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Cognitive Radio Networks -Technology and Challenges: A Review

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Abstract: **Cognitive radio (CR) is a smart radio used as a communication technique which is capable of detecting vacant communication channels in selected spectrum and assign these free channels to the users. Spectrum assigned to a particular user may not be used at a particular time or location which leads to spectrum holes or white spaces. This leads to inappropriate exploitation of spectrum. One solution for spectrum management is dynamic spectrum access (DSA). This helps in optimizing the spectrum and helps in minimizing the interference to different users. Main elements of CRN namely spectrum sensing, spectrum sharing and spectrum mobility are discussed in detail along with related issues..**

Keywords - CR, CRN, RF, white spaces, dynamic spectrum access (DSA), opportunistic spectrum access (OSA), spectrum sensing, spectrum sharing, spectrum mobility.

I. INTRODUCTION

A cognitive radio (CR) is one type of radio that can dynamically program and configure to detect vacant wireless channels to users. This helps in preventing interference and crowding of users. Radio is capable of automatically detecting free channels in the spectrum environment and change its transmissions receptions parameters. Parameters such as operating frequency, transmission power, modulation order etc. This process can be referred to as dynamic spectrum management. CR's performance is monitored continuously by itself. If the user is making use of licenced spectrum then user will be primary user or user be secondary. Part of the spectrum given to any user is not utilized each and every time, these unutilized parts of spectrum forms spectrum holes also called as white spaces. White spaces can be defined parts of spectrum bands is not been used at that particular time and location. All the actions taking place in cognitive radio system can be represented using cognitive cycle which is shown in figure 1.

A) COGNITIVE CYCLE

Cognitive cycle helps knowing how radios act in a radio environment.

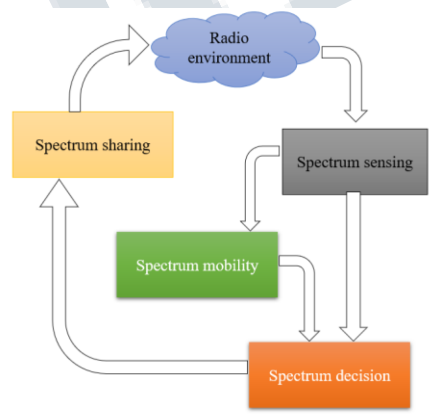

Figure 1: Cognitive cycle in CRN

Cognitive cycle consisting of following processes
Spectrum Sensing (SS): Spectrum sensing is the most important function performed by radio. It starts its process by initially examining the allocated frequency bands to users in order to determine the spectrum holes or white spaces. After determination of white spaces CR changes its parameter and assigns the vacant spaces to cognitive or secondary user to transmit and receive data.
Spectrum management: Spectrum management makes sure that best appropriate available frequency band is captured which satisfies user and Quality of service. Spectrum analysis (SA) and Spectrum Decision (SD) are its two functions. SA provides characteristics of white spaces. SD is responsible in choosing best available frequency band based on the decision made by SA. Therefore, spectrum management is responsible

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in giving right communication requirements with lucrative and better service for communication.
Spectrum Mobility: Spectrum mobility is the function of CR. This function is characterized by the CR shifting from one segment of band to another. Priority of usage of spectrum bands are given to PU, on detection of PU using the band SUs are vacated.
Spectrum Sharing: This is an acute function of CR. Spectrum sharing function is made to give ideal spectrum scheduling process and strategies of allocation among several users.
The CR standards for making use of white spaces effectively and monitor congestion caused by users. IEEE 802.22, IEEE 802.11n and IEEE 802.16h are the standards. Major characteristics of these standards are

• Greater range and improved coverage,
• Greater data rates, R
• Resistant to interference,
• Enabling operation in licensed and Unlicensed bands.

Table 1: Operational parameters of CRN

Standards	IEEE 802.22, 802.11n, 802.16h
Range	30km-100km
Bandwidth	6/7/8MHz
Channel capacity	18Mbps
Uplink and downlink	384kbps and 1500kbps
Operating frequency	54 to 862MHz
Data rate	4 to 23Mbps
Spectral efficiency	0.76 to 3.78bits/s/Hz
Modulation	QPSK/16-QAM/64-QAM for payload modulation, OFDMA for multiple access
Cyclic prefix	1/4 or 1/8 or 1/16 or 1/32

CR systems have few objectives to be achieved

• Evolving algorithms on spectrum sensing which aids in preventing interference.
• Establishing tactics to security threats for CR network.
• Establishing effective resource allocation strategies.
• Establishing mature transceiver for CRN.
• Promoting adaptive medium access control (MAC) layer protocols
• Enabling admission controller strategies which will aid in effective resource sharing for QoS requirements.

B) Spectrum Management

Federal communications commission (FCC) controls the radio spectrum. For today's communication procedures radio spectrum is greatly used by large number of users. Hence, spectrum has become limited resource. Wireless technologies includes ascertaining channels to individual user using licenced spectrum bands. Those users will have opportunity to transmit and receive the data, meantime other users are not allowed to used that particular portion of spectrum.
Few many times allocated bands are not used by the users i.e PUs who creates spectrum holes or white space. Spectrum is incompletely exploited. Hence, spectrum scarcity is a concern because spectrum is not used by the allocated user at that particular time and location. To turn around this problem of spectrum scarcity sharing of unused channels with secondary users (SUs) without having PUs interference. This management is called as dynamic spectrum access (DSA) or opportunistic spectrum access (OSA), also called dynamic spectrum access (DSA). DSA helps in managing the spectrum portions with licenced and unlicensed users
A CR system will help in optimizing the radio environment and accepts to environmental changings.

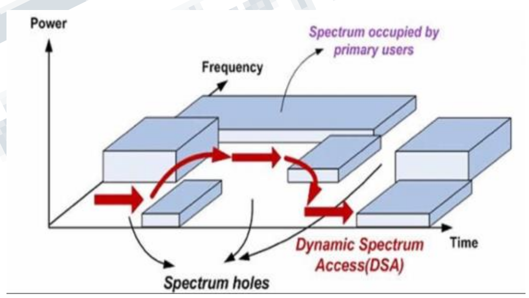

Figure 2: Dynamic spectrum access.[4]

DSA is illustrated in the figure 6. IEEE 802.22 is the standards for CRNs. These CR systems being research topic in the current generation aids in solving spectrum allocation problem in communication.

The main essence of the CRNs are:

Cognitive capability: It points out the capability of a node to sense and acquire the information regarding radio environment.

Reconfigurability: It points out the capability to adjust the parameters based on sensed information. Parameters include operating frequency, modulation, transmission power, etc

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II ARCHITECTURE OF CRN

A) PHY, MAC, Network layer functions in CRN

As seen in other types of networks CRN will also have more than one node and architecture can be classified as infrastructure dependent or ad-hoc architecture network. In CRN each node has its own level of cognitive capability. This sometimes acts as overlay network hence nodes in CRN can belongs to different co-existing network. Thus, developing a full-fledged CR network is a challenging task.

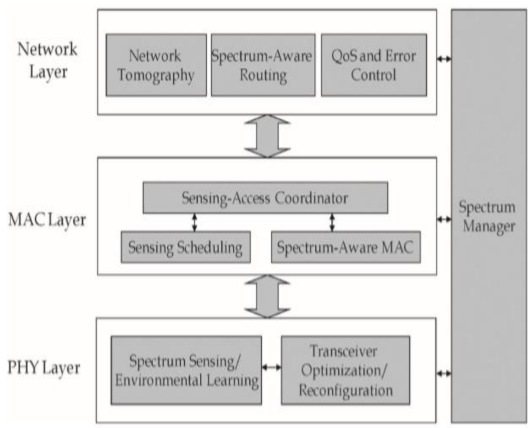

Figure 3: Functions of PHY, MAC and Network layer in CR network.[12]

Figure 2 embody the functions of PHY, MAC and Network layer in CRN. The foremost component of CRN is spectrum sensing which is taken care by PHY layer. It will permit CR user to identify spectrum holes. Environmental learning provides CR user to gain more knowledge about radio environment like channel-state information (CSI). Optimization and reconfiguration of transreceiver has to be done and is another crucial part of network is spectrum access. Few undertakings of MAC layer will be spectrum scheduling and spectrum aware access control. Spectrum scheduling helps in controlling sensing operation and spectrum access control monitors to access to particular white spaces. The sensing-access coordinator takes care of both the functions intelligently on the basis of time. Important functions of network layer are network tomography, QoS and error control, and spectrum aware routing. Lastly spectrum manager links all the layers and aids in accessing the spectrum dynamically and effectively. This architecture can be referred as functional architecture for this overview paper. Main motivation of this paper is to provide reader an overview on CRN. We reflected the functions of PHY, MAC and network layer and how they are linked or related.

B) Network platform for CRN

This section describes about a network platform for CRNs. This platform has cognition engine and simulation engine. Cognition engine will be present in all the layers and is responsible for attaining performance of network and implementing algorithms for spectrum sensing, spectrum management etc. controlling of simulations are taken care by simulation engine.

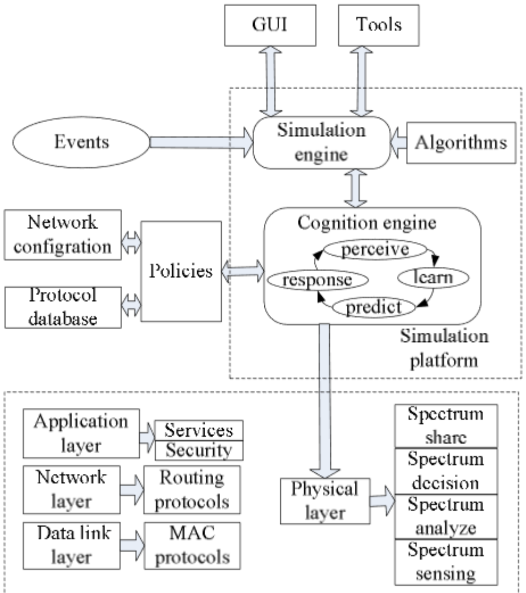

Figure 4: Components of the CR network platform.[13]

Cognition engine: Core of simulation platform is cognition engine. Whole cognition process including perceive, learn and interact in the radio environment is implemented using cognition engine. It can undergo cognition in physical layer, data link layer, network and application layer. There are four cognition tasks as follows:

- Physical layer cognition:
- Link layer cognition:
- Network cognition:
- Application layer cognition

GUI: Graphical user interface governs the platform on the basis of user request and accept the data from simulation engine. Main function of GUI is to display the error if any function does not work satisfactorily.

Tools: realising the work like network performance, topology, state of nodes, utilization of resources are done using performance governing tools.

Policies engine: Policies engine has software modules which are read by machines and applied to problem. It is capable of interpreting and invoke the policies to modify the processing of radio.

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C) Functional architecture of CRN

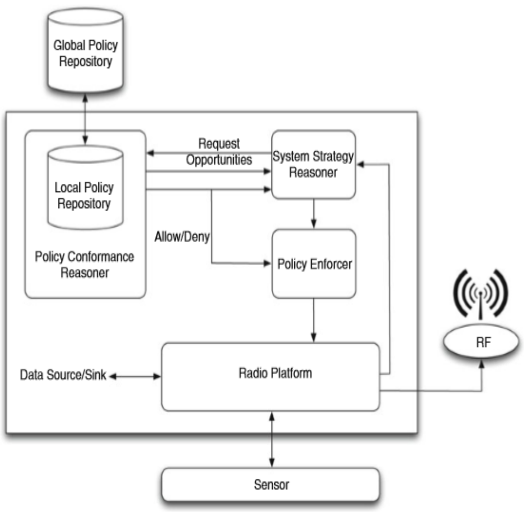

Figure 5: Functional architecture of CRN.[11]

In this section we describe functional architecture for designing and implementing cognitive radios. Proposed functional architecture is as shown figure 4. Following are the components of the architecture

Sensors: environment is sensed using sensors for detection of spectrum holes and transmission circumstances.

Radio platform: It includes DSP and software control which helps in providing interfaces to RF, sensors, sink, and the policy enforcers.

System strategy reasoner (SSR): SSR consists of strategies which helps in controlling the radio.

Policy Conformance Reasoner (PCR): Correct policy set is executed to make sure radio transmission fit to the policy.

Policy Enforcer (PE): It makes sure that any transmission data sent from SSR to radio platform acquiesce the policies.

Global Policy Repository: it stores all the policies for the network and is shared to other network as well since it contains global policies.

Local Policy Repository: It download policies from global policy repository using interface. It is sometimes present inside SSR.

D) CR Transreceiver

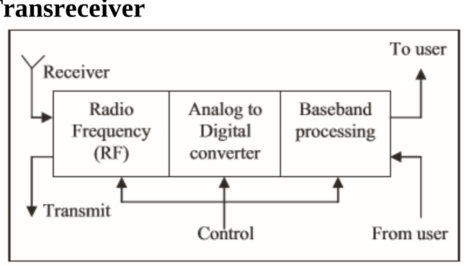

Figure 6: CR Transreceiver.[6]

RF unit, ADC, baseband processing unit are the components of CR Transreceiver. RF unit and ADC are combined to form RF front end. CR transreceiver is as shown in figure 5. Received signal is converted into digital signal, amplified using amplifiers, modulated/demodulated using modulators and demodulators and finally encoding and decode at base processing unit.

III SPECTRUM SENSING

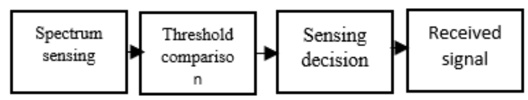

Figure 7: General approach of spectrum sensing.[4]

Main pivotal part of SS technique is detection of white spaces. It is going to start by searching for presence of PU. Main limitations of SS are more the sensing period lesser the transmission time and more is the accurate decision. To turn around this problem co-operative sensing is used. The general model of spectrum sensing method is shown in the figure 7. number of sensing techniques have been proposed in the literature.

SS is approached based on signal processing technique, co-operative technique and machine learning techniques.

A. Energy detection (ED)/periodogram/blind detection/ radiometry technique: In this received signal strength indicator is compared to a threshold to identify the presence of PU.

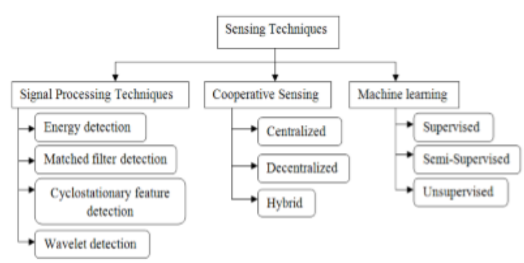

Figure 8: Classification of SS techniques.[2]

B. Matched filter detection technique (MFD): In this technique sample of a signal and signal observed is correlated in order to determine the presence of PU.

C. Cyclostationary feature detection technique (CFD): In this technique periodic nature of received signal is used for the determination of PU. It can work well even in the state of low SNR. Limitation of this technique is it is complex and cannot determine fast SS.

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D Wavelet detection technique (WD): This works by partitioning spectrum band into chunks and deploying detection procedures.

E. Centralized cooperative detection technique: Its main goal is to mitigate fading and interferences and improve performance of the system. It has a database unit for precipitating the information sent by different radios present in its cluster. Then, CR deploys the SS techniques, sends the sensed information to other radio to become co-operative with each other to control traffic.

F. Decentralized cooperative detection technique: In contrast to centralized spectrum sensing technique decentralized technique will send sensed information to other cluster. Therefore, it requires a unit which has more storage capacity. It is more economical than centralized technique interms of cost and infrastructure.

G. Hybrid cooperative detection technique: This approach is union and centralized and decentralized techniques which offers shorter sensing period but includes committed hardware hence increases cost.

Deploying machine learning techniques in software or machines to work based on collected data and learning from available information helps in optimizing the system. Intelligence of smart radio is increased by deploying the approach in the system.

IV. SPECTRUM SHARING

Spectrum sharing is a process of sharing the spectrum with other CR. Some features are common between spectrum sensing and spectrum sharing Classification of spectrum sharing has been showed in Figure 9.

A. Based on utilization of spectrum:

1) Unlicensed spectrum sharing: In unlicensed spectrum sharing, both the types of users can use the channel if the channel is detected free by sensing techniques.

2) Licensed spectrum sharing: PU has the higher priority than SU. SU can access the channel only in the absence of PU.

B. Based on network architecture:

1) Centralized sharing: Centralized spectrum sharing has a database unit that governs allocation and access to the spectrum. User in the requirement forwards its essentials to the central database. On the basis of this essential information database constructs spectrum allocation map.

2) Distributed sharing: In distributed system each node is committed for its allocation and access to the spectrum.

C. Based on access technology

1) Underlay spectrum sharing: CR user can transmit data concurrently with PU without having to face any interference in underlay spectrum sharing. power lever of CR user should be below particular threshold in order to avoid interference with PU.

2) Overlay spectrum sharing: In contrast in underlay sharing technique overlay spectrum sharing, the CR user has access to channel only in the absence of PU.

D. Based on allocation behaviour:

1) Cooperative spectrum sharing: co-operative spectrum sharing is referred as collaborative spectrum sharing. Its accounts the interference measurements in a central entity and shares measurements with other nodes. Thus, it has a better performance than non- cooperative sharing.

2) Non-cooperative spectrum sharing: Non co-operative spectrum sharing is referred as non-collaborative spectrum sharing. In contrast to co-operative spectrum sharing, non cooperative spectrum sharing will not account and exchange information about anything in other words they act independently.

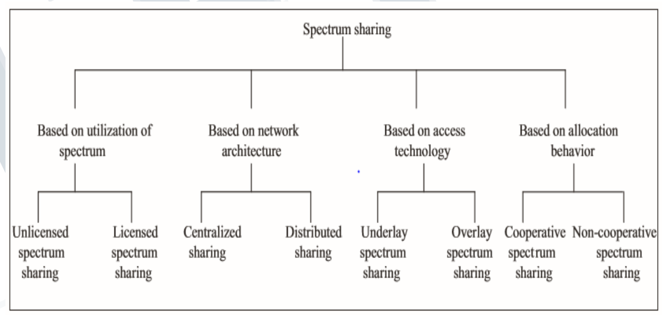

Figure 9: Classification of Spectrum Sharing.[6]

Several issues encountered in spectrum sharing are:

A. Location information: SU is able to calculate the interference level by using power transmitted and power level.

B. Distributed power allocation: Network should have entity that controls the power because when using distributed sharing approach power of node is calculated in distributed manner in the absence of entity.

C. Topology discovery: Non-uniform usage of channels by different user will creates complexity in finding topology.

V SPECTRUM MOBILITY

A CR user has to vacate the portion of spectrum whenever PU arrives at that particular portion of spectrum to continue communication process and fulfil QoS requirements. This is spectrum mobility. Main essence of spectrum mobility is spectrum handover/handoff. Spectrum mobility can happen when there is failure in link, reappearance of PU and user mobility. Spectrum mobility can occur due to link failure, PU reappearance. Different handoff strategies are:

A. Non-handoff strategy: In this technique CR user has to wait until channel is free In non-handoff strategy, the CR user remains idle until the channel becomes free i.e. the CR user takes the current channel as its next target channel. Its main disadvantage is wastage of CR user time. The CR user can transmit the data when the channel becomes free. Next disadvantage is high waiting latency.

B. Pure reactive handoff strategy: In pure reactive handoff strategy, the CR user switches the spectrum only after detecting the link failure i.e. CR applies reactive spectrum sensing and reactive handoff action. Delay in spectrum sensing is the major disadvantage in this handoff.

C. Pure proactive handoff strategy: In pure proactive handoff strategy, CR user switches the spectrum before the detection of link failure because the CR user has the ability to predict the future i.e. CR applies proactive spectrum sensing and proactive handoff. CR users perform the spectrum sensing to provide a backup channel before the handoff triggering occurs. Advantage is it has low handoff latency. It can plan everything in advance. Overall spectrum mobility performance can be degraded by poor spectrum sensing.

D. Hybrid handoff strategy: Hybrid handoff combines pure reactive and pure proactive strategy. CR user prepares the target channel but it transmits to new channel only after the handoff triggering occurs. Faster spectrum handoff time can be achieved.

Several issues encountered in spectrum mobility are:
A. Spectrum mobility in time domain: CR user selects the available spectrum for current transmission. The available spectrum changes as time goes. So enabling QoS requirements for entire transmission is a challenge.
B. Spectrum mobility in space: As the user moves from one place to another, the available spectrum also changes. So the continuous spectrum allocation is a challenge.
C. Energy efficiency: Spectrum mobility methods depend on the spectrum information update and spectrum sensing. Limited resources of CR node are a major factor of energy efficiency of network.
D. Adaptive spectrum handoff strategy: Based on the PU traffic pattern the secondary user should apply the most suitable handoff strategy. Whenever the PU traffic patterns changes the SU adapt the handoff strategy accordingly.
E. Switching delay: While moving from one spectrum to another, the switching time should be minimized. Otherwise the data transmission discontinued.

VI. RESEARCH CHALLENGES

There have been a number of recent papers which explore the information theoretic analysis of CR channels, i.e., channels where CR users operate in licensed bands in the presence of legacy users. Commonly referred to as dynamic spectrum allocation, this is one of the more pressing issues in cognitive radio since regulatory bodies have declared their intention to allow for secondary use of this underutilized spectrum. One of the important challenges for a cognitive radio system is to identify the primary users over a wide range of spectrum. This process is very difficult as we need to identify various primary users employing different modulation schemes, data rates and transmission powers in presence of variable propagation losses, interference generated by other secondary users and thermal noise. Based on the information of available spectrum as determined by the spectral sensing schemes, the next challenging task is to allocate and utilize the available spectrum in an optimal fashion. As CR systems are expected to operate in dynamically changing environments, maintaining QoS requirements of services offered by a CR system is challenging. Hence, proper design of the cognitive physical layer to facilitate high data rate access with high spectral efficiency is very important.
CR technology can be used in future wireless devices which helps in bringing forth additional bandwidth, reliable broadband communications and providing growth in data rates. The potential of CR networks to execute dynamic spectrum access can be driving factor for modern IoT in smart environment and 5G technology. Several challenging issues still need further investigation, making CR an open research area.

VII. CONCLUSIONS

In this paper, the fundamental concepts of cognitive radio with the help of cognitive cycle has been presented. Spectrum is a valuable resource for wireless communication therefore spectrum can be dynamically managed and is referred to as dynamic spectrum access (DSA) or opportunistic spectrum access (OSA). Therefore, CRN can be a solution for optimizing radio environment. These radios are smart radios has ability to sense the radio environment using different types of sensing techniques and accept the parameter changes such as transmission power, modulation order, etc. cognitive radio solves spectrum scarcity in wireless communications. Every CR network has to be realised using a platform including functionalities of PHY,

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MAC and network layer and its architecture with appropriate transceivers. Following spectrum sensing, spectrum sharing is processed to give user access to communication channel. If channel is occupied by a PU then, automatically SU should vacate the channel. In other words, PU has higher priority than SU. This is known as spectrum mobility. Different types of spectrum sharing and spectrum mobility and issues associated with it are presented.

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