum and is coordinated by the primary base stations. PUs communicate among each other through the base station only. Generally the PUs as well as the primary base stations do not have CR properties.

On the other hand, a secondary network comprises of one or more SUs and may or may not contain a secondary base station. For SUs, the spectrum access is managed and handled by the secondary base station which acts as a hub/access point for the SU network. The SUs under the range of the same base station communicate with each other through the base station. If more than one secondary base station shares a single spectrum band then their spectrum usage and coordination is done by a central spectrum broker. A set of SUs can also connect to each other and communicate among themselves without the presence of the secondary base station. This kind of network is called an ad-hoc network. Internets of things (IoT) as well as vehicular ad-hoc network are some of the examples.

As the SUs should not cause interference with the PUs transmissions, all the SUs along with the secondary base stations are equipped with the CR properties. So whenever SUs detect the presence of a PU in a spectrum band they should immediately stop using that band and should move to some other available band to avoid interference with the PU transmission.

As shown in the figure 2, spectrum band consists of licensed as well as unlicensed bands. PUs are authorized to use the licensed bands while the SUs can only use the licensed bands when the licensed bands are idle and are not being used by the PU. If a PU starts using the licensed band on which a SU is transmitting, the SU should immediately detect PU's presence and should stop transmitting on that band and should move to some other available band. The information regarding the available bands as well as the occupied bands is provided to the SUs by the secondary base station.

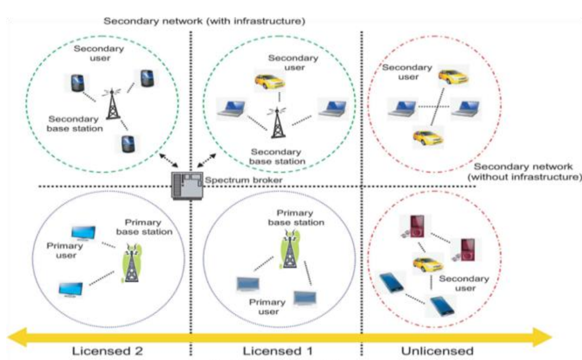

Figure 2: Cognitive Radio Architecture

 ISBN: 978-93-86171-32-0

The secondary base station is supposed to handle the band allocation and maintain coordination among all the SUs within that network. Whenever a SU detects the presence of a PU, it sends this information to the secondary base station and the secondary base station then informs all other SUs regarding the presence of PU on that band and asks all the SUs to give up that particular band. If SUs are using an unlicensed band then they can form an ad-hoc network and can coordinate among themselves without the secondary base station.

V. APPLICATIONS

1. Cognitive Mesh Networks: Traditional wireless mesh network are challenged by the scarcity of the wireless bandwidth needed to meet the high-speed requirements of existing wireless applications. Opportunistic Spectrum Access can be used to alleviate the bandwidth scarcity problem of mesh networks by allowing the mesh nodes to dynamically explore any available spectral opportunities.

2. Public Safety Networks: Public safety networks are used for communications among police officers and fire and paramedic personnel. Such networks are also challenged by the limited amount of allocated spectrum. The cognitive radio technology can offer public safety networks more bandwidth through Opportunistic Spectrum Access.

3. **Disaster Relief and Emergency Networks:** Natural disasters such as hurricanes, earthquakes, wild fires, or other unpredictable phenomena usually cause the communications infrastructure to collapse. This results in a set of partially or fully damaged coexistent networks that were previously deployed and then became disconnected. CRNs can be used for such emergency networks. The use of Opportunistic Spectrum Access in disaster relief networks can provide a significant amount of bandwidth that can handle the expected huge amount of voice, video, and other critical and time-sensitive traffic.

4. **Battlefield Military Networks:** A battlefield communication network provides the only means of communications between soldiers, armed vehicles, and other units in the battlefield amongst themselves as well as with the headquarters. This implies that such networks do not only require significant amount of bandwidth, but also mandate secure and reliable communications to carry vital information. The cognitive radio is the key enabling technology for realizing such densely deployed networks which use distributed Opportunistic Spectrum Access strategies to fulfill the bandwidth and reliability needs.

5. **Leased Networks:** A primary network can benefit from leasing a fraction of its licensed spectrum to secondary operators adopting cognitive radio technology to opportunistically access the spectrum. The entrance of the secondary operator to the market of the incumbent primary network can increase the revenue of the primary licensed operator.

6. Authentication Applications: A CR can learn the identity of its user(s). Authentication applications can prevent unauthorized users from using the CR. Since a radio is usually used for voice communications, there is a microphone in the system. The captured signal is encoded with a VoCoder and transmitted. The source radio can authenticate the user and add the known identity to the data stream. At the destination end, decoded voice can be analyzed for the purposes of authentication. Recently cell phones have been equipped with digital cameras. This sensor coupled with facial recognition software may be used to authenticate a user. Other biometric sensors may be used for authentication and access control.

VI. CONCLUSION

Spectrum is a very valuable resource in wireless communication systems and is fully crowded with more and more devices and applications using the spectrum. It has been a major research topic from last several decades. Cognitive radio is a promising technology which enables spectrum sensing for opportunistic spectrum usage by providing means for the use of unused frequency bands. Considering the challenges raised by cognitive radios, the use of spectrum sensing method appears as a crucial need to achieve satisfactory results in terms of efficient use of available spectrum and limited interference with the licensed primary users.

REFERENCES

1. Yan Zhang, Jun Zheng, Hsiao-Hwa Chen: Cognitive Radio Networks-Architecture, Protocols and Standards
   Ahmed Khattab, Dmitri Perkins and Magdy Bayoumi: Cognitive Radio Networks- From Theory to Practice
2. Kwang Cheng and Ramjee Prasad: Cognitive Radio Networks
3. Shaowei Wang: Cognitive Radio Networks-Dynamic Resource Allocation Schemes
4. http://www.cse.wustl.edu/~jain/cse574-14/ftp/cr/index.html
5. https://pdfs.semanticscholar.org/2905/e35303febc72228355969ba6f15dbb1c7036.pdf

About the Authors:

Mr. **G. Mukesh,** has completed his B.E. in Electronics and Telecommunication. He has completed his M. Tech. .in Embedded Systems. He has 3 years industrial experience and 10 years of teaching experience. He has guided about 20 UG projects and 10 PG projects. He has interests in various fields. His research areas, specifically include Embedded Systems, VLSI Design, Antennas and Electromagnetics and Signal Processing. Currently he is working as Assistant Professor at Sphoorthy Engineering College, Hyderabad.

Mr. K.Santhosh Kumar has completed B.Tech (ECE) from JNTU University, Hyderabad, and M.Tech (Embedded Systems) from JNTU Hyderabad, AP. He is having 6 years of experience in Academic & 3 years of industry. He has guided 15 UG Projects and 8 PG projects. Currently he is working as Assistant Professor at Sphoorthy Engineering College, Hyderabad.