REPUBLIC OF TÜRKIYE

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Electrical and Computer Engineering

EFFICIENT SPREAD SPECTRUM SHARING TECHNIQUE BASED ON 5G MIMO COGNITIVE NETWORKS

Mahdi Abbas Sarhan ALMALIKI

Master's Thesis

Supervisor

Prof. Dr. Osman Nurı UÇAN

Istanbul, 2022

EFFICIENT SPREAD SPECTRUM SHARING TECHNIQUE BASED ON 5G MIMO COGNITIVE NETWORKS

Mahdi Abbas Sarhan ALMALIKI

Electrical and Computer Engineering

Master's Thesis

ALTINBAŞ UNIVERSITY

2022

The thesis titled ENERGY OPTIMIZATION IN WSN ROUNTING BY USING THE K-MEANS CLUSTERING ALGORITHM AND WHALE OPTIMIZATION ALGORITHM prepared by MAHDI ABBAS SARHAN ALMALIKI and submitted on 15/12/2022 has been **accepted unanimously** for the degree of Master of Science in Electrical Computer Engineering.

____

Prof. Dr. Osman Nuri UÇAN

the Supervisor

Thesis Defense Committee Members:

Prof. Dr. Osman Nuri UÇAN	Department of Electrical and Electronic Engineering, Altinbas University	__________________
Asst. Prof. Dr. Abdullahi Abdu IBRAHIM	Department of Computer Engineering, Altinbas University	__________________
Assoc. Prof. Dr. Adil Deniz DURU	Department of Trainer Education Marmara University	__________________

I hereby declare that this thesis meets all format and submission requirements of a Master's thesis.

Submission data of the thesis to Institute of Graduate Studies: ____/____/____

I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Mahdi Abbas Sarhan ALMALIKI

Signature

DEDICATION

To my Parents, the reason of what I become today. To my sister & brothers. A special thanks to Prof. Dr. Osman UÇAN for his support, worth notes and close follow up.

ABSTRACT

USING ARTIFICIAL INTELLIGENCE METHODS TO IMPROVE THE PREDICTION RATE AND ACCURACY

ALMALIKI, Mahdi Abbas Sarhan

M.Sc., Electrical and Computer Engineering, ALTINBAŞ University,

Supervisor: Prof. Dr. Osman Nuri UÇAN

Date: 12/2022

Page: 50

A model based on the combination of spectrum access techniques (underlay, overlay, and interweave) with an ant lion optimization strategy was developed in this study. This supports towards improves the system behavior of primary and secondary communication network through conserving the essential signal to noise ratio of primary and secondary users. Moreover, transmitting data from source to destination nodes that operate in the underlay, overlay and interweave mode. Further introduced the optimization techniques towards offers optimized results throughout the MIMO CR network. Then, based on the hamming precoding method to the number of channels used based on the PUs and SUs in the network, the number of channel users that is close to the orthogonal that gives the results was chosen. Meanwhile the channels are selected based on the transmitter time at unique time duration. Throughput, outage probability, and efficiency are used to evaluate how well the given approach performs (Detection Time). The suggested technique is implemented in MATLAB 2016b version, and its performance is assessed by comparing it to the prior methods, namely overlay, underlay, and interweave. The proposed MIMO CRs with optimization approach gives better result than the exiting approach named as underlay, overlay, interweave and hybrid spectrum access without optimization in terms of less computational complexity of the system with increased channel capacity. Also enables the maximum channel bandwidth despite the channel variations.

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

TABLE OF CONTENTS

Pages

LIST OF TABLES

Pages

LIST OF FIGURES

Pages

ABBREVIATIONS

CCC:	Common Control Channel
CCRN:	Cognitive Cooperative Radio Networks
CDMA:	Code Division Multiple Access
CR:	Cognitive Radio
FCC:	Federal Communications Commission
FD:	Full Duplex
HD:	Half - Duplex
MAC:	Medium Access Control
MC-CDMA:	Multi-Carrier - Code Division Multiple Access
MIMO:	Multiple Input and Multiple Output
PID:	Proportional-Integral-Derivative regulator
RF:	Radio Frequency
SSC:	Spread Spectrum Communications
SU:	Secondary User
UCC:	Underlay Control Channels
UWB:	Ultra-Wideband Systems

1. INTRODUCTION

1.1 BACKGROUND

Next-generation wireless networks face acute shortage of capacity, and the sharing of Radio Frequency (RF) spectrum is emerging as a practical option for decongesting networks. Multiple wireless systems that coexist within one spectrum band brings about sharing of spectrum, and this is achieved through multiple options that include signal processing, Medium Access Control (MAC) and spatial multiple access techniques. Sharing of the spectrum, if delivered or achieved successfully, possesses the potential to leverage spectral efficiency for maximum advantage [1]. By virtue of swelling demand, Spectrum has become a resource that is both scare and necessary. The expanding demand for Internet access, devices that consume greater bandwidth, has led to this growing demand for spectrum [2]. Cellular operators, who will find it increasingly difficult to meet the growing demands for bandwidth, will find spectrum sharing as a viable option for meeting the crunch in the spectrum. Of late, multiple issues related to seamless co-existence have cropped up, that are raised either by the Federal Communications Commission (FCC) or one or many of the various stakeholders in the industry including wireless service operators and manufacturers of wireless products [1]. Additionally, the presently available standards of wireless networks are governed by an allocation policy of static spectrum, which entails the allocation of wireless spectrum in favors of licensed players. This license typically extends over extensive geographical regions and is valid over a long-term [3]. Significant portions of spectrum that is assigned end up being used intermittently – in other words, the spectrum is not fully utilized. In order to resolve these issues of spectrum inefficiency, a proposal was mooted for utilization of dynamic spectrum access techniques [4]. For the purpose of effectively utilizing scarce spectrum resources, this method of dynamic spectrum sharing promises to be a sound approach that can efficiently optimize and dynamically use the spectrum. This is proposed to be achieved by permitting secondary users, considered as unauthorized wireless users, access to spectrum bands held by primary users, i.e. the spectrum holders [1].

Dynamic spectrum sharing by Cognitive Radio (CR) networks is finding greater acceptance of late, and this is related to the improvements in the allocation of communication resources over space, over time, and over frequency [5]. The phrase "cognitive radio mitola" [6] refers to a wireless terminal's capacity to continue being aware of the RF environment, allowing them to adjust and adapt settings on the go. The majority of legacy systems do not fully use or take advantage of the band granted, according to metrics of the efficiency of spectrum consumption by licensees of the principal band [7]. At the same time, new approaches to share this spare bandwidth with new entrants must be explored because of the rise in smartphones and other personal wireless devices. Cognitive radios provide an innovative solution in this case because of their ability to adapt to their environment. The three categories of cognitive radio information theoretical treatments are overlay, underlay, and interweave [8]. Primary differences among these categories of cognitive models are the manner in which interaction is carried out between primary users and secondary users [9].

1.2 PROBLEM STATEMENT

CR (Cognitive Radio) as a concept is quickly emerging as a solution that appears promising in order to overcome issues of spectral scarcity in radio systems, by taking advantage of licensed spectrum that is not utilized. Resource allocation problems rank among the significant problems in cognitive radio networks. In literature, as per the manner of SUs that have access to licensed spectrum, three main CR models of network implementation exist - overlay, Underlay and interweave Spectrum Sharing. Here, the overlay mode permits SUs to carry out transmissions in any power if the performance of PUs' is maintained. This mandates that every SU should make use of one part of the transmission power for the purpose of repeating packets of a PU which will take advantage the other part of the power and carry out transmission of own packets. In the interweave mode, the SUs will carry out transmission only when no activity of PUs' is detected. Underlay mode involves the parallel transmissions of PUs and SUs without conflicts. However, in underlay mode, interference mitigation will continue to be an important issue in spectrum utilization, whereas, overlay scheme performs better than the underlying scheme when it comes to terms of probability of outage. But, when the interference avoidance becomes a part of spectrum sharing, the underlying scheme of avoiding interference will offer a guarantee of a lesser outage probability when compared with that of pure interference avoidance. Here, a need exists to focus on hybrid schemes which will allow the secondary users to optimize transmission rates the moment a spectrum opportunity arises.

1.3 THESIS AIMS

Based on the statement of the problem, the researcher identified a set of problems which needs resolution. In this regard, the researcher aims at the development of an efficient dynamic Spread Spectrum technique for CR networks wherein the following objectives are framed:

To design and develop a novel cooperative spectrum access scheme which could avert resource allocation and spectrum utilization issues Objectives to increase bandwidth utilization overall while reducing congestion to verify the effectiveness of the suggested strategy using the throughput metric, outage probability, efficiency, data drop rate and detection time which could outperform other previous spectrum sharing techniques

1.4 THESIS ORGANIZATION

The remainder of this thesis has been compiled in the following manner (Figure 1.1) – Chapter 2 elaborates on the background and fundamentals related to the present research topic especially overview of cooperative network, CRs and spectrum sharing technique. It includes the summary of cooperative networks, cognitive radio cycle. In chapter 3, briefly lays down the spectrum sharing technology and different types of techniques used in spectrum sharing technology. The chapter also discusses the literature studies related to the work and identified the proceedings need in the field of research. Also, incorporated the merits and demerits of these techniques in elaborated manner. Chapter 4 discussed the methodology, system architecture, flow diagram, algorithm and the model of the system relied in the approach that is suggested. In addition, the performance of the suggested model is dealt with in the chapter. Chapter 5 discusses the simulation setup, process, and evaluated using the experimental results, based on comparison with the existing methods. Further, chapter 6 discusses the conclusion and future directions drawn out from the outcome of the research.

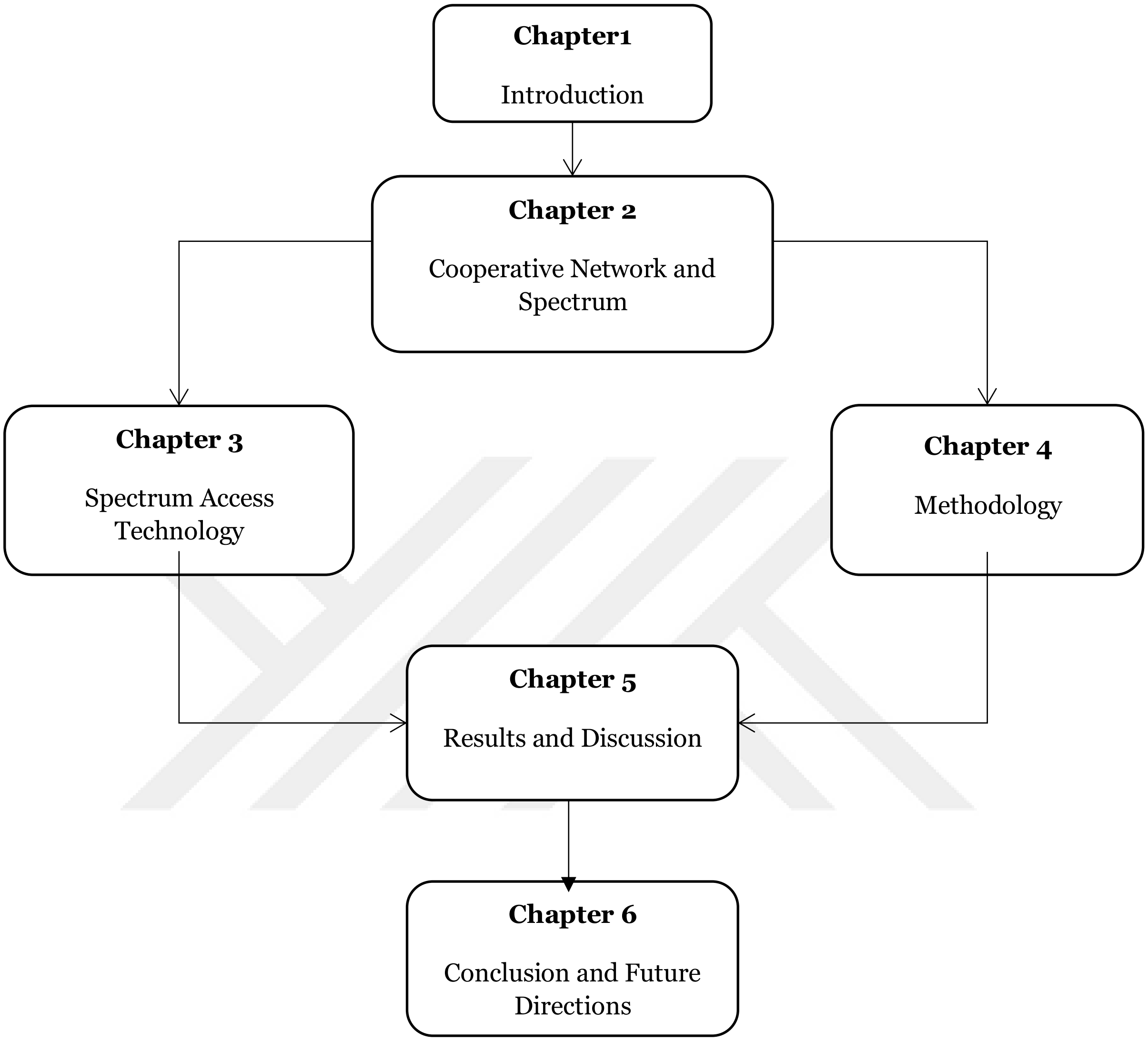

Figure 1.1: Thesis Organization

2. CONCEPT AND DEFINITIONS OF COOPERATIVE NETWORK

2.1 INTRODUCTION

Radio spectrum is turning out to be one of the most valuable resources in wireless communication systems, and wireless communication and its relevance are proven to be the foundation that effects coverage and capacity for fixed as well as mobile broadband networks. A large number of innovations that demand connectivity have created a demand for increased spectrum. The access of users with diverse needs has been increased in scope and rendered smooth and seamless, from average to versatile services which require high data rates. The rise in cause occurs because of using cells of smaller size and in addition to larger spectrum requirement. The issue, which started with a shortage of scarce resource now, got transferred to spectrum management problem. This change in the direction of the requirement motivated many researchers to renovate new policies for accessing the spectrum which is licensed and also to develop techniques which will lead to better consumption of the spectrum [10]. In this regard, the researcher examined the various state of the art techniques used for spectrum sharing in order to arrive at a consensus regarding the best technique suitable and the ways of improving the same through the examination of previous studies wherein the chapter flow is displayed in Figure 2.1.

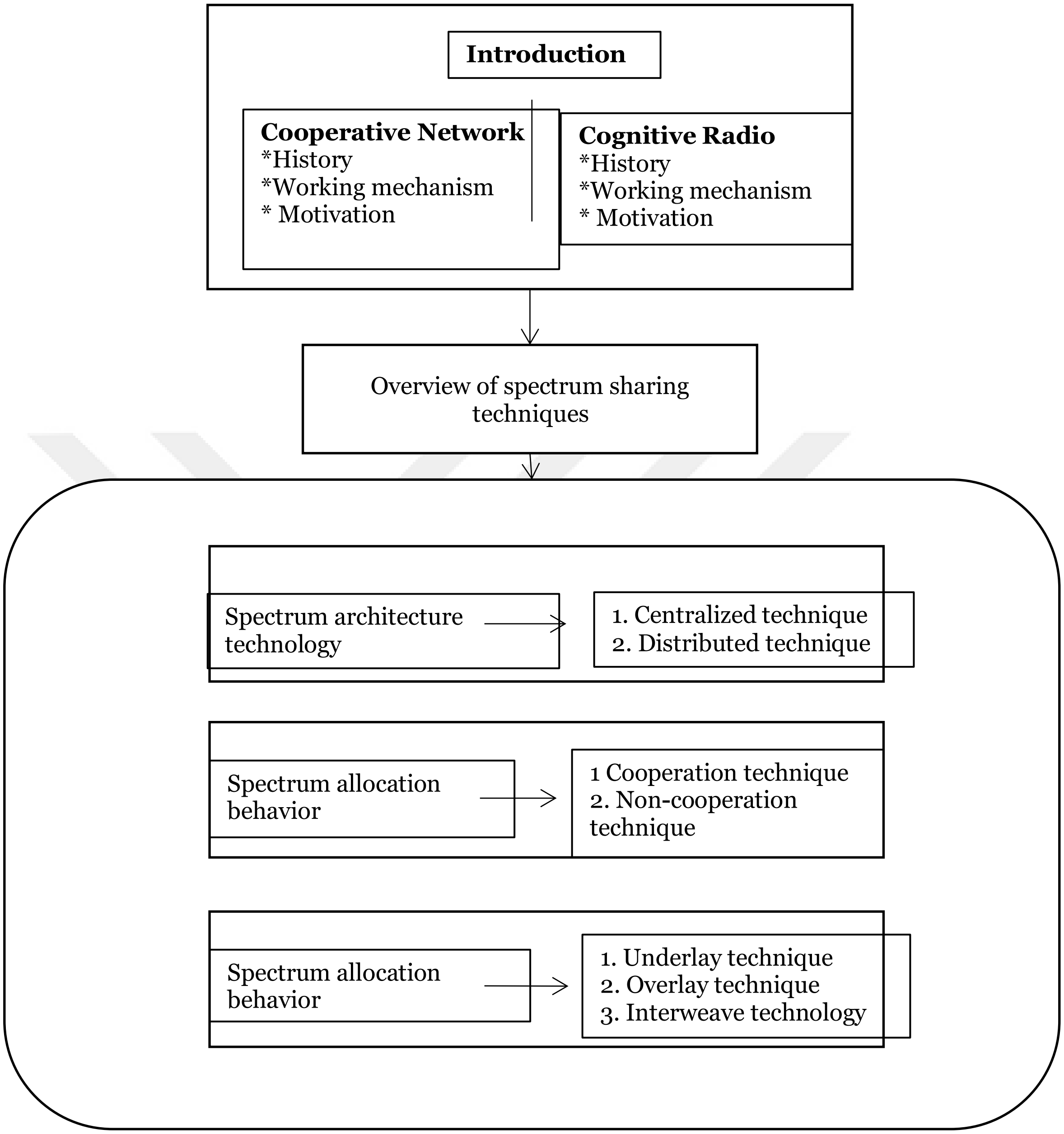

Figure 2.1: Chapter flow

2.1 COOPERATIVE NETWORK

The notion of cooperative networks in the arena of wireless communication was presented in Kotobi [11]. The key technique employed in cooperative networks is the use of diversity. In this technique, the addition of new channels is made to the direct channel with the use of a relay. Similar to the receiver, the relay can listen to the message, and there will be no need of extra energy for retransmission of message, again to the relay. So in case if the LOS (Line of Sight) gets blocked, the relay helps in retrieval of the received signal. Hence, the functionality of the relay is same as that of the sender and receiver. Therefore, the sender or the receiver in transmission can also be the relay in another transmission [11]. The distribution of power between the relay and the transmitters is represented as in the following equation:

$$P_{tr} + \sum_{i=1}^{N_r} P_i = P_{total} \tag{2.1}$$

The Portal, Ptr, Pi in the equation given above denotes total power allocated to send a certain message, transmitter's power and relay's power respectively. Nr denotes the no. of relays present in the network. Further, cooperative networks make use of two protocols, the first being Amplify and Forward (AAF), while the second one is Decode and Forward (DAF) [12]. Here, AAF functions in a model where the relay receives the signal noise, amplifying it and forwarding it to the destination. The design complexity in AAF is minimum, and it achieves enhanced network reliability due to space diversity. While in DAF protocol, the relay decodes the transmitted signal from the source and later forwards it to the destination.

Moreover, while taking account of the real-time cooperative networks, not only data transmission, control level must also be addressed. Cooperative networks provide diversity gain, but it requires improved methods of cooperative signaling so as to enable the cooperation between terminals. This drawback can reduce the performance in cooperation and even can impact the performance of the system. Also, the application of spatial diversity incorporating cooperative networks in wireless communication will reduce the consumption of power [11]. Thus, techniques have to be developed for improving the performance of cooperative networks and for minimizing the resource consumption in terms of data exchanges [13].

2.3 COGNITIVE RADIO

Cognitive radio as a concept emerged in the 2000s when Joseph Mitola [14] first proposed the concept in his/ her PhD dissertation and is found to be a promising solution for the usage of spectrum in a dynamic manner. The idea refers to the moment at which wireless Personal Digital Assistants (PDAs) and the networks that support them are sufficiently clever in terms of processing and in relation to the radio resources. This apart, the related communications between computers for detecting user communications that is required as a function of user content and providing/distributing radio resources, wireless services that are suitable to meet those requirements. Elaborated, it is the radio for wireless communications, where the network or the wireless node modifies the parameters of reception or transmission depending on how it interacts, especially with the environment for the efficient communication without interference [15]. The Federal Communication Commission [16] has deemed that cognitive radios could incorporate with the following features for enabling more flexible and efficient spectrum usage.

I. Frequency Agility: Ability to change its operating frequency for adaptation
II. Frequency Mobility: The capacity to respond by changing its operation frequency
III. Dynamic Frequency Selection: signals are sensed by cognitive radio from transmitters nearby to select an optimal environment
IV. Adaptive Modulation: Waveforms of transmission and its characteristics can be reconfigured so as to make full use of opportunities to use spectrum efficiently.
V. Transmit Power Control: Here, transmission power can be rejigged to operate at full power as and when required, while lowering levels for the purpose of increased sharing of spectrum.
VI. Location Awareness: Ability to determine the location and other device locations that operate in the same spectrum for the optimizing of transmission parameters towards increasing re-usability of the spectrum
VII. Negotiated Use: cognitive radio might have algorithms which could enable spectrum sharing in terms of agreements that are prearranged between the third party and a licensee or on an ad-hoc/real-time basis [17].

2.3.1 Spectrum Sensing

When the primary user leaves the band, it creates an opportunity for the secondary user to allocate a portion of the free spectrum. This clearly defines the function needed to allow the secondary user to keep an eye on the permitted spectrum band while transmitting and to dynamically switch to another opportunity spectrum when a main user is found [39]. As a result, the radio should be aware of its surroundings by monitoring the available spectrum bands and collecting data on the major and secondary users of these bands in order to identify spectral avoidance. Secondary users, or a number of secondary users, may utilize it. These include interference, cooperative detection, and the primary transmission detection (energy detection, cycle-stationary feature detection, which completes the; filter detection) [40]. Figure 1 depicts the taxonomy of spectrum sensing techniques.

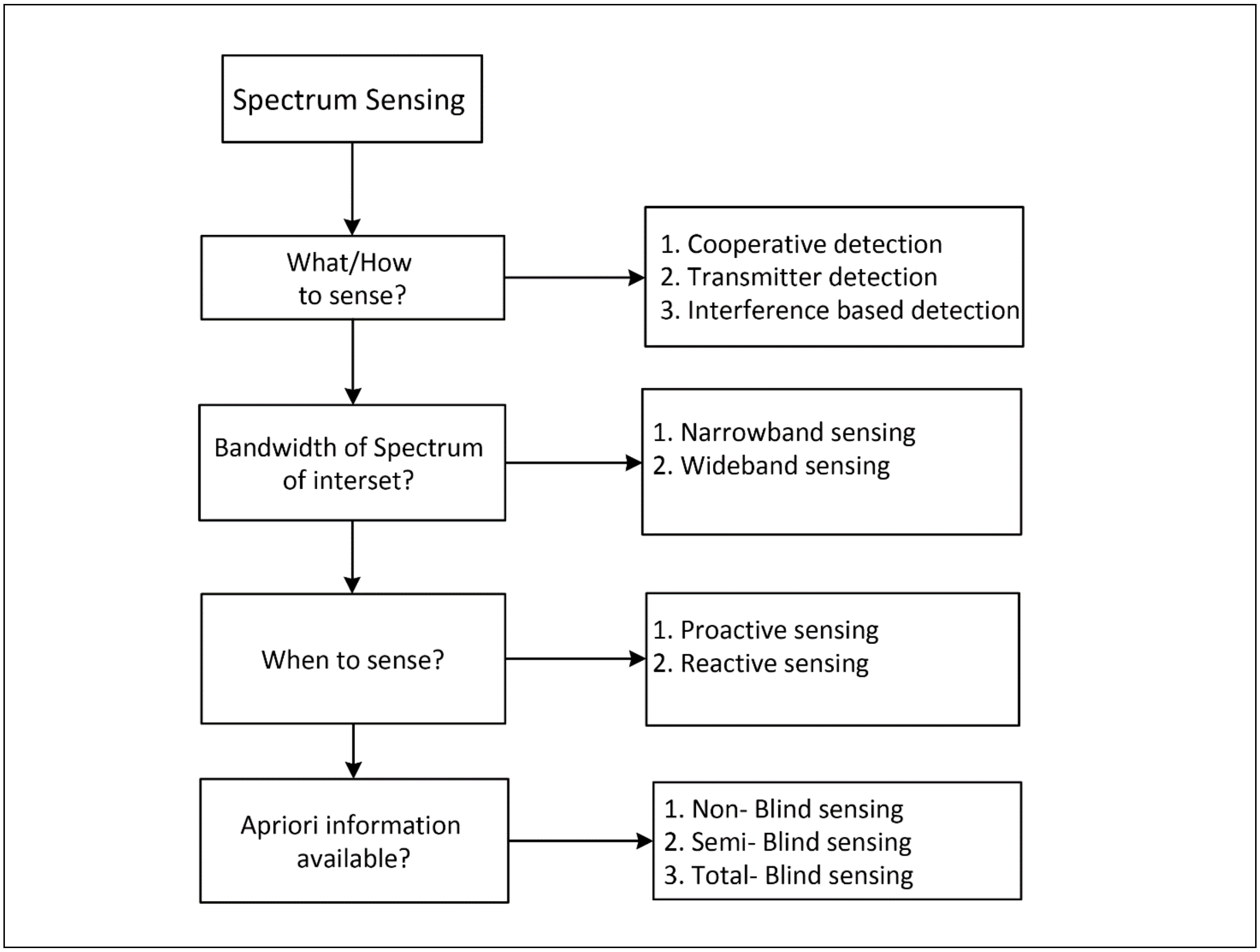

Figure 2.2: The taxonomy of spectrum sensing methods

2.3.2 Spectrum decision

According to the information of the accessible and employable spectrum holes in the spectrum sensing, the spectral decision is a process that can select the most suitable spectrum for multiple secondary bands for each secondary user [41]. All spectral bands are categorized, the spectrum decision ought to be based on user QoS demands and needs and spectral characteristics. On the substructures and grounds of the QoS requirements, data rates, an allowable bit of error rates, delay limits, transmission modes, and transmission bands that could be determined [42]. In the figure

5.3, the spectrum decision is expressed as internal process (doing decision making). that fits a function in regards of input (QoS demands and needs and spectral characteristics), output (selected suitable band).

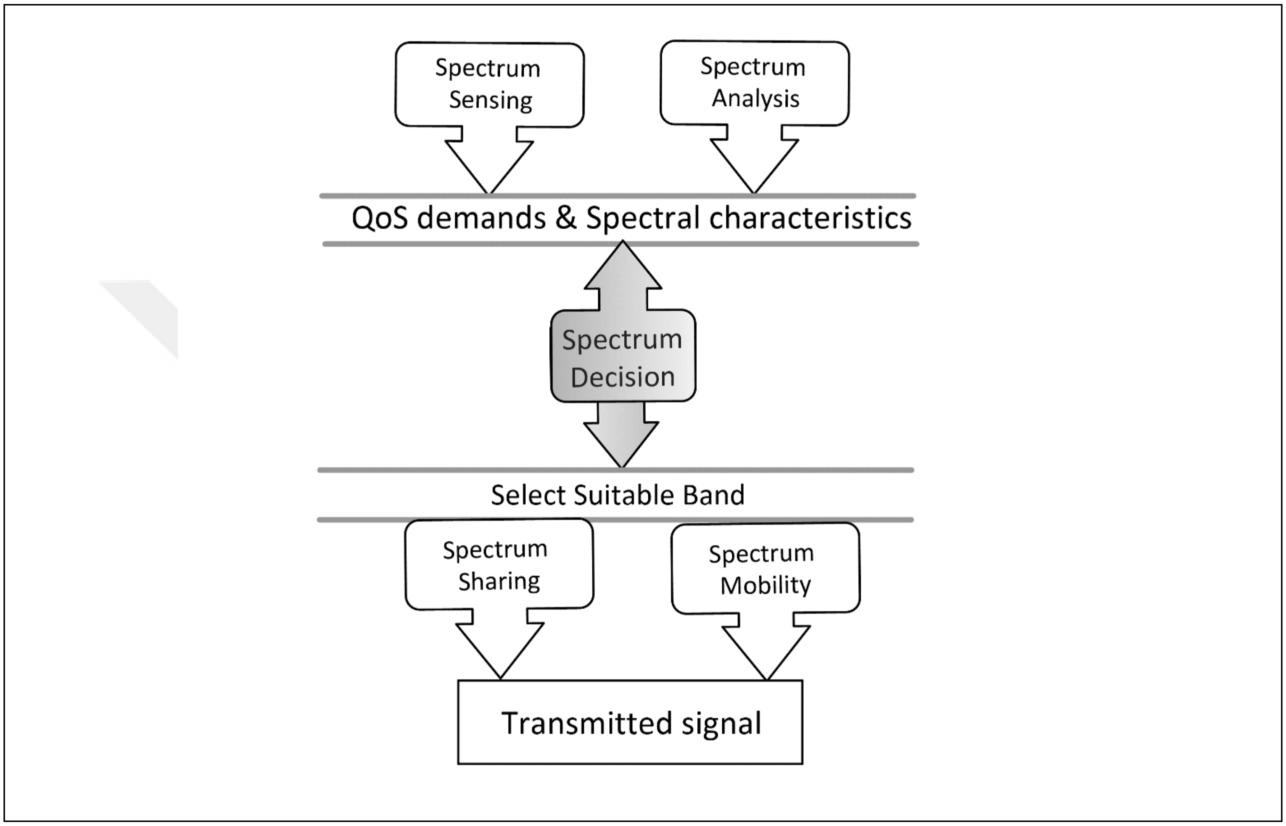

Figure 2.3: Spectrum Decisions Process

2.3.3 Transmitter-receiver handshake

The intended receiver must be informed of the channel on which it desires to send only, when, and immediately after the user is permitted to access the designated channel. This access is integrated and synchronized via a handshake protocol between the sender and the receiver [43]. There could be more participants in this exchange.

2.3.4 Spectrum mobility

The aim and goal are to provide the best transmission density and quality to the transmitting radio or cognitive radio. For this to be effectively carried out and achieved, the network must and should be able to track changes that may occur in the radio environment that may; influence and interfere with the channel quality. In addition, the information ought to be provided to the transmitted cognitive radio or a vast number of radios so that they can change the transmit channel in a suitable manner. The mechanism by which the transmission radio modifies its transmission density and quality is known as spectrum mobility [42]. Since the network performs the spectrum shift, in this instance, the transmission goes smoothly and without difficulty. The switching that takes place as a result of the spectrum's movement differs from the scene during regular transmission. The many protocols used in the network architecture layer must adjust their settings on a regular basis. In order to address changes in operational parameters at the lowest level of the architecture and planning, spectrum switching should also be visible to higher levels. It is also required to specify in order to make up for the delay brought on by the change in transmission frequency. The ability of cognitive radios to adjust to variations in broadcast frequency is known. The frequency at which each user transmits varies, and various levels of protocols need parameter modifications. Spectrum mobility management aims to minimize disruptions during these changes [43].

2.4 SPECTRUM SHARING TECHNIQUES

The idea of wireless services and its applications has gained traction in recent years, which is related to the rising demand for the use of wireless spectrum. As a result, there are now more concerns about a lack of spectrum. A significant amount of the licensed radio spectrum is often maintained unused in the temporal and spatial domains, according to a number of recent kinds of study [18, 19]. These inferences have motivated towards the improvement in the dynamic spectrum sharing techniques which could aid towards enhancing the flexibility and the efficiency of the utilization of the spectrum. Several types of research in the dynamic spectrum techniques have focused on three directions of research wherein the same are as follows: dynamic spectrum allocation behavior, [20]. These three directions, there are different techniques proposed and are found to act as the state-of-the-art techniques till date (Figure 2.2). In the present chapter, the researcher elaborated on the techniques that are used in spectrum sharing wherein the analysis of previous researchers will provide the basis for the identification of the research gap and the development of a new spectrum sharing approach for CR networks.

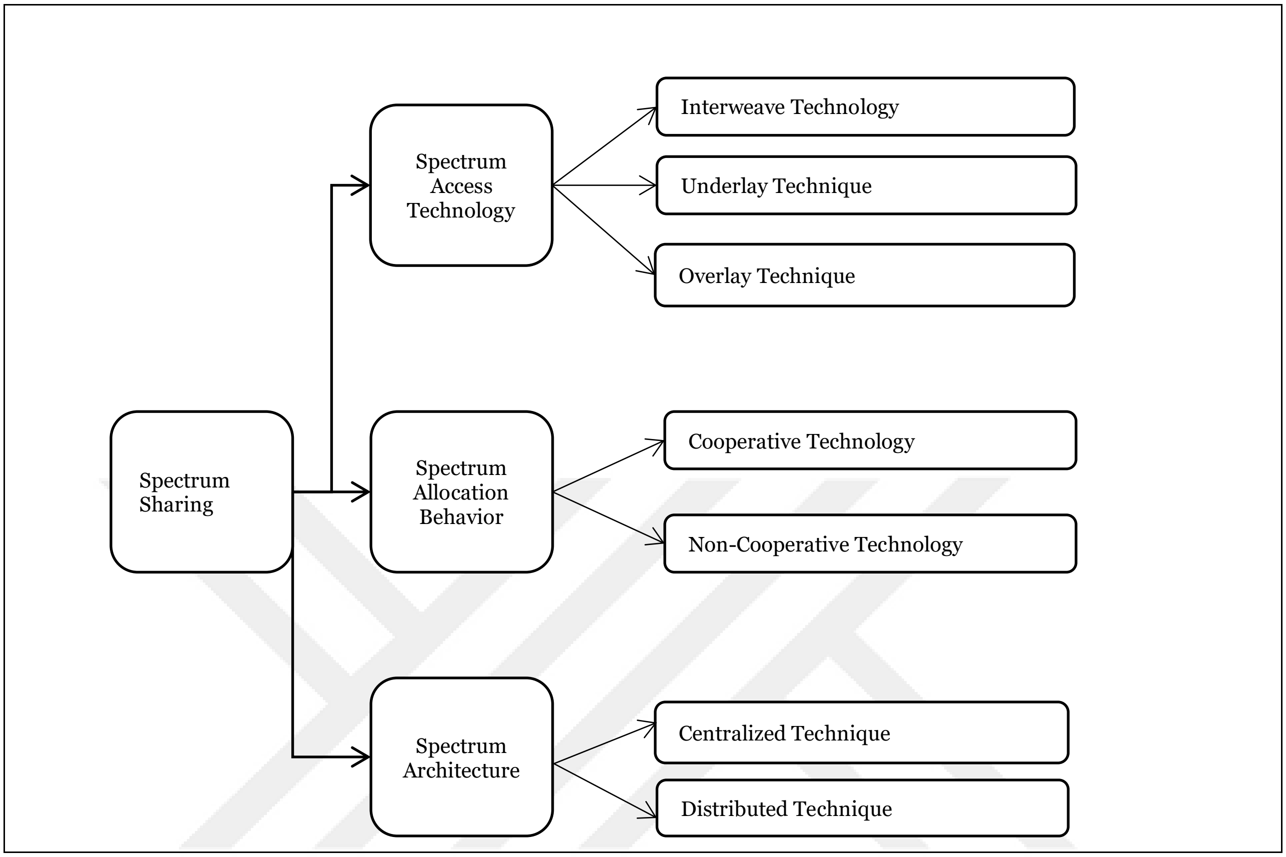

Figure 2.4: Classification of dynamic spectrum sharing (Source: Adopted from Shalmashi [21])

2.5 RELATED WORK

A study performed by Belasco-Serrano et al. [59] deliberated briefly regarding the overlap of cognitive radio channels which comprises of learning phase through the secondary transmitter the knowledge of primary message could be attained. A transmission method was designed primarily for the channels to decode and progress principles that decrease the interferences developed by relating the communication from private with transmitting on foremost messages. Subsequently, the designed transmission method was associated with an underlying system through which limitations are being posed for the interface with the foremost individuals to regulate the initiation of interference. From the investigational fallouts, it is depicted that, though the technique is being superior in several circumstances it could agonize from momentous rate loss due to the learning phase. Further, it is being deduced as a competent design which underlay system performances through overlay techniques by initiating interference decoding techniques.

A study by Perez-Salgado et al. [60] presented an Underlay Control Channels (UCC) for accessing the nodes in a cognitive network by employing two sorts of UCC. One sort of channel is utilized for synchronization of network whereas the other sort of channel is utilized for local synchronization towards each pair of nodes. The Code Division Multiple Access (CDMA) is on the basis of the method in DSSS which is Direct Sequence Spread Spectrum which is being amalgamated along with adaptive frequency hopping is involved in alleviating intrusions in the primary transmission and further to exploit the bit rate of control messages towards cognitive radio devices.

An investigation performed by Anamalamudi and Jin [61] was towards a hybrid IOB-CCC which is Out-of-band or In-band intersection on the basis of CCC or Common Control Channel technique that is based on MAC protocol in improving the presentations of CR network in reverence with the multi-channel hidden terminal, the CR nodes synchronizes and the network connectivity period. From the observational fallout is being inferred that the anticipated hybrid CCC on the basis of MAC protocol overtakes when being associated with prevailing saturated unlicensed In-band CCC-MAC protocols and Out-of-band CCC - MAC protocol with greater PU free channels. To analyze the performance metrics of IOB-CCC on the basis of MAC protocol along with twenty and twenty-five 8-MHz channels is being performed in upcoming performances and it is also further associated with the dedicated-CCC based CR MAC protocol and sequential licensed based.

The study performed by Gmira et al. [62] developed and analyzed the performance of a new and innovative hybrid CR system which incorporates the underlay as well as modes of overlay access. The proposed method permits the SU in improving the throughput and further improves the spectrum efficiency with minimum congestion. The method of SU with the minimum flow is permitted to circumvent the sensing phase and simultaneously attains the access towards the canal beside to PU under SINR (Signal to-Interference Noise Ratio) conditions since other SUs with higher flow could access the bands with free frequencies in transmitting signals. Moreover, the anticipated model was deliberate with Nash Equilibrium, from the obtained consequences it was construed that the hybrid model could enrich the throughput seen in SU in addition to channel utilization. Further, the anticipated model provided enriched throughput when compared to the overlay only, apart from underlays only cognitive radio systems.

Research by Jasbi and So [63] recommended a hybrid transmission model which utilizes both overlay and underlay by integrating Multi-Carrier Code Division Multiple Access (MC-CDMA) due to the interference rejection capabilities and diversity exploitation. The prevailing models which utilize the overlay and underlay spectrums discretely have projected the method which uses the complete spectrum for underlay transmission such that interference of PU is decreased and it utilizes the spectrum holes for overlay transmission in achieving the maximum data rate. Moreover, the techniques are projected which is being operated at the full-load and overload scenarios. And further, the overload scenario is extended for multi-user underlay scheme in enhancing the usage of spectrum.

Chu et al. [64] conducted a study which accesses the technique for amplify-and-forward relay cognitive network which is a novel hybrid interweave-underlay spectrum through which relay drives the signals forward of primary and secondary networks. This performs the system in attaining the possibility of each and every state in the Markov chain. The effect and possibilities of spectrum sensing that is not perfect, the possibility of every operation mode are obtained from the proposed hybrid scheme. In assessing the primary and secondary network performance, outage probability, and outage capacity as inferred through analytical expressions and Nakagami-m fading channels utilizing symbol error are calculated. An assessment is obtainable among the hybrid interweave-underlay Cognitive Cooperative Radio Networks (CCRN) and the functioning of underlay CCRNs such that the benefits of the suggested spectrum access scheme could be attained. Consequently, on the basis of the designated numerical results, the performance enrichments of primary network and application of secondary relay are performed.

Research by Satheesan and Sudha [65] implements the amalgamation of MIMO with hybrid cognitive radio networks. Beamforming technique was presented in this method into the MIMO antennas for reducing the levels of interference within an explicit anticipated direction. The results of the investigation depleted that the data rate of both SU and PU is amplified since Beamforming in MIMO is implemented. Further, on the source of the game theory of Nash Equilibrium is incorporated for regulating power in PUs and SUs.

Research by Tang et al. [66] examined the concerns regarding the power regulation in a network of underlay CR through which the nodes have the competence in FD transmission (Full-Duplex). The research aimed at providing the necessary Quality of Service (QoS) in the form of SINR, an acronym for Signal-to-Interference-Plus-Noise Ratio to each and every CR users and retains the interference with PUs less than a recommended threshold. Further, an effective method of distributed power control technique was suggested which combines with a PID (Proportional-

Integral-Derivative) regulator along with the power limitation technique to attain the proposed objectives. Subsequently, scrutinized the anticipated scheme's stability performances and additionally developing a hybrid scheme which could switch between the FD modes and HD modes (Half Duplex). Finally, with extensive simulations, the validation of the proposed scheme was performed.

2.6 RESEARCH GAP

The detailed literature review on spectrum sharing technique has identified that the studies have mainly focused towards underlay mode [60], overlay mode [59], interweave-underlay [64], a combination of overlay-underlay [62] spectrum accessing technique. However, the main challenge has been identified [63]. In order to overcome this challenge, some studies have been performed by undergoing the overlay spectrum utilization mode [59]. Subsequently, regarding outage probability, the overlay scheme overtakes the underlay scheme. At the same time, if interference avoidance is added to the spectrum sharing then the underlay scheme with interference avoidance will secure the smaller outage probability more compared to the pure interference avoidance [42]. So, some of the researchers suggested focusing hybrid technique towards improving the spectrum sharing performance [62]. This kind of schemes could be more beneficial when it permits the secondary users to extend their amount of transmission once an opportunity of a spectrum is identified. From the review of previous studies, very few have considered The proposed method which is a combination of techniques. Still, the issues need to be addressed in MIMO cognitive network [65] towards reducing the interference, outage probability and extend their transmission rate after the identification of spectrum opportunity. So, in this study focus combination of this three-access technique in cognitive network towards enhancing the performance.

3. METHODOLOGY

3.1 INTRODUCTION

Recently, cognitive radio has been considered as one among the biggest changes of wireless communications, which is designed using optimal use of radio resources. In this chapter the system model architecture is developed to meet the requirements discussed in the previous chapter. Further, the algorithm is discussed for the proposed system along with the flow chart with mathematical expressions. Additionally, the method of interference avoidance through the proposed approach is elaborated. Finally, the simulation setup which includes the parameters and process of simulation using MATLAB is discussed.

3.2 SIGNIFICANCE AND CONTRIBUTION OF THIS RESEARCH

The following is the research's primary contribution:

I. In this study, we suggest a unique method for a MIMO cognitive network that combines overlay, underlay, and interweave spectrum access techniques in order to minimize interference, increase transmission rate, and optimize outage probability whenever a spectrum opportunity is identified. This new mode of access permits the secondary user (SU) towards enhancing its throughput while resulting in an overall improvement of overall spectrum efficiency in addition to maintaining lower congestion levels.

II. Second, the transmission power of every channel is at its optimal best by Ant Lion Optimizer (ALO) [67], a meta-heuristic algorithm. The algorithm enables to access the maximum channel bandwidth despite the channel variations and compared with state-of-the-art techniques such as chain based, and ant based cognitive radio technique.

III. Third, the selection order of optimal sensing channels is evaluated in both experimental and theoretical ways (Mathematical model). Finally, Throughput, outage probability, and efficiency are used to evaluate how well the given approach performs (Detection Time). The proposed method is compared with the previous approaches namely overlay, underlay and interweave by implementing it in MATLAB 2016b version, and its performance is evaluated.

The most significant aspects of the proposed approach are as follows

I. At the spectrum allocation stage, the PUs will track and detect the varying pattern of PUs in the entire channel of the network
II. The entire user in the network will collect the detected information at the stage of spectrum allocation period which is sent to entire users through the control channel
III. Cooperative detection is done separately by each user by applying the identical deterministic algorithm; hence, all the users accessing the information will infer the correctly decoded control information; in addition, they can get access to the same collection of free channels
IV. The transmission assignments are done by the resource allocation algorithm only to free the channels which are operated independently by every user, and few users will be ordered to switch even to the busy channels for the reason of PU detection

3.3 PROPOSED ARCHITECTURE

In the traditional wireless network system, can fixed the number of accessible channels while the available channels in the cognitive transmission system varied based on the space and time response. This available channel is varied based on the primary users. In addition, the spectrum inflicts unique challenges in MIMO cognitive radio system like seamless cognitive communication, QoS provisioning and interference avoidance. To address these challenges, need to be select the best channel to attain required QoS, determine the available spectrum bands during CR transmission, evacuate the channel in the presence of PUs and access towards mitigating collision and interference. These competencies are attained through various spectrum functionalities such as spectrum decision, sensing, sharing and analysis. In CRs system, the term spectrum decision is the process towards chosen suitable PUs to fulfil the QoS requirements (without the effect of interference to PUs). The spectrum sensing is the process for attaining spectrum or radio information for a given location and time duration. Moreover, it focuses on interference via PUs, idle PUs channel as well as calculating the channel gain amongst CRs. The functionality of spectrum sharing is accountable towards fulfilling the avoiding harmful interference to PUs, QoS requirement of CRs, spectrum access, analysis and allocation procedures. The following architecture depicts the overview of the proposed framework while system model is shown below. The pictorial representation of unified proposed system architecture is shown in figure 3.1.

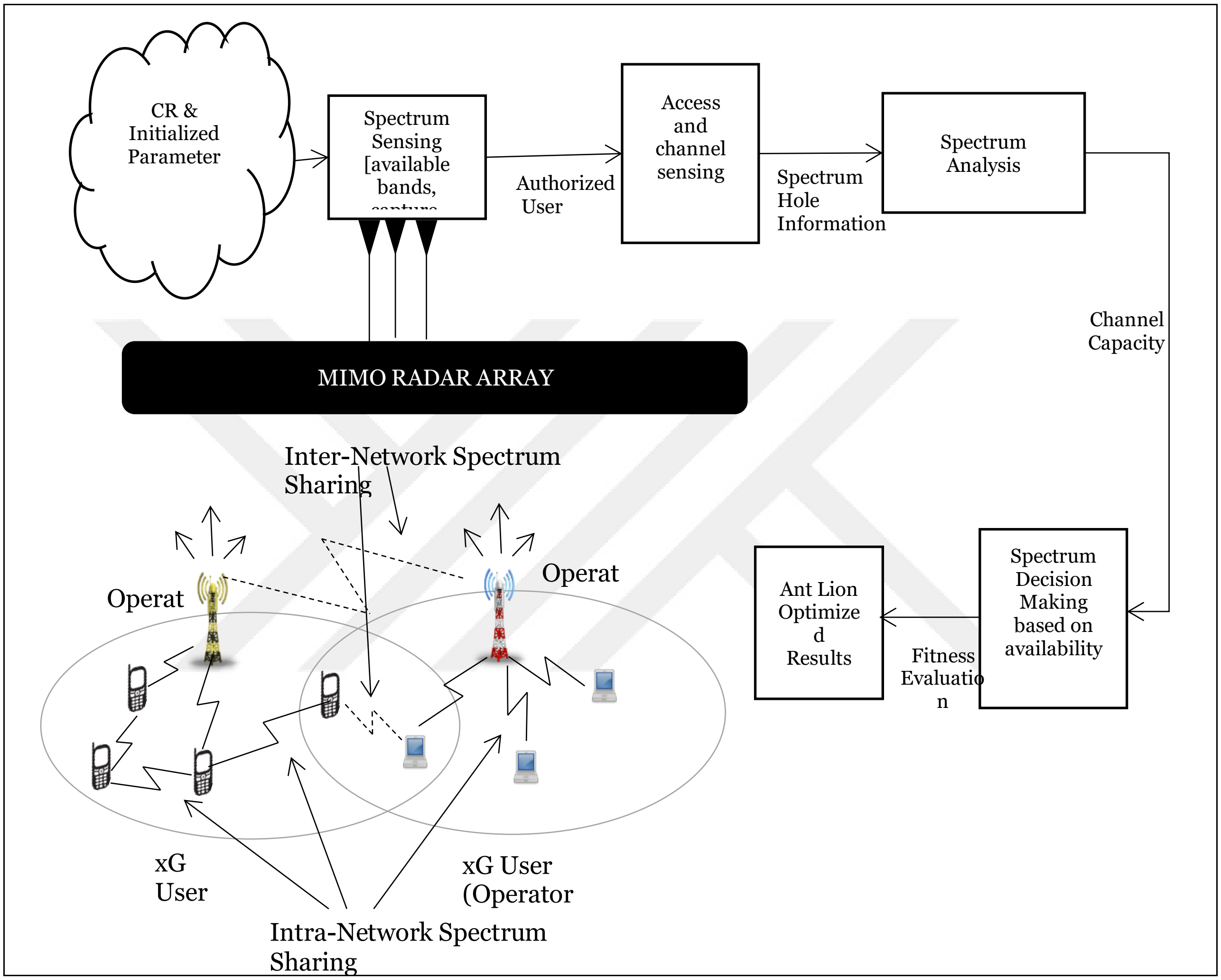

Figure 3.1 Overview of Proposed Framework

3.3 SYSTEM DESCRIPTION AND ASSUMPTION3.3.1 NOTATIONS

3.3.1 Notations

For the proposed approach, the overall symbols used, and their description is provided in Table 3.1.

Table 3.1: Symbol with Description

Symbol	Description
$N_{p,\,s}$	The proportion of main and secondary systems' antenna counts
NPBS	Number of Primary base station
NSBS	Number of Secondary base station
h_0	Channel coefficient between SU-Tx and PU-Rx
N_s	Signal corrupted by the noise process
P_1	Signal vector sent via primary transmitter
P_2	Signal vector sent via secondary transmitter
$m_{1,1}$	CH coefficient vector amongst primary transmitter (Tr) and receiver (Rr)
$M_{2,1}$	CH coefficient vector amongst secondary Tr and Rr
$m_{1,2}$	CH coefficient vector amongst primary Tr and Rr
$M_{2,2}$	CH coefficient vector amongst secondary Tr and Rr
M_{stx}	Matrix channel coefficient amongst two Tr
N_{stx}	Signal corrupted by the noise process (Both Tr)
q_{stx}	Observations at the primary Rr and secondary Tr

X	X denotes the matrix while
D	The number of nodes that are available in the network.
D_N	position matrix on behalf of the ant lion based on network nodes
O_{D_N}	Matrix of fitness value

3.3.2 System Model and Assumption

In this research, we have considered MIMO cognitive network with underlay, overlay and interweave spectrum access. The PUs and SUs in the underlay and overlay approach concurrently utilized the same spectrum where the interweave approach, the SUs frequently examined for the spectrum holes as well as utilized these holes for communication. Moreover, by using the MIMO cognitive spectrum access approach, the whole cell in the system, which comprises of a multi-user primary and secondary system, is able to share the frequency spectrum. Distributed user nodes and a base station are present in both the main and secondary system (primary and secondary). For the proposed approach, the overall symbols used, and their description are provided in Table 3.1.

The performance of secondary user is improved via scheduling the PUs transmission like attain interference-free transmission for the SUs. Since the SU-Rx is far from the PU-Tx, the SU is not affected by the interference from the PU since the interference formed is weak and in these situations mostly PU does not transmit. Subsequently, the performance of secondary user is improved via scheduling PUs transmission like to attain interference-free transmission for the SU. In underlay technique, the transmit power has to be controlled by the SU-Tx in order to ensure that no interference is triggered to PU-Rx. Moreover, the transmission quality of the primary network is determined based on the SINR named as signal-to-interference-plus-noise ratio and the required outage probability. The SU-Tx transmits until the PU-Rx's outage probability is retained below the predefined threshold. In this approach, the SU-Tx has knowledge of the other SU's codebooks present in the network and its messages. The data could be attained, for instance, if any SUs broadcast their codebooks or employ a uniform standard for communication-based on a exposed codebook. By decoding the message at the SU receiver, one may get knowledge of messages (SU-Rx). Figure 4.2 displays a visual depiction of the suggested system model.

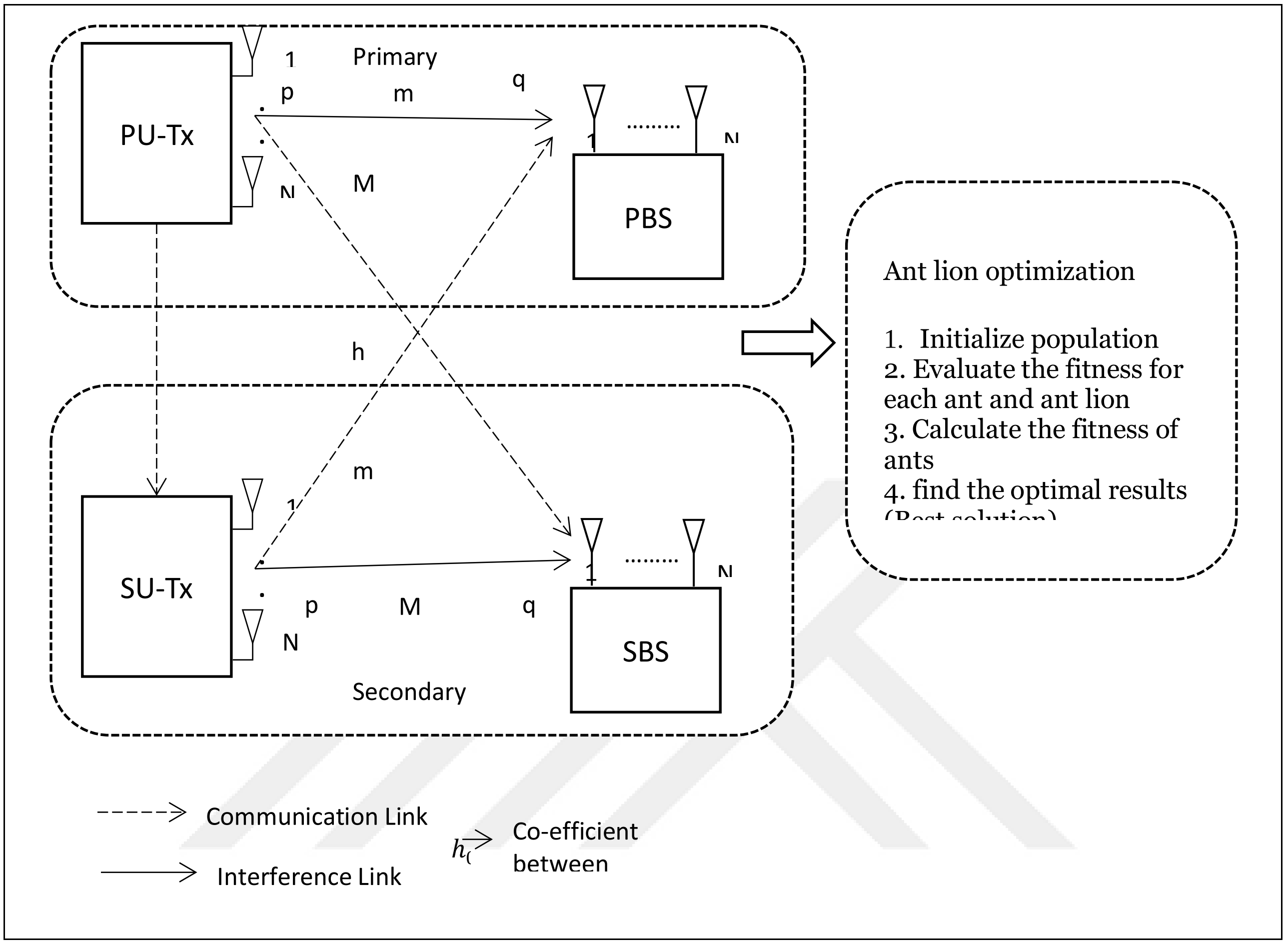

Figure 3.2: System model of spectrum access (Interweave, underlay, Overlay)

The ratio amongst the numbers of antennas at the primary and secondary systems is defined as

$$N_{p,s} = NPBS / NSBS.$$

Case 1: The transmitter sends a signal which is observed through the envisioned receiver antenna in the presence of noise and interference. It's mathematically written as,

$$q_1 = m_{1,1}^{M} \; p_1 + m_{2,1}^{M} p_2 + N_{s1} \ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$q_2 = M_{1,2} p_1 + M_{2,2} q_2 + N_{s2} \ldots\ldots\ldots \quad (3).2$$

Where,

p1 - X, 1×1 signal vector sent via primary transmitter

p2 - X, 2×1 signal vector sent via Secondary transmitter

Ns1, Ns2 - noise processes.

Case 2 (1): In this case, transmits (Primary transmitter) its message towards envisioned receiver as well as secondary transmitter. It also defined as,

$$q_1 = m_{1,1}^{M} \; p_1 + N_{s1} \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

$$q_{stx} = M_{tx}^{M} \; p_1 + N_{stx} \ldots\ldots\ldots\ldots\ldots (3.4)$$

p1 - X, 1×1 Signal vector sent via primary transmitter

m1,1- X, 1×1 Channel coefficient vector amongst primary transmitter and receiver

Mstx – X1, X2 Matrix channel coefficient amongst two transmitters

Nstx- Signal corrupted by the noise process

qstx - Observations at the primary receiver and secondary transmitter

Case 2 (2): The second phase, the secondary transmitter utilizes the knowledge of the primary message (Obtained from the first phase) and it's mathematically written as,

$$q_1 = m_{1,1}^M \quad p_1 + m^M{}_{2,1} p_2 + N_{s1} \ldots\ldots\ldots\ldots\ldots (3.5)$$

$$q_2 = m_{1,2}^M \quad p_1 + m_{2,2}^M \quad p_2 + N_{s2} \ldots\ldots\ldots\ldots\ldots (3.6)$$

Case 3: PUs is inactive in the secondary transmission and it's mathematically written as,

$$q_2 = m_{2,1}^M \quad p_1 h_0 + m_{2,2}^M \quad p_2 + N_{s2} \ldots\ldots\ldots\ldots (3.7)$$

3.3.3 Ant-Lion Optimization based Spectrum Sensing Framework

The nodes replace the Ant-Lion, which means that there is one Ant-Lion at every node, while the position of the node is regarded to be the same as that of the ant-lion position [68-70]. Position matrix that shows the ant-lion on the basis of nodes is explained through equation 8 as,

$$D_N = \begin{bmatrix} D_{N_{1,1}} & D_{N_{1,2}} & D_{N_{1,n}} \\ D_{N_{2,1}} & D_{N_{2,2}} & D_{N_{2,n}} \\ . & . & . \\ D_{N_{n,1}} & D_{N_{n,2}} & D_{N_{n,n}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots (3.8)$$

Here, DN denotes the matrix position matrix on behalf of the ant lion based on nodes while N denotes the number of nodes that are available in the network. The subsequent fitness value is derived by calculating the distance between the current node and the destination. This fitness value is arrived at, through Equation 9.

$$D_{N_1} = \sqrt{(D_{N_{d,1}} - D_{N_{1,1}})^2 + (D_{N_{d,2}} - D_{N_{1,2}})^2 + (D_{N_{d,3}} - D_{N_{1,3}})^2} \ldots\ldots\ldots (3.9)$$

The corresponding matrix of fitness value is shown in equation (10):

$$O_{D_N} = \begin{bmatrix} O_{D_{N1}} \\ . \\ O_{D_{Nn}} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The matrix (equation 10) denotes the position matrix of the most appropriate neighbour node for selecting the route across any node. This whole process can be clearly understood through Calculate fitness value

$$D_{Ni} = \sqrt{\left(D_{N_{d,i,1}} - D_{N_{i,1}}\right)^2 + \left(D_{N_{d,2}} - D_{N_{i,2}}\right)^2 + \left(D_{N_{d,3}} - D_{N_{i,3}}\right)^2}$$

$$F_N = Best(D_N)$$

$$O_{FN} = Best(O_{DN})$$

$$Current_{node} = Source$$

While

$$Current_{node} \neq Destination$$

$$\text{d} = | F_j - D_i |$$

$$D_{D_i,F_j} = d * e^{bt} * \cos(2\pi t) + F_j$$

The above discussed algorithm is utilized towards create an optimized path.

Algorithm for the proposed approach

Step A: Define the input data, size of the population, acceleration constants, total number of iterations, and contraction factors as well as the adjustable parameters.

Step B: Perform spectrum sensing

Step C: PUs (Primary User) and CRs (Cognitive Radio) which access the spectrum band simultaneously will not perform this operation; CRs will access the unlicensed band once the PU activity is not detected

Step D: Check whether there is any spectrum available for sharing;

Step D.a: IF ‘No’: support to be provided for sensing of spectrum sensing

Step D.b: IF ‘YES: two distinct kinds of users based on PUs and SUs

Step E: Iteration counter is set up.

Step F: Compute each channel’s objective function

Step G: Ask if the termination condition reached (SEARCH Step, Poll Step)

Step H: Output the results

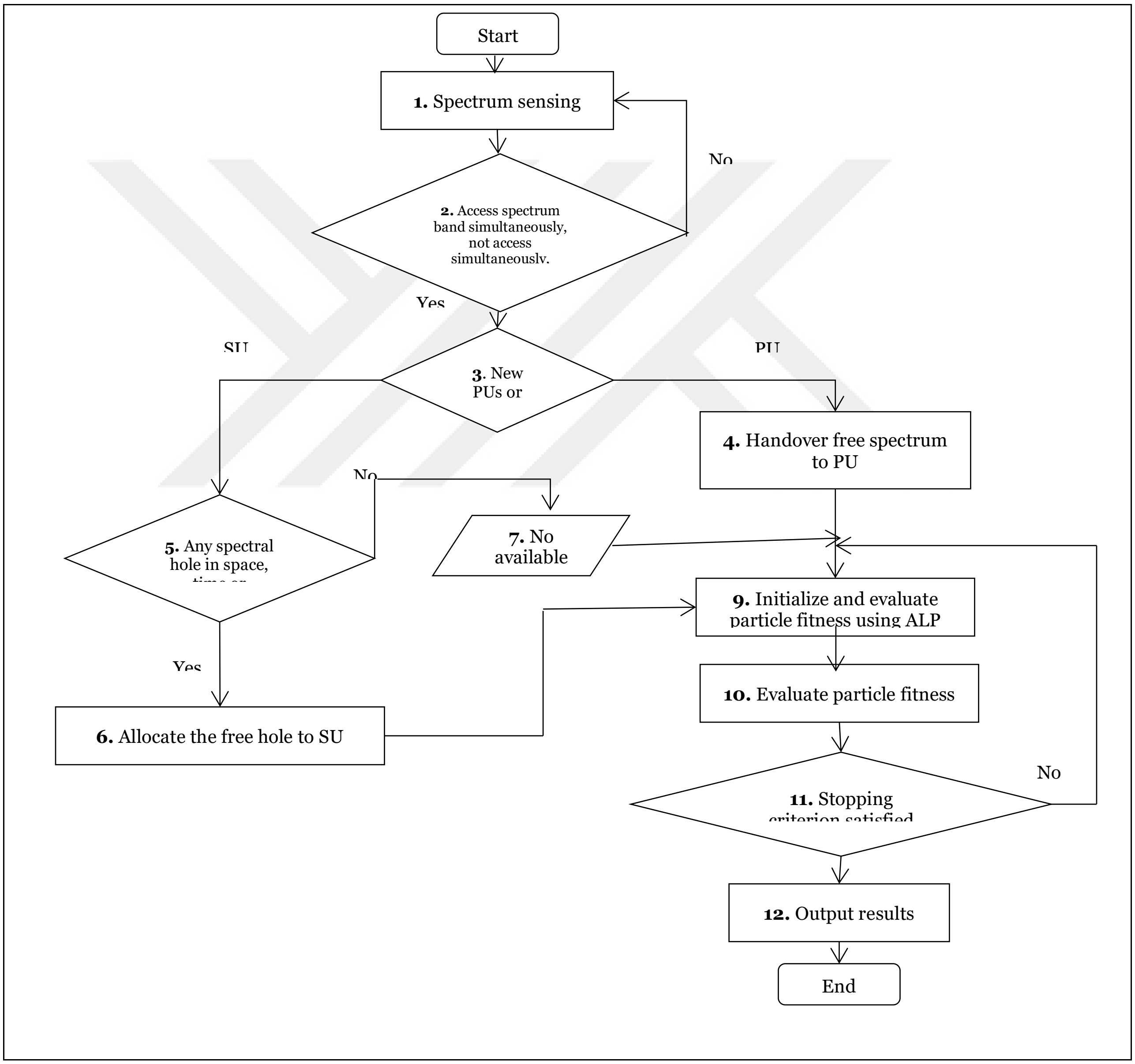

Figure 3.3: Flowchart of Proposed Approach

3.4 PERFORMANCE EVALUATION

Throughput, outage probability, and efficiency are used to evaluate how well the given approach performs (Detection Time). Further, the comparison of these strategies is needed to be done by utilizing MATLAB 2016b version and demonstrate the proposed method works better than the previous approach named as overlay and underlay, interweave-underlay in the cognitive network.

3.4.1 Throughput Calculation

According to [71], the definition of throughput is the ratio of packets transmitted to packets received. However, it is described as,

$$Throughtput = \frac{\text{No.of received packets}}{\text{Total no.of sent packets}}$$

3.4.2 Outage probability

The term outage probability is utilized for the design that allows interference from the SUs transmitter to the PUs receiver [62, 72]. Moreover, the interference channel gain is measured based on the SUs transmitter to the PUs receiver as well as PUs transmitter to the SUs receiver. The outage probability is mathematically written as,

$$P_o = 1 - P_S = 1 - \frac{R_m}{\log_2(1+\gamma_s)}$$

Where,

P_o - Outage probability

γ_s - SU's SNR threshold (SINR if PUs is present)

R_m - minimum achievable rate

P_S - probability of successful transmission

The term Rm is attained via multiplication of Ps which consists of hypothesis by less transmission rate log2 (1 + γs) obtained as absence of fading once there is no failed tranmission, primary traffic and interference [73].

3.4.3 Energy Efficiency

The total rate to the number of channels employed in the CR system is used to calculate the energy efficiency [74] [75]. It is represented mathematically as,

$$, \eta = \frac{SE}{PC},$$

Where, η - Energy efficiency

SE – Sum error rate (in bits)

PC – Number of channels used

3.4.4 Data Drop Rate

In CRs system the term drop rate is measured based on the difference amongst total number of transmitted packets and total number of received packets to the total number of sent packets [79]. Also written as,

$$Data\ Drop\ Rate = \frac{Total\ no.of\ sent\ packets - Total\ no.of\ received\ packets}{Total\ no.of\ sent\ packets}$$

3.4.5 Detection Time

The detection time is measured based on difference amongst finishing time [79]. It also defined as,

$$Detection\ Time = Finishing\ Time - Starting\ Time$$

3.5 SUMMARY

This chapter goes into great detail on the methodology of the suggested approach. Further, the algorithm and flowchart for the proposed approach are developed to overcome the limitations in existing models. Additionally, its significance is validated by the proposed spectrum allocation model, and its optimization is briefly elaborated. Finally, the simulation setup, followed by the process and the performance evaluation based on the measure of throughput, outage probability, energy efficiency, drop rate and detection time is discussed.

4. RESULTS AND DISCUSSION

4.1 SIMULATION SETUP

The proposed system is simulated in MATLAB 2016b version based on specific parameters. Fundamental simulation and channel parameters are used to run the system in step-by-step process. The total number of channels used is 5-10 and with a listing interval of 20ms-30ms for each channel. The symbols collected in each estimation cycle for every channel is taken as 1000-1500 symbols. The proposed system flow chart is shown in figure 4.4.

Table 4.1: Simulation parameter

Simulation	Value
Number of channels	10
Number of clusters	3
Correlation factor	2
Transmitter antenna pair	0 DBi
SNR threshold	10 DB
Oversampling factor	4
Number of runs	10000
Modulation scheme	BPSK
Frequency range	5GHz

4.2 SIMULATION PROCESS

In our study, the initialization of spectrum frequency bands and sample frequency for users is done. While initializing, all the channels are presumed to be unfilled. If the QoS requirements are met by the channels, the optimization is carried out directly for the system, if not, then the proposed approach is applied. But certain channels will be left non-utilized, and they are considered as spectrum holes and hence can be used by the secondary users. Furthermore, interference distribution is approximated via Gaussian distribution function which makes the system more realistic. To visualize the output plots, the percentage of attenuation is included.

4.3 RESULTS

This section compares the performance of the suggested methodology under different circumstances to that of the existing method and discusses the simulation findings. Implement MATLAB 2016b to support the MIMO network architecture that consists of several cells and assumes a range of user numbers from 20 to 40 in order to assess the performance of the proposed dynamic spectrum access strategy. Each cell's transmission range is divided equally. Furthermore, will take into account licensed spectrum bands with various PUs activities that are evenly spread across the network, as well as interference levels that are set to be twice as high as the transmission range.

4.4 DISCUSSION

Using the chapter 3's study goals as a guide, this part examined the experimental findings for a variety of challenges. Moreover, the various experimental results are displayed with the support of simulation software as MATLAB 2016b version which related to the above-mentioned approach. The experimental results are discussed as follows:

The best channel conditions were used in the suggested system model to look for users (PUs and SUs). In addition, the number of channel users chosen in the MIMO CRs network should be almost orthogonal to that which yields the desired results when using the hamming precoding technique. Meanwhile the channels are selected based on the transmitter time at unique time duration. The proposed MIMO CRs with optimization approach gives better result than the exiting approach named as underlay, overlay, interweave and hybrid spectrum access without optimization in terms of less computational complexity of the system with increased channel capacity. This might be attained based on the various frequency ranges and number of PUs and SUs used in the suggested CR MIMO system. By the experimental, various plots are depicted based on the measure of different performance metric such as outage probability, throughput, efficiency and detection time in terms of transmission of SUs and PUs in the proposed MIMO cognitive network.

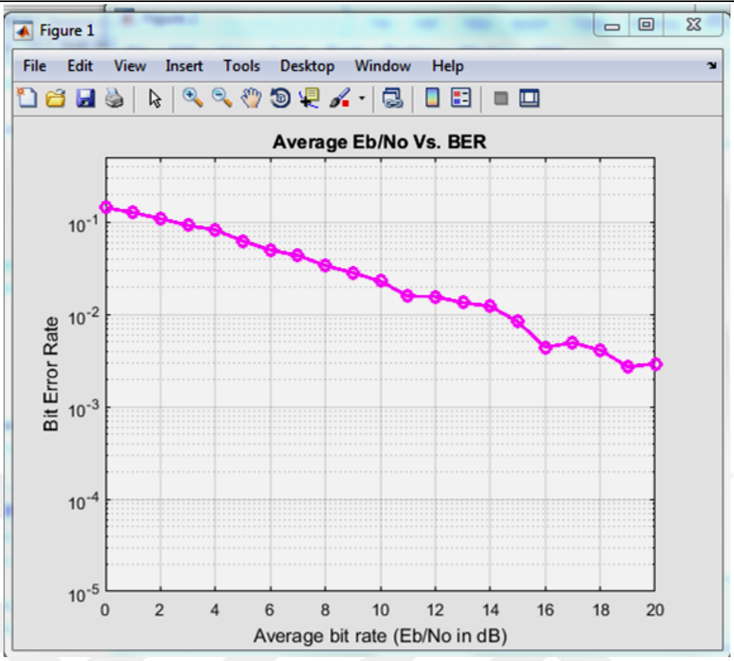

Figure 4.1: Simulated results of average Eb/No Vs BER

The figure 4.1 depicts the experimental results of average Eb/No Vs BER in terms of dynamic radio spectrum access approach with usage of spectrum band which transfer data based on the usage of radio resources in a system. If the new user attains the spectrum access, first it get verifies the shared data is from secondary or primary user. Subsequently, the minimum and maximum value is predicted and shown in the plot.

In the experimental, the bit error rate shows the various threshold values as well as the ratio of MIMO CRs via maintaining the signal to noise ratio (SNR) assumed the value as 10 DB. Moreover, its shows our proposed method provides the low BER and outer performs than the existing technique.

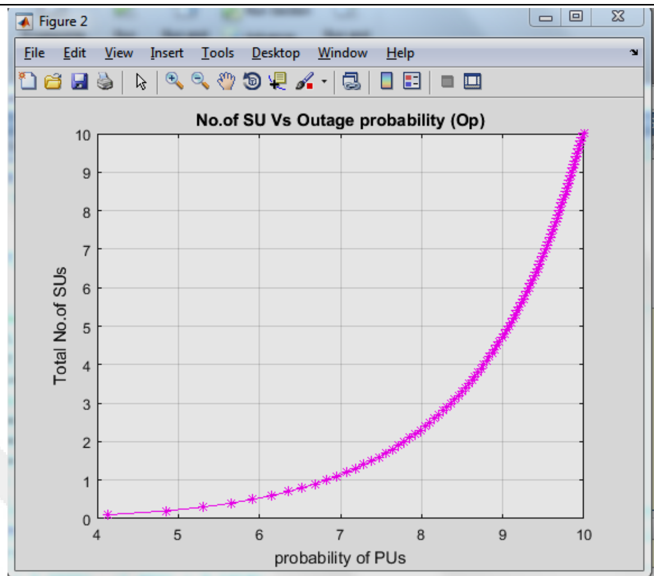

Figure 4.2: Simulated results of probability of PUs vs. Total number of SUs

In the proposed MIMO CRs system, the probability function of PUs is shown in figure 5.2 as a function of the total number of SUs employed. It demonstrates the rise in linearity of spectrum access while assuming that the available frequency channels were allocated equally from 0 to 1.

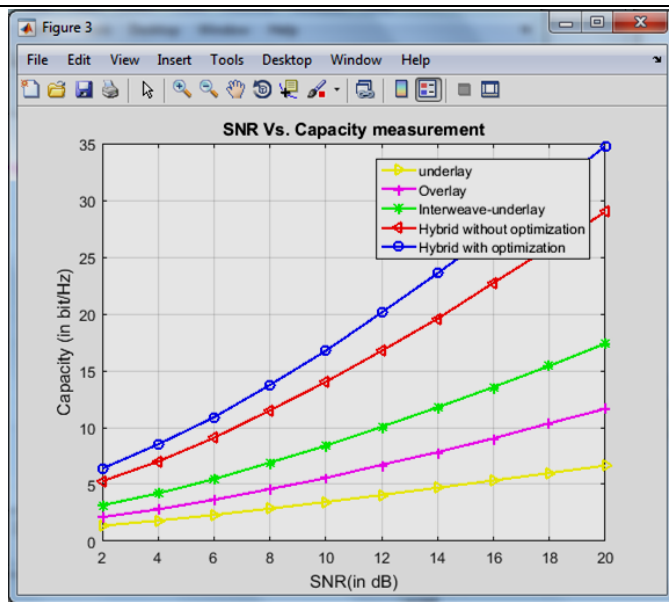

Figure 4.3: Experimental results of SNR vs. capacity

The signal to noise ratio in DB and channel capacity are contrasted in figure 5.3. We deduced from the experimental findings that high signal-to-noise ratio retrievals had low bit error rates and high channel capacity. The result seems, the proposed method provides improved results than the existing method. The figure, yellow color highlights the spectrum access approach by underlay mode, pink color denotes overlay mode, green color denotes the combination of interweave and underlay, red color denotes the experimental results of hybrid spectrum access approach without optimization and blue color denotes the output results of proposed hybrid spectrum access with optimization technique.

Table 4.2: Comparison of spectrum access technique

S. No	Method	SNR (10 DB)	
		Bit error rate	Capacity channel
1	Underlay[76]	0.18	0.5
2	Overlay[77]	0.8	0.2
3	Interweave [78]	0.08	0.49
4	Underlay-Overlay [79]	-	0.01
5	Interweave-Underlay [80]	0.016	0.58
6	Hybrid without optimization	0.01	1.4
7	Hybrid with optimization	0.007	1.7

From the above table, the performance of the proposed hybrid model can be interpreted. The table depicts the Bit error rate for corresponding channel capacity in the techniques considered such as underlay, overlay, interweave, the combination of underlay and overlay, combination of interweave and underlay, without the optimization of proposed hybrid model (Underlay, overlay and interweave) and with optimization of the same. From the values attained through the experimental results, it can be illustrated that the BER is significantly reduced to 0.01 for channel capacity of 1.4 for the hybrid model and BER is further reduced to 0.007s for channel capacity of 1.7 for the optimized hybrid model.

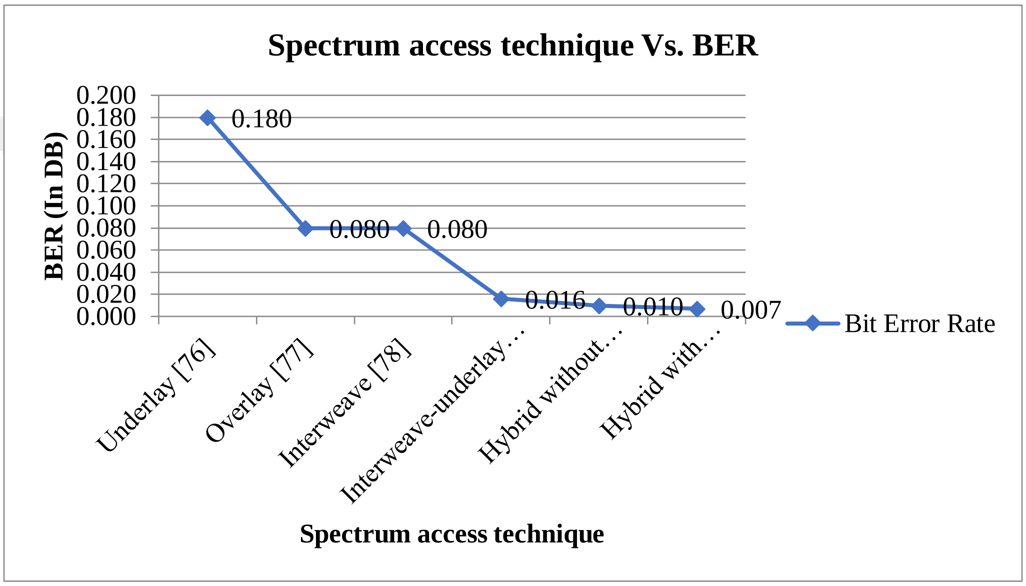

Figure 4.4: Pictorial representation of proposed spectrum access Vs BER

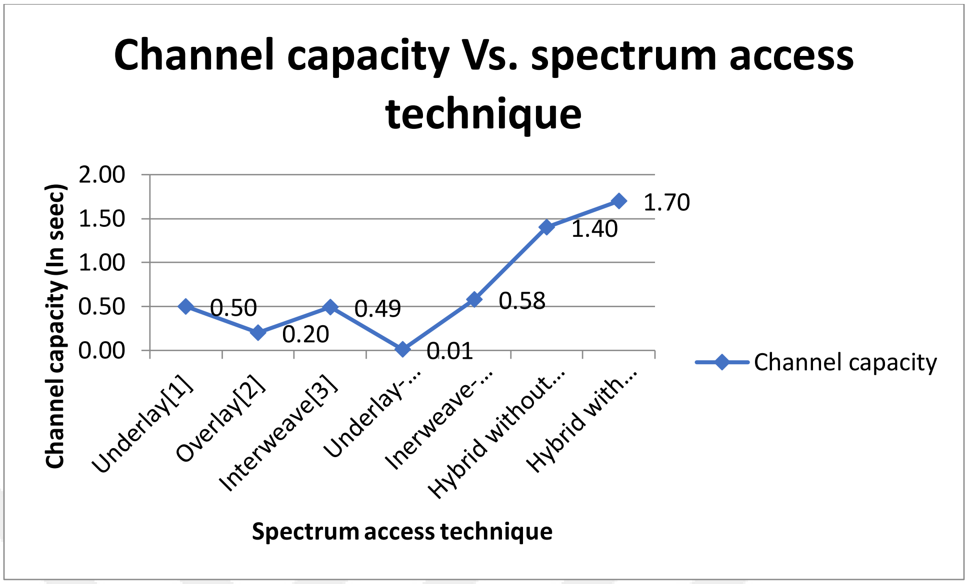

Figure 4.5: Pictorial representation of proposed spectrum access Vs channel capacity

The above figure illustrates the performance comparison chart for several techniques accessed, in which the BER is considered in the y-axis and channel capacity is considered in the Y-axis. From the figure obtained it can be interpreted that for the proposed hybrid model the BER is significantly reduced. For instance, the BER without optimization of the proposed model is 0.01, and it is further reduced to 0.007 when the proposed model is optimized. From this, the performance and efficiency of the proposed hybrid model can be interpreted.

5. CONCLUSION FUTURE DIRECTIONS

5.1 CONCLUSION AND FUTURE DIRECTIONS

A model based on the combination of spectrum access techniques (underlay, overlay, and interweave) with an ant lion optimization strategy was developed in this study. This supports towards improves the system behavior of primary and secondary communication network through conserving the essential signal to noise ratio of primary and secondary users. Moreover, transmitting data from source to destination nodes that operate in the underlay, overlay and interweave mode. Further introduced the optimization techniques towards offers optimized results throughout the MIMO CR network. Then, based on the hamming precoding method to the number of channels used based on the PUs and SUs in the network, the number of channel users that is close to the orthogonal that gives the results was chosen. Meanwhile the channels are selected based on the transmitter time at unique time duration. Throughput, outage probability, and efficiency are used to evaluate how well the given approach performs (Detection Time). The suggested technique is implemented in MATLAB 2016b version, and its performance is assessed by comparing it to the prior methods, namely overlay, underlay, and interweave. The proposed MIMO CRs with optimization approach gives better result than the exiting approach named as underlay, overlay, interweave and hybrid spectrum access without optimization in terms of less computational complexity of the system with increased channel capacity. Also enables the maximum channel bandwidth despite the channel variations.

I. In our research, have used the performance metrics utilized towards spectrum sensing are probability of correct detection. In future, this can be enhanced by apply filter in noisy channel before and after optimization.

II. Also, the tradeoff amongst bit error rate and reliability of the data will be optimized. When a target detection probability is reached to safeguard the main users, this may improve the accuracy of spectrum sensing findings and optimize throughput for secondary users.

REFERENCES

[1] S. Kim, "Coexistence of Wireless Systems for Spectrum Sharing," Doctor of Philosophy Doctoral Dissertations, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2017.

[2] G. Kim, "What is Spectrum Sharing, and Why Does It Matter?" in Business Model, Internet Access, Mobile, Spectrum, Spectrum Futures Conference, 2015.

[3] FCC. (2003). Notice of proposed rule making and order: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies. Available: http://web.cs.ucdavis.edu/~liu/289I/Material/FCC-03-322A1.pdf

[4] I. F. Akyildiz, L. Won-Yeol, M. C. Vuran, and S. Mohanty, "A survey on spectrum management in cognitive radio networks," IEEE Communications Magazine, vol. 46, pp. 40-48, 2008.

[5] R. Zhang, Y.-c. Liang, and S. Cui, "Dynamic Resource Allocation in Cognitive Radio Networks," IEEE Signal Processing Magazine, vol. 27, pp. 102-114, 2010.

[6] J. Mitola, "Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio," Ph.D. dissertation, Doctor of Technology, Royal Institute of Technology (KTH), Kista, Sweden, 2000.

[7] V. Valenta, R. Marsalek, G. Baudoin, M. Villegas, M. Suarez, and F. Robert, "Survey on spectrum utilization in Europe: Measurements, analyses and observations," in Proceedings of the 5th International ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications, Cannes.

[8] A. Goldsmith, S. A. Jafar, I. Maric, and S. Srinivasa, "Breaking Spectrum Gridlock with Cognitive Radios: An Information Theoretic Perspective," Proceedings of the IEEE, vol. 97, pp. 894-914, 2009.

[9] S. A. Hesammohseni, K. Moshksar, and A. K. Khandani, "A combined underlay and interweave strategy for cognitive radios," in 2014 IEEE International Symposium on Information Theory, 2014, pp. 1396-1400.

[10] N. H. S. Adam and M. Abdel-Hafez, "Spectrum sharing with QoS awareness in cognitive radio networks," in Wireless Communications and Mobile Computing Conference (IWCMC), 2016 International, Paphos, Cyprus, 2016.

[11] K. Kotobi, "Energy Conservation of Cooperative Communication over Composite Channels," Master Thesis, Department of Telecommunications, Delft University of Technology, 2011.

[12] T. E. Hunter and A. Nosratinia, "Diversity through coded cooperation," IEEE Transactions on Wireless Communications, vol. 5, pp. 283-289, 2006.

[13] W. Panichpattanakul, "Cooperative Communications in Ad Hoc Networks," University of Toulouse, 2010.

[14] J. Mitola. (1995). Special Issue on Software Radio. Available: http://ethesis.nitrkl.ac.in/2641/1/B_tech_Final_Thesis.pdf

[15] S. Jain and R. B. Jain, "Spectrum Sensing Methods in Cognitive Radio," Bachelor of Technology Bachelor thesis, Electronics and Communication Engineering, ational Institute of Technology, New Delhi, 2011.

[16] F. C. C. S. E. W. Group, Report of the Spectrum Efficiency Working Group. U.S.A: Federal Communications Commision Spectrum Policy Task Force, 2002.

[17] R. F. Ustok, "Spectrum Sensing Techniques for Cognitive Radio Systems with Multiple Antennas," Master of Science Master Thesis, Electronics and Communication Engineering, Izmir Institute of Technology, İzmir, Turkey, 2010.

[18] M. G. Kibria, G. P. Villardi, K. Ishizu, F. Kojima, and H. Yano, "Resource allocation in shared spectrum access communications for operators with diverse service requirements," EURASIP Journal on Advances in Signal Processing, vol. 1, pp. 1-15, 2016.

[19] S. Bakşi and D. C. Popescu, "Distributed power allocation for spectrum sharing in mutually interfering wireless systems," Physical Communication, vol. 22, pp. 42-48, 2017.

[20] C. Liu, "Spectrum Sharing in Dynamic Spectrum Access Networks: WPE-II Written Report," Technical Reports (CIS), Department of Computer & Information Science, University of Pennsylvania, 2009.

[21] S. Shalmashi, "Cooperative Spectrum Sharing and Device-to-Device Communications," Licentiate Thesis, Communication Systems Department, Information and Communication Technology, Stockholm, Sweden, 2014.

[22] V. U. Kanth, K. R. Chandra, and R. R. Kumar, "Spectrum Sharing In Cognitive Radio Networks," International Journal of Engineering Trends and Technology, vol. 4, pp. 1172-1175, 2013.

[23] S. Delaere and P. Ballon, "Flexible Spectrum Management and the Need for Controlling Entities for Reconfigurable Wireless Systems," in IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2007, pp. 347-362.

[24] [T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," IEEE Communications Surveys & Tutorials, vol. 11, pp. 116-130, 2009.

[25] A. Sabharwal, P. Schniter, D. Guo, D. W. Bliss, S. Rangarajan, and R. Wichman, "In-Band Full-Duplex Wireless: Challenges and Opportunities," IEEE Journal on Selected Areas in Communications, vol. 32, pp. 1637-1652, 2014.

[26] W. A. Gardner, "Signal interception: a unifying theoretical framework for feature detection," IEEE Transactions on Communications, vol. 36, pp. 897-906, 1988.

[27] I. F. Akyildiz, B. F. Lo, and R. Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: A survey," Physical Communication, vol. 4, pp. 40-62, 2011.

[28] K. G. M. Thilina, E. Hossain, and D. I. Kim, "DCCC-MAC: A Dynamic Common-Control-Channel-Based MAC Protocol for Cellular Cognitive Radio Networks," IEEE Transactions on Vehicular Technology, vol. 65, pp. 3597-3613, 2016.

[29] M. U. P. Kaur, M. Uddin, and A. Khosla, "Adaptive bandwidth allocation scheme for cognitive radios," International Journal of Advancements in Computing Technology, vol. 2, pp. 1-35, 2010.

[30] O. Naparstek and K. Cohen. (2017). Deep Multi-User Reinforcement Learning for Distributed Dynamic Spectrum Access. Available: https://arxiv.org/pdf/1704.02613.pdf

[31] B. F. Lo, "A survey of common control channel design in cognitive radio networks," Physical Communication, vol. 4, pp. 26-39, 2011.

[32] M. T. K. Gamacharige, "On Spectrum Sensing, Resource Allocation, and Medium Access Control in Cognitive Radio Networks," Doctor of Philosophy, Department of Electrical and Computer Engineering, University of Manitoba, Winnipeg, 2015.

[33] C. Ghosh, S. Roy, and M. B. Rao, "Modeling and Validation of Channel Idleness and Spectrum Availability for Cognitive Networks," IEEE Journal on Selected Areas in Communications, vol. 30, pp. 2029-2039, 2012.

[34] Q. Liang, S. Han, F. Yang, G. Sun, and X. Wang, "A Distributed-Centralized Scheme for Short- and Long-Term Spectrum Sharing with a Random Leader in Cognitive Radio Networks," IEEE Journal on Selected Areas in Communications, vol. 30, pp. 2274-2284, 2012.

[35] I. Podder and M. Samajdar, "Spectrum Sensing in Cognitive Radio under different fading environment," International Journal of Scientific and Research Publications, vol. 4, pp. 1-17, 2014.

[36] H. Zhou, Q. Yu, X. Shen, S. Wu, and S. Wu, Dynamic Sharing of Wireless Spectrum. United State: Springer, 2016.

[37] H. Zhou, Q. Yu, X. Shen, S. Wu, and Q. Zhang, "Overview of Dynamic Sharing of Wireless Spectrum," ed Cham: Springer International Publishing, 2017, pp. 17-35.

[38] B. Benmammar, A. Amraoui, and F. Krief, "A Survey on Dynamic Spectrum Access Techniques in Cognitive Radio Networks," International Journal of Communication Networks and Information Security, vol. 5, pp. 68-79, 2013.

[39] A. S. Ibrahim, T. M. Salem, S. Abdel-kader, and H. S. Eissa, "Mapping Spectrum Sharing TechniquesWith Cognitive Radio Applications Mapping Spectrum Sharing TechniquesWith Cognitive RadioApplications," International Journal of Application or Innovation in Engineering & Management, vol. 5, pp. 109-122, 2016.

[40] A. Garhwal, "A Survey on Dynamic Spectrum Access Techniques for Cognitive Radio," International Journal of Next-Generation Networks, vol. 3, pp. 15-32, 2011.

[41] L. Won-Yeol and I. F. Akyldiz, "A Spectrum Decision Framework for Cognitive Radio Networks," IEEE Transactions on Mobile Computing, vol. 10, pp. 161-174, 2011.

[42] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," Computer Networks, vol. 50, pp. 2127-2159, 2006.

[43] S. Swami, "aph Theoretic Approach to QoS Guaranteed Spectrum Allocation in Cognitive Radio Networks," 2008.

[44] A. Wisniewska, "Spectrum sharing in Cognitive Radio Networks: A Survey," Computer Science Department, City University of New York Graduate Center, New York, NY, 2016.

[45] J. Liu, W. Chen, Z. Cao, and Y. J. Zhang, "Delay Optimal Scheduling for Cognitive Radios with Cooperative Beamforming: A Structured Matrix-Geometric Method," IEEE Transactions on Mobile Computing, vol. 11, pp. 1412-1423, 2012.

[46] Z. Zhang. (2016). Cognitive Networks/Dynamic Spectrum Access in Wireless Networks: Overview. Available: http://s3.amazonaws.com/sdieee/1917-Dsa-overview-sd.pdf

[47] A. Goldsmith, Wireless Communications. Cambridge: Cambridge University Press, 2005.

[48] M. Zareei, A. K. M. M. Islam, S. Baharun, C. Vargas-Rosales, L. Azpilicueta, and N. Mansoor, "Medium Access Control Protocols for Cognitive Radio Ad Hoc Networks: A Survey," Sensors, vol. 17, 2017.

[49] A. Diab, Self-Organized Mobile Communication Technologies and Techniques for Network Optimization. USA: IGI Publishing Hershey, 2016.

[50] Y. Li and Y. Wang. (2017). Reconfigurable Antennas for UWB Cognitive Radio Communication Applications. Available: https://www.intechopen.com/books/cognitive-radio/reconfigurable-antennas-for-uwb-cognitive-radio-communication-applications

[51] A. Abraham, J. Mauri, J. Buford, J. Suzuki, and S. Thampi, Advances in Computing and Communications. Berlin, Heidelberg: Springer, 2011.

[52] A. Chaoub. (2014). Cognitive Radio - Underlay, Overlay or Interweave: How the spectrum is shared? Available: http://cognitive-radio-networks.blogspot.in/2014/05/cognitive-radio-underlay-overlay-or.html

[53] Y. Xiao and F. Hu, Cognitive radio networks. Boca Raton: CRC Press/Auerbach Publications, 2009.

[54] P. Pillai, R. Shorey, and E. Ferro, Personal Satellite Services. Berlin, Heidelberg: Springer, 2012.

[55] F. Yu, Cognitive radio mobile ad hoc networks. United States: Springer, 2011.

[56] T. Dhope, Cognitive Radio Networks Optimization with Spectrum Sensing Algorithms. Aalborg: River Publishers, 2014.

[57] F. Fitzek and M. Katz, Cognitive wireless networks. Dordrecht: Springer, 2007.

[58] F. Hu, B. Chen, X. Zhai, and C. Zhu, "Channel Selection Policy in Multi-SU and Multi-PU Cognitive Radio Networks with Energy Harvesting for Internet of Everything," Mobile Information Systems, vol. 2016, pp. 1-12, 2016.

[59] R. Blasco-Serrano, J. Lv, R. Thobaben, E. Jorswieck, A. Kliks, and M. Skoglund, "Comparison of Underlay and Overlay Spectrum Sharing Strategies in MISO Cognitive Channels," in Proceedings of the 7th International Conference on Cognitive Radio Oriented Wireless Networks, 2012.

[60] S. Perez-Salgado, E. Rodríguez-Colina, M. Pascoe-Chalke, and A. Prieto-Guerrero, "Underlay control channel using adaptive hybrid spread spectrum techniques for dynamic spectrum access," in 2013 International Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS), 2013.

[61] S. Anamalamudi and M. Jin, "Hybrid Common Control Channel Based MAC Protocol for Cognitive Radio Ad-Hoc Networks," International Journal of Information and Electronics Engineering, vol. 4, 2014.

[62] S. Gmira, A. Kobbane, E. Sabir, and J. Ben-othman, "A game theoretic approach for an hybrid overlay-underlay spectrum access mode," in 2016 IEEE International Conference on Communications (ICC), 2016, pp. 1-6.

[63] F. Jasbi and D. K. C. So, "Hybrid Overlay/Underlay Cognitive Radio Network With MC-CDMA," IEEE Transactions on Vehicular Technology, vol. 65, pp. 2038-2047, 2016.

[64] T. M. C. Chu, H.-J. Zepernick, and H. Phan, "Hybrid spectrum access with relay assisting both primary and secondary networks under imperfect spectrum sensing," EURASIP Journal on Wireless Communications and Networking, vol. 2016, pp. 244-244, 2016.

[65] U. Satheesan and T. Sudha, "Achievable Data Rate in Hybrid MIMO Cognitive Radio Networks," Procedia Technology, vol. 24, pp. 873-879, 2016.

[66] N. Tang, S. Mao, and S. Kompella, "On power control in full duplex underlay cognitive radio networks," Ad Hoc Networks, vol. 37, pp. 183-194, 2016.

[67] L. Xu, J. Wang, Y.-p. Li, Q. Li, and X. Zhang, "Resource allocation algorithm based on hybrid particle swarm optimization for multiuser cognitive OFDM network," Expert Systems with Applications, vol. 42, pp. 7186-7194, 2015.

[68] V. K. S. Anshu, "Ant-lion based efficient cognitive radio routing," International Journal of Latest Trends in Engineering and Technology, vol. 9, pp. 241-248, 2017.

[69] K. B. S. Manosha, N. Rajatheva, and M. Latva-aho, "Overlay/Underlay Spectrum Sharing for Multi-Operator Environment in Cognitive Radio Networks," 2011, pp. 1-5.

[70] G. Yogarajan and T. Revathi, "A Discrete Ant Lion Optimization (DALO) Algorithm for Solving Data Gathering Tour Problem in Wireless Sensor Networks," Middle-East Journal of Scientific Research vol. 24, pp. 3113–3120, 2016.

[71] N. Kaur, I. K. Aulakh, and R. Vig, "Analysis of Spread Spectrum Techniques in Cognitive Radio Networks," International Journal of Applied Engineering Research, vol. 11, pp. 5641-5645, 2016.

[72] R. Zhang, S. Cui, and Y.-C. Liang, "On Ergodic Sum Capacity of Fading Cognitive Multiple-Access and Broadcast Channels," IEEE Transactions on Information Theory, vol. 55, pp. 5161-5178, 2009.

[73] S. S. Kalamkar and A. Banerjee, "On the Effect of Primary User Traffic on Secondary Throughput and Outage Probability Under Rayleigh Flat Fading Channel," in Signal Processing and Communications (SPCOM), 2014 International Conference on, Bangalore, India, 2014.

[74] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and Spectral Efficiency of Very Large Multiuser MIMO Systems," IEEE Communications Society, vol. 61, pp. 1436 - 1449, 2013.

[75] Y. Li, M. Sheng, X. Wang, Y. Zhang, and J. Wen, "Max–Min Energy-Efficient Power Allocation in Interference-Limited Wireless Networks," IEEE Transactions on Vehicular Technology, vol. 64, pp. 4321 - 4326, 2015.

[76] J. M. Moualeu, W. Hamouda, and F. Takawira, “Cognitive Coded Cooperation in Underlay Spectrum-Sharing Networks Under Interference Power Constraints,” IEEE Trans. Veh. Technol., vol. 66, no. 3, pp. 2099–2113, Mar. 2017.

[77] W. Liang, S.-X. Ng, and L. Hanzo, “Cooperative Overlay Spectrum Access for Cognitive Radio Networks,” IEEE Commun. Surv. Tutorials, no. November, pp. 1–22, 2017.

[78] P. Yadav and P. P. Bhattacharya, “Performance Study of Interweave Spectrum Sharing Method in Cognitive Radio,” Int. J. Adv. Res. Comput. Eng. Technol., vol. 2, no. 5, pp. 1866–1872, 2013.

[79] K. B. S. Manosha, N. Rajatheva, and M. Latva-aho, “Overlay/Underlay Spectrum Sharing for Multi-Operator Environment in Cognitive Radio Networks,” in 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring), 2011, pp. 1–5.

[80] T. M. C. Chu, H. Phan, and H.-J. Zepernick, “Hybrid Interweave-Underlay Spectrum Access for Cognitive Cooperative Radio Networks,” IEEE Trans. Commun., vol. 62, no. 7, pp. 2183–2197, Jul. 2014.