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A Review on Modern Spectrum Sensing and Assignment Techniques in CRN

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ABSTRACT

Cognitive radio (CR) is ascending as an advanced technology with the aim of utilizing the unused spectrum bands in an opportunistic and dynamic way. Fixed spectrum allocation done by government based agencies leads to underutilization of resources. The segments of spectrum bands that are unused, are called "spectrum holes" or "white spaces". The solution to this issue is provided by implementing CR technology. It allows users to determine the unused bands in spectrum, choose the suitable one (depending on availability and accessibility of the spectrum) and use them in the best way possible. Spectrum assignment plays a vital role in minimizing any possibility of interference between secondary and primary users. Because of the varying parameters of available spectrum along with the different QoS specifications of various networks, CR technology raise a range of challenges. Spectrum management functions should tackle these problems and ensure that the CR network runs smoothly. This article therefore presents a brief survey on CR networks, its architecture and other relevant functionalities like spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

Keywords : Cognitive radio, Spectrum Sensing, Spectrum Assignment, Spectrum Sharing, Spectrum Mobility, Medium Access Control.

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I. INTRODUCTION

The demand for proper spectrum band usage has risen dramatically as a result of users' growing interest in wireless services. Due to this constantly increasing requirement for wireless connection and the advent of new wireless applications, the demand is said to be continue in the upcoming years as well.

Currently, wireless networks use a static spectrum allocation scheme, in which government entities delegate wireless spectrum to license holders for broad geographic areas on a long-term basis. This results in spectrum scarcity in specific bands. J. Mitola proposed the principle of Cognitive Radio (CR) technology in [1], [2] to leverage the unused spectrum. Software Defined Radio (SDR) was introduced to free radio networks from hardware constraints such as bandwidth, channel coding and frequency bands [3]. CR is a term derived from SDR. Using CR technology, reutilization of accessible spectrum portions can be facilitated using adaptive spectrum allocation strategies. Cognitive radio (CR) is a modern technology that allows unlicensed users to utilize the communication channel in absence of licensed user through dynamic spectrum access strategies [4]. This objective can only be achieved by means of efficient and dynamic spectrum management techniques. Owing to the high variance in usable spectrum and the varied QoS requirements of different applications, CR networks, also, face a number of challenges. To meet the solution to these issues, each cognitive user present within the network should follow below mentioned parameters:

• Analyze the range of spectrum that is available
• Choose the best communication channel as per availability
• Coordinate with other users to access a particular channel
• Vacate and switch to another channel when a PU's presence is detected [5]. Spectrum management functions can accomplished these parameters by addressing four major challenges: spectrum sensing, spectrum decision-making, spectrum sharing, and spectrum mobility.

This paper sets out the functions, definitions and recent issues in CR networks with their proper functioning. More specifically, the survey focuses on the implementation of CR networks such that no changes are required in the present networks [4]. An overview of CR network technology is provided, along with a brief idea of CR network architecture.

II. SPECTRUM SENSING

In CR network only an unused part of the spectrum may be allocated to a CR device. The CR use, therefore, should sense the spectrum bands, store that data, and identify the white spaces. Spectrum sensing processes can generally be divided into three main category:

A. Primary Transmitter Detection

In this technique the basic idea is to identify primary transmitter's signal though the signal is very weak. It is achieved through local observation. The schemes that are used for detecting the transmitter are:

1) Matched Filter Detection: If the CR user is aware of the primary user's signal information, Matched filter, is an efficient detection technique for Gaussian noise (which is stationary). Any signal which might be lost in interference and noise, can be identified using matched filter because of the spectral correlation properties of the signals are usually distinctive.

2) Energy Detection: Energy detection is a smarter choice when the CR user is unaware of primary signal information. During an observation period energy obtained on a primary band is determined by an energy detector, which confirms a spectrum hole, if the analyzed energy is lesser than a pre-defined threshold. Due to their inability to distinguish between signal types, energy detectors often produce false alarms caused by unknown signals. An analysis for threshold optimization and reduced probability of error is explained in [6].

3) Feature Detection: Usually, built-in periodicity or cyclostationarity characterizes any signal which is modulated. A spectral correlation function can be used to distinguish this attribute [10]. The resistance of feature detection to noise power instability is its main advantage. It is, however, computationally difficult and necessitates longer observation periods.

B. Primary Receiver Detection

In this technique the goal is to locate Primary Users which receives data within the transmission range of a CR recipient. The primary receiver detection process uses LO leakage power to detect the presence of the primary receiver.It will require additional hardware, for example a supporting sensor network for primary receivers in that region. While it is the most effective tool for locating spectrum gaps, it is currently only applicable to the detection of TV receivers.

C. Interference Based Detection

The FCC has developed interference temperature model for interference measurement. The radio station's signal is built to function in a range where the incoming power reaches the noise floor is depicted in this model. The noise floor rises as other interfering signals emerge at different points in the service area. In this model an interference threshold is set and using this threshold value interference at the receiver is regulated. Since it is difficult for cognitive users to identify interference and signals received from PU, the challenge of this model is calculating the interference temperature perfectly.

SPECTRUM ASSIGNMENT

Spectrum assignment is a fundamental feature of CRNs since it influences the network's regular activity. SA is in charge of allotting the most suitable frequency to a cognitive radio device's interface(s) based on a set of parameters. Spectrum holes found by spectrum sensing are fed into spectrum assignment, which determines the best spectrum segments for the SU to utilize based on its necessity.

In CRNs, resolving the problems of spectrum assignment is normally broken down into three stages. To solve the SA dilemma, parameters (which identify the goal objectives) are first chosen. The second step requires the specification of methodologies for modelling the SA challenges in a way that suits the purpose appropriately. Thirdly, the last step is to choose the most appropriate method to solve and overcome the issues of SA.

A. Criteria

There are several conditions in CRNs, for assigning spectrum to SUs, which differ depending on the algorithm's target objectives. Table 1 briefly presents these criteria [8].

Table 1 : Possible criteria for Cognitive Spectrum Assignment

Criterion	Target Objective	Issues
Throughput	Increase the throughput of users or networks. Both centralized and distributed methods are possible.	It has the potential to amplify network interference. Some SUs may be treated unfairly or starved as a result of this.
Spectral efficiency	Maximize the use of spectrum. When a single SU selects a channel, maximize the amount of channels used or the amount of SUs served.	May not take into account the various demands of SUs. Complexity can be extremely high in multi- channel multi-radio SUs. This is only possible in case of centralized SA.
Interference	Reduce the amount of interference between SUs and the amount of interference caused by PUs. It's possible to look into this in conjunction with power management. Reduces network congestion, resulting in improved efficiency. Ensures the PUs are not	Does not always guarantee that various user QoS demands are met.

	harmed in any way.	
Fairness	Ensure that SUs have a balanced throughput and spectrum allocation.	The network efficiency is not maximized. Does not consider the standards for Quality of Service (QoS).
Delay	Often used in conjunction with routing, its target is to set channels in order to reduce spectrum switching delay as well as total end-to-end delay.	This method does not attain optimal efficiency and is not responsible for Pus interference.
Price	Each SU chooses a channel based on its price and the incentive for accessing it. Another strategy is for network operators to delegate channels to SUs with the aim of raising their own profits.	SUs must have knowledge of the price of each spectrum band, or they must challenge spectrum owners in real time, causing delays.
Energy efficiency	Reduce SU energy usage thus meeting QoS requirements.	May not work to its full potential. In order to be used in centralized network, the nodes must exchange their battery levels on a regular basis.
Risk	Reduce the likelihood that an emerging primary user will block a flow path.	While it strives for less spectrum handovers, it does not achieve optimum efficiency. It divides the network into locations and makes assumption that each location uses only one channel, which results in poor spectrum usage.
Network connectivity	Its target is to maintain connectivity in network and reduce interference within the cognitive network, and is primarily used for CRAHNs.	It does not promise maximum spectrum utilization, maximum network performance and QoS of the users.

B. Approaches

This portion of the paper, gives a description of Approaches possible in spectrum assignment. Table 2 presents these approaches with their specifications [8].

Approach	Characteristics	Advantages	Disadvantages
Distributed	SUs make decisions on their own or jointly with other users. Neighboring SUs share knowledge in order to come up with good solutions. There is	Decisions made more quickly. High adaptability - can easily adapt to network outages, node failures, and other issues.	Decisions were not optimal. Achieving equal importance to SUs is difficult.

	no central entity.		
Centralized	Centralized user collects measurements from other user (SUs) and performs accordingly.	Clear sequence of instructions for each user connected. Quick decision implementation. Lower implementation cost. Improved efficiency and lower power consumption.	Require constant updates between SUs and the centralized head. Spectrum server failures are not resilient.
Multichannel selection	Accumulation of spectrum. Using a single radio device, it is possible to transmit on several spectrum fragments (contiguous or not).	Increased data rates. Maximum use of the spectrum.	Higher switching costs. Transceivers with a limited maximum duration can have lower spectrum usage. When broadcasting in different networks, this may cause further interference.
PU not considered	Only SUs are taken into consideration. Assumed, that there are multiple channels that are not used by PUs. The aim is to minimize SU interference while maximizing their utility.	A simple and direct strategy.	Requires a predefined collection of channels, however these channels can become inaccessible later due to the complex nature of the network and activities of PUs.
PU considered	The existence of PUs is taken into account when making decisions. The goal is to make least interference with SUs.	A more practical solution.	To quantify the interference caused to PUs, requires coordination with PUs in order to share measured values of PUs' position and approaches.
CCC-based	It is expected that a CCC should exist for the synchronization of spectrum assignment among the CRs.	Simple and clear approach that ensures SU cooperation.	DoS or jamming attacks are possible. If there are many SUs in the region, CCC can become congested. A CCC allocation algorithm is needed. The spectrum is not used to its full potential.
no CCC	It is assumed that the transmission of control messages among the SUs occurs without any CCC.	For transmission process all channels are accessible, thus achieving maximum spectrum utilization.	More exposed to problem of deafness and hidden node.
Segment-	Network is parted in	Simplified approach,	Constant coordination between

based	different segments, such that the nodes of each segment have minimum, one channel in common.	requires least channel switching.	nodes is required along with initial handshake, which is not defined how it should be done.
Cluster based	The emphasis is on clustered cognitive mesh networks. A cluster head collects node's data at each cluster. Cluster heads share data and make decisions for spectrum allocation.	By dividing users into clusters, improved load balancing is achieved. Reduces the amount of time spent collaborating.	Cluster heads can quickly become clogged. Failure of cluster head result in new cluster formation, thus consuming more time.

C. Problem solving techniques

On the basis of our analysis, we present some modern solutions for solving problems related to spectrum assignment in CRNs:

- Evolutionary algorithms
- Heuristics
- Game theory
- Graph Theory
- Fuzzy logic
- Linear programming

SPECTRUM SHARING

Knowing that the wireless channel has shared nature, coordination is required for transmission attempts between cognitive users along with the coexistence of licensed user. In this regard, spectrum sharing can involve a lot of features of a MAC protocol. There are four elements in existing work in spectrum sharing: spectrum allocation behavior, architecture, scope and spectrum access technique.

The first category is given depending on the allocation behavior:

• **Cooperative spectrum sharing:** Formation of clusters occurs to exchange information related to interference locally, cooperative solutions take advantage of interference measured by each node. This integrated activity strikes a good balance between a decentralized and a completely centralized system.

• **Non-cooperative spectrum sharing:** Since a particular node is taken into consideration, spectrum consumption can be decreased. However, unlike cooperative solutions, this sharing scheme do not necessitate regular exchange of message between neighboring nodes.

Cooperative approaches usually outperform in terms of fairness, throughput, and energy use as compared to individual approaches.

The second classification given is on the basis of architecture:

• **Centralized spectrum sharing:** In this approach for spectrum access and allocation, a centralized body is given responsibility. Furthermore, a distributed sensing technique can be used to send data of allocation to a centralized agency, which can then create a spectrum allocation map. Furthermore, taking into account consumer rivalry, the central agency can rent out spectrum to users for a defined period and for a specified location [10].

• **Distributed spectrum sharing:** Spectrum access and allocation are determined by localized protocols implemented in a distributed manner by each node [11]. Recent comparison work shows that distributed sharing basically adapt centralized sharing, but at the expense of exchanging messages between nodes.

In article [13] the media access schemes are given as below:

- **VX Scheme (Virtual-Xmit-if-Busy):** The channel is detected by the SU. Packet is transmitted by SU only if it is sensed that the channel is unoccupied. The SU then goes on holiday. If the channel is sensed busy, the SU enters a "virtual transmission" period before moving on to the holiday stage. The time for which the SUs wait (equal to the length of the packet) before transmission is referred as virtual transmission. The SU detects the channel once more after vacation.

- **KS Scheme (Keep-Sensing-if-Busy):** The SU detects the available channels after a vacation. The SU transmits a packet and then if the channel is sensed idle, SU goes on holiday. If as per SU detection the channel is sensed occupied, it will continue to detect until the channel is free. The SU then sends out a packet and begins a random holiday.

Further classification depending on access technology is [12]:

- **Overlay spectrum sharing**: In such network, nodes are connected by using spectrum band that isn't occupied by licensed users. This reduces the level of interference on the primary network.
- **Underlay spectrum sharing:** This technique is used to make approved users consider the transmission of a cognitive user's node to be noise. Hybrid strategies can take advantage of increased bandwidth at the expense of minimal complexity increase, so they can be considered.

Finally, as discussed in the following, spectrum sharing strategies are typically of two types, which are: spectrum sharing among collectively coexisting CRN and spectrum sharing within a CRN:

- **Intranetwork spectrum sharing:** This approach is based on spectrum sharing among entities of CR network. As a result, CR network users attempt to use the available spectrum without interfering with primary users.
- **Internetwork spectrum sharing:** Multiple devices can be implemented in overlapping locations and bandwidth due to the CR Architecture. By including some operator rules, the internetwork sharing options have so far given a wider angle of important elements of spectrum sharing.

SPECTRUM MOBILITY

Now it's time to talk about spectrum mobility management. Spectrum Mobility is defined as the situation in which a cognitive user needs to adjust its operating frequency band(s) due to primary user operation on that spectrum. Spectrum versatility has resulted in the emergence of a new form of handoff known as spectrum handoff. In CR networks, the management of spectrum mobility is aimed to ensure there is minimal performance degradation (in terms of delay and security) while handoff takes place. Knowledge about the length of a spectrum handoff is an essential prerequisite for maintaining protocols of mobility management. The sensing algorithm can provide this detail. The continuing communication can be maintained with only minor performance loss once the information about latency is accessible. Two new ideas emerged from the inherent features of a CR network: spectrum mobility and spectrum handoff.

III. COGNITIVE RADIO ARCHITECTURE

In order to resolve the dynamic spectrum challenges and to create feasible communication protocols it is important to discuss a detailed overview of CR network architecture. Figure 1 shows a representation of CRN. Features of CRN are discussed as below:

A. Network Components

It can be categorized as:

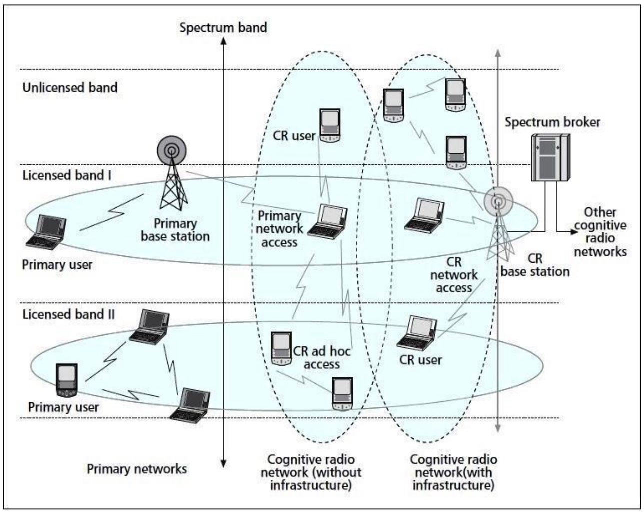

Figure 1 : Cognitive Radio Networks Architecture [4]

1) The primary network: In this type of network licensed users are permitted to operate in a spectrum band which is allotted to them.
2) The CR network: The CR functions without a license in the chosen band in an opportunistic manner (without interfering with licensed user).

B. Spectrum Heterogeneity

The operation types are given below:

1) Licensed band operation: The primary user has the authority to use the licensed band. Therefore, CR networks are primarily concerned with detecting primary users.
2) Unlicensed band operation: CR users have the similar authority to occupy the spectrum as licensed users only when the licensed user is absent. Therefore, modern methods are needed for spectrum sharing of unlicensed band among CR users.

C. Network Heterogeneity

Users of the CR can choose from three types of access:

1) CR network access: On both unlicensed and licensed spectrum band, CR users can connect their own CR base station. As we know all the communications will take place within the CR network, their spectrum sharing strategy may be distinct from the primary networks.
2) CR ad hoc access: On both spectrum bands (either licensed or unlicensed), CR users can communicate with each other through an ad hoc link.
3) Primary network access: In this type of access bands which are allotted to primary users can also be utilized by CR users to connect to the primary base station. CR users, unlike other access criteria, need an adaptive MAC protocol that allows transmission through several primary networks.

MAC PROTOCOLS IN CRNS

Several cognitive radio functions rely on Medium Access Control, including spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility. Measured by the method suggested in [17], a general representation of cognitive MAC protocols can be attained, where protocols are grouped as per the following characteristics:

- Protocol architecture
- Complexity
- Signaling and data transfer management during communication
- Network level of cooperation

Dynamic Spectrum Allocation (DSA) and Direct Access Based (DAB) are the two major MAC protocol groups shown in Fig 2.

A. Dynamic Spectrum Allocation MAC protocols

The advanced optimization algorithms are used in DSA-driven MAC protocols to achieve intelligent, equal, and effective spectrum allocation. To efficiently leverage the attainable resource, each secondary user adjusts its transmitting boundaries to specified modifications in the given network. They usually have poor scalability, which has an effect on negotiating time and complexity. Therefore, decentralized methods have been suggested to minimize complexity such as game theory [20], graph coloring theory, genetic algorithms, swarm intelligence algorithms [21] and stochastic theory.

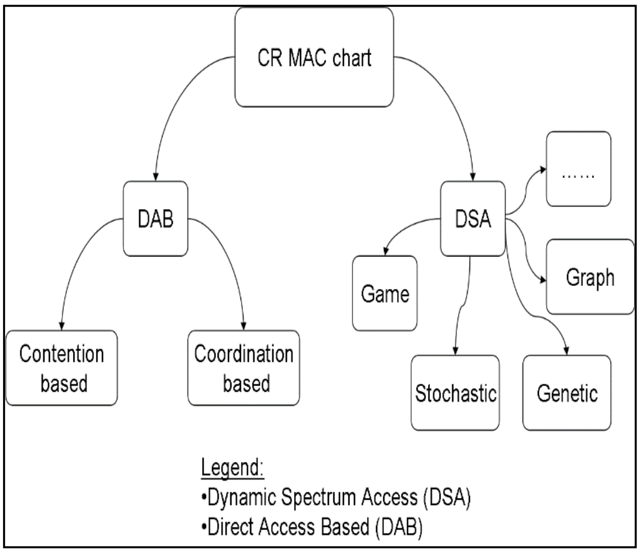

Figure 2 : Cognitive Radio MAC Protocol [17]

B. Direct Access Based MAC protocols

DAB protocol can be categorized in one the two mentioned groups:

1) **Contention based protocols:** In this, CR transmitters and receivers simply handshake to exchange results of their sensing. The pair then compares available resources and negotiates a communication channel. Channel Filtering Sender Receiver (CFSR) handshake is the term given to the entire process.
2) **Coordination based protocols:** To improve sensing **efficiency** and overall device performance, each node shares channel consumption information with its neighbors.

IV. CHALLENGES

For the advancement of CRN, there are many challenges and issues for researchers that must be investigated:

- **Heterogeneity in network:** The channel list that is available may be different for different CR user at a given time. As a result, finding the ideal channel/group of channels becomes an issue in such heterogeneous networks. Therefore, heterogeneity is a challenge in CRN.

- **Multichannel spectrum sensing:** As the spectrum bands is time varying and might not still be idle until the CR's transmission is finished. So, non-contiguous spectrum bands can be sensed simultaneously to improve the reliability of the CR's communication.

- **Cooperation with reconfiguration:** Transmission parameters can be reconfigured using CR techniques for optimum activity in a specific spectrum band. As a result, in spectrum decision, a cooperative system with reconfiguration is needed.

- **Common control channel:** Many spectrum sharing functions are made easier with the use of a standard control channel (CCC). A fixed CCC, on the other hand, is impossible to enforce since whenever a primary user selects a channel, it must be vacated at that instance.

- **Dynamic radio range:** The neighboring nodes might need to swap their frequency range due to the interdependency between operating frequency and spectrum range. Till date, no work has been done in CR networks to fix this critical problem.

- **Spectrum mobility in the space/time domain:** Depending on the accessible spectrum, CRNs adjust to the frequency bands, which evolve over time, making QoS difficult to achieve in this setting. When a user changes its position, the available bands change as well. As a result, continuous spectrum allocation is a big challenge.

- **Self-organization schemes in CR functionalities:** Since the self-organization schemes completely depends on local sensing measurements and nature of each user, the idea of decentralization may give rise to new problems [22]:

  - The optimum is not always achieved in self-organization.
  - A need for new theory of decentralized scheme and decentralized management; in order to create a reliable CR's communications with high scalability and accurate spectrum sensing report

V. CONCLUSION

For potential wireless networks, CR is a budding technology. It seeks to take advantage of unused spectrum bands and mitigate the unlimited use of free bands by allowing users to use the part of spectrum that is not being utilized rather than being restricted to exclusive free frequencies, as is the case with current wireless networks. The ability of CR devices to sense the environment in which it is operating and adapt to the changes, is the key feature of this technology. This means that CR devices can detect and access available non-utilized spectrum bands at any time, without interfering with licensed transmissions. The performance limit and elemental properties of opportunistic spectrum access are better understood in this survey. Spectrum sensing, spectrum allocation, spectrum sharing, and spectrum mobility were all explained in depth. Later in this paper we have discussed in brief about the CRN architecture with its various components and MAC-protocols that are used in CRN.

Many researchers are working on the protocols and communication technologies that are needed for CR networks right now. However, more research along the lines of this survey is needed to ensure effective spectrum aware communication.

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