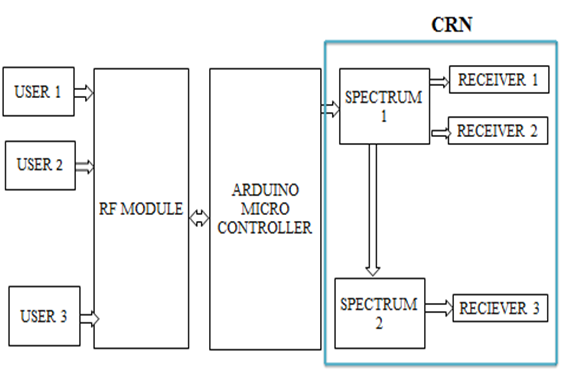
**CHAPTER 5**

**WORKING PRINCIPLE**

**5.1 PRINCIPLE OF OPERATION**



**Figure 5.1 Proposed Methodology**

Cognitive radio network is used for the automatic spectrum sharing technique and efficient mobile communication. Initially, primary user and secondary user connected the call to primary and secondary receiver by using their respective spectrum.

When primary spectrum can be overloaded the call will automatically connected to the another free spectrum

Wireless networks are based on a fixed spectrum assignment policy that is regulated by governmental agencies. Although spectrum is licensed on a long-term basis over vast geographical regions, recent research has shown that significant portions of the assigned spectrum are utilized, leading to waste of valuable frequency resources .

Toward this end, cognitive radio technology is envisaged that enables the identification and use of vacant spectrum, known as spectrum hole or white space. Since most of the spectrum is already assigned, a key challenge is to share the licensed spectrum without interfering with the transmission of other licensed users. If this band is found to be occupied by a licensed user, the CR user moves to another spectrum hole to avoid interference.

In Cogitive Radio Ad Hoc Networks the distributed multihop architecture, dynamic network topology, diverse quality of service (QoS) requirements, time and location varying spectrum availability are some of the key factors that must be considered in network design.

These challenges necessitate novel design techniques that simultaneously address a wide range of communication problems spanning several layers of the protocol stack. In CRAHNs CR users can communicate with each other in a multihop manner on both licensed and unlicensed spectrum bands.

In order to adapt to the dynamic spectrum environment, the CRAHN requires spectrum-aware operations, which form a cognitive cycle, the steps of the cognitive cycle consist of four spectrum management functions: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

To implement CRAHNs, each function needs to be incorporated into the classical layering protocols. The following are the main features of spectrum management functions.

**5.2 COGNITIVE RADIO NETWORK**

A cognitive radio is a [radio](https://en.wikipedia.org/wiki/Radio) that can be programmed and configured dynamically to use the best [wireless channels](https://en.wikipedia.org/wiki/Wireless_channel) in its vicinity to avoid user interference and congestion. Such a radio automatically detects available channels in [wireless spectrum](https://en.wikipedia.org/wiki/Radio_spectrum), then accordingly changes its [transmission](https://en.wikipedia.org/wiki/Transmission_(telecommunications)) or [reception](https://en.wikipedia.org/wiki/Telecommunication) parameters to allow more concurrent [wireless communications](https://en.wikipedia.org/wiki/Wireless_communications) in a given spectrum band at one location. This process is a form of [dynamic spectrum management](https://en.wikipedia.org/wiki/Dynamic_spectrum_management).

In response to the operator's commands, the cognitive engine is capable of configuring radio-system parameters. These parameters include [waveform](https://en.wikipedia.org/wiki/Waveform), protocol, operating frequency, and networking. This functions as an autonomous unit in the communications environment, exchanging information about the environment with the networks it accesses and other cognitive radios. A CR monitors its own performance continuously, in addition to reading the radio's outputs; it then uses this information to determine the [RF](https://en.wikipedia.org/wiki/Radio_frequency) environment, channel conditions, link performance, etc., and adjusts the radio's settings to deliver the required quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints.

Some smart radio proposals combine [wireless mesh network](https://en.wikipedia.org/wiki/Wireless_mesh_network)-dynamically changing the path messages take between two given nodes using [cooperative diversity](https://en.wikipedia.org/wiki/Cooperative_diversity); cognitive radio-dynamically changing the frequency band used by messages between two consecutive nodes on the path; and [software-defined radio](https://en.wikipedia.org/wiki/Software-defined_radio)-dynamically changing the protocol used by message between two consecutive nodes.

Depending on transmission and reception parameters, there are two main types of cognitive radio:

* Full Cognitive Radio, in which every possible parameter observable by a wireless node is considered.
* Spectrum-Sensing Cognitive Radio, in which only the radio-frequency spectrum is considered.

Other types are dependent on parts of the spectrum available for cognitive radio:

* Licensed-Band Cognitive Radio, capable of using bands assigned to licensed users. The [IEEE 802.22](https://en.wikipedia.org/wiki/IEEE_802.22)working group is developing a standard for wireless regional area network , which will operate on unused television channels, also known as TV [white spaces](https://en.wikipedia.org/wiki/White_spaces_(radio)).
* Unlicensed-Band Cognitive Radio, which can only utilize unlicensed parts of the radio frequency spectrum. One such system is described in the [IEEE 802.15](https://en.wikipedia.org/wiki/IEEE_802.15)Task Group 2 specifications, which focus on the coexistence of [IEEE 802.11](https://en.wikipedia.org/wiki/IEEE_802.11) and [Bluetooth](https://en.wikipedia.org/wiki/Bluetooth).
* Spectrum mobility: Process by which a cognitive-radio user changes its frequency of operation. Cognitive-radio networks aim to use the spectrum in a dynamic manner by allowing radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during transitions to better spectrum.
* Spectrum sharing: Spectrum sharing cognitive radio networks allow cognitive radio users to share the spectrum bands of the licensed-band users. However, the cognitive radio users have to restrict their transmit power so that the interference caused to the licensed-band users is kept below a certain threshold.
* Sensing-based Spectrum sharing: In sensing-based spectrum sharing cognitive radio networks, cognitive radio users first listen to the spectrum allocated to the licensed users to detect the state of the licensed users. Based on the detection results, cognitive radio users decide their transmission strategies. If the licensed users are not using the bands, cognitive radio users will transmit over those bands. If the licensed users are using the bands, cognitive radio users share the spectrum bands with the licensed users by restricting their transmit power.
* Database-enabled Spectrum Sharing: In this modality of spectrum sharing, cognitive radio users are required to access a [white space database](https://en.wikipedia.org/wiki/TV_White_Space_Database) prior to be allowed, or denied, access to the shared spectrum. The white space database contain algorithms, mathematical models and local regulations to predict the spectrum utilization in a geographical area and to infer on the risk of interference posed to incumbent services by a cognitive radio user accessing the shared spectrum. If the [white space database](https://en.wikipedia.org/wiki/TV_White_Space_Database) judges that destructive interference to incumbents will happen, the cognitive radio user is denied access to the shared spectrum.

Although cognitive radio was initially thought of as a [software-defined radio](https://en.wikipedia.org/wiki/Software-defined_radio) extension , most research work focuses on spectrum-sensing cognitive radio. The chief problem in spectrum-sensing cognitive radio is designing high-quality spectrum-sensing devices and algorithms for exchanging spectrum-sensing data between nodes. It has been shown that a simple energy detector cannot guarantee the accurate detection of signal presence, calling for more sophisticated spectrum sensing techniques and requiring information about spectrum sensing to be regularly exchanged between nodes. Increasing the number of cooperating sensing nodes decreases the probability of false detection.

Applications of spectrum-sensing cognitive radio include [emergency-network](https://en.wikipedia.org/wiki/Professional_Mobile_Radio) and [WLAN](https://en.wikipedia.org/wiki/Wireless_LAN) higher [throughput](https://en.wikipedia.org/wiki/Throughput) and [transmission](https://en.wikipedia.org/wiki/Transmission_(telecommunications))-distance extensions. The evolution of cognitive radio toward [cognitive networks](https://en.wikipedia.org/wiki/Cognitive_network) is underway; the concept of cognitive networks is to intelligently organize a network of cognitive radios.

**5.3 FUNCTIONS OF COGNITIVE RADIO NETWORK**

Power Control: Power control is usually used for spectrum sharing CR systems to maximize the capacity of secondary users with interference power constraints to protect the primary users.

**5.3.1 Spectrum Sensing**:

Detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive-radio network is to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Spectrum-sensing techniques may be grouped into three categories:

* + Transmitter detection: Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. There are several proposed approaches to transmitter detection:
* Energy detection: Energy detection is a spectrum sensing method that detects the presence/absence of a signal just by measuring the received signal power. This signal detection approach is quite easy and convenient for practical implementation. To implement energy detector, however, noise variance information is required. It has been shown that an imperfect knowledge of the noise power may lead to the phenomenon of the [SNR](https://en.wikipedia.org/wiki/Signal-to-noise_ratio) wall, which is a SNR level below which the energy detector can not reliably detect any transmitted signal even increasing the observation time. It has also been shown that the SNR wall is not caused by the presence of a noise uncertainty itself, but by an insufficient refinement of the noise power estimation while the observation time increases.
* [Cyclostationary](https://en.wikipedia.org/wiki/Cyclostationary_process)-feature detection: These type of spectrum sensing algorithms are motivated because most man-made communication signals, such as [BPSK](https://en.wikipedia.org/wiki/Phase-shift_keying), [QPSK](https://en.wikipedia.org/wiki/Phase-shift_keying), [AM](https://en.wikipedia.org/wiki/Amplitude_modulation), [OFDM](https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing), etc. exhibit cyclostationary behavior. However, noise signals do not exhibit cyclostationary behavior. These detectors are robust against noise variance uncertainty. The aim of such detectors is to exploit the cyclostationary nature of man-made communication signals buried in noise. Cyclostationary detectors can be either single cycle or multicycle cyclostatonary.
  + Cooperative detection: Refers to spectrum-sensing methods where information from multiple cognitive-radio users is incorporated for primary-user detection

**5.3.2 Spectrum Management:**

Capturing the best available spectrum to meet user communication requirements, while not creating undue interference to other users.

Cognitive radios should decide on the best spectrum band to meet [quality of service](https://en.wikipedia.org/wiki/Quality_of_service) requirements; therefore, spectrum-management functions are required for cognitive radios. Spectrum-management functions are classified as:

* + Spectrum analysis
  + Spectrum decision

The practical implementation of spectrum-management functions is a complex and multifaceted issue, since it must address a variety of technical and legal requirements. An example of the former is choosing an appropriate sensing threshold to detect other users, while the latter is exemplified by the need to meet the rules and regulations set out for radio spectrum access in international and national legislation.

**5.4 COGNITIVE RADIO NETWORK ARCHITECTURE**

A comprehensive description of the CR network architecture is essential for the development of communication protocols that address the dynamic spectrum challenges. The CR network architecture is presented in this section.

**5.4.1 Network Component**

The components of the CR network architecture can be classified as two groups: the primary network and the CR network.

The primary network (or licensed network) is referred to as an existing network, where the primary users have a license to operate in a certain spectrum band. If primary networks have an infrastructure, primary user activities are controlled through primary base stations.

Due to their priority in spectrum access, the operations of primary users should not be affected by unlicensed users. The CR network does not have a license to operate in a desired band. Hence, additional functionality is required for CR users to share the licensed spectrum band. CR networks also can be equipped with CR base stations that provide single-hop connection to CR users. Finally, CR networks may include spectrum brokers that play a role in distributing the spectrum resources among different CR networks.

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**Figure 5.2 Cognitive Radio Network**

**5.4.2 Spectrum Heterogeneity**

CR users are capable of accessing both the licensed portions of the spectrum used by primary users and the unlicensed portions of the spectrum through wideband access technology. Consequently, the operation types for CR networks can be classified as licensed band operation and unlicensed band operation.

• Licensed band operation: The licensed band is primarily used by the primary network. Hence, CR networks are focused mainly on the detection of primary users in this case. The channel capacity depends on the interference at nearby primary users. Furthermore, if primary users appear in the spectrum band occupied by CR users, CR users should vacate that spectrum band and move to available spectrum immediately.

• Unlicensed band operation: In the absence of primary users, CR users have the same right to access the spectrum. Hence, sophisticated spectrum sharing methods are required for CR users to compete for the unlicensed band

**5.4.3 Network Heterogeneity**

The CR users have the opportunity to perform three different access types:

• CR network access: CR users can access their own CR base station, on both licensed and unlicensed spectrum bands. Because all interactions occur inside the CR network, their spectrum sharing policy can be independent of that of the primary network.

• CR ad hoc access: CR users can communicate with other CR users through an ad hoc connection on both licensed and unlicensed spectrum bands.

• Primary network access: CR users can also access the primary base station through the licensed band. Unlike for other access types, CR users require an adaptive medium access control protocol, which enables roaming over multiple primary networks with different access technologies.

**5.4.4 Spectrum Management Framework**

CR networks impose unique challenges due to their coexistence with primary networks as well as diverse QoS requirements. Thus, new spectrum management functions are required for CR networks with the following critical design challenges:

• Interference avoidance: CR networks should avoid interference with primary networks.

• QoS awareness: To decide on an appropriate spectrum band, CR networks should support QoS-aware communication, considering the dynamic and heterogeneous spectrum environment.

• Seamless communication: CR networks should provide seamless communication regardless of the appearance of primary users.

To address these challenges, we provide a directory for different functionalities required for spectrum management in CR networks. The spectrum management process consists of four major steps:

• Spectrum sensing: A CR user can allocate only an unused portion of the spectrum. Therefore, a CR user should monitor the available spectrum bands, capture their information, and then detect spectrum holes.

• Spectrum decision: Based on the spectrum availability, CR users can allocate a channel.

This allocation not only depends on spectrum availability, but is also determined based on internal policies.

• Spectrum sharing: Because there may be multiple CR users trying to access the spectrum, CR network access should be coordinated to prevent multiple users colliding in overlapping portions of the spectrum.

• Spectrum mobility: CR users are regarded as visitors to the spectrum. Hence, if the specific portion of the spectrum in use is required by a primary user, the communication must be continued in another vacant portion of the spectrum.

**5.4.5 Spectrum Sensing**

A CR is designed to be aware of and sensitive to the changes in its surroundings, which makes spectrum sensing an important requirement for the realization of CR networks. Spectrum sensing enables CR users to adapt to the environment by detecting spectrum holes without causing interference to the primary network. This can be accomplished through a real-time wideband sensing capability to detect weak primary signals in a wide spectrum range. Generally, spectrum sensing techniques can be classified into three groups: primary transmitter detection, primary receiver detection, and interference temperature management.

**5.4.6 Primary Receiver Detection**

Although cooperative detection reduces the probability of interference, the most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range of a CR user.

Usually, the local oscillator leakage power emitted by the RF front-end of the primary receiver is exploited. However, because the LO leakage signal is typically weak, implementation of a reliable detector is not trivial. Currently, this method is only feasible in the detection of TV receivers.

**5.5 SPECTRUM DECISION**

CR networks require the capability to decide which is the best spectrum band among the available bands according to the QoS requirements of the applications. This notion is called spectrum decision and constitutes a rather important topic in CR networks. Spectrum decision is closely related to the channel characteristics and operations of primary users.

Furthermore, spectrum decision is affected by the activities of other CR users in the network. Spectrum decision usually consists of two steps: first, each spectrum band is characterized, based on not only local observations of CR users but also statistical information of primary networks. Then, based on this characterization, the most appropriate spectrum band can be chosen. In the following we investigate the channel characteristics, decision procedures, and research challenges in CR networks.

**5.6 CHANNEL CHARACTERISTICS IN COGNITIVE RADIO NETWORKS**

Available spectrum holes show different characteristics that vary over time, each spectrum hole should be characterized considering both the time-varying radio environment and spectrum parameters, such as operating frequency and bandwidth. Hence, it is essential to define parameters that can represent a particular spectrum band as follows:

• Interference: From the amount of interference at the primary receiver, the permissible power of a CR user can be derived, which is used for the estimation of channel capacity.

• Path loss: The path loss is closely related to distance and frequency. As the operating frequency increases, the path loss increases, which results in a decrease in the transmission range. If transmission power is increased to compensate for the increased path loss, interference at other users may increase.

• Wireless link errors: Depending on the modulation scheme and the interference level of the spectrum band, the error rate of the channel changes.

• Link layer delay: To address different path loss, wireless link error, and interference, different types of link layer protocols are required at different spectrum bands. This results in different link layer delays. It is desirable to identify the spectrum bands that combine all the characterization parameters described previously for accurate spectrum decision.

**5.7 DECISION PROCEDURE**

After the available spectrum bands are characterized, the most appropriate spectrum band should be selected, considering the QoS requirements and spectrum characteristics. Accordingly, the transmission mode and bandwidth for the transmission can be reconfigured. To describe the dynamic nature of CR networks, a new metric primary user activity is proposed, which is defined as the probability of a primary user appearance during CR user transmission.

Because there is no guarantee that a spectrum band will be available during the entire communication of a CR user, it is important to consider how often the primary user appears on the spectrum band. However, because of the operation of primary networks, CR users cannot obtain a reliable communication channel for a long time period. Moreover, CR users may not detect any single spectrum band to meet the user’s requirements. Therefore, multiple noncontiguous spectrum bands can be simultaneously used for transmission.

**5.8 SPECTRUM SHARING**

The shared nature of the wireless channel requires the coordination of transmission attempts between CR users. In this respect, spectrum sharing should include much of the functionality of a MAC protocol. Moreover, the unique characteristics of CRs, such as the coexistence of CR users with licensed users and the wide range of available spectrum, incur substantially different challenges for spectrum sharing in CR networks.

The existing work in spectrum sharing aims to address these challenges and can be classified by four aspects: the architecture, spectrum allocation behavior, spectrum access technique, and scope. The first classification is based on the architecture, which can be centralized or distributed:

• Centralized spectrum sharing: The spectrum allocation and access procedures are controlled by a central entity. Moreover, a distributed sensing procedure can be used such that measurements of the spectrum allocation are forwarded to the central entity, and a spectrum allocation map is constructed. Furthermore, the central entity can lease spectrum to users in a limited geographical region for a specific amount of time. In addition to competition for the spectrum, competition for users can also be considered through a central spectrum policy server.

• Distributed spectrum sharing: Spectrum allocation and access are based on local policies that are performed by each node distributively. Distributed solutions also are used between different networks such that a base station (BS) competes with its interferer BSs according to the QoS requirements of its users to allocate a portion of the spectrum.

The recent work on comparison of centralized and distributed solutions reveals that distributed solutions generally closely follow the centralized solutions, but at the cost of message exchanges between nodes.

The second classification is based on allocation behavior, where spectrum access can be cooperative or no cooperative.

• Cooperative spectrum sharing: Cooperative (or collaborative) solutions exploit the interference measurements of each node such that the effect of the communication of one node n other nodes is considered. A common technique used in these schemes is forming clusters to share interference information locally. This localized operation provides an effective balance between a fully centralized and a distributed scheme.

• Non-cooperative spectrum sharing: Only a single node is considered in non-cooperative solutions. Because interference in other CR nodes is not considered, non-cooperative solutions may result in reduced spectrum utilization. However, these solutions do not require frequent message exchanges between neighbors as in cooperative solutions.

Cooperative approaches generally outperform no cooperative approaches, as well as closely approximating the global optimum. Moreover, cooperative techniques result in a certain degree of fairness, as well as improved throughput. On the other hand, the performance degradation of non-cooperative approaches are generally offset by the significantly low information exchange and hence, energy consumption.

The third classification for spectrum sharing in CR networks is based on the access technology:

• Overlay spectrum sharing: Nodes access the network using a portion of the spectrum that has not been used by licensed users. This minimizes interference to the primary network.

• Underlay spectrum sharing: The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users. Underlay techniques can utilize higher bandwidth at the cost of a slight increase in complexity. Considering this trade-off, hybrid techniques can be considered for the spectrum access technology for CR networks. Finally, spectrum sharing techniques are generally focused on two types of solutions.

Spectrum sharing inside a CR network and among multiple coexisting CR networks,are explained below:

• Intranet work spectrum sharing: These solutions focus on spectrum allocation between the entities of a CR network. Accordingly, the users of a CR network try to access the available spectrum without causing interference to the primary users. Intranet work spectrum sharing poses unique challenges that have not been considered previously in wireless communication systems.

• Internetwork spectrum sharing: The CR architecture enables multiple systems to be deployed in overlapping locations and spectrum. So far the internetwork spectrum sharing solutions provide a broader view of the spectrum sharing concept by including certain operator policies.

**5.9 SPECTRUM MOBILITY**

The fourth step of spectrum management, is spectrum mobility management. After a CR captures the best available spectrum, primary user activity on the selected spectrum may necessitate that the user change its operating spectrum band, which is referred to as spectrum mobility. Spectrum mobility gives rise to a new type of handoff in CR networks, spectrum handoff.

Protocols for different layers of the network stack must adapt to the channel parameters of the operating frequency. Moreover, they should be transparent to spectrum handoff and the associated latency. Each time a CR user changes its frequency of operation, the network protocols may require modifications to the operation parameters. The purpose of the spectrum mobility management in CR networks is to ensure smooth and fast transition leading to minimum performance degradation during a spectrum handoff.

An important requirement of mobility management protocols is information about the duration of a spectrum handoff. This information can be provided by the sensing algorithm. After the latency information is available, the ongoing communications can be preserved with only minimum performance degradation. The intrinsic characteristics of a CR network give rise to two novel concepts: spectrum mobility and spectrum handoff.

**5.10 INTERFERENCE AVOIDING BEHAVIOR**

Secondary spectrum licensing and cognitive radio was arguably conceived with the goal and intent of implementing interference-avoiding behavior [J.M00, Hay05]. Indeed, in this intuitive approach to secondary spectrum licensing cognitive radios sense the spatial, temporal, or spectral voids and adjust their transmission to fill in the sensed white spaces. Cognition in this setting corresponds to the ability to accurately detect the presence of other wireless devices; the cognitive side-information is knowledge of the spatial, temporal and spectral gaps a particular cognitive Tx- Rx pair would experience.

The cognitive radios would adjust their transmission to fill in the spectral void with the potential to drastically increase the spectral efficiency of wireless systems. The cognition required for this type of behavior is knowledge of the spectral gaps. In a realistic system the secondary transmitter would spend some of its time sensing the the channel to determine the presence of the primary user.

Under idealized assumptions, the rates R1 of the primary Tx-Rx pair and R2 of the cognitive Tx-Rx pair achieved through ideal white-space filling. When a single user transmits the entire time in an interference-free environment, the axes intersection points are attained. The convex hull of these two interference-free points may be achieved by time-sharing (TDMA fashion). Where on this line a system operates depends on how often the primary user occupies the specific band

**5.11 INTERFERENCE AVOIDANCE THROUGH MIMO**

In addition to detecting the spectral white-spaces, interference at the primary user may be avoided or controlled if the cognitive user is equipped with multiple antennas, and is able to place its transmit signal in the null space of the primary users receive channel the fundamental tradeoff a cognitive transmitter faces between maximizing its own transmit throughput and minimizing the amount of interference it produces at each primary receiver.

sThis from an information-theoretic perspective by characterizing the secondary user’s channel capacity under both its own transmit-power constraint as well as a set of interference-power constraints each imposed at one of the primary receivers.

The secondary transmitter to effectively balance between spatial multiplexing for the secondary transmission and interference avoidance at the primary receivers.