Mapping Spectrum Sharing TechniquesWith Cognitive RadioApplications

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ABSTRACT

The rapid growth of the wireless communication services, has led to under-utilization of the spectrum .Cognitive Radio (CR) is a solution of the increasing demand of the spectrum. The CR includes four main cycles: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. The CR network architecture is divided into the primary network and the secondary network. This paper presents the Cognitive Radio network architecture for both infrastructure network and Ad Hoc network. The spectrum sharing techniques for the CR will be discussed. The most spectrum sharing functions are included in MAC. So, the spectrum sharing solutions will be explained for cognitive radio MAC design. Finally, CR applications and the proposed issues will be explained to solve research challenges in spectrum sharing.

Keywords:CR, CRN, CR-MAC, DSA, Overlay, Underlay, Interweave

1. INTRODUCTION

Although the mobile applications and services are increased rapidly, most wireless networks still follow the static spectrum allocation which causes the spectrum scarcity. A new technique is needed to exploit a temporal unutilized licensed spectrum. According to Federal Communication Commission (FCC) regulator, more than 70% of the available spectrum is not utilized optimally [1]. FCC makes the licensed spectrum available to the secondary user [2]. It allows Secondary User (SU) to use the licensed spectrum of Primary User (PU) without interference.

Figure 1 illustrates how to opportunistically exploit the unutilized wireless spectrum hole. This technique is called the opportunistic spectrum access. Cognitive radio is a novel method that is used to alleviate the spectrum scarcity problem and to provide the optimum utilization for the radio spectrum band. The cognitive radio was defined by different ways from many previous points of view:
S.Haykin: "Cognitive radio is an intelligent wireless comm. system that is aware of its surrounding environment and uses the methodology of understanding by building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency stimuli by making corresponding changes in certain operating parameters in real time"[3].
Mitola: "A radio or system that senses, and is aware of its operational environment and can dynamically and autonomously adjust its radio operating parameters accordingly" [4].
FCC: "a radio or system that sense its electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets".
The CR enables SU to sense the licensed spectrum band of a primary user by measuring it via the spectrum sensing techniques. Then, SU selects an appropriate free band by using the spectrum decision or selection techniques. If multiple secondary users try to access the common licensed band, the spectrumsharing of CR coordinates the secondary user's access to avoid interference and collision between them.In the spectrum mobility, SU should be learn if the primary user will use its own band or not, then SU moves from that licensed band to another free band when the primary user needs to use it. The cognitive radio includes the four main cycles according to its capability: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

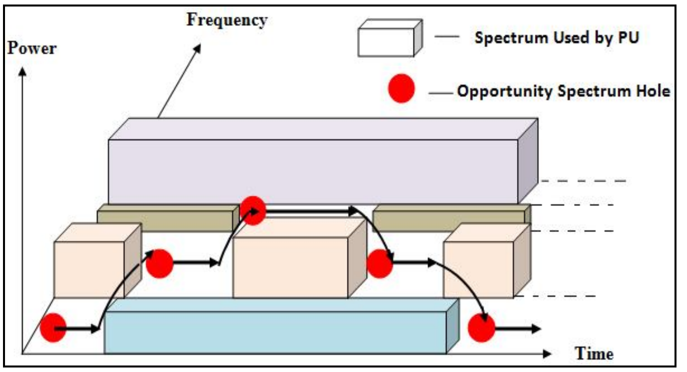


Figure 1 The Dynamic spectrum access technique

There are two distinct CR features: capability and re-configurability.

In ***the CR capability feature***, the CR enables SU to sense the licensed spectrum band of a primary user by measuring it via the spectrum sensing techniques. Then, SU selects an appropriate free band by using the spectrum decision or selection techniques. If multiple secondary users try to access the common licensed band, the spectrum sharing of CR coordinates the secondary user's access to avoid interference and collision between them. In the spectrum mobility, SU should be learn if the primary user will use its own band or not, then SU moves from that licensed band to another free band when the primary user needs to use it. As seen in figure 2, the cognitive radio includes the four main cycles according to its capability: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

The re-configurability feature refers to dynamically modify the CR parameters to enhance the Quality of Service (QoS) and to be aware of the surrounding radio environment. It is a Software-Defined Radio (SDR) that can be programmed according to its environment to adapt/change the transceiver parameters like operating frequency, transmit power control, and modulation type [5] [6].

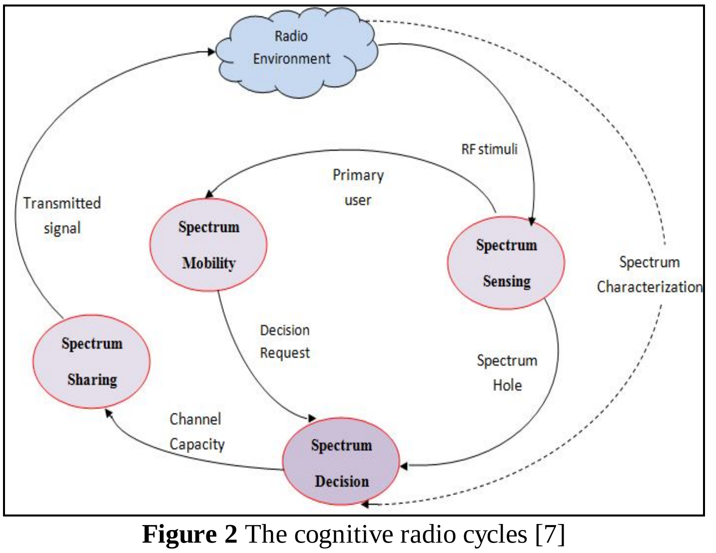


Figure 2 The cognitive radio cycles [7]

The paper focuses on the spectrum sharing techniques that are based on the three main aspects i.e. network architecture, spectrum allocation, and spectrum access. It also introduces the medium access control (MAC) sub layer for cognitive radio especially the Dynamic Spectrum Access (DSA) functions. Finally, the paper explains the three spectrum sharing categories; Underlay, overlay, and interweave. The paper is organized as follows: Section 2 introduces the CR network architecture. Section 3 shows the default functionality of cognitive radio MAC especially the spectrum sharing techniques for the DSA. The spectrum sharing techniques for CR applications and the open research issue of the spectrum sharing are discussed in section 4 and 5 respectively. Finally, section 6 shows the survey conclusion.

2. COGNITIVE RADIO NETWORK

Generally, most wireless network systems are categorized into two parts: the network architecture and the radio interface protocols. Similarly, the cognitive radio system is divided into the Cognitive Radio Network (CRN) architecture and CRN protocol layers.

2.1 Cognitive Radio Network Architecture

The basic components of cognitive radio network are; mobile station, base station and backbone networks depending on this there are three kinds of network architecture in cognitive radio i.e., infrastructure, ad hoc and mesh architecture. Because of the SU exploits the licensed spectrum of the PU. Therefore, the CRN architecture components include both a primary network and a secondary network as shown in figure 3 [5].

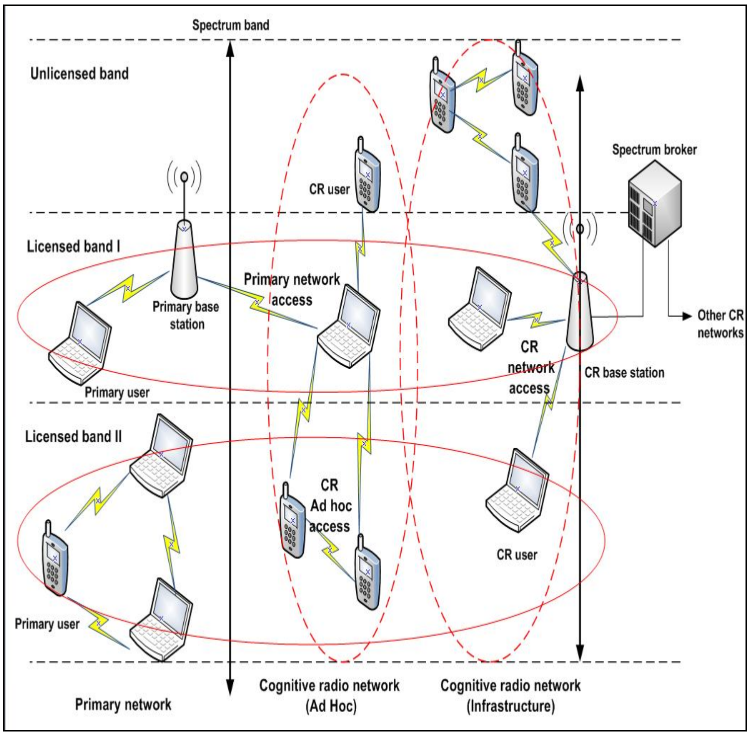


Figure 3 The cognitive radio network architecture [8]

2.1.1 The primary network

A licensed network is an existing network that gives the primary user a license to operate in certain spectrum band. Due to their priority in spectrum access, the operations of primary users should not be affected by secondary users. If primary networks have an infrastructure support, the activities of the PUs are controlled through primary base stations e.g., Cellular systems and TV broadcast networks. [6][8]. On the other side, if primary networks have ad hoc support, the PUs can communicate with each other in a multi-hop manner.

2.1.2 The secondary network

THE CR network (also called the dynamic spectrum access network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users (or secondary user) to share the licensed spectrum band. The secondary network (CR network) can be classified as a decentralized network like Ad Hoc network and a centralized network like an infrastructure network as depicted in figure 3 [8]. The CR infrastructure network has one or more CR base stations that provide single-hop connection to CR users and perform decisions on how to avoid interfering with primary networks. According to this decision, each CR user reconfigures its communication parameters. On the contrary, in the Cognitive Radio Ad Hoc Network (CRAHN), each user needs to have all CR capabilities and is responsible for determining its actions based on the local observation.
CRNs may include spectrum brokers that play a role in distributing the spectrum resources among different CR networks [5, 6, 8]. A spectrum broker is a central network entity that is responsible for the spectrum sharing in that secondary network. It collects operation information from each secondary network and coordinates the common

spectrum band usage to share with that band. It allocates the network resources to achieve efficient and fair spectrum sharing [5].
Based on the CR user's capability to access both the licensed portions of the spectrum used by primary users and the unlicensed portions of the spectrum through wideband access technology, thus, the operation types for CR networks can be classified as *licensed band operation* and *unlicensed band operation* as in figure 3 [8].

(a) Licensed band operation
The licensed band is primarily used by the primary network. The CR networks are focused mainly on the detection of primary users. Furthermore, if primary users appear in the licensed spectrum band during CR transmission, CR users should vacate that spectrum band and move to another available spectrum immediately.

(b) Unlicensed band operation
In the absence of primary users, CR users have the same right to access the spectrum. In this case, the spectrum sharing methods are required to coordinate (allocate) CR user's access.According to the CRN architecture as shown in figure 3, the CR users have the opportunity to perform three different access types [8]:

CR network access: CR users access their CR base station, on both licensed and unlicensed spectrum bands. Because all interactions occur inside the CR network, their spectrum sharing policy in CR network can be independent that in 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 access the primary base station through the licensed band. Unlike for other access types, CR users require an adaptive medium access control (MAC) protocol, which enables roaming over multiple primary networks with different access technologies.

2.2 **Cognitive Radio Protocol Stack**
According to the CR re-configurability feature, the parameters of the communication protocols (cross layer protocols) are adopt to implement the CRN using the CR capabilities at different layers of the protocol stack (e.g. physical, MAC, network, transport) [9]. The four CR capabilities are:

Spectrum sensing: it enables the CR users to allocate a part of the free spectrum when the primary user vacates this band. In the other word, it's a capability required to make the CR users monitor the licensed spectrum band during transmission and leave that band to another opportunistic spectrum dynamically when the primary user presence is detected. Therefore, the CR should be aware of the geographical surrounding environment, monitor the available spectrum bands, and detect the usage statistics of the primary and secondary users in these bands to determine the spectrum holes. It can be used by one CR user or multiple CR users. i.e. primary transmission detection (energy detection, cyclostationary feature detection, matched filter detection), cooperative detection, and interference based detection [10].

Spectrum decision: based on the information of the available spectrum holes from the spectrum sensing, the cognitive radio capabilities decide the suitable licensed spectrum band to SU access. It enables the secondary user to allocate the channel of an unused spectrum. i.e. cooperative allocation (mobile systems within base station) and non-cooperative allocation (Ad Hoc network)

Spectrum sharing: As result of a multiple secondary users trying to access the unused spectrum band(s), the CR coordinates between SU with the changes of radio environment to govern the SU transmission and to avoid the collision and the interference. It also provides the capability to maintain the QoS of CR users. i.e. interweave, underlay, and overlay.

Spectrum mobility: The CR is able to maintain/keep the secondary user transmission even the presence of the primary user on the licensed spectrum. Furthermore, when the primary user is detected through the spectrum sensing information, it moves the SU from that licensed spectrum band to another vacant portion of the spectrum. i.e. proactive handoff and reactive handoff.

Figure 4 shows the communication protocol layers of the CRN and the CR capabilities at these layers. In figure 4, the spectrum sharing functions are included in the data link layer. The link layer is divided into two sub layers; Logic Link

Control (LLC) and MAC. We will discuss the detailed spectrum sharing functions to adapt the MAC sub layer functionality.

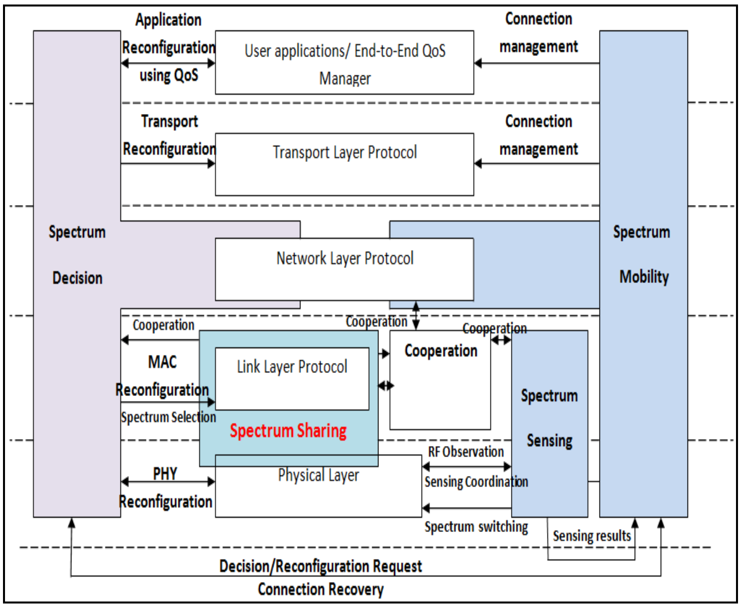


Figure 4 CR capabilities at the CRN protocol stack [7]

3 COGNITIVE RADIO OF MEDIUM ACCESS CONTROL

Because of the MAC functionality nature is related to the spectrum sharing functions. So, this survey presents the MAC for the cognitive radio especially the spectrum sharing functions on MAC. The data link layer in the context of 802.11 consists of two sub layers. These are the Logical Link Control (LLC) and Medium Access Control (MAC). The Logical Link Control layer manages traffic flow and error control over the physical medium. The Medium Access Control sub layer is designed to support multiple users on a shared medium within the same network [11]. Medium Access Control has an important role in several cognitive radio functions: spectrum mobility, channelsensing, resource allocation, and spectrum sharing[12]. MAC protocol is a core part for the operation of any network system. It is responsible for coordinating access of multiple users to spectrum channels.Therefore, designing an appropriate MAC protocol is the main task for realizing white space Dynamic Spectrum Access (DSA). The Cognitive Radio Medium Access Control (CR-MAC) protocols are classified into DSA functions and network infrastructure [13].

3.1 Dynamic Spectrum Access Functions

In [14], DSA is a new spectrum sharing paradigm that utilizes the spectrum holes and hence alleviates the spectrum scarcity problem as well as increases spectrum utilization. With DSA operation, CR users dynamically search for idle spectrum bands by continuously monitoring the spectrum bands and yield to PUs. They temporarily access those bands for wireless communications until PUs starts using a band.

Spectrum sensing, spectrum access, spectrum sharing, spectrum allocation, and spectrum mobility are the five DSA functions executed at MAC. The spectrum sharing function is significantly depends on both the spectrum access and spectrum allocation functions. So, this survey presentsa literature review of spectrum access, spectrum allocation, and spectrum sharing functions in DSA of CR-MAC.

3.1.1 The spectrum access

When a multiple CR users trying to access the common spectrum band. The CR-MAC protocols allow CR users to access another spectrum band (secondary spectrum) to avoid the collision. CR-MAC protocols are classified into three types according to different spectrum access modes: contention-based-MAC, time-slot-based MAC, and hybrid MAC [5, 13, 15].

(a) Contention-based-MAC

In the contention-based MAC protocols, called the random access protocols, the spectrum access of CR users is based on demand. The contention mechanism is based on the collision Sense Multiple Access/Collision Avoidance (CSMA/CA) principle. The CR user monitors the spectrum band to detect the absence/presence of any transmission from the other CR users and transmits after random backoff duration to prevent simultaneous transmissions then avoid the collision between them. Thus, the time synchronization is not required. The architecture of the contention-based-MAC protocols is a simplest and can be discussed in several previous works [16] [17].

(b) Time-slot-based MAC

These MAC protocols require network-wide synchronization. Each CR users has a specified time slot for both data transmission and control channels. So, there is no interference and collision. The time slot-based protocol achieves better network performance than the contention-based protocol. However it is a complicated design and suffers from some problems that need to be handled like, how to allocate the slots and how to synchronize the time of CR uses. The time-slot-based MAC protocols are explained in [18, 19].

(c) Hybrid MAC

The hybrid MAC is a combination between the contention-based-MAC protocols and the time-slot-based-MAC protocols. It achieves the simplest architecture of the contention-based-MAC protocols and effectiveness spectrum utilization of the time-slot-based-MAC protocols. These protocols use a partially slotted transmission, in which the control signaling generally occurs over synchronized time slots. However, the following data transmission may have random channel access schemes, without time synchronization. In a different approach, the super frame consists of control and data transfer duration that is predefined for all the CR users in the network. Therefore, a hybrid protocol provides higher spectrum utilization than a contention-based protocol and lower complexity than the time-slot-based-protocol. The hybrid MAC protocol is investigated in [20, 21].The comparison among the three spectrum access modes is listed in table 1.

Table 1: the spectrum access comparison

	Contention-MAC	Time slot-MAC	Hybrid-MAC
Spectrum Access	On demand	Reservation	A combination
Techniques	CSMA/CA	Time slot for both data transmission and control channels	Partially time slotted and partially random access
Design	Simplest	Complicated	Lower complexity
Time synchronization	Not required	Required	Synchronized for control, Not synchronized for data
Performance	Less performance of the collision avoidance (high collision)	Better network performance than contention-MAC (utilize the spectrum)	Higher spectrum utilization than a contention-MAC and effectiveness than time slot-MAC
Application	IEEE 802.11 DCF standards, LAN, WLAN	IEEE802.22 standard	IEEE 802.15.3, IEEE 802.15.4, IEEE 802.11ad, and video streaming over wireless networks

3.1.2 The spectrum allocation

Dynamic spectrum allocation is a process of distributing CR users into available spectrum bands. This process has two approaches; cooperative spectrum allocation and non-cooperative spectrum allocation [3].

(a) Cooperative spectrum allocation

The cooperative spectrum allocation (collaborative) refers to as the effect of the communication of one node on other nodes is considered. Where, the interference measurements are shared among these nodes. It allows the users more flexible spectrum access without the collisions.The cooperative users have a high degree of fairness and justice in coordination and distributing the allocation among them. It also improves throughput and provides the spectrum utilization. All the centralized spectrum sharing solutions are considered as the cooperative spectrum allocation [1] [8].Collaborative spectrum allocationis widely used for thetelecommunication networks based broadcast,IEEE 802.22/GSM base station, and the navigation.

(b) Non-cooperative spectrum allocation

In this approach, there is only one node. It is callednon collaborative spectrum allocation (selfish) solution. CR users perform the spectrum allocation based on their own local measurements and decision.The non cooperative spectrum allocation suffers from the lack of the communication with its neighbor networks. This lack produces the limited

available spectrum bands that are used by CR users. Therefore, throughput, fairness, and spectrum utilization are degraded. It is suitable for the local node [1] [8]. i.e. military, emergency and rescue case.
Actually, the cooperative protocol is better performance than non-cooperative protocol. But, the non-cooperative spectrum allocation protocol has much simpler architecture and computation complexity than a cooperative spectrum allocation protocol [13]. Several approaches will be discussed in order to enhancethe cooperative spectrum allocation as follows:

- ***Stochastic algorithms***

Stochastic algorithm is a process of utilizing the higher channel availability. Markov chain process is one of several stochastic approaches. In this algorithm, each node estimates the channel usage based on the statistics of historical channel access and the current local spectrum sensing results.Therefore, the stochastic algorithm performs the optimum allocation strategy [13].

- ***Game theory algorithms***

Game theory provides a natural mathematical framework to analyze and model interactions between several decision makers. As result, the dynamic interaction between the CR users can be represented as a game, and network interaction modeling and MAC protocol optimization in CR network can be archived by game theory. Moreover, each transmitter is a player, the choice of its transmitting parameters is its strategy, and its utility function is described either in terms of its individual or network QoS parameters. Optimization techniques are adopted to find optimal strategies for spectrum sharing in this game theory approach [15].

- ***Bio-Inspired algorithms***

Because of Many challenges of cognitive radio networks such as dynamic spectrum access, distributed and heterogamous network architecture, and so on can be modeled and resolved. By interesting characteristics such as autonomy, adaption and collective intelligence of collaborative individuals of biological systems, bio-inspired algorithms have been developed to provide a new method for achieving decentralized spectrum sharing [13]. The authors proposed several algorithms such as Biological-Inspired Spectrum Sharing (BIOSS) algorithm [22] and Biological Forging-inspired Communication (BFC) algorithm [22]. BIOSS algorithm performs a decentralized spectrum sharing based on the adaptive task allocation model in insect colonies. It also provides an efficient multiple spectrum bands sharing without any coordination among CR users. BFC algorithm provides a maximum spectrum utilization and minimum energy consumption.

3.1.3 The spectrum sharing

The spectrum sharing refers to the coexistence between the CR users to access the spectrum band based on the received spectrum sensing information from the surrounding environment networks. This approach can be classified into three categories: Interweave, Underlay, and Overlay [23].

(a) Interweave spectrum sharing

As can be seen from figure 5, after the process of sensing the licensed spectrum hole by CR user, the Interweave spectrum sharing allows the secondary user(s) to exploit an identified licensed spectrum hole(s) in absence of the primary user(s). Therefore, the spectrum sensing is prerequisite. If PU is detected, CR users dynamically must vacate the channel and try to establish a connection in another channel. No need for CR users to have the prior knowledge of the primary signal and restrict the transmission power of CR users in interweave spectrum sharing approach compared to the two previous approaches [13].
It's more appropriate for slow changing primary signal status scenario in expense of the spectrum utilization.

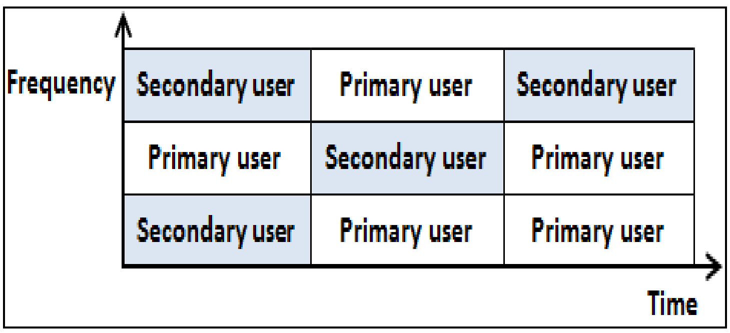


Figure 5 Interweave spectrum sharing technique

(b) Underlay spectrum sharing

This technique is illustrated in figure 6. The CR user transmits simultaneously with the primary user at the same licensed spectrum band without exceeding the interference temperature limit/threshold. According to this concept, it enables the CR user to interfere with the primary user and causes the interference. CR transmission is regarded as noise at primary licensed user if the interference temperature limit is exceeded by the CR user.This technique is widely used in the cellular networks (CDMA). It also allows communication over short range. Finally, this solution requires increased bandwidth compared to the overlay technique due to the interference.

In [13], CR users are allowed to simultaneously transmit with PU if the transmission powers of CR users are constrained below the interference temperature limit of PU.

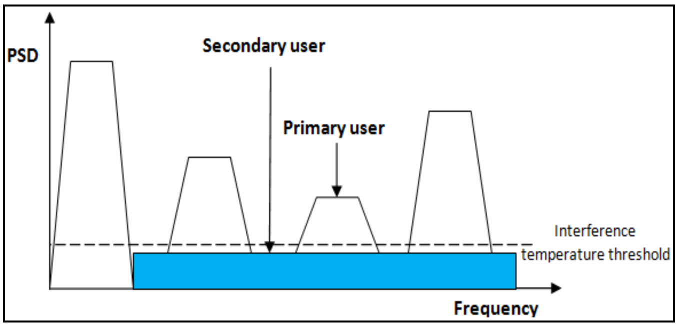


Figure 6 The underlay spectrum sharing [1]

To perform this method: CR users can access the licensed spectrum band at any time with limited interference. The underlay spectrum protocol should be adopted with the variation of the PU signal status. The spectrum sensing does not need to be performed. The underlay spectrum can be used in the spread spectrum techniques like CDMA and Ultra Wide Band (UWB), whichare able to access the underlay spectrum with very low transmission power for obtaining the high data rate.

So, the main function of CR-MAC for underlay spectrum system is how to optimize the power allocation of CR users without the primary transmission interrupt and with maintaining the transmission rate.

(c) Overlay spectrum sharing

In the overlay spectrum sharing, the CR user can access the spectrum hole of a licensed band. If the primary user transmits its signal through that band, the overlay process is concerned with interference mitigation between PU and SU. This process can maintain QoS of the primary user and improve its transmission. Furthermore, CR user has the prior knowledge of the PU transmission via several ways such as selfish approach and selfless approach to cancel the interference at PU and CR user. For selfless (cooperative) approach, the CR user has the knowledge of the PU by using the power enough to relay the PU signal to its licensed band and the remaining power is exploited to send its data to a licensed spectrum hole. Several coding schemes are used to maintain QoS of PU and provide the PU and SU transmission. For selfish (non-cooperative) approach, CR user exploit all transmission power to delete the interference between PU and SU at the cognitive receiver and by using sophisticated techniques (signal processing and coding) such as Dirty Paper Coding DPC [23].

In other words, the SU controls the interference with the PU as shown in figure 7. Based on the interference channel model, there are two transmitters and two receivers. Each transmitter i wishes to send a message W_i to receiver i, $i \in [P:S]$. For cognitive radio system, the transmitter/receiver P pair refers to the primary user and transmitter/receiver S pair refers to the secondary user (cognitive user). In normal case, the primary user transmitter PU_{Tx} send its message W_P to the licensed primary user receiver PU_{Rx}. While, the SU transmitter SU_{Tx} try to access PU_{Rx} if idle or another free licensed band like SU receiver SU_{Rx} when the PU_{Rx} occupied by the licensed PU_{Tx}. For the overlay spectrum sharing technique, CR user coexists with PU to share the licensed band. It use its available power to hear the gain of channel between transmitter and receiver, to know the PU codebook (standard encoding technique), and to assist PU for transmission. For selfish approach, CR user uses all available power to send W_S message to SU_{Rx}. Based on the local observation, the CR transmitter exploits the knowledge of W_P to null the interference at the secondary receiver side.For selfless approach, the part of CR user power is used to relay the PU message W_P to the primary user receiver PU_{Rx}. While, the remaining SU power is used for transmission its message W_S to the secondary user receiver SU_{Rx}. Based on the codebook knowledge of PU, the decoding scheme at SU_{Rx} estimates any of the two messages W_P , W_S and suppresses theinterference between them at the licensed receiver SU_{Rx} [23,24].

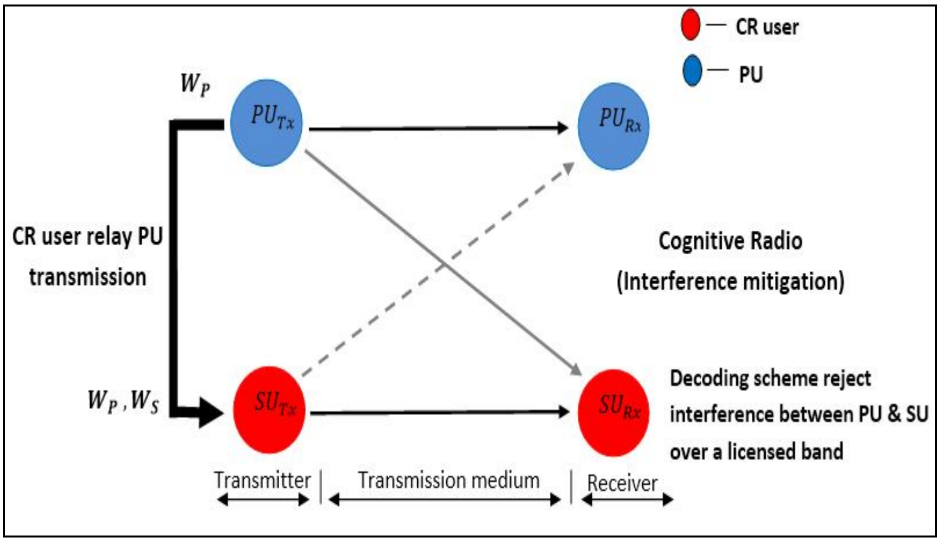


Figure 7 The overlay spectrum sharing over the interference channel model [24]

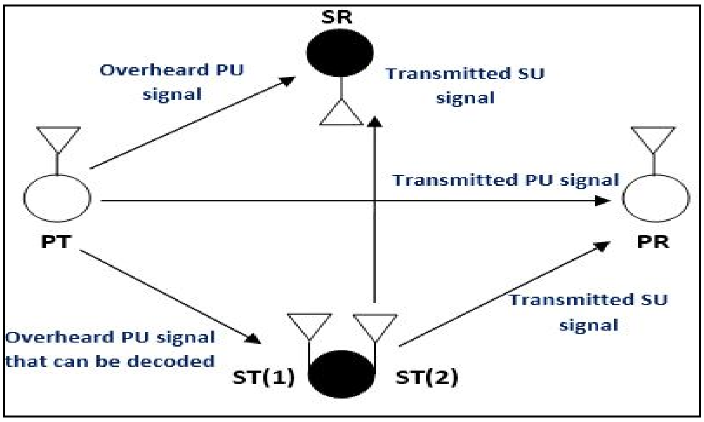
As well as, overlay spectrum sharing was introduced by the following researchers:

The authors [25] proposed a two-phase overlay spectrum sharing protocol based on cooperative decode-and forward relaying. Suppose the system model, comprising of primary transmitter PT, primary receiver PR, secondary transmitter ST which has two antennas ST (1) and ST (2) , and secondary receiver SR. This system model has two stages: A practical handshake mechanism for cooperation stage and two-phase transmission protocol stage.

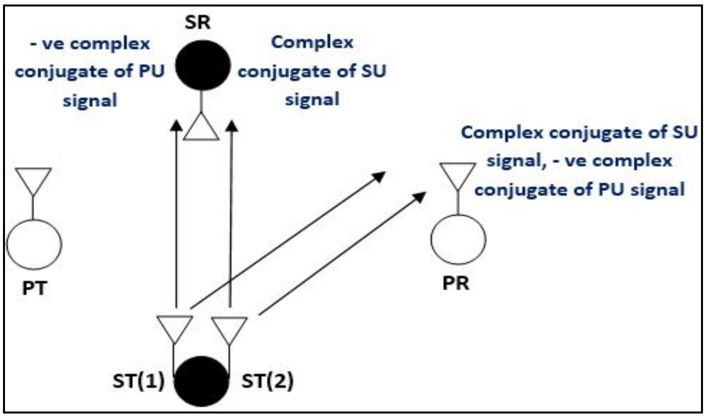
In the first stage, PT is one of the two entities combining an advanced primary system that performs the relay functionality. PT will seek the cooperation from the neighboring terminals to enhance its transmission performance by using the handshake mechanism for cooperation with PR as follows: PT broadcastsa cooperative right-to-send (CRTS) message to PR, which responds to CRTS by transmitting a cooperative clear-to-send (CCTS) message. As result of overhearing CRTS and CCTS, ST estimates the channel gains of PT-ST and PR-ST links. ST decides whether the primary system requirements can be achieved if it runs as a cooperative relay using decode-and forward (DF) scheme for the primary system. If yes, ST responds by sending a cooperative clear to help (CCTH) message to PT and PR, ST becomes a relay terminal and the primary system switches to the second stage. If the primary system requirements can’t achieved by ST that remains silent, PU signal is transmitted directly from PT to PR.

In the second stage, if ST serves as the cooperation relay, the system model operates in two phases. In the first phase, as shown in figure 8(a), the PU signal transmitted by PT to PR is overheard by ST (1) as well as SR. Simultaneously, ST (2) transmits the SU signal that is received by SR and PR. ST (1) try to decode the overheard PU signal in the first phase.

With successful decoding, in the second phase, as shown in figure 8(b), the negative complex conjugate of PU signal and the complex conjugate of SU signal are transmitted by ST (1) and ST (2) respectively. After the two-phase transmission, PR uses an orthogonalization vector which is multiplied by the combined received PU and SU signals tocancel out the interference SU signal and retrieve PU signal. SR also retrieves the SU signal using the same method.



(a)



(b)

Figure 8 System model of two-phase overlay spectrum
Sharing techniques [25]: (a) Transmission phase 1, (b) Transmission phase 2

In [26], the authors proposed a model that uses the cooperation relay in overlay spectrum sharing to cancel the interference between PU and SU. In this model, PU leases half of its time slots to the CR user for transmission at the cooperative relay, based on amplify and forward protocol.

This model is depicted in figure 9. It consists of the primary transmitter/receiver pair (PT and PR) with single antenna, secondary receiver SR with single antenna, and the secondary base station ST with N antennas, which work as the cooperative relay. There are two time slots for transmission. The PU signal can be transmitted directly from the PT to the PR by using the first time slot. In the second time slot, the PU signal is transmitted to the ST that amplifies and forwards the PT’s signal, and atthe same time, transmits its own signal (SU’s signal) while the PT remains silent. The primary user signal is retrieved by measuring the Maximum Ratio Combining (MRC) of the two PU signals. While, CR user signal is retrieved at the SR from the signal obtained from the ST in the second time slot and canceling the PU signalfrom the PT in the first time slot.

Authors at this survey show a conventional underlay scheme as a benchmark to demonstrate the advantages of the system model for the proposed cooperative overlay scheme. The design of antenna weights was designed at the secondary base station to achieve high performance of PU and SU, and to cancel the interference between them.

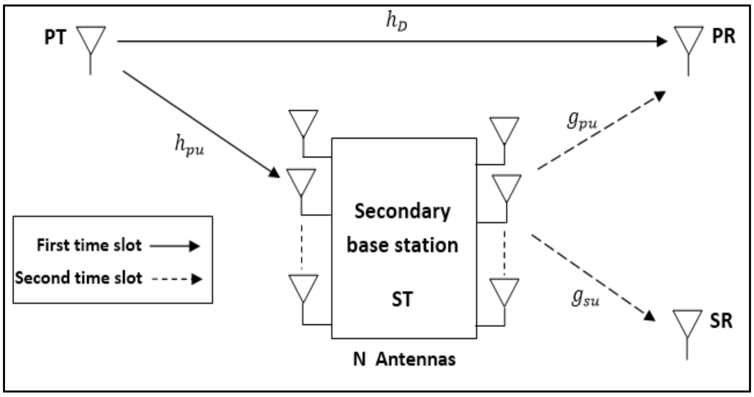


Figure 9 System model of cooperation relay in overlay spectrum sharing technique [26]

3.2 The network Infrastructure of CR-MAC

The network infrastructure includes the network architecture (centralized or decentralized), the transmission channel (single or multiple), Radio (single or multiple), and the control channel (in band, out-of-band, and underlay).The network architecture will be introduced in the CR-MAC network infrastructure in order to show the effect of that architecture on the spectrum sharing techniques. The network architecture of CR-MAC can be classified as:

3.2.1 Centralized network

A central entity has an important role in this solution. It controls and coordinates the spectrum allocations to the secondary users. Based on the spectrum sensing information, each entity forwards the measurements of the free available spectrum bands into the central entity which constructs the allocation map to provide the access user to an appropriate spectrum bands [1][8]. The centralized network is applicable for infrastructure networks that contain a huge number of subscribers such as IEEE802.22 included a central base station entity. It was the first standard for Wireless Regional Area Networks (WRAN) based on the CR techniques. It provided TV bands to achieve the spectrum utilization by opportunistically explosion of the idle licensed bands without causing interference to licensed users.The Centralized controller model is not suitable for ad hoc emergency or military use.

3.2.2 Distributed network

In the distributed network, there is no central entity. The users themselves make their own decision regarding spectrum access based on their local observation (policies) of the spectrum dynamics [1] [8].I.e. IEEE802.11.a.f (standard for wireless local area network that is used to describe the WI-FI technology within the TV white spectrum bands using the CR). The distributed network is relatively less expensive.

Finally, the spectrum sharing techniques on the basis of architecturecan be classified as Intra-network and Inter-network [1] [8]:

- **Intra-network spectrum sharing**

This technique provides the spectrum allocation inside the CR network. The CR userstry to access the available spectrum without causing interference to the primary users.

- **Inter-network spectrum sharing**

This technique provides the coexisting among CR users on the multiple CR networks. The CR architecture enables multiple systems to be deployed/ broadcasted in overlapping locations and spectrum. It provides a broader view of the spectrum sharing concept by including certain operator policies.
The combination between those techniques was proposed to enhance the spectrum sharing solutions. Thesecombinations are:

Centralized-Intra-Network Spectrum Sharing:
It contains the spectrum server(central entity) that coordinates all the cognitive radio users.All users in this case exhibit the cooperative nature.

Centralized-Inter-Network Spectrum Sharing:
A centralized inter network spectrum sharing technique is similar to intra network spectrum sharing technique but it is used for the wide spectrum range. Therefore, the spectrum broker distributes the spectrum among the users of the CR networks.

Distributed-Intra-Network Spectrum Sharing:
There is no central entity (user). In this technique, each CR user hasthe own sharing decision for transmission on the appropriate spectrum band.

Distributed-Inter-Network Spectrum Sharing:
In this scheme, each cognitive radio network makes the sharing decision in the spectrum sharing process.

4 THE SPECTRUM SHARING TECHNIQUES FOR CR APPLICATIONS

There are several applications and fields depended on the cognitive radio concept such as communication, network, security, scientific research, and rescue cases. The survey listed the previous DSA functions included the spectrum sharing techniques, which are used for those applications. Several previous researches for CR applications are presented as follow:

YU LUO et al. [27], because of using the acoustic signals for communication, echolocation, sensing and detection in ocean, this produces a congestion of the spectrum channels shared by various underwater acoustic systems. Thus, a smart UAN should be aware of the surrounding environment and dynamically reconfigure their operation parameters (e.g. frequency band, modulation scheme, and transmission power). Cognitive Acoustic (CA) users in underwater cognitive acoustic network (UCAN) are able to intelligently detect whether any portion of the spectrum is occupied, and change their operation parameters to temporarily use the idle frequencies without interfering with other networks.

Wendong Hu et al.[28], this paper presents the real-time spectrum sharing protocol called On Demand Spectrum Contention (ODSC) protocol for MAC that enables the coexisting network cells to compete for the scarce spectrum by exchanging and comparing randomly generated contention access priority numbers in an on-demand, distributed, and cooperative manner. In order to support internetwork coordination functions such as ODSC in 802.22 standard of Wireless regional Area network WRAN for DTV bands and other CR systems. Therefore, ODSC protocol provides efficient, scalable, and fair inter-network spectrum sharing among the IEEE802.22 cells.

Mubashir Husain Rehmaniet al. [29], natural disasters like earthquake or storms are unpredictable and cause the collapse of communications infrastructure, the lack of connectivity between sensors and sink in static WSNs, damage in the existing WLANs etc. Therefore, Cognitive Radio Ad-Hoc Networks (CRNs) is a promising technology and capable to federate the communication of coexistent networks temporarily. CRN architecture is consists of CR devices, Cognitive multi-radio mesh routers (CMRs), and Internet Portal Point. During the infrastructure discovery, CR devices already aware of distinct network entities and they are capable of changing their operation parameters according to the environment.Thus, the CR devices communicate with distinct networks. They exploit the unoccupied spectrum to restore the connectivity and access the internet of partially destroyed coexistent networks.

SaziaParvin et al. [30], the objective of CRN architecture is to improve the whole network operation to fulfill the user’s demands anytime and anywhere, CRNs are more flexible and exposed to wireless networks compared with other traditional radio networks. Hence, there are many security threats to CRNs, more so than other traditional radio environments. This research work aims to address the problem (the security issues) of spectrum management for CRNs and Attacks on different protocol layers. The countermeasures were presented to secure CRNs and try to solve the security challenges in CRNs. Table 2 introduces a summary for the spectrum sharing techniques and CR applications used in the previous research along with the spectrum access, spectrum allocation, and architecture type.

5 OPEN RESEARCH ISSUES OF THE SPECTRUM SHARING

In fact, there is no spectrum sharing technique outperforms the others. So, many issues will be proposed to enhance those techniques and overcome their challenges. The main spectrum sharing challenges are: 1- how the CR users share with the PU on the licensed spectrum band without interference and 2- how to select among the three spectrum sharing techniques according to the spectrum access toward increasing the spectrum utilization without interference. This survey analyzes those techniques to solve their challenges that will be the open research issues.

The major issue of interweave spectrum CR-MAC design is how to optimize spectrum sensing. CR users try to avoid interference with the PUs by periodically sensing for the occupied licensed bands. So, many interweave spectrum sharing approaches and MAC protocols for cognitive radio were mentioned to discuss the fast sensing problem in the interweave techniques and enhance the performance of it.
For the underlay spectrum sharing, the spectrum sensing should feed the underlay spectrum sharing by information such as the Adaptive modulation/ Coding (AMC), Transmit Power Control, and the position of the primary signal.

The challenge her is how to control the transmission power of CR users with the change of PU signalstatus in order to reduce the collision. Based on the literature review of the overlay spectrum sharing, the cooperative spectrum allocation is required to provide the overlay spectrum sharing by the information of available spectrum band from its neighbor networks and then enhance the spectrum utilization. Therefore, the research should be focused on two points: 1- the cooperative allocation effectiveness to make CR user gets the prior knowledge of the primary user within an appropriate power 2- How SUs create interference-free transmission to the PUs by using advanced techniques.

Table 2:Spectrum sharing techniques for CR applications

Paper title	Application	Spectrum access	Spectrum allocation	Network architecture	Spectrum sharing
Challenges and Opportunities of Underwater Cognitive Acoustic Networks	Navigation ship, comm., Offshore wind farms, echolocation, sensing and detection, oil drilling installation, and monitoring system	All	Collaborative (cooperative) and local (non-cooperative)	Ad-Hoc network and centralized	The overlay and the underlay spectrum
Efficient, Flexible, and Scalable Inter-Network Spectrum Sharing and Communications in Cognitive IEEE 802.22 Networks	IEEE802.22 standard of Wireless regional Area network WRAN for DTV bands	On demand-Contention	Cooperative	Distributed	Inter-network spectrum
A Cognitive Radio Based Internet Access Framework for Disaster Response Network Deployment	Rescue and disaster response of the infrastructure networks i.e. wireless sensor networks' nodes, sink, Wi-Fi access points, GSM base stations	without contention in distributed	Non cooperative spectrum sharing using a temporary CR Ad-Hoc network	Centralized (infrastructure) and decentralized (ad -hoc)	Inter-network using overlay strategy
Cross Layer Design of Multimedia Transmission Over Cognitive Radio UWB Multiband OFDM System	wireless standards such as IEEE.11a/g WLAN, IEEE802.16 WIMAX and IEEE802.22 3GPP are based on OFDM technology	Hybrid MAC Contention for MBOA, Time slot for IEEE802.15.3	(WiMEDIA/MBOA) led to non-cooperative allocation/ (IEEE802.15.3) led to cooperative allocation	Distributed (WIMEDIA/MBOA)/ Centralized (IEEE802.15.3)	A combination between overlay and underlay spectrum sharing
Cognitive radio network security: A survey	Security/ anti-threats of hackers	All	Cooperative	Distributed in each cluster of infrastructure	inter-network and intra-network

6 CONCLUSION

Cognitive radio was explained to support the spectrum utilization in the wireless communication services through increasing the spectrum usage. In this survey, the spectrum sharing techniques were successfully proposed and their policies to show how CR users coexist with the primary users to share the spectrum bands without interference. Spectrum access, spectrum allocation, and spectrum sharing were investigated through MAC design. With help of the previous works, the overlay, underlay, and interweave spectrum sharing techniques were introduced for CR-MAC protocols. The several approaches have been proposed to enhance the spectrum sharing categories. This work concluded that the game theory is exploited to analyze the behavior of the cognitive radio for spectrum allocation, spectrum access, and spectrum sharing. Last but not least, this survey looked for presenting some CR applications and open research issues for the spectrum sharing schemes.

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