



A Review on Cognitive Radio Spectrum Sensing Candidature for 5G and Next Generations

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Abstract

Each generation of technology has its goals. The goals of Fifth Generation (5G) technology are to improve system capacity, reliability, and energy efficiency, while reducing latency and massively increasing connection density. At present, the advancement in mobile devices and the ever increasing mobile users consumes the limited mobile radio resources daily which tends to impact negatively on the 5G goals. To mitigate this radio resources challenges in order to meet 5G and Next Generations (xG) technology requirements, necessitates the development of a Dynamic Spectrum Access (DSA) called Cognitive Radio (CR). This research presents a review of an overview on Spectrum Sensing (SS) using Centralized Cooperative Spectrum Sensing (CCSS) technique of Cognitive Radio Network (CRN) for Optimal Spectrum Sensing Time (OSST). To properly utilize the radio spectrum and perform transmission in the legal spectrum bands, the Secondary User (SU) needs to spy the Primary User (PU) presence proactively to identify spectrum white holes and avoid harmful interference.

Keywords: Cognitive Radio, 5G, xG, Spectrum Sensing.

1. Introduction

The advent of wireless communication technology and higher demands of broadband multimedia services have triggered the use of radio-waves to carry information far and wide as discussed in (Sharma, N. 2016). New wireless technologies such as smart phones, wireless computers, business networks, and Wireless Local Area Network (LAN), mostly used for personal, homes, as well as Industrial, Scientific and Medical (ISM) purposes are rapidly consuming a large portion of the mobile radio spectrum in (Lall *et al.*, 2016). In 2020, the number of unique mobile internet users stood at 4.28 billion, indicating that over 90 percent of the global internet population use a mobile device to go online because the wireless network has become a great business source where users can fulfill their daily communication needs (Statista, 2021). Different wireless communicating devices result to using different frequencies of the radio spectrum to transmit and receive information. Wireless frequencies used by simplex, half-duplex, and duplex devices are static in nature and are assigned to Corporate Organizations (CO) by a regulatory body of the International Telecommunication Union (ITU) in accordance to Institute of Electrical and Electronics Engineers (IEEE) set standard. This static frequency assignment policy is also domestically regulated by individual countries commissions like Nigerian Communication Commission (NCC), Nigerian Broadcasting Commission (NBC), and Federal Communication Commission (FCC) of United State of America as in (Jia *et al.*, 2016). In (Akyildiz *et al.*, 2008), these local regulatory bodies assigned spectrum to licensed holders, also known as primary users on a long-term basis for large geographical regions. A large portion of the assigned spectrum remains underutilized. In most cases, the bandwidth enabled ranges from 15% to 85% in many countries, with a time increase from milliseconds to hours in most countries. (Danesh and Vasuhi, 2021). It is also evident that almost all of the radio spectrum from 3 kHz to 300 GHz has been licensed (Jain & Goel, 2017). Cognitive radio networks have been found to be effective and intelligent solutions, which by a sequence of intelligent sensing, aggregation of sensed information and decision making, provide an optimal method of allocation of spectrum to demanding users (Sivagurunathan *et al.*, 2021). In (Ahmad *et al.*, 2015), it was estimated that by the end of 2020, there will be over 50 billion wireless devices connected to the Internet of Things (IoT). At present, CR through the adoption of four spectrum management functionalities (spectrum sensing, decision, sharing, and mobility) is now becoming one of the most important techniques for high utility of these unutilized spectrum holes in emerging technology like 5G and other advanced technologies (Liao, 2021). CRN allowed unlicensed spectrum owners known as SUs to operate in the licensed spectrum bands seamlessly without tampering with the PUs transmission as illustrated in Figure 1.

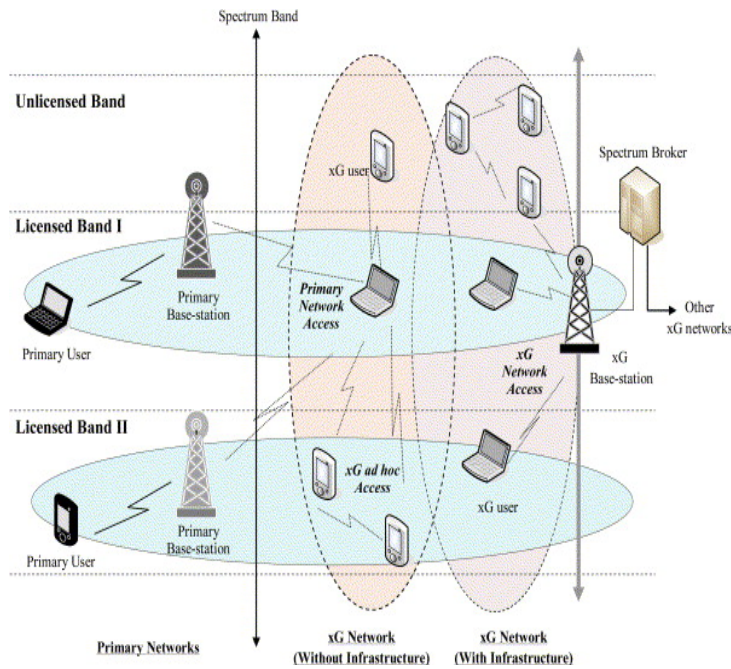


Figure 1. CRN with Next Generation Architecture (Akyildiz at al., 2008).

Spectrum sensing in CRN is an important technique for efficient utilization of the radio spectrum, where the SUs need to sense the frequency spectrum by sending spying signals along the channels in the PU spectrum as fast as possible to avoid harmful interference. According to IEEE “Cognitive radio is defined as a transmission system that senses its operational electromagnetic environment and dynamically and autonomously adjusts its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, and access secondary markets.” The cognitive idea is to convert the interference links separating different radio frequency bands into cognitive links, thereby creating access to the PUs idle channels in order to increase the mobile network system bandwidth to meet 5G and xG transmission requirements.

2. Cognitive Radio

Cognitive radio is a wireless technology that adjust transmission parameters dynamically and autonomously through communication with the radio environment (de Carvalho *et al.*, 2015). The aim of CR is to evaluates and use the wireless network idle natural resources (frequency, time, and transmitted energy) effectively (Kanti & Tomar, 2016). This cognitive assignment is championed by a function known as spectrum sensing. When a spectral freedom is detected (also known as a white hole), the radio modifies its Transmitters (Tx) and Receivers (Rx) to transmit in that channel. The concept of CR was built on modified Software Defined Radio (SDR) platform, and can sense and react to environmental changes (Ritu & Malhotra, 2016).

SDR were the confined software which were capable of handling the emerging technologies of radio. The term SDR coined by a computer scientist, Joseph Mitola in 1992 (Ritu & Malhotra, 2016), is an autonomously programmable radio system in which radio parameters support broad range of frequencies, air interfaces, application software, and has ability to change initial programs to satisfy user requirements. CR does not only offer dynamic spectrum access but also grant the ability to reprogram its parameter according to changing radio environment conditions. Table 1 shows application based comparison between conventional Radio (cR), Software Radio Networks (SRN) and CRN.

Table 1. Comparisons between Conventional Radio, SRN and CRN (Ritu & Malhotra, 2016).

Conventional Radio	Software Radio	Cognitive Radio
Support specific number of users	Support Multiple variable systems, interference and its own. protocols dynamically.	Can create new waveform on
Configurability is done	Interface with	Can negotiate

at the same time of design	diverse radio systems.	interface.
Support multiple users but only at the time of design.	Has a wide range of services with variable QoS. to meet system QoS.	Has inbuilt SDR intelligence that adjust operation

3. Cognitive Radio Management Functionality

Cognitive radio is an opportunistic spectrum management technique that has four main functionalities, which are spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility as described in (Anusha & Mahanraj, 2016). These cognitive management functionalities are itemized hereunder and shown by a sequence of events called cognitive cycle as depicted in Fig 2.

3.1. Spectrum Sensing

This is the ability for a CR user to have proactive information about the PU availability and operations in a spectrum band. Thus, a CR user sent spying signals on the PU spectrum bands, observe their information to detect spectrum white holes.

3.2. Spectrum Decision

CR can allocate spectrum channels based on the observation of the spectrum sensing. This allocation depends on spectrum availability and possibly external policies that prioritized Quality of Service (QoS).

3.3. Spectrum Sharing

There may be multiple CR users trying to access the spectrum, hence CR network access should be coordinated to prevent multiple users colliding in overlapping portions of the spectrum.

3.4. Spectrum Mobility

CR users are regarded as visitors to the spectrum, hence, if a specific portion of the spectrum in use is required by a primary user, the SU will vacate the PU channel and communication must be continued in another channel. Figure 2 illustrate the Cognitive Cycle Domain (CCD).

For the purpose of this review paper, the focus is on the spectrum sensing technique.

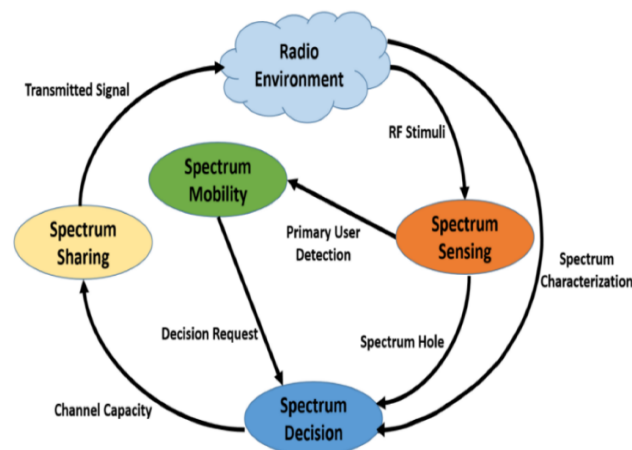


Figure 2. Cognitive Cycle (Shuaib *et al.*, 2016).

4. Spectrum Sensing

Spectrum Sensing (SS) is the ability for a CR user to spy and observe the PU information in the legal spectrum band in order to determine spectrum holes as illustrated in (Anusha & Mahanraj, 2016). In (Likhar & Bharnagar, 2017), these radio

channel parameters are determined using the PU transmitted power, frequency, bandwidth, modulation type, and pulse shaping. Radio frequency spectrum can be sensed in different ways (Datta & Khushbu, 2017). The broad categories spectrum sensing are illustrated in Figure 3 as: cooperative and non-cooperative SS. Non cooperative SS is also referred by (Anusha & Mahanraj, 2016) as Signal Processing Technique (SPT) or Transmitter Detection Technique (TDT) and cooperative SS as Receiver Detection Technique (RDT).

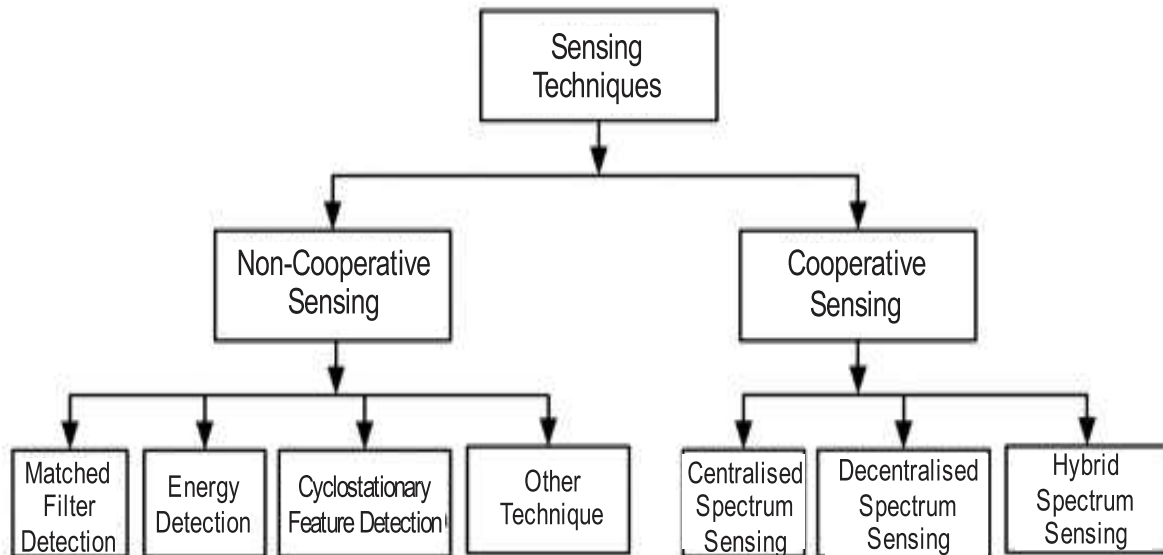


Figure 3. Sensing Techniques Block Diagram (Anusha & Mahanraj, 2016).

4.1. Cooperative Sensing

In this technique, the PU channels are been sense when multiple cognitive users collaborate with each other (Liu & Jia, 2017). Cognitive radio users are able to share their own sensing information with other cognitive nodes in order to make a global decision through collaboration or cooperation (Datta & Khushbu, 2017). This idea is proven to be more specified than individual decisions.

Five merits of cooperative spectrum sensing are discussed in (Datta & Khushbu, 2017) as follows:

- i) Noise uncertainty; fading and shadowing problem can be solved
- ii) The probability of false detection and false alarm is mitigated
- iii) The problem of hidden primary user is also solved
- iv) It provide primary user detection higher accuracy.
- v) It reduces sensing time and iterations.

Three demerits of cooperative spectrum sensing are listed in (Datta & Khushbu, 2017) as:

- i) It trade in with system complication.
- ii) It strengthen traffic overhead.
- iii) The method requires a control channel to send it sensing information for global decision with other sensing nodes.

Various types of cooperative sensing are centralized cooperative, distributed cooperative, and hybrid sensing in (Vikil & Nagamani, 2017). These three sensing techniques uses collaborative method of sensing and are mostly used for efficient optimization of sensing time and accuracy to mitigate harmful interference and maximized transmission bandwidth.

4.1.1 Centralized spectrum sensing

This technique uses regular dependent management principle, where a central unit known as Fusing Center (FC) collects sensing information from individual nodes (Datta & Khushbu, 2017). The FC identifies the available spectrum and allocates the free bands to the SUs as illustrated in Figure 4. It can be implemented in hard and soft scheme [17].

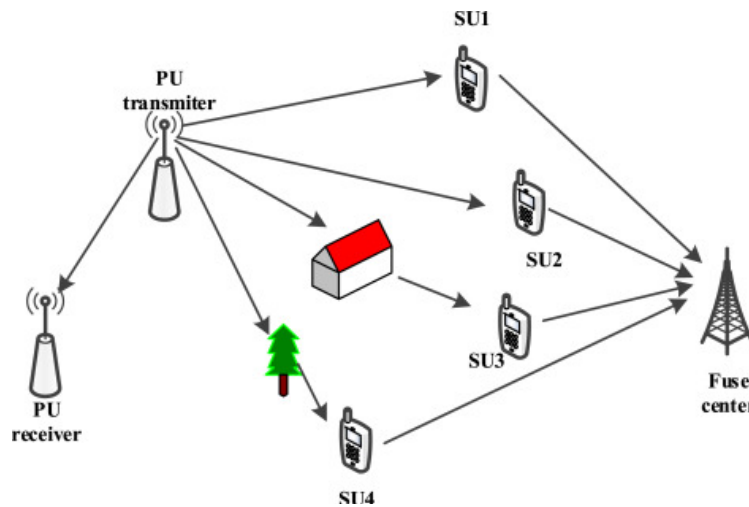


Figure 4. Centralized Network (Liu & Jia, 2017)

4.1.2. Distributed spectrum sensing

In this technique, CR nodes does not require a FC to learn from the closest node (Datta & Khushbu, 2017). These cognitive nodes share information among neighbors and make their own decisions about the unused spectrum.

4.1.3. Hybrid spectrum sensing

This technique is used to obtain spectrum information with minimum sensing duration and low computational complexity (Anusha & Mahanraj, 2016). This method is a balanced combination of other sensing approaches already discussed.

5. Conventional Spectrum Sensing Model

The spectrum sensing model is illustrated in (Kanti & Tomar, 2016) as:

$$H_0 : y(n) = w(n) \quad (1)$$

$$H_1 : y(n) = g(n)s(n) + w(n) \quad (2)$$

where:

H_0 is the hypothesis for the PU's absence.

H_1 is the hypothesis for the PU's presence.

$s(n)$ is the PU transmitted signal.

$g(n)$ is the received signal gain.

$y(n)$ is the SU received signal.

A decision statistics, W is used to describe the parameter(s) to be determined by the sensing detector and is formulated in (Liu & Jia, 2017) as:

$$W = \frac{1}{N} \sum_{n=1}^N |y(n)|^2 \quad (3)$$

The channel occupancy is obtained in (Liu & Jia, 2017) by comparing the decision metric, W against a fixed decision threshold, λ . If $W \geq \lambda$, there is detection of PU presence, but if $W < \lambda$, then the PU is absent and the channel is free for SUs to transmit. The decision statistics, W is the conceptual hyperspace (information highway) occupied by radio wave, with a dimensions of locating signal incident, modulation type, frequency, pulse shaping, time, energy, and possibly other.

6. Application of Spectrum Sensing

CR has a wide range of applications with economy importance (Vikil & Nagamani, 2017), which may include the following seven:

- i) Military and public security applications.
- ii) Domestic devices applications.



- iii) Bandwidth-Intensive applications.
- iv) Real-Time surveillance applications.
- v) Mobile and vehicular networks.
- vi) Industrial, scientific, and medical purposes.
- vii) Asynchronous transmission.
- viii)

7. Conclusion

CRN technology is an enabler technology for 5G and xG. Spectrum sensing techniques of CRN give the SU the leverage to operate in an unused frequency channels of the PU. This is achieved by converting the interference links into cognitive links to increase the transmission bandwidth of the SUs, improve the system throughput in Gbps, as well as maximize spectral efficiency.

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