Abstract
Cognitive radio networks (CRNs) has emerged as a promising technology for wireless networks, in order to overcome the underutilization problem of the licensed spectrum bands. Its major difference from the traditional wireless networks is that here needy unlicensed users are allowed to access the channel. But they shouldn’t pose any type of harmful interference to the primary users i.e. the licensed users. But with this distinct feature of CRNs, an essential and challenging question raised, i.e. how to estimate interference accurately at the primary users end as well as from the secondary users side. Interference is an effect caused by the superposition of two systems of waves, such as a distortion on a broadcast signal due to atmospheric or other effects. In this paper, we studied about various factors those are causing interference to the wireless signals of cognitive radio networks and also different recent techniques developed for minimizing interference.

Keywords: cognitive radio, spectrum management, wireless interference, interference mitigation

Introduction
The usage of radio spectrum resources and the regulation of radio emissions occur at radio environment are coordinated by various govt. organizations and national regulatory bodies like the Federal Communications Commission (FCC). These organizations assign spectrum to licensed holders, also known as primary users, on a long-term basis for large geographical regions. However, it is seen that a large portion of those assigned spectrum remains under utilized by the primary users as illustrated in Fig. 1.

The inefficient usage of the limited spectrum necessitates the development of dynamic spectrum access techniques, where users have no spectrum licenses, and are also called as secondary users. They are allowed to use temporarily unused licensed spectrum. In recent years, the FCC has been considered as more flexible and comprehensive utilization of available spectrum, through the use of cognitive radio technology. Cognitive radio is the key enabling technology that enables next generation communication networks, known as dynamic spectrum access (DSA) networks so as to utilize the spectrum more efficiently without interfering with the primary users. A Cognitive Radio (CR) is the way of communication that modifies its source factor and transmission parameters depending on the interface with the atmosphere in which it is working [1]. It varies from conventional radio devices as cognitive radio can equip users with cognitive capability and reconfigurability. Cognitive capability is defined as the ability to sense and gather information from the surrounding environment, such as information about transmission frequency, bandwidth, power, modulation, etc. With this, secondary users can classify the best available spectrum. Reconfigurability defined as the ability to quickly adapt the operational parameters according to the sensed information to achieve the optimal performance. By exploiting the spectrum in an opportunistic manner, cognitive radio enables secondary users to sense the availability of spectrum, select the best available channel, coordinate spectrum access with other users, and vacate the channel when a primary user reclaims the spectrum usage right.

Fig. 1. Spectrum usages [1]
Spectrum holes/white spaces/underutilized spectrum of licensed users (i.e. Available for Unlicensed users) [4]

Cognitive radio is an approach used to overcome these perceptible spectrum problems as well as to improve the efficiency of communication. It has the potential to take decision, plan, sense, orient, learn and etc. Therefore, it is required to learn the parameters; recognize the necessities and objectives of the client so that a proper decision can be made to advance the efficiency of the radio communications. It is mainly used when the wireless networks get damaged or the base stations and access points become powerless. Opportunistic spectrum access creates the opening of underutilized portions of the licensed spectrum for reuse, provided that the transmissions of secondary radios do not cause harmful interference to primary users. Such a system requires secondary users to be cognitive as they sense the varying spectrum usage and rapidly reacts to it. Therefore, it is important to characterize the effect of cognitive network interference and proper management of spectrum.

Spectrum management includes four basic processes namely spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility. Spectrum Sensing process determines which portions of the spectrum are available and spectrum decision selects the best available channel among all the available spectrums. Underutilized spectrums (i.e. available for reuse) are also known as white spaces or spectrum holes. Spectrum sharing process coordinates with other users to access the channel. And in spectrum mobility process secondary user vacate the channel when the licensed users are detected. Spectrum sensing plays a critical role in CRNs. Secondary users have to sense the channel before they transmit. A two-state sensing model is commonly used to classify the state of the channel (either busy or idle state). Secondary users can only utilize a channel when it is detected to be in idle state.

Due to spectrum sharing nature, a CR network can utilize the spectrum more efficiently when synchronized with the primary user on an interference tolerant basis. Here, the secondary or primary user’s interference are carefully managed and well maintained below a certain level by the CR network so as to protect the primary user’s priority. Therefore, it is desirable to model CR-primary interference to reveal the cause of deterioration of primary network and arrangement of CR networks.

In our paper, spectrum sensing, interference analysis, various system models purposed by scholars and various techniques for interference mitigation at PUs due to SUs in CRNs is being described. With the two-state sensing model, SUs can only use a channel when it is in idle state. In other words, if any user is occupying the channel, other SUs are prohibited from concurrently transmitting on the same channel. Therefore, with this sensing model, the SUs detects an active user in their sensing range and do not participate in transmission. This observation will significantly simplify interference modeling and analysis due to the bounded maximum number of interfering SUs, which will be studied in detail in the subsequent sections.

**Interference in Cognitive Radio Network**

Interference is an effect caused by the superposition of two systems of waves, such as a distortion on a broadcast signal due to atmospheric or other effects. Interference occurs when two or more electromagnetic waveforms are combined to form a resultant wave in which the displacement is either reinforced or cancelled. The fading or disturbance of received radio signals are caused by unwanted signals from other sources, such as unshielded electrical equipment, or broadcast from other channels.

**Factors causing Interference**

Various possible factors affecting signals during communication resulting interference can be classified in terms of their following attributes:-

**A. Source**

i. Wi-Fi source: cell phones, wireless headphones, Bluetooth devices,

ii. Non Wi-Fi source: microwave oven, video camera, Or
a. Internal: system noises (thermal noise, shot noise, transit-time noise)
b. External: external noises (atmospheric noise, industrial noise, extraterrestrial noise), different infrastructural obstacles, sun light ray

**B. Type**

a) Passive: Traffic monitoring, eavesdropping
b) Active: Disruption in service, alteration of data, dynamic change in route information

**Impact of interference in communication**

There are various types of impacts of interference on both type of users i.e. primary users and also secondary users. We can detect interference at different process stages of communication during with different scenarios like secondary user to primary user, secondary user to secondary user or primary user to a secondary user. There occurs a very much less interference in case of primary user to primary user communication (i.e. overlay condition). It can be ignored as it can be minimized with some technological effort. But there is more interference occurs when secondary users are introduced in to the licensed spectrum band (i.e. underlay condition) with cognitive radio capabilities.

Let say \( \text{Signal}_{d}= \text{Signal \text{ Strength at Destination Point}} \)
\( \text{Signal}_{r}= \text{Signal \text{ Strength at Receivers Point}} \)

Then,
\( \text{Signal}_{d}= \text{Signal}_{r}+ \text{Noise} \) (Overlay Cond. primary to primary user)
\( \text{Signal}_{d}= \text{Signal}_{r}+ \text{Noise}+ \text{Interference} \) (Underlay Cond. secondary user involvement)

There we can categorise the mechanisms which causes interference to two categories i.e. basic mechanisms and security mechanism. Resource consumption and disruption in routing are some basic mechanisms and key management is security mechanism that can cause interference.

Interference occurs due to different factors at different layers like

A. Physical layer: Communication jamming, eavesdropping, message interception

B. Data link layer: traffic analysis and monitoring, service disruption

C. Network layer:
   i. Route discovery: Routing table overflow, message flooding, routing cache poisoning
   ii. Route maintenance: fake control messages
   iii. Data forwarding: Blackhole attack, wormhole attack

iv. Other complex attacks: Sleep bereaving, disclosing location of all nodes

D. Transport layer: Session hijacking
E. Application layer: Rejection route request (RREQ) of other nodes, Mobile virus, worm attack

Interference occurred by various wifi and non-wifi sources, due to which wireless signals got distracted. It should be minimized to maintain Quality of service (QoS).

![Image](https://example.com/image.jpg)

**Recent developments for minimizing interference**

Spectrum sensing is an essential process in CRNs, categorized into two set of groups i.e. local sensing and cooperative sensing [2]. In case of local spectrum sensing technique, each SU independently make the decision about the channel state from its own information gatherings. This local spectrum sensing includes some techniques like matched filter detection [3], energy detection [4] and cyclostationary detection [5]. But in case of cooperative sensing technique, multiple SUs have to cooperate with each other, within a centralized or distributed mode, to determine the channel availability at the desired network [6]. The common local sensing model is referred to as a two-state model: idle and busy. It is defined with energy detection as defined as below [7].

\[
A_i = \begin{cases} 
  x_i & \text{Idle} \\
  s + x_i & \text{Busy}
\end{cases}
\]

Where, \( A_i \) is the signal that SU \((i)\) receives, and here \( x_i \) is the \( AWGN \), \( (s) \) is the signal that the PU transmits. Interference plays a critical role in CRNs, especially in wireless transmission environment. In [8], the distribution of the interference power at primary receiver was studied, when the interfering SUs follow a Poisson field distribution. They found that the interference probability density functions (PDFs) follows heavy-tailed a-stable distributions. In [9], interference model with power and contention control was presented. In [10], the authors proposed a statistical interference model. They reflect on the sensing...
Routing in CRN is difficult because of its dynamic variation of the available channels, data rates, and bandwidth. The routing protocols in CRN can be classified as proactive, reactive, hybrid, and adaptive per hop, and the routing model can be centralized or distributed [11]. Depending upon the protocol operation, the routing protocols for CRN can be classified as spectrum-aware-based, multi path-based, local coordination-based, reactive source-based, and tree-based [12]. In [13–16], route discovery is incorporated with spectrum sensing. On [13] authors have proposed high-throughput packet transmission using spectrum-aware routing (SPEAR) protocol. SPEAR is an on-demand routing protocol, and it makes routing decisions based on the collaboration of physical and MAC layers. Ma et al. [14] modified the AODV protocol, and routing decision. It is done by intermediating the SU node, so that the available time for data transmission between SU source and destination increases in so as to reduce the switching delay. This routing protocol introduces extra overhead of broadcasting RREQ messages, and deafness introduces extra delay to RREQ messages. The authors in [15] have proposed a routing protocol called SAMER which considered spectrum availability and quality. SAMER protocol enhances route robustness and improves throughput performance of the network. This protocol establishes route; based on periodically collected information, and the path is selected depending on minimum hop count and spectrum availability. Cheng et al. [16] have also proposed an on-demand routing protocol for CRN called spectrum-aware on-demand routing protocol (SORP), where the best channel is selected based on minimum channel switching delay and back-off delay. In local coordination-based routing, nodes choose the flow direction based on neighborhood interaction. The authors in [17] have presented a routing protocol, which minimizes the channel switching delay for SUs and help to minimize channel contention among SUs. This protocol improves the end-to-end performance of the network. The [18, 19] considers multipath routing in CRN. Multipath routing discovers multiple routes between source and destination. This minimizes inter-path contention and interference and enhances route reliability. The authors in [20, 21] proposed a tree-based routing protocol. In this type of routing protocols, a tree-structured network is enabled by configuring a root. The tree-based algorithm works along with channel selection mechanism. The tree-based scheme suffers from scalability problems because of overhead incurred in establishing and maintaining tree structure. Gymkhana, a distributed routing protocol proposed in [22], collects key parameters for routing between source and destination, and mathematical framework is modeled and evaluated to find the connectivity of different paths by considering PUs activity. The authors in [23] considered AODV as a pure on demand route acquisition system, as nodes do not maintain routing information or participate in exchange of routing tables. In ad hoc network, AODV routing protocol minimizes the number of required broadcasts for creating the routes. So, the modification of AODV routing protocol for CRN is considered in this paper.

Conclusion
Cognitive radio technology has been proposed in recent years as a revolutionary solution towards more efficient utilization of the scarce spectrum resources in an adaptive and intelligent way. By tuning the frequency to the temporarily unused licensed band and adapting operating parameters to environment variations, cognitive radio technology provides future wireless devices with additional bandwidth, reliable broadband communications, and versatility for rapidly growing data applications. In this survey, the basic concept about cognitive radio, its characteristics, functions, network architecture and interference are presented, and then various research topics on interference mitigation in cognitive radio networks are discussed. Interference to PUs caused by SUs is a critical issue in CRNs.

References
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