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A Proposed Hybrid Spectrum Sensing Method for Cognitive Radio Networks

A Thesis

Submitted to the Council of the College of Information Technology for Postgraduate Studies of the University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Information Technology / Information Networks

By

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بسم الله الرحمن الرحيم

(وَقُلْ رَبِّ زِدْنِي عِلْمًا)

صدق الله العلي العظيم

(طه : 114)

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Publication Associated With This Thesis

(First Paper)

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Dedication

To my *dear father*, my biggest hero

To ***my dear mother,*** may God prolong her life

To those who encouraged me to continue my scientific career, my ***husband Hussein Taawedh***

To all ***my family members*** who were the best support and encouragement

And to ***everyone*** who encouraged and helped me complete this work

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I thank God Almighty and praise Him, for He is the Most Gracious and Most Merciful above all else. I thank Him for achieving what I aspire to. It enabled me to complete a master's degree in information technology to join the University of Babylon

I extend my great thanks and appreciation to ***Prof.Dr. Sattar B. Sadkhan*** for his good cooperation, as he provided me with what I needed to him from sources and inquiries and was present step by step in order to complete this study.

Grateful thankfulness and warm gratitude also extend to Information Technology College by its dean, it is head of the Information Networks department, its staff, and all my colleagues for their great potential in learning and encouraging me through my B.S.C and M.S.C studies.

Abstract

Spectrum Sensing (SS) in Cognitive Radio Networks (CRN) is crucial for determining the availability of channel frequency resources. By offering opportunistic employment of the frequency bands that are not widely occupied by licensed users, CR offers a solution to the issue of spectral scarcity. The main problem is scarcity of spectrum band allocation in radio communication in general and in cognitive radio specially.

The proposed mode based on increasing the efficiency of permitted spectrum band by using hybrid spectrum sensing methods. Different secondary users (SUs) in CRN can share sensing data over a hybrid cooperative CRN, improving the quality of primary user identification. The issue of power consumption is addressed, and the sensing strategy is improved by using a Fusion Center (FC) to carry out the spectrum sensing technique.

The proposed system simulates sending (text file) and (image file) data types in the environment of the cognitive radio network. Additionally, the proposed system is implemented using the simulation tool OMNET++. The proposed hybrid sensing system of Fusion Center (FC) enhanced throughput as 135.026 % for 2 nodes, 75.2 % for 4 nodes, 34.26667% for 6 node and 30.6 % for 8 nodes compared with the case without FC. For better throughput, the power used reduced by 25.3104%, 8.370582%,3.329049 % and 1.989248%, in the cases of 2 CR, 4 CR, 6CR, and 8 CR respectively.

The increase in CR life time for higher results is 74.68961%, 91.62942%,95.75109 and 98.01075 % In the scenarios of 2 CR nodes, 4 CR,6 CR and 8 CR, respectively. Throughput decreases with increases number of nodes due to increasing time for sensing signals and the applied cooperative spectrum sensing increases the waiting time to acquire idle channel for data transmission.

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List of Abbreviation

NO	Abbreviation	Definition
1.	ADC	Analog-to-digital converter
2.	ANN	Artificial Neural Networks
3.	AWGN	Additive white Gaussian noise
4.	CAV	Covariance Absolute Value
5.	CAF	Cyclic Autocorrelation Function
6.	CTS	Clear to send
7.	CU	Cognitive user
8.	CSS	Cooperative Spectrum Sensing
9.	CRN	Cognitive Radio Network
10.	CNN	Convolutional Neural Network
11.	CWSNs	Cognitive Wireless Sensor Networks
12.	DCF	Distributed Coordination Function
13.	DISH	Distributed Information SHaring
14.	DQN	Deep Q-Network
15.	DVB	Digital Video Broadcast
16.	ED	Energy Detection
17.	EDEV	Energy Detection &Eigen Value
18.	EGC	Equal Gain Combining
19.	ELM	Extreme Learning Machine
20.	EMD	Experimental Decomposition
21.	EME	Energy to the minimum Eigen value
22.	FC	Fusion Center
23.	GUI	Graphical User Interface
24.	GSMs	Global System for Mobile Communications
25.	HD	Hybrid detector
26.	HDF	Hard Decision Fusion
27.	LAN	Local area network
28.	LRS-G2	Likelihood Ratio Test statistic
29.	MAC	Medium Access Control
30.	MED	Max Eigen value detection
31.	MLP	Multilayer perceptron
32.	MME	Max-Min Eigen value detection
33.	MUMIMO	Multi-user multiple-input and multiple-output
34.	OFDM	Orthogonal Frequency-Division Multiplexing
35.	PCF	Point Coordination Function

36.	PSD	Power spectral density
37.	PSHU	Probability Of Spectrum Hole Utilization
38.	PSO	Particle Swarm Optimization
39.	PU	Primary User
40.	QoS	Quality of Service
41.	RA	Receiver Address
42.	RTS	Request To Send
43.	RF	Radio Frequency
44.	RMT	Random Matrix Theories
45.	SCL	Signaling & Communication Link
46.	SDF	Soft Decision Fusion
47.	SNR	Signal to Noise Ratio
48.	SS	Spectrum Sensing
49.	SU	Secondary User
50.	SVM	Support Vector Machine
51.	TA	Transmitter Address
52.	TDM	Time-Division Multiplexing
53.	WBAN	Wireless Body Area Network
54.	WEVD	Weighted-Eigenvalue Detection
55.	WiMAX	Worldwide Interoperability for Microwave Access
56.	WSN	Wireless sensor network

Chapter One

General Introduction

1.1 Introduction

CR is a method for managing radio frequency reduction that can intelligently discover changes in the environment and the transmission parameters respond by changing (modulation, frequency, frame format, etc.) [1]. There are authorized and illegal frequency bands in the radio spectrum. the licensed spectrum made available to private uses. Anyone can utilize the unlicensed spectrum, which is available for free. By allowing secondary users CR to independently access spectrum holes at specific times and locations, CR makes advantage of unlicensed radio frequencies, also known as spectrum holes, to boost performance [2].

The main attributes of CR are cognitive strength and the possibility of reconfiguration. Cognitive strength refers to the capacity to detect and gather data from surrounding environment. Reconfigurability refers to the capacity to quickly change operating settings in response to sensed data to get the best performance [3].

The CR ables to use the best available channel thanks to dynamic spectrum access algorithms. More specifically, the CR technology will allow the user to identify the available spectrum, identify the primary users' existence (spectrum sensing), choose the best channel that is available (spectrum management), coordinate the channels access with other users (frequency sharing), and migrate to a different channel whenever the prime user is found (spectrum mobility) [4]. The cognitive radio operation cycle is depicted in Figure 1.1 along with operations that are tightly related to CR characteristics [5].

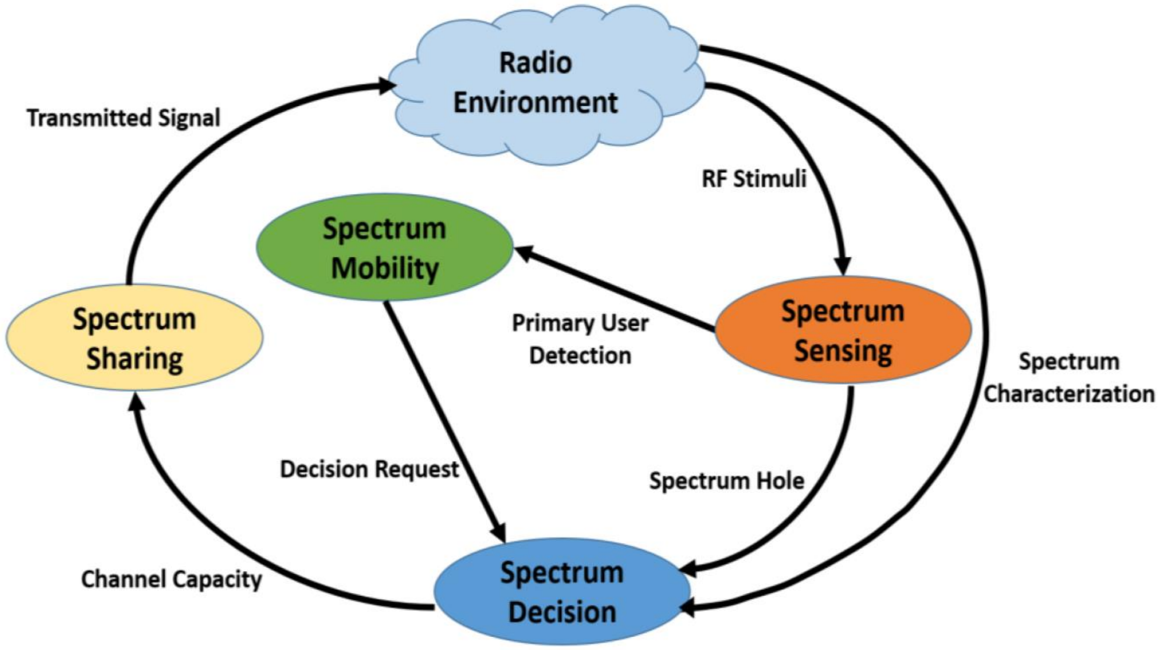


Figure 1.1cognitive Radio Operation Cycle [5]

A cognitive radio may assess, learn, and become percipient of its operating environment through spectrum sensing, including the status of interference and the availability of spectrum. Therefore, spectrum sensing is possible in the domains of time, frequency, and location [6].

As a result, secondary users may be given access to spectrum in the directions where a main user (PU) is not broadcasting, and spectrum sensing must additionally account for the angle of arrivals [7]. In general, radio spectrum can be divided into two categories: licensed, which is given solely to main users for independence use, and unlicensed, which is given to every citizen for non-exclusive use subject to various regulatory limits, such as limitations on transmission power, as showing in Figure 1.2.

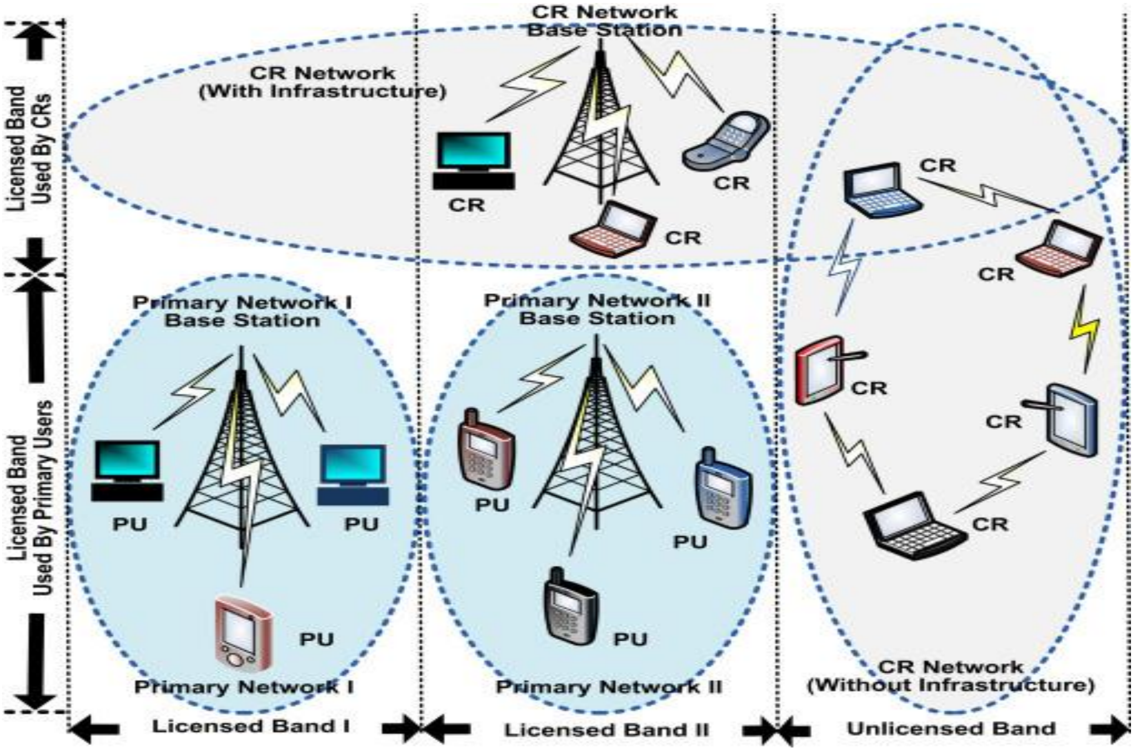


Figure 1.2 license and unlicense band[8]

Spectrum sensing generally carries out the following duties [9]:

1- Spectrum hole detection;
2- Spectrum hole spectral resolution determination;
3- Assessment of the locative directions of an arriving interfering signal; and
4- Signal classification.

Spectrum sensing determines the appearance or the absence of primary users in the underlying band. The most crucial of these tasks is detection of spectrum holes which investigated using a binary hypothesis-testing problem. simply it used to describe the finding spectrum gaps on a particular band of frequencies [10].

1.2 Problem Statement

The proposed system solves different problems explained as follow:

- Maximum collisions between secondary users and PU which lead to interference with PU (licensed user), and this is not allowed in CRN.

- Computation power management in CRN due to increasing number of sensing signals which exhausted secondary cognitive radio.
- Detect the PU in case of without fusion center due to the increasing number of active nodes which leads to dynamic packets for sensing the appearance of PU.
- Identify the idle channel in case of more than one PU channel.
- In case of non-cooperative spectrum sensing in different CRN topologies is important to manage spectrum channel sharing especially in case of complexity increased number of CRs.

1.3 The Aim of the thesis

The main objective of this thesis is to suggest a hybrid spectrum sensing method for CRN. The proposed method has the ability to improve the sensing approach by employing an external node (fusion center) to do spectrum sensing instead of secondary user sensing and applying eigen value approach in fusion center node and energy detector method. We consider achieving these objectives by:

1) Reduce power consumption through reduce number of sensing message which lead to increase data rate, and throughput in secondary user through reducing loading traffic and therefore CR lifetime increases.
2) Modifies the input parameter that are influenced by decision making process for choosing the best idle available channel by FC.

1.5 Related Works

Researchers have proposed a variety of strategies for spectrum management, including spectrum sensing, spectrum identification, and spectrum selection for SUs.

Nasr, Amr in (2017) presented an energy detector in unoccupied channels (dominant noise) based on the experimental decomposition (EMD) approach. The energy straight from the EMD signal processing is employed to occupy a specific area of interest. The suggested EMD-based detector's performance is evaluated at various sound intensity and sample size. In addition, the efficacy of the suggested detector is compared to that of existing detection methods utilizing traditional spectroscopic sensing techniques, with the outcomes indicating that it outperforms them [11].

Xiangli et al., in (2018) presented an updated machine learning (Support Vector Machine (SVM))-based collaborative spectrum sensing (CSS) model that uses user grouping approaches to decrease the price of cooperation and increase detection efficiency. Before the cooperative sensing procedure, cognitive radio users are properly sorted using samples of energy data and an SVM model. The user group that participates in cooperative sensing methods as a result is safe, less redundant, or optimized [12].

Woongsup et al., (2019) developed a CSS for CR based on CNN (Convolutional Neural Network), which is the first attempt to use deep learning and Cooperative Sensing. CNN is utilized in DCS (Deep Cooperative Sensing) to acquire a skill for blending the SUs' individual sensing findings, which might be Boolean or real-valued [13].

Convolutional Neural Networks (CNN) are employed in (2019) to extract the detected signal's features and, as a result, enhance the sensing achievement. To be further precise, a brand-new two-dimensional dataset of the received signal is created, and three traditional CNN-based CSS schemes (LeNet, AlexNet, and VGG-16) are trained and evaluated on the suggested dataset. Additionally, comparisons of the sensing performance of the AND, OR schemes and the anticipated CNN-based CSS schemes [14].

Shakeel et al,. (2019) in [15] SUs with many classes using a hybrid interweave-underlay spectrum access approach developed an analytical model based on Markov to determine the improvement in non-switching spectrum handoff techniques. This study examined the effects of a hybrid spectrum access method for traffic that is prioritized across many classes of SUs in order to meet the QoS considerations for traffic that is susceptible to delays. Results show a significant advancement in spectrum usage, average system throughput, and longer data delivery time arbitrage to conventional CRN use only spectrum access with interweave.

A particle swarm optimization-based cooperative spectrum sensing approach for CWSNs (Cognitive Wireless Sensor Networks) has been proposed by Yongcun et al. in (2020). The mathematical model for energy efficiency is first built after a quantitative analysis of the System performance and energy usage. Second, under the constrained parameters of false alarm probability and detection probability, the particle swarm optimization (PSO) technique was employed to produce the ideal selected node set [16].

Md. Sipon Miah (2020) in [17] suggested cognitive radio system for the Internet of Things (CR-IoT) based on multi-user multiple-input and multiple-output (MUMIMO) with weighted-eigenvalue detection (WEVD) in order to analyze sensing, system performance, energy usage, and expected longevity. Each CR-IoT user is given MIMO antennas in this scheme, and it compute the WEVD ratio, which is calculated since the ratio of the distinction between the maximum and minimum eigenvalues to the sum of the maximum and minimum eigenvalues. This lessens the impact of the spectrum scarcity issue while also increasing system throughput, usage of less energy, extending projected lifetime, and reducing mistake likelihood.

Both the number of samples and the signal-to-noise ratio of the secondary users are the only factors on which the probability of detection and false alert is derived. In [18], Tavares et al,. (2020), used the detection of channel occupancy produced by well-established analytical techniques similar AND/OR rules and maximum ratio combining is compared to various ML techniques like multilayer perceptron (MLP). They get the computational efficiency of the examined models throughout the training phase by using common profiling tools, which is a crucial step for working in CRNs. Last but not least, the outcomes show that the MLP ML approach offers a better balance between the effectiveness of channel detection and training duration.

To determine the presence of Primary User, (2021) uses a Soft Decision Fusion (SDF) approach called Equal Gain Combining (EGC) and a Hard Decision Fusion (HDF) technique called logical OR (PU). For spectrum sensing, a cooperative energy detection technique is used, and an advanced optimization technique called the Jaya algorithm is used to attain the lowest Probability of Error [19].

Giri et al., (2021) in [20] discussed a cooperative spectrum sensing method (CSS) Using the Extreme Learning Machine (ELM), ELMs are feedforward neural networks where only the output weights are optimized and the hidden layer parameters are left unaltered. For calculating channel occupancy detection, several activation configurations functions and weight initialization schemes are used. These findings show that ELM may be better than conventional techniques. A superior trade-off between training time and detection effectiveness is demonstrated by the work described here.

Table (1-1) illustrates the goal of the earlier research on the cognitive radio networks concept.

Number of References	The main aim	Performance metrics	Result
[11] (2017)	They provide an outline of recent advancements in hardware and software design for CR transceivers.	N/d	Shows developments in CR hardware and software design and algorithms.

[12] (2018)	Enhanced machine learning-based cooperative spectrum sensing model for cognitive radio networks	N/d	significant raised in the quality of the senses.
[13] (2019)	Convolutional neural networks are utilized in cooperative spectrum sensing.	Probability of detection, false alarm probability.	SVM scheme, DCS with HD, DCS with SD, and K-out-of-N scheme have computed false alarm probabilities vs detection probabilities that are 0.838, 0.945, 0.95, and 0.952, respectively.
[14] (2019)	Convolutional neural networks are used in cooperative spectrum sensing.	N/d	The suggested systems offer a significant increase in sensing accuracy.
[15] (2019)	To provide quality of service (QoS) in many classes of SUs with different delay needs during handoff while operating on a single homogeneous spectrum access becomes difficult under conditions of high primary network traffic.	Speed of data transfer and throughput.	increased average system throughput, better spectrum use, and longer data delivery times
[16] (2020)	Based on particle swarm optimization, a cooperative spectrum sensing approach for CWSNs	N/d	Increasing system throughput while maintaining sensing performance and successfully achieving energy efficiency.

[17] (2020)	a cognitive radio system built on a multi-user, multiple-input system and multiple-output (MUMIMO) and Weighted-eigenvalue detection (WEVD) for Internet of Things (IoT) sensor analysis (CR-IoT).	Throughput, energy effectiveness and anticipated lifetime.	increase system performance, increase energy efficiency, increase projected lifetime and decrease the probability of errors.
[18] (2020)	Machine learning for cooperative spectrum sensing in cognitive radio networks (ML) models (CRNs).	The probability of exposure and false alarm.	The outcomes show that there is a superior trade-off inter channel detection execution and training time with the MLP ML approach.
[19] (2021)	Enhancing improving the Cognitive Radio spectrum sensing technique.	N/d	When compared to TLBO, the Jaya algorithm reduces the probability of error by 20%.
[20] (2021)	Extreme Learning Machine (ELM)-based cooperative spectrum sensing (CSS) is suggested.	Detection performance, and energy consumption.	These findings show that ELM may be better than conventional techniques. The work described here, in particular, demonstrates a superior balance between training duration and detection performance.

- N/D: Not Define

1.7 Outlines of Thesis

The remaining chapters of this thesis are organized as follows:

Chapter Two: Introduction, spectrum sensing techniques: Benefits, and Challenges of spectrum sensing, and spectrum sensing method are presented in first section. Spectrum sensing analysis and cooperative sensing in cognitive radio networks, classification and framework of cooperative sensing, type of hybrid spectrum sensing in cognitive radio networks and applications are discussed in this chapter.

Chapter Three: This chapter, the suggested strategy is presented, along with examples of the system's actual steps and an explanation of the proposed approach.

Chapter Four: This chapter discusses the result strategy.

Chapter Five: The results are summarized in this chapter. It also offers suggestions for new works.

Chapter Two

Theoretical Background of Hybrid Spectrum Sensing in CRN

2.1 Introduction

The goal of Cognitive Radio is to maximize the use of superior sources like spectrum while maintaining high quality of service. A smart wireless communication system with awareness of its surrounding environment variation. The two primary entities are PU and SU that are introduced. When the PU are not using the licensed spectrum, secondary (without licenses) users can send and receive signals over all or a portion of the licensed spectrum. When PU are using the licensed spectrum, the SU should be able to assess the radio environment, use it wisely, and give it up [21].

Spectrum sensing is a phase that never ends in the life cycle of cognitive radio communications. It must be performed initially to identify an unoccupied channel and then on a regular basis to safeguard the PU. If the PU becomes active again, sensing is then used to identify another unoccupied channel. The fundamental goal of CR is to maximize wireless spectrum usage, hence cutting down on sensing time results in more space being left for transmission. Additionally, sensing is essential to the overall process effectiveness since it places restrictions on how to use the PUs channel while still protecting it. Sensing is used to protect PU. Because of this, sensing has attracted a lot of attention in order to be carried out effectively [22]. Therefore, a range of frequencies where a secondary can communicate without harming with any primary users is formally referred to as a spectrum hole, this issue is clearly shown in Figure 2.1.

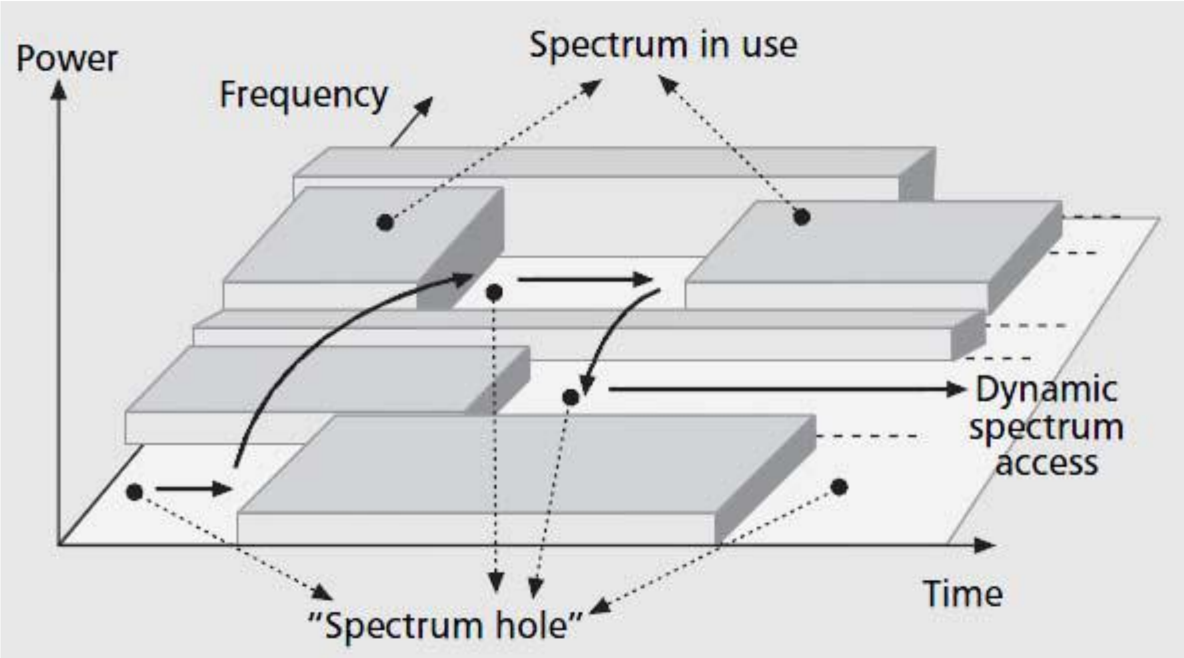


Figure 2.1:spectrum sensing hole concept [23].

Sensing is the method of identifying a primary transmitters presence on a certain channel. This channel is not open if the PU is real.

In Cooperative Spectrum Sensing, there is a fusion center that gathers the sensing data from various cognitive users and determines whether or not a PU is present as display in Figure 2.2.

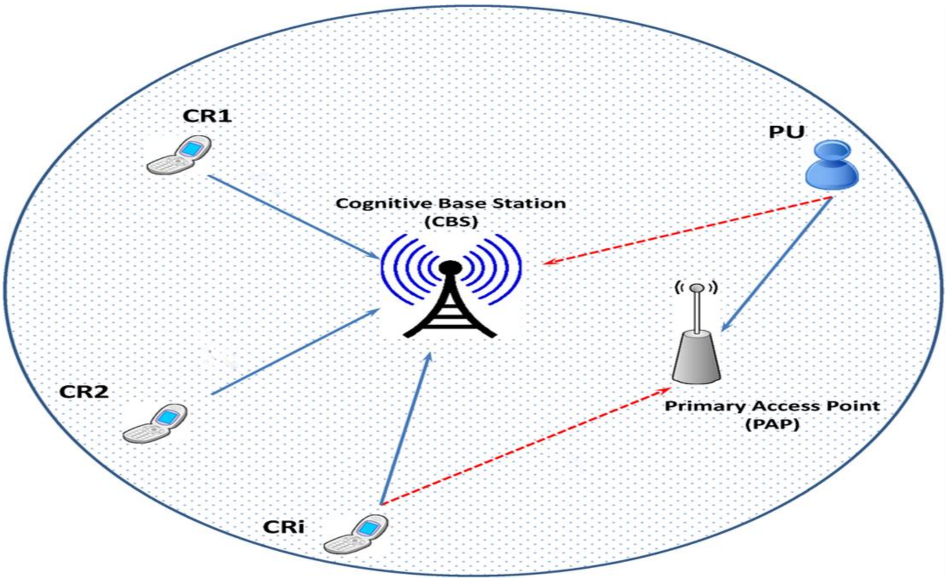


Figure 2.2:parallel fusion model

Despite the fact that sensing in CR is one of the most researched topics, research has been focused on either safeguarding the PU or shortening the sensing time so that more space is available for transmission [24].

In [25], authors look at sensing from the perspective of lowering energy consumption or raising energy efficiency. During sensing, energy is used in three stages:

1- Energy is used during the sensing stage, and longer sensing times use more energy.
2- Reporting phase: As more nodes cooperate, more CR nodes report to the fusion center, consuming more reporting energy.
3- The transmission stage is impacted by the sensing outcome [26].

Meng et.al [28] focuses on two goals: lowering the total amount of energy used during the various stages of sensing, such as sensing, reporting, and transmission. The second goal is to maximize energy efficiency, which is the relationship between good throughput and energy consumed. In order to achieve that goal, he determined the number of nodes that should execute cooperative sensing as well as the sensing time needed each CR node jointly [27].

2.2 Spectrum Sensing Techniques

A CR can measure, educate, and be conscious of its operational environment with the use of spectral sensing, including the availability of spectrum and the presence of interference, for example. SU can use the spectrum when it is discovered that the primary/licensed user is underusing a certain frequency band at a specific time in a specific location, which is when a spectrum opportunity exists. As a result, spectrum sensing is possible in all three of these domains: time, frequency, and space. Multiple users can use the identical channel or frequency occurring at the same time and location thanks to recent advancements in beamforming technology. As a result, secondary users may be given access to spectrum in the directions where a (PU) is not broadcasting, and spectrum sensing must additionally account for the angle of arrivals [28]. Sharing or frequency hopping allow the principal users to use their Spectrum allotted bands, while secondary users are permitted to transmit on the same band concurrently without significantly interfering with the primary users as long as they employ a unique code than the PU [29].

Spectrum sensing generally carries out the following duties (1) spectrum hole detection; (2) spectrum hole spectral resolution determination; (3) assessment of an incoming interfering signal's spatial directions; and (4) signal classification. The most crucial of these tasks detection of spectrum holes is investigated using a binary hypothesis testing problem. Spectrum sensing, which determines the existence or not existence of main users, is therefore commonly used to describe the detection of spectrum gaps on a restricted frequency band [30].

There are two basic kinds of spectrum sensing techniques: cooperative detection and non-cooperative/transmitter detection as showing in (Fig. 2.3). The basis of transmitter detection techniques is the local observation of CR users who can identify signals sent from a primary system. Techniques for detecting transmitters, or non-cooperative transmitters, are typically predicated on the notion that the cognitive device is unaware of the primary transmitters' location. Therefore, in order to execute spectrum sensing, cognitive users need only rely on the identification of weak primary transmitter signals and to make use local observations.[31]

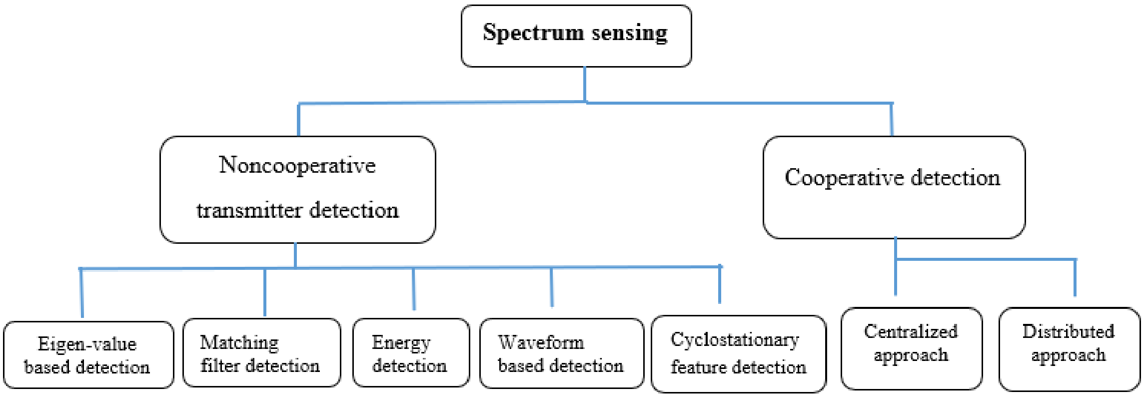


Figure 2.3: Spectrum sensing techniqes

The establishment of Spectrum Sensing is thought to be the most important of all the activities of CR. According to the bandwidth that is important for spectrum sensing, a variety of SS techniques have been proposed recently. These techniques can be divided into two groups: wideband and narrowband. Wideband spectrum sensing studies numerous frequencies at once, as opposed to narrowband spectrum sensing, which only checks one frequency band at a time [32]. The requirement for prior knowledge of PU signals, which are classed as coherent and noncoherent detection is another approach to define sensing systems. However, three separate methods for detecting spectrum holes are commonly categorized as spectrum sensing techniques: transmitter-based, interference-based, and receiver-based detection this approach it show in Figure (2.4) [33].

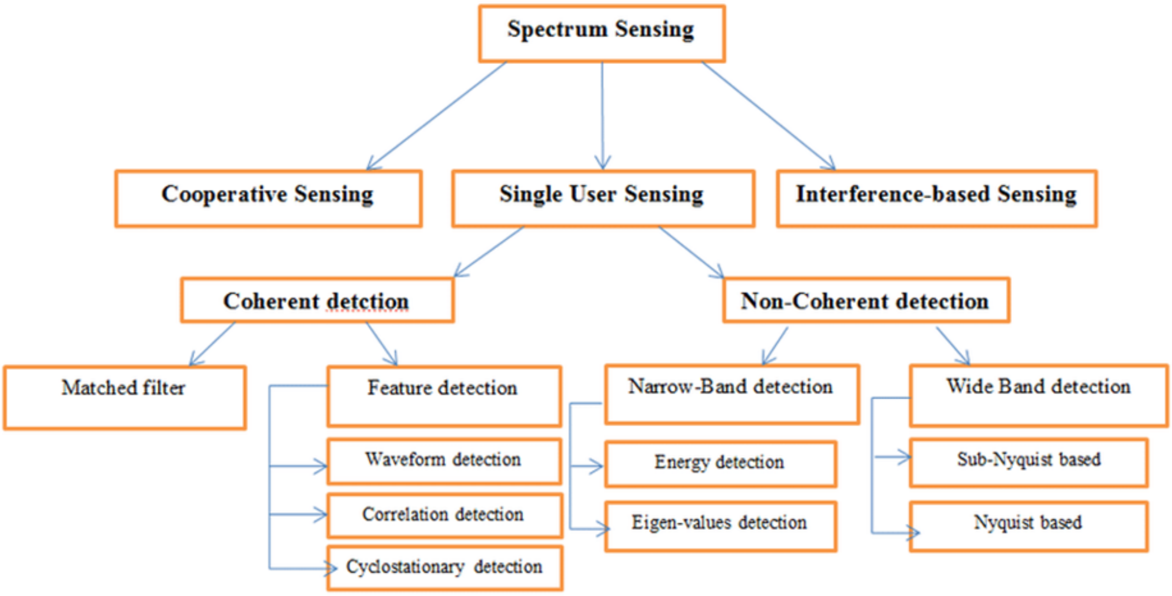


Figure 2.4: Classification of Spectrum Sensing Techniques

A cognitive device's coverage area's spectrum occupancy is not entirely known to it. As a result, detrimental interference with PU cannot be totally avoided. Furthermore, a hidden terminal issue cannot be stopped by transmitter identification [34]. For primary transmitter detection, five strategies are typically used:

A- Matching filter detection

B- Energy detection

C- Waveform based detection

D- Detection based on Eigenvalue.

E- Cyclostationary feature detection.

The shadowing phenomenon is to blame, which is highly regularly attend in urban and indoor environments, a cognitive user (CU) may have a strong line of sight with a primary receiver but may not be able to distinguish the existence of a primary transmitter (hidden terminal). To lessen this issue, cooperative detection procedures are used. A variety cognitive radios can exchange their local sensing data using cooperative detection techniques, which improve the accuracy of primary transmitter detection [35]. Either centralized or decentralized implementations of cooperative detection are possible. A center component gathers sensing data from cognitive devices, determines the spectrum bands that are open, and transmits this knowledge to other cognitive radios in the centralized manner. The sensory data is shared across the cognitive devices in a distributed manner since it has not a fusion center [36] [37]. Compared to centralized detection, which is more accurate and can successfully counteract both multi-path fading as well as shadowing effects, distributed detection is simpler to deploy and does not need a backbone infrastructure. To lessen fading phenomena, the central node can additionally give each spectrum sensing result a certain weight [38]. Depending on the type of information shared across cognitive users, cooperative detection approaches can also be divided into soft and hard combinations. The term "soft combination" describes a cooperative method wherein each node senses a specific frequency band and then communicates towards the center node the results of its measurements, or the energy of the signal received [39].

In contrast, each node in a hard combination strategy determines whether a PU is present before reporting solely the results of that determination to the central node [40][41]. Given that signals from far-off nodes typically aren't coupled, soft detection is typically more reliable. Although hard detection is less accurate, it requires less communication between nodes. Multiple antennas on a cognitive device allow for the implementation of advanced sensing techniques that take advantage of spatial, time, and/or frequency coding [42]. In section 2.9 a detailed discussion of such cooperative spectrum sensing is provided.

Spectrum sensing systems must be able to recognize gaps in the spectrum and any sudden changes in the status of frequencies in use, securely, accurately, and dependably if they are to work at their best. Figure 2.5 illustrates possible specifications for spectrum sensing.

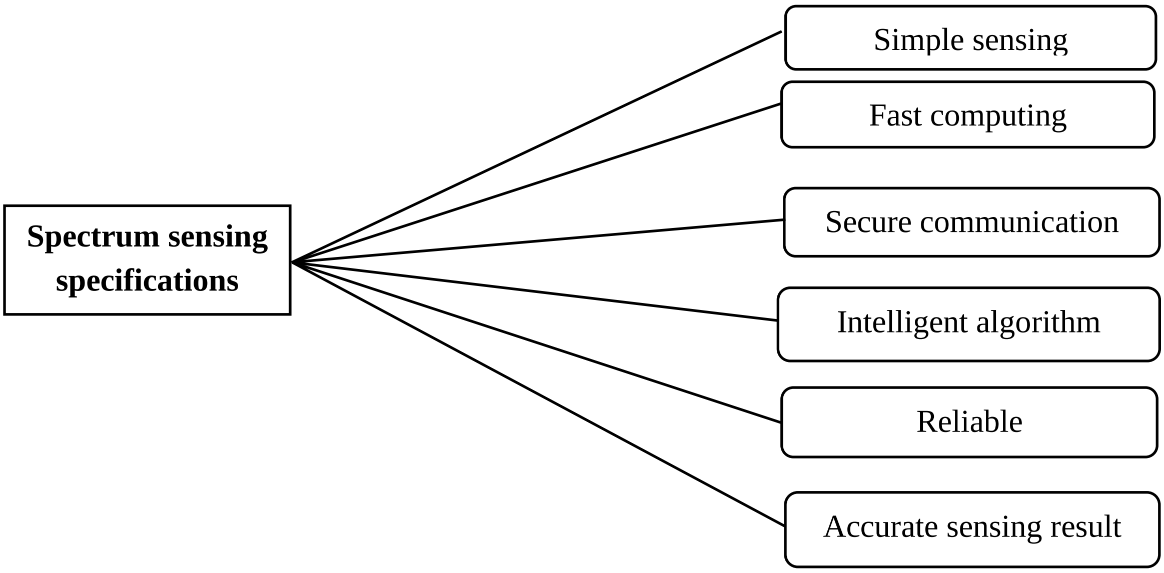


Figure 2.5: Prospects for spectrum sensing requirements

2.3 Spectrum Sensing Methods:

There are numerous spectrum sensing methodologies that can be used depending on the surroundings, in this section many methods will be described.

2.3.1 Energy detection

determine the presence or absence of a licensed user, the received signal energy in an energy detector has been compared to a predetermined threshold value over an observational interval [43]. When the received signal exceeds the threshold, PU is present; otherwise, absence is signaled. It is a non-coherent system because no prior knowledge of PU signals is necessary. It is the most often used and simplest detector due to its simplicity in terms of processing, implementation, and time when compared to other approaches. However, its performance has significantly declined when there is low SNR or noise uncertainty [44].

2.3.2 Matched filter detection

SUs has access to information about the PU signal, this is the best technique of detection. In order to detect the presence of PU signal and maximize SNR, this detector correlates known PU signal with received signal [45]. Convolution of the unknown signal with the time-reversed version of the signal has been used as an analog for this.

2.3.3 Waveform based detection

of preambles, mid-ambles, pilot carriers, and spreading patterns. Preambles, which are an arrangement of data patterns with known bits, are sent right before the data sequence, and mid-ambles are delivered in the midway through the data. The PU transmits the pilot signal as a signature signal. It could be a simple sine wave tone. These are purposefully included in the signal since understanding these patterns aids in the detection and synchronization processes. Systems with well-known signal patterns have already exploited this coherent sensing technique. Receiving a signal has been associated with its well-known copy (known characteristics) in the presence of known signals, and a threshold value has been used to compare the received output against. to determine whether a PU is available or absent [46][47] in order to carry out sensing.

2.3.4 Eigen-value based detection

The Eigen values of the covariance matrix in the received signal at each SU were utilized in this procedure. The samples received signal covariance matrix can be expressed as [48]. The main explanation about this section showed in section (2.8.2).

2.3.5 Cyclostationary feature detection

The signals cyclostationary characteristics have been used in this manner for spectrum sensing [49]. It makes use of the periodicity that is frequently present in the original signals that have been received (modulated signals coupled with sinewave carriers, cyclic prefixes, hopping sequences, etc). These cyclostationarity signals [50] display periodic statistics-like characteristics coupled with spectral correlation, which are absent from stationary noise and interference.

2.4 Potential Benefit and Challenges of Spectrum Sensing in CRN

2.4.1 Challenges of Spectrum Sensing

Within different applications, spectrum sensing has obstacles, which can be characterized as follows:

1) The most essential challenging aspect of the cognitive radio paradigm is creating an effective spectrum-sensing technique since spectrum sensing involves complexity, precision, dependability, computing cost, and sensing time [51].
2) Any specific spectrum detecting method finds it challenging to deliver excellent performance for all of these spectrum sensing requirements [52].

3) Sensing the wideband spectrum for cognitive radio applications demands fast signal processors, many analog front-end circuits, and high sampling rates. [53]

Fig. 2.6 illustrates a number of potential obstacles that could make spectrum sensing a difficult operation [54].

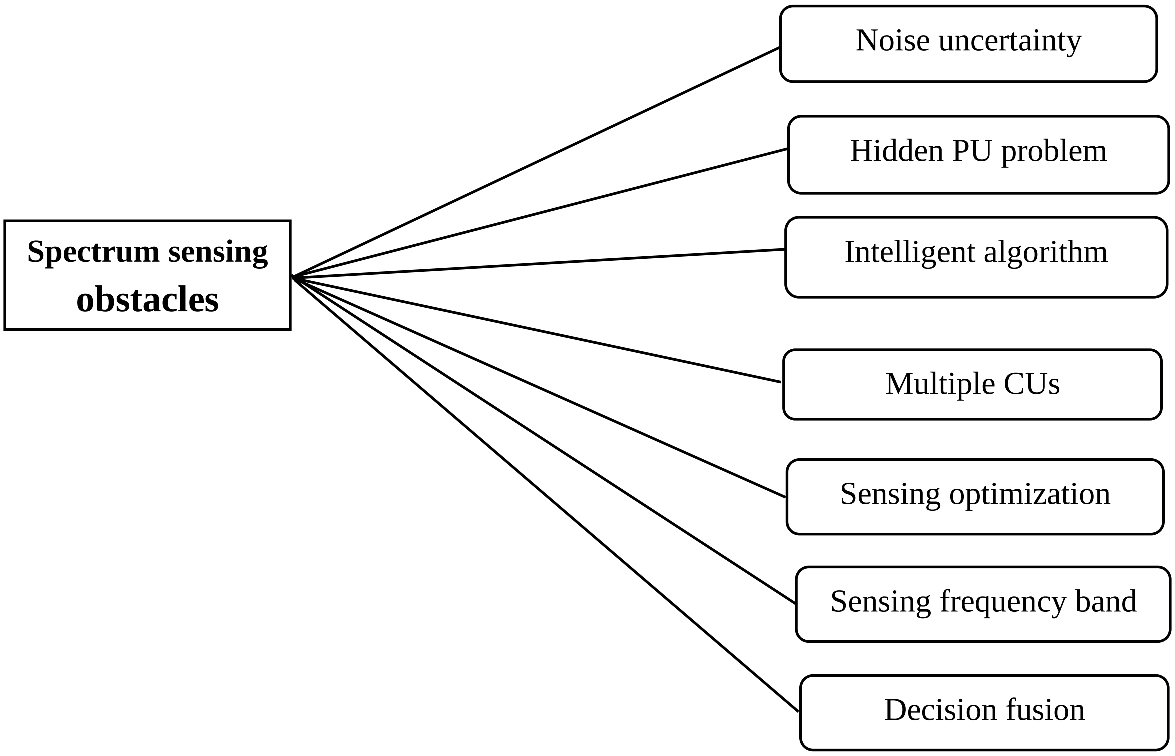


Figure 2.6: Possible issues with spectrum sensing

2.4.2 The Numerous Benefits of Spectrum Sensing:

The following statements [55] outline the advantages of spectrum sensing in cognitive radio network:

1) Is a crucial role for sensing operation to avoid harmful interference with authorized users.
2) Determine the available spectrum to increase the usage of the spectrum.
3) Reduce a number of processing to detect PU.
4) Increasing band utilization.
5) Spectral performance in real time.

6) Lowering the price of radio spectrum.

2.5 Spectrum Sensing Analysis

A frame structure for analysis of heterogeneous traffic in CRNs, where data transmission and sensing are concurrent phenomena, is investigated in order to study the impact of inaccurate spectrum sensing. By taking state dependent transition rates into consideration [56]. And how the SU a occupied channel when it is idle or a primary user leaves the channel which analyze spectrum access and sensing mechanisms together as showing in Figure 2.7.

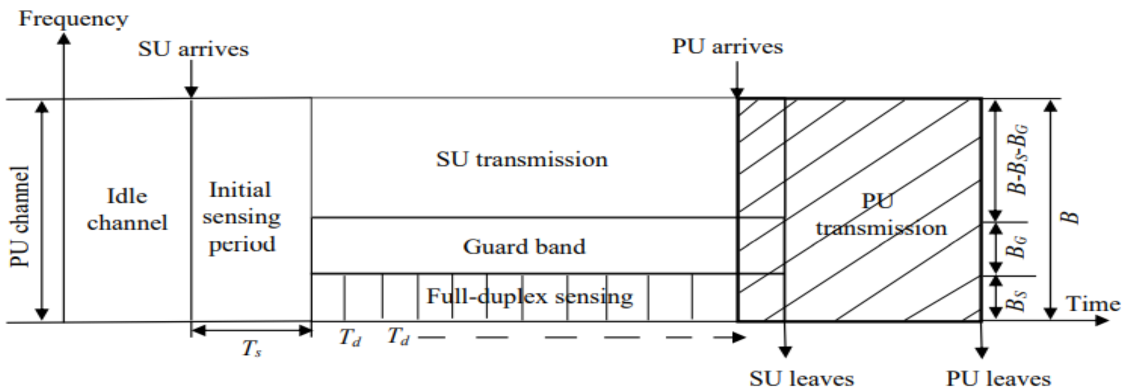


Figure 2.7: simulation sensing and data transmission [57].

2.7 Types of Hybrid Spectrum Sensing in Cognitive Network

Hybrid sensing is a compelling and effective way to overcome multipath fading and shadowing while also reducing receiver uncertainty. Hybrid sensing's major goal is to improve sensing performance by leveraging the spatial diversity of observations from spatially distributed CR users. CR users can exchange their sensing data in order to make a combined choice that is more accurate than individual ones [58]. The authors have created a hybrid spectrum sensing system that effective perceives the spectrum by combining a variety of spectrum sensing technologies in Figure (2.11). These hybrid techniques are summarized as follows:

1. Absolute Covariance Value, Energy Detection, and Cyclic Autocorrelation Function [59].
2. The Distributed Information SHaring (DISH) system is created using this as a base, the protocol VISH-I was created [60].
3. Detecting energy and cyclostationary [61].
4. Detection based on Max-Min Eigen values and energy detection [65].
5. A cooperative spectrum sensing method uses detectors based on energy and Eigen values [62].
6. Temperature-based detector, GLRT, Robust Estimator Correlator, Match Filter detector, Energy detector [63].
7. Combining conventional energy detection with the LRS-G2 likelihood ratio test statistic and artificial neural networks (ANN) [64].
8. Makes use of the Covariance Absolute Value (CAV) and Cyclic Autocorrelation Function (CAF) approach in addition to the energy

detection (ED) theory [65].

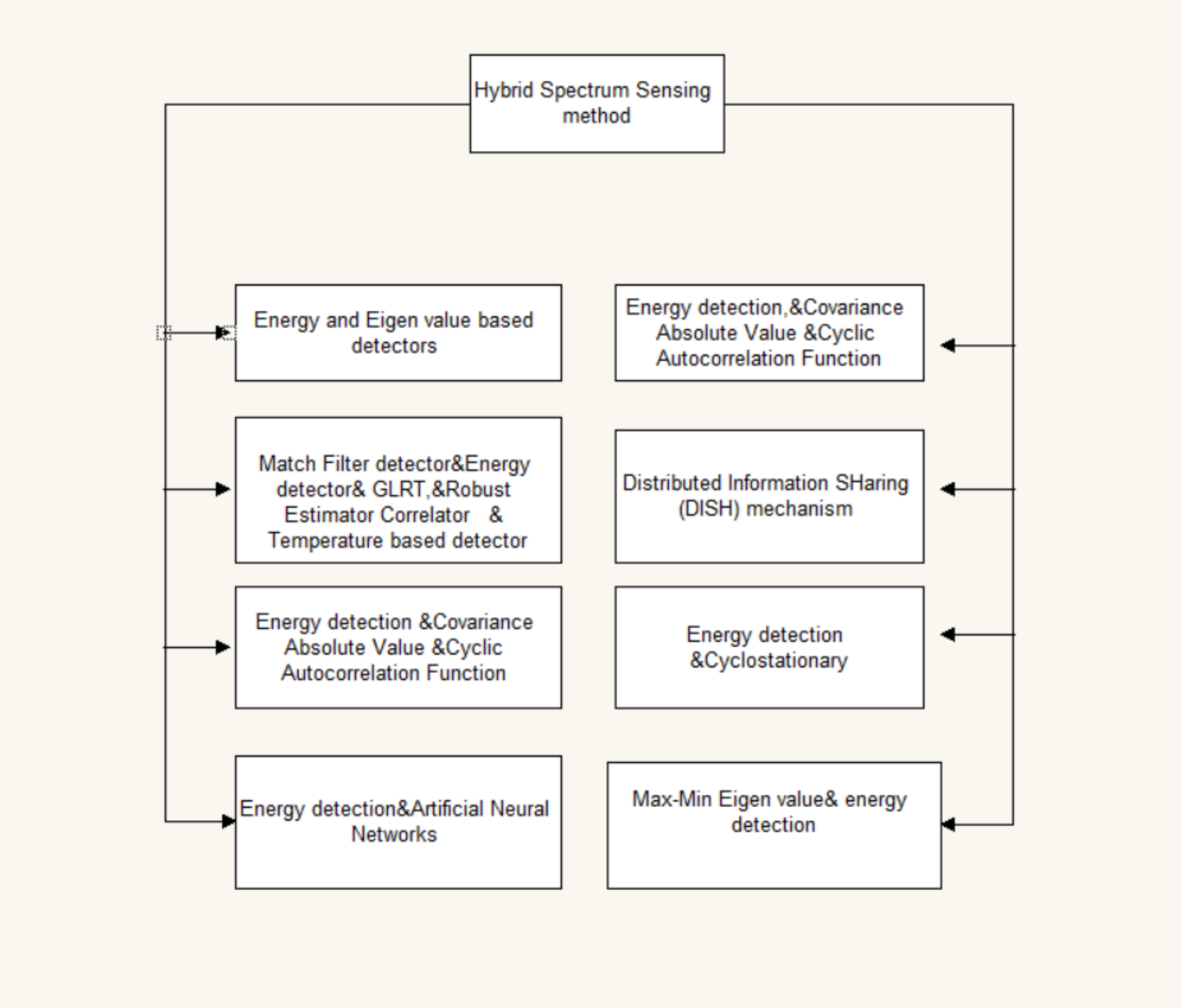


Figure 2.8: Hybrid Spectrum Sensing Method.

2.8 Eigen Value and Energy Detector in CRN

Techniques for detecting and the incoming signal is compared to a threshold established using attributes not dependent on the knowledge of the originating signal. The basic two technique are used in this research are explained in detail as flow:

2.8.1 Energy Detection

The most popular spectrum sensing method for figuring out if a PU signal is there requiring no knowledge of the primary user signals characteristics. It does this by using energy detection. Since there is no a priori requirement for the primary signal, energy detection is resistant to variations in the primary signal. The energy of a received signal is used in the energy detection technique, which is illustrated in Fig. 2.12, to detect a primary user signal. If the energy present is noticeably higher than just noise, a signal is detected as being present in the channel [66]. The unwanted signal from the undesirable frequency band is initially removed by the energy detector [67]. The signal energy is then calculated by squaring and adding the output samples from the filter. The output is then contrasted with a threshold k [68] to identify whether or not a licensed user is present.

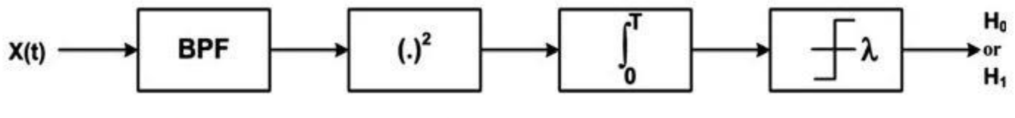


Figure 2.9: The method of energy detection

The simplest type of detection is energy detection. However, since the noise energy level is unknown, it is important to know it beforehand [69]. Additionally, energy detection has a low level of complexity that is particularly suited for wideband spectrum sensing and does not require complex signal processing. However, it is better to finish wideband spectrum sensing using the two steps below:

1) To look for potential empty sub-bands, low-complexity energy detection is used.
2) More complicated spectrum sensing methods are used for precise idle band identification since they have higher detection sensitivity [70].

A CRN also optimizes periodic sensing intervals and sensing times to increase cognitive user throughput or sensing accuracy. Sensing time affects the energy detector's effectiveness in terms of the likelihood of false alert and the likelihood of missed detection [71].

The following are some limitations of energy detection: Noise power can affect energy detection uncertainty; it requires prior awareness of noise power or a reliable estimate of it to achieve best performance; and dependable detection below a specific SNR is impossible due to noise level uncertainty. As a result, the energy detector is unable to differentiate between signals from the primary user, signals from the secondary user, and interference [72][73]. As a result, the performance of the energy detector largely depends on the precision and dependability of the noise level estimate [74].

2.8.2 Eigen Value

A technique based on auto-correlations or statistical covariances of the received signals. The test statistic is the highest eigenvalue of the sample covariance matrix. The suggested method is superior to energy detection for correlated signals because the covariance matrix captures the correlations between the signal samples. Since it includes energy detection as a specific case, the method is a generalization of that concept [75]. The threshold is determined and the procedure is examined using the random matrix theory. The techniques are similar to energy detection don't require any a priori knowledge of the signal or channel. No synchronization is also required. Three categories can be made for this strategy based on test statistics [76]:

- Test thesis data are defined as the ratio of the Max and Min Eigen values of the covariance matrix in the Max-Min Eigen value detection (MME) method [77].
- Test results data are defined as the ratio of the average received signal energy to the minimum Eigen value (EME).
- Max Eigen value detection (MED): Max Eigen value provides test statistics.

In this research (MED) is used and it will be explained barfly in next section

2.9 Cooperative Sensing Classification and Framework

It describes the cooperative sensing classification and framework.

2.9.1 Classifications of Cooperative Sensing

According to how CR users cooperative sharing the sensing data from the network, cooperative spectrum sensing may be divided into three categories:

centralized, distributed, and relay-assisted. These three cooperatives sensing approaches are displayed in Figure2.13 [78].

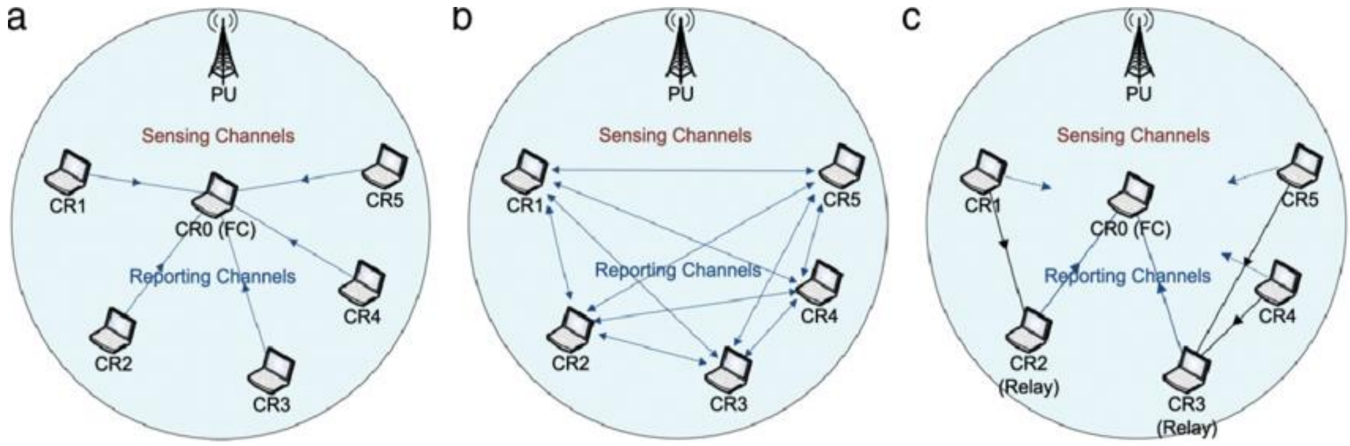


Figure 2.10: Three Types of Cooperative Sensing: (a) Centralized (b) Distributed and (c) Relay-assisted

A. Centralized Cooperative Sensing

The three-step procedure of cooperation of senses is managed by a central entity known as Fusion Center (FC). First, the FC chooses a frequency range or a channel that is suitable for sensing and orders each collaborating CR user to conduct local sensing independently. The findings of all collaborating CR users sensing are then reported over the control channel. In the third step, the FC aggregates the data from local sensing, identifies the existence of PUs, and then relays the decision to the cooperating CR users. According to Figure 2.13 (a), CR0 is the FC, and CR1–CR5 are working together as cooperative CR users to do local sensing and transmit their findings to CR0. A sensing channel is a physical point-to-point connection between the PU transmitter and each collaborating CR user for the purpose of viewing the primary signal. For local sensing, all CR users are set to the chosen licensed channel or frequency band. The control channel for data reporting is tuned to by all CR users, and a reporting channel a physical point-to-point connection between each participating CR user and the FC is used to deliver the sensing results [79].

B. Distributed Cooperative Sensing

It does not depend on an FC to decide cooperatively. In this instance, CR users converse with one another and eventually come to an agreement on whether there are PUs present or not through iterations. The distributed cooperation is depicted in Figure 2.13 (b). Following local sensing, users within the transmission range of CR1-CR5 exchange the local sensing findings with one another. Based on a uses distributed approach, each CR user sends its own sensing information to other users, mixes it with the sensing data received, and uses a local criterion to determine whether or not the PU is present [80].

C. Relay-assisted Cooperative Sensing

Due to the imperfection of both the sensing channel and the record channel, a CR user who observes a weakly sensing channel and a robust report channel, as well as a CR user who observes a strong sensing channel and a weak report channel, can cooperate and complement one another to enhance the rendering of cooperative sensing. In Figure 2.13 (c), CR1, CR4, and CR5 may have a weak report channel despite observing significant PU signals. Strong report channels on CR2 and CR3 allow them to act as relays to help the FC receive the sensing data from CR1, CR4, and CR5. The record channels from CR2 and CR3 to the FC in this situation are also referred to as relay channels [81].

2.9.2 Framework of Cooperative Sensing

The cooperative sensing framework is made up of the PUs, cooperating CR users, including a FC, all of the cooperative sensing components, the RF environment, which includes an optional remote database, licensed channels, and control channels. The centralized collaborative sensing architecture is depicted in figure 2.14 from the viewpoint of the physical layer [82].

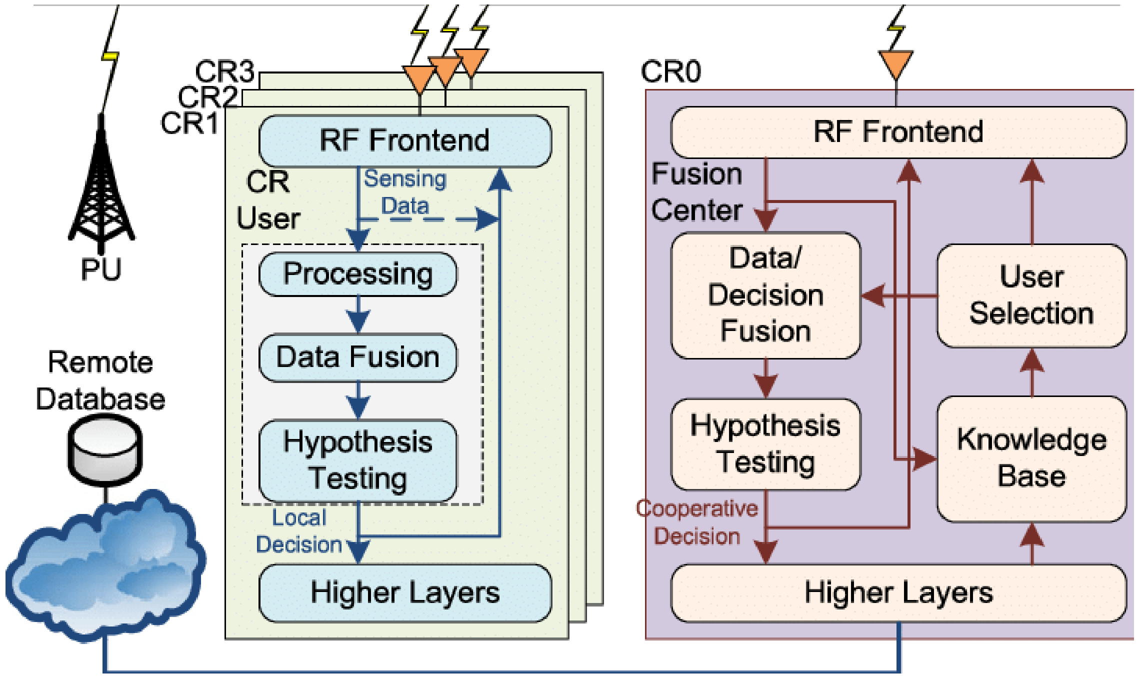


Figure2.11: Framework of Centralized Cooperative Sensing

With a local processing unit and an RF frontend, a group of cooperative CR users conducts local sensing in this architecture. RF frontend could be set up for spectrum detection or data transmission. RF frontend also incorporates an analog-to-digital converter (ADC) that down converts RF signals and samples data at a Nyquist rate. The FC may receive the raw sensing data from the RF frontend or may process it locally for local decision-making. Definite local processing is typically required to reduce the control channel's bandwidth requirement. The processing contains a threshold device for local decision-making as well as the calculation of test statistics. When the local decisions or the raw sensing data are prepared, a Medium Access Control (MAC) scheme is necessary to gain access to the control channel for reporting the sensing findings [83]. Additionally, higher network protocol levels may use the sensing results. For spectrum-aware routing selection, the higher layer of the network can also use the findings of the sensing [84].

2.10 Evaluation Metrics

- **Throughput (Kbps)**: frequently describe how much data the network can send in a given amount of time [85].

$$\textit{Throughput} = \frac{\textbf{Total Data signal(Kbps)}}{\textbf{Time}} \tag{2.3}$$

- **CR lifetime(ms)**: the duration of battery power before it ran out, directly affecting the freedom of the sensor node [86].

$$\textbf{lifetime} = 100 - Power\ consumption \tag{2.4}$$

- **Power consumption (mW)**: It measures the amount of energy used by each sensor node per unit of time [87].

$$\textbf{Power consumption} = total\ size * 0.35 \tag{2.5}$$

2.11 The proposed system message type

In the first Section of Packet, Spectrum Sensing in CR to determine idle proposed channel to transmission data messages and take consideration not harmful Primary user known as Global System for Mobile communication (GSM) then decide which channel free or busy. When the simulator starts, three values for the data type are entered as text, images, and files that will be considered as initial input state to the environment of the cognitive radio network:

2.11.1 Data message

It consists of the header segment bits define the basic feature of the frame, and payload segment (0 - 254 bytes) contains the main data. It consists from proposed components below and Figure (3.16) describes them:

Proposed channel: it represents which free channel used as idle channel to transmission messages.

Frame ID : it is designed as a slot position. The frame ID indicates the slot in which the frame should be transmitted. A frame ID is used no more than one time on each channel during one communication cycle. Each frame has a unique assigned frame ID corresponding with a unique slot. The frame ID ranges from 1 to 2047 (00000000001 to 11111111111), and the frame ID 0 is an invalid frame ID.

Data length: it is used to indicate the size of the Encapsulation Field. encapsulation Field size is encoded in this field by setting it to the number of encapsulation data bytes divided by two (data length x 2 = number of encapsulation data bytes).

Source (Src): it describes source MAC address.

Destination (Des): destination MAC address.

Control (Ctrl): it describes control information like in mac layer like RTS/CTS (Request to Send / Clear to Send) to reduce message collisions.

Data (Text, Image, Files):it specifies input keyword entered during initial simulation state for the used application.

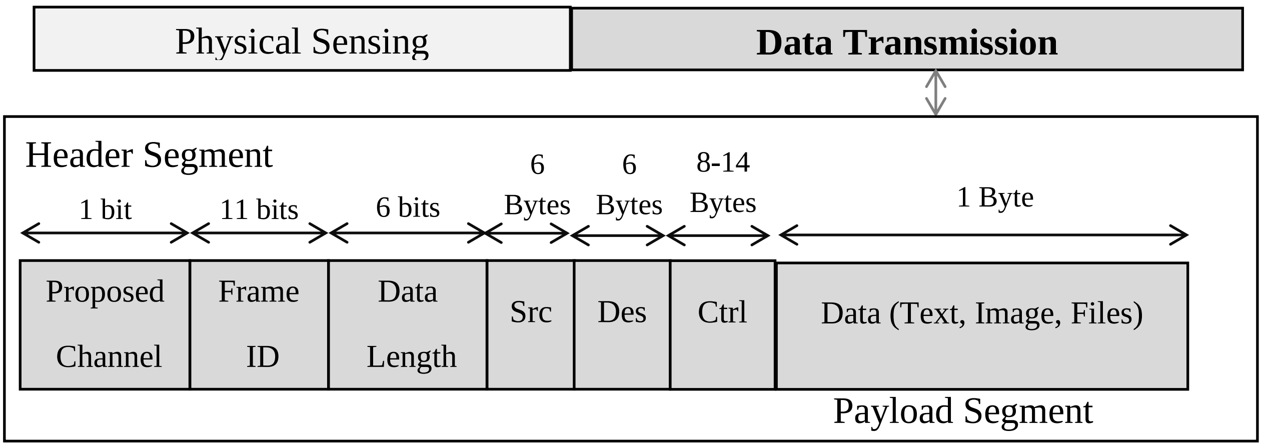


Figure (2.12) the proposed Data Frame Format.

2.11.2 The proposed Sensing Frames

RTS (Request to Send) & CTS (Clear to Send) frames are used to enhance the virtual carrier sense process. RTS/CTS is simulated to prevent collisions from occurring.

A. RTS (Request to Send) Frame

Format of a RTS frame. It is 14 Bytes in length. Each octet represented by (8 bits) as showing in Figure 3.17. The RTS frame contains three fields, which are:

1. Duration: 2 Bytes, including the time needed for the subsequent frames in the transmit operation to be transmitted.
2. RA (Receiver Address): 6 Bytes, Receiver Address indicating the MAC Address of the station that shall receive frame.
3. TA (Transmitter Address): 6 Bytes, Transmitter Address indicating the MAC address of the station which has transmitted frame.

Bytes: 2	6	6
Duration	RA	TA

MAC Header: Control Field

Figure (2.13) the proposed RTS Frame Format

B. CTS (Clear to Send) & Acknowledgement (ACK) Frames

Formats of RTS and ACK frames it shows in Figure 3.18 and Figure 3.19. It is 8 bytes in length for each frame.

1- Duration: 2 Bytes = 16 bits.

2- RA (Receiver Address): 6 Bytes = 48 bits.

Bytes:	2	6
	Duration	RA

MAC Header: Control Field

Figure (2.14) the proposed CTS Frame Format

Acknowledgement frame send to transmitter to confirming the data frame received by receiver node. As duration always set to 0. It is worth noting to the field (Duration) just within (ACK) frame. It always set to zero in order to represent the next frame request.

Bytes:	2	6
	Duration	RA

Figure (2.15) the proposed Acknowledgement Frame Format

2.12 Simulation tools

The following are examples of common simulation tools: There are several tools and programming languages that can be used to emulate the cognitive radio networks.

A. ***MATLAB:*** is a high-level technical programming language. MATLAB also provides powerful data structures, integrated edit and debugging tools, and object-based programming capabilities. This software can simulate various cooperative sensing approach. For spectrum sensing simulation purposes, the toolbox in MATLAB and Simulink is crucial. It was created and distributed by numerous research experts and business developers [88].

B. ***NS2:*** It's an event-driven open-source simulation program for use in research into computer networks for communication. NS2 now provides modules for a variety of network elements, including routing, transportation layer protocol, and application, after years of constant investigation and improvement. Of fact, NS2 has been the most popular network simulator available for free as well as is among the most popular network simulation programs [89].

C. ***Monte Carlo:*** It uses a probability distribution strategy to deal with a number of dependent variables. employed in many modules in cognitive radio networks, such as cooperative spectrum sensing in CRNs. Additionally, another study improved sensing and improved detection probability for a specified Signal to Noise Ratio (SNR) in CRN [90].

D. ***OMNeT++:*** It is free software and licensed under the Academic General Licence as non-commercial software. The goal of OMNeT++ was to create a comprehensive, tool for free discrete event simulation that could be used to model computer networks and distributed systems or parallel systems by academic, educational, and research organizations. OMNeT++ aims to bridge the gap between free simulation tools like NS-2 and expensive business solutions like OPNET. GCC Toolchain or Microsoft Visual++ are required to run OMNeT++ on all popular systems, inclusive Linux, Mac OS/X, and Windows. Compilers are required. The framework approach is represented by OMNeT++. Instead of directly offering the components for the simulation in computer networks, queuing networks, or other domain systems, it provides the essential machinery and equipment for such simulations [91].

All of the simulations in this thesis have been implemented using the simulation program OMNET++. Choosing OMNET ++ because it has a Graphical User Interface (GUI) for Windows that is simple to use (Tkenv). This GUI offers various execution, debugging, and tracing options.

1. It is advised throughout the main development simulation stage because it enables the user to have a thorough understanding of the simulation's status at any level of the execution timeline [92].
2. It is a modular system containing various (Frameworks, Libraries, Models, etc.) that helps researchers conduct research simulations that are accurate to real situations with less time and effort.
3. observing what occurs within the network.
4. The flexibility of learning where the C ++ programming language is concerned.
5. The absence of installation conditions in the Windows operating system. The primary-secondary user model, where primary users serve as a base station and secondary users serve as transmitters, is the basis for all communication, according to the general network architecture of the Cognitive Radio Network.

It takes many steps to create and run C++ code in the Omnet++ simulator, which is based on many simulation settings that are drawn from various header, source, initial, and supporting files for core messages and network descriptive files.

Additionally, there are a variety of simulation tools available for use in cognitive radio networks, including J-Sim, NetSIm, Qualnet, COOJA, and others. For example, there are research directions regarding the first layers of communication (Physical layer, data link layer), and others regarding the routing features as the network layer, etc. There are various simulation tools because there are many research directions on various parts of the network and even at the level of application of the network. Additionally, the variety of cognitive network applications led to a variety of CRN simulators and programming languages that are used as application tools [93]. Table 2.1 lists the main programming language and general simulation tools that can be used to create a cognitive radio network.

Table 2-1: Spectrum Sensing for Cognitive Radio Network Simulation tools and Official Websites

Simulation-Tool	**Core programming language**	**Official-Website**	**Benefit &limitation**	**License**
MATLAB	C, C++, C#, Java, Fortran and Python	https://www.mathworks.com/	• Ease of Use • Platform Independence • execute more slowly than compiled language • high cost	• Licensed
NS_2	OTcl, C++	https://www.isi.edu/nsnam/ns/	• Real system too complex to model • Bugs are unreliable • Cheap- Does not require costly equipment • Results can be quickly obtained	• Open-source software
NS_3	Python, C++	https://www.nsnam.org/	• provides a lower base level of abstraction • actively maintained with an active, responsive user's mailing list	• Open-source software
OMNeT++	C++, Java, C#, NED	https://omnetpp.org/	• Dynamic behavior of software systems • Other than C++ programming languages can be	• open-source

			mapped to Simulation Library API. • Widely used network simulator • The graphic editor supports parametric topologies.	
OPNET	C, C++	www.opnet.com	• The topology of OPNET models is always static. • It can be challenging to programmatically generate OPNET models. OMNeT++ models are straightforward text files that may be generated, whereas it requires building a C program that leverages an OPNET API.	• open free software
MONTE CARLO	JavaMonte	http://www.goldsim.com/Home/	• It offers a clearer picture than a deterministic forecast • Computationally inefficient when you have a large amount of variables	• open-source software

COOJA	Java/C	http://www.contiki-os.org/	• allows the large and small networks to be simulated • open-source network simulator.	• open-source software
J-Sim	Java	https://www.physiome.org/jsim/	• easer and simpler to apply • higher cost • more difficult compere to other simulation	• free software

Chapter Three

The Proposed System

3.1 Overview

This chapter explains the main steps of the proposed system. It shows the network architecture, network elements, and network layers. Explains and manages the eigen value approach, and how the proposed system organizes the sensing approach depending on the used methodology.

3.2 The proposed System

The proposed system is based on enhancing sensing approach in CR by implementing eigen value model in intermediate device as fusion center to decrease number of sensing messages from secondary users. The used CR nodes are dynamically used the spectrum and it considered as a contemporary approach to improve spectrum utilization in the wireless environment. A general wireless communication technique that is conscious of its surroundings is applied. Additionally, it chooses the best idle available channel. The CR applies the methodology of understanding and learning/discovering from the environment to specific parameters.

In this thesis, a technique to improve spectrum sensing in CR is proposed through cooperative manner by achievement:

1) Energy detection as a method of sensing, detect the existence of PU.
2) Enhancing Cooperative Cognitive Radio (CCR) using key simulation parameters like the (Throughput, Power consumption, and CR life Time).
3) Eigen value model in Fusion Center is applied as the identifier of appearance of primary users, and the proposed model in fusion center continuously matching the incoming signals of primary users with the current state of signals to determine PU is idle or not.

The OMNET++ built in C++ programming language is used to run all simulations components.

The general steps for simulation process are described in Figure (3.1):

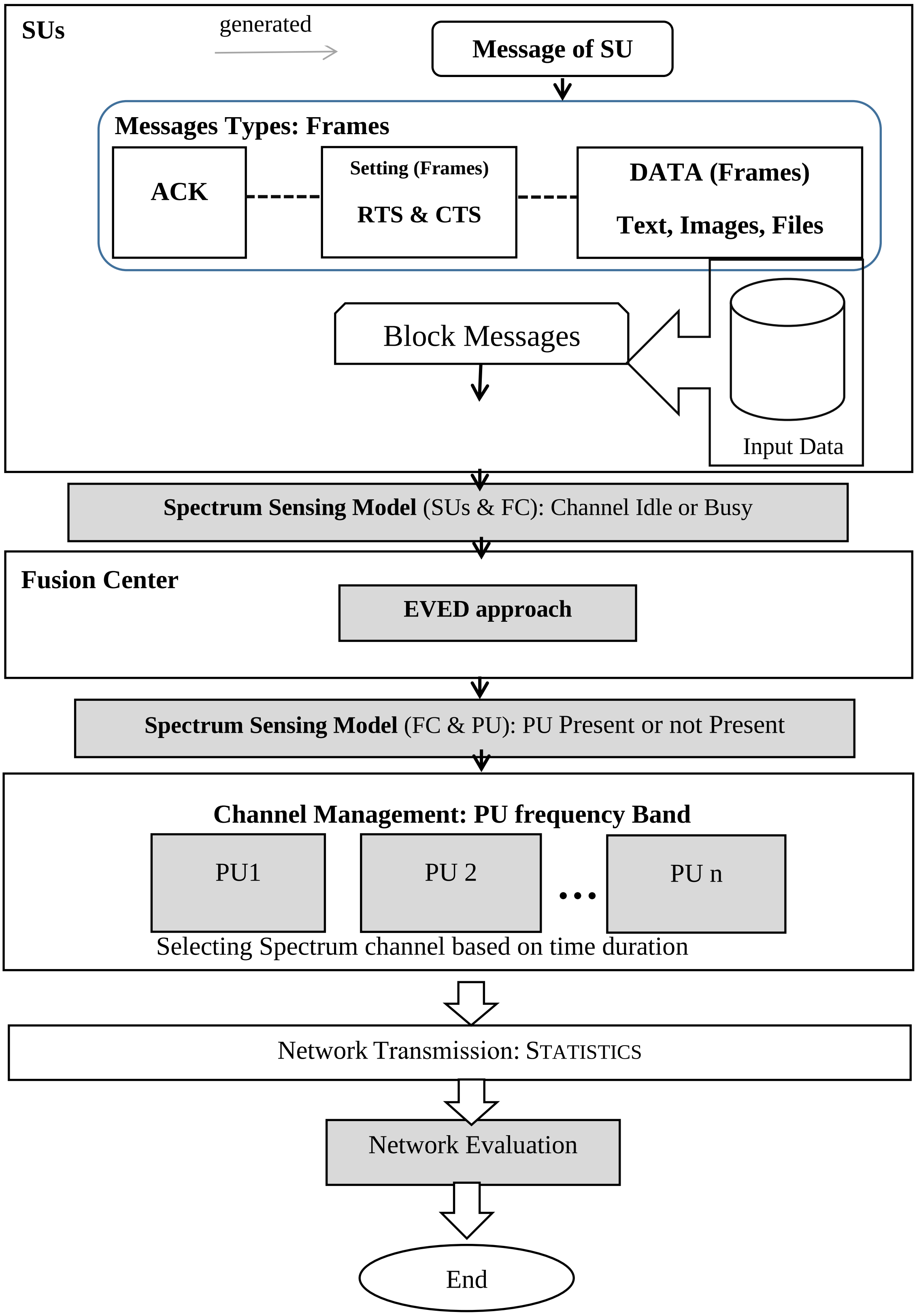


Figure (3.1) The proposed message signals Scheme Block Diagram.

In the initial state of building the proposed model in Figure (3.1) the following steps are summarized:

1) SUs: generate three main types of messages as ACK (acknowledgement message), (Request to send (RTS) and CTS (clear to send) as setting message for sensing information), and Data messages signals as Text string messages, Images, and Files with different size of files. These signals are passed to the Fusion center and fusion center redirect setting signals to determine the appearance of primary users or not.
2) Fusion center: it contains the sensing model approach to pass sensing information in two manners:
   - Idle or busy state information signals between SU and FC.
   - Present or absent state information signals between FC and PU.

   Fusion Center Input: represents sensing information from both PU, and SU, also used as pipeline to pass configuration or changed signals information.

   Fusion Center Output: process to determine which primary channel is idle channel from connected PU channels.
3) PU: licensed user to provide cognitive network with channel resources to increase bandwidth of radio spectrum in cognitive radio network.

3.3 The proposed Cooperative Sensing model in Cognitive Radio Networks

The proposed cooperative sensing model in CR is implemented in FC elements as an intermediate network element to control sensing packets exchanged among SU to PU. FC decreased number of sensing messages which affects the network performance especially throughput and exhausted secondary user lifetime. It important to notify that there are three main messages packets, the first is sensing messages it is the main focus of the proposed system, the second is the data messages which it is generated as text message, and the third is the setting (configuration messages) as acknowledgement, time synchronizing messages, and network settings messages as signaling messages to pass packets, frames, and bits from lower layer to upper layer and vice versa.

3.3.1 Fusion Schemes for Cooperative Spectrum Sensing

Given that the solutions provided are based on (Information) data form, "Cognitive Radio Network's" design is exactly like additional wireless networks that broadcast and receive data using the five transmission layers as well as other data types including text, image, and files. Each concept will be represented by an OMNET++ simulation-influenced C++ module.

The used method based on studying the functional aspects of each of these modules as C++ code using the assumptions it made during the development of each component.

This approach is explaining the two techniques the eigen value and energy detector process as showing in Figure (3.12).

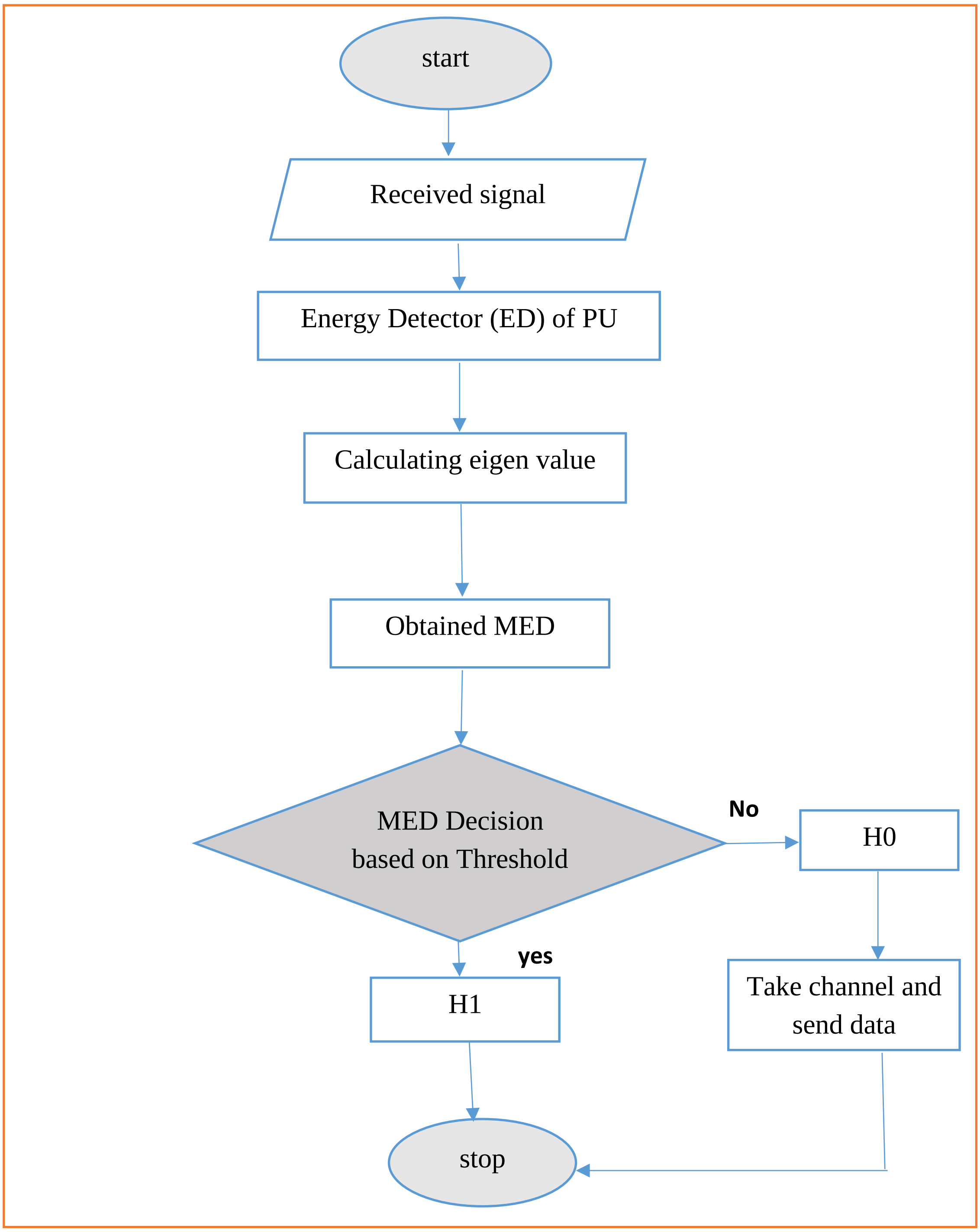


Figure3.2 Hybrid spectrum sensing approach

Figure 3.11 shows the used spectrum sensing approach with Eigen value method with the following steps:

1) When spectrum sensing information coming from PU to the FC, the Fusion center is identifying the idle channel to use by secondary user depending

on energy detector model and calculate eigen value for incoming signals with the condition:

- If incoming signal value is greater than or equal to stored value it will broadcast busy channel information with number of busy PU channel to pass to all SU nodes to leave this channel and change the used channel for another channel.
- If incoming signal value is less than the threshold value or stored value, the FC will broadcast idle channel as the same channel still used by SU for specific time duration until it notifies as busy.

2) When channel allocation is changed state, the FU is sent broadcast signals to all SU nodes. This procedure is repeated while network connection established.

For signal detection, two hypotheses can be formulated: (1) hypothesis H0: there exists no signal (only noise); (2) hypothesis H1: there exists both the signal and additive white noise. The binary hypothesis test can be replaced by:

H0: $x(n) = w(n), n = 0, 1, N$ (3.1)

H1: $x(n) = Xh(k)s(n - k) + w(n)$ (3.2)

$k=0$

Where *x(n)* denotes the discrete signal at the secondary receiver, *s(n)* is the primary signal seen at the receiver,

Xh(k) is the channel response, *N* is the order of the channel, and *w(n)* are the noise samples.

Chapter Four

Simulation, Results, and Discussion

4.1 Introduction

This chapter introduces the simulation and discussion of results for the proposed hybrid spectrum sensing in CR presented in chapter three. It simulated using OMNET++ built in C++ programming language to implement the network performance in adaptive way to be equivalent for both CRN elements in the cognitive radio channel without interference of secondary user to primary user.

The table below 4.1 shows the used omnet++ version and its installation requirements and the pc specifications used through the application of the proposed system.

Table 4.1: The used installation requirement.

<table>
<tr><th>Tools</th><th>Installation Requirements</th><th>Goal of using the tool</th></tr>
<tr><td>Omnet++ 4.6</td><td>1. Windows 10 (32-bit or 64-bit)
2. 1 GB (32-bit) or 2 GB (64-bit) RAM</td><td rowspan="2">Simulating the proposed development hybrid spectrum sensing approach in CRNs.</td></tr>
<tr><td>Used PC</td><td>1. Windows 10 Pro (64-bit) RAM 16 GB,
11th Gen Intel(R) Core (TM) i7-1165G7</td></tr>
</table>

The used system describes a developed hybrid spectrum sensing method for CR in OMNET++. All of the used CRNs components in the proposed regions contain (2,4,6,8) secondary user's nodes and (4,8,12,16) Primary users as shown in Table 4.2.

Table 4.2: The used CRNs Elements.

CRN Elements				
SUs Nodes	2 CRs	4 CRs	6 CRs	8 CRs
PU Nodes	4PU	8 PU	12PU	16 PU

Besides, the main simulation parameters are showing in Table 4.3:

Table 4.3: The main simulation parameters for the all-case studies.

Parameters	**Value**
Simulation Time	5 minutes = 300 seconds
Total Frames	2028
Sensing interval	0.05 millisecond
Proposed Channel	4,8,12,16
Number of nodes	2 SU, 4 SU, 6 SU, 8SU, 4 PU,8 PU, 12PU,16PU, FC
Number of Cluster	1 cluster
MAC Layer	802.11b standard
Data Type	Image, Document files
Sensing signal size	256 Bytes
Data signal size	Document file = 100 Bytes
Image size	Image file = 60 Bytes
Ack signal size	32 Bytes

The proposed system results based on the two main case studies as:

4.2 Cooperative Spectrum Sensing Without Fusion Center (FC)

4.2.1 The 1st case study

The first state of the 2 CR (secondary user) nodes simulated with 4 PU and the evaluation parameters based on the different variables. The sensing signals details shown in Table 4.4.

Table 4.4: the Sensing signals details of the 2 CR nodes.

No. of Sensing signal		Size of each signal	Total size	Total Average
CR1	217	256 Bytes	55552	56320 Bytes
CR2	223		57088	

While the data signals details shown in Table 4.5.

Table 4.5: the data signals with total size in Bytes.

No. of Data signal		Size of each signal in Bytes	Total size	Total Average
CR1	157	100	15700	12800 Bytes
CR2	165	60	9900	

Besides, the Acknowledgement signals shown in Table 4.6.

Table 4.6: The Ack signals of the 2 CR nodes.

No. of Ack signal		**Size of each signal**	**Total size**	**Total Average**
CR1	116	32 Bytes	3712	3888 Bytes
CR2	127		4064	

Table 4.7 is showing the total sensing signal, total data signal, total ACK signals with the summation, total size in Kbps, the Summation in Bytes and total size for 2 CR signals

Table 4.7: Summation and total size for 2 CR signals.

Active CR Nodes	**Total Sensing signal with size**	**Total Data signal with size**	**Total Ack signal with size**	**Summation In Byte**	**Total size in Kbps**
CR1	55552	15700	3712	74964	73.20703
CR2	57088	9900	4064	71052	69.38672

Table 4.8: Throughput for the data signals of 2 CR nodes.

Active CR Nodes	**Total Data signal with size**	**Total size in Kbps**	**Throughput in Kbps**
CR1	15700	15.33203	0.051107
CR2	9900	9.667969	0.032227
Total Throughput in Kbps	0.083333 **Kbps =** 83.333 **Bps**		

Besides, Table 4.10, and Figure 4.1 is showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.9: Power Consumption and CR Life Time of 2 CR case.

Active CR Nodes	**Total size in Kbps**	**Power Consumption**	**CR Life Time**
CR1	73.20703	25.9885	74.0115
CR2	69.38672	24.63229	75.36771

As a result of the total size calculation (data, sensing and acknowledge) for 2 CR and recognize the power consumption and CR life time the figure 4.1 shows explanation chart of these results.

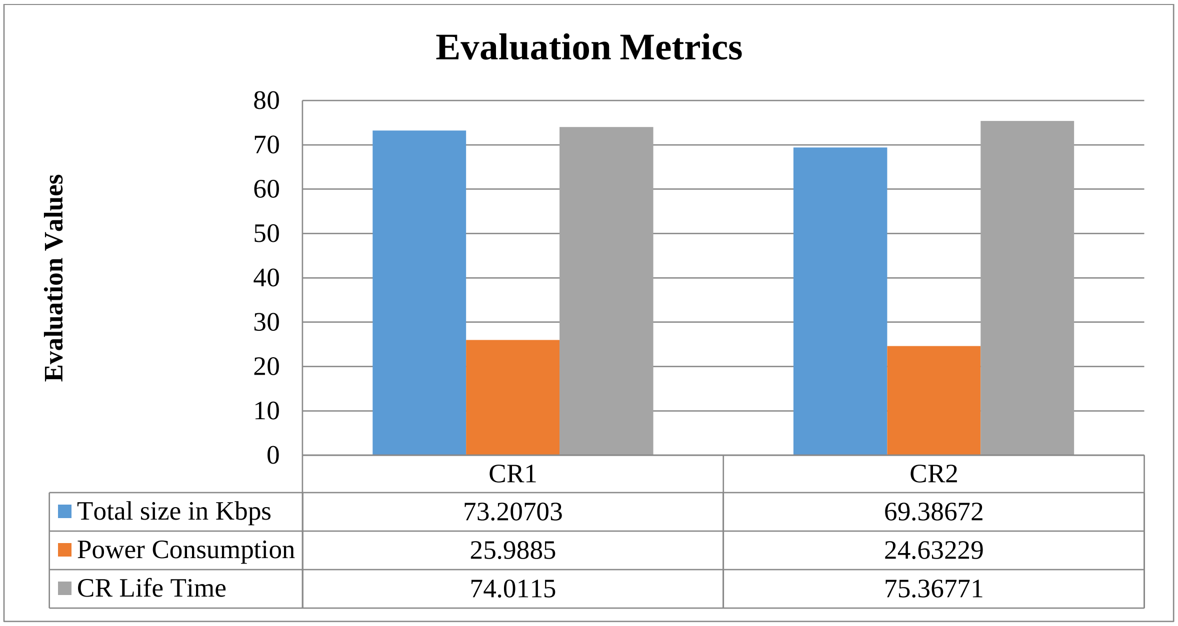


Figure 4.1: Power Consumption and CR Life Time of 2 CR nodes.

And Figure 4.2 is showing the implementation of this case.

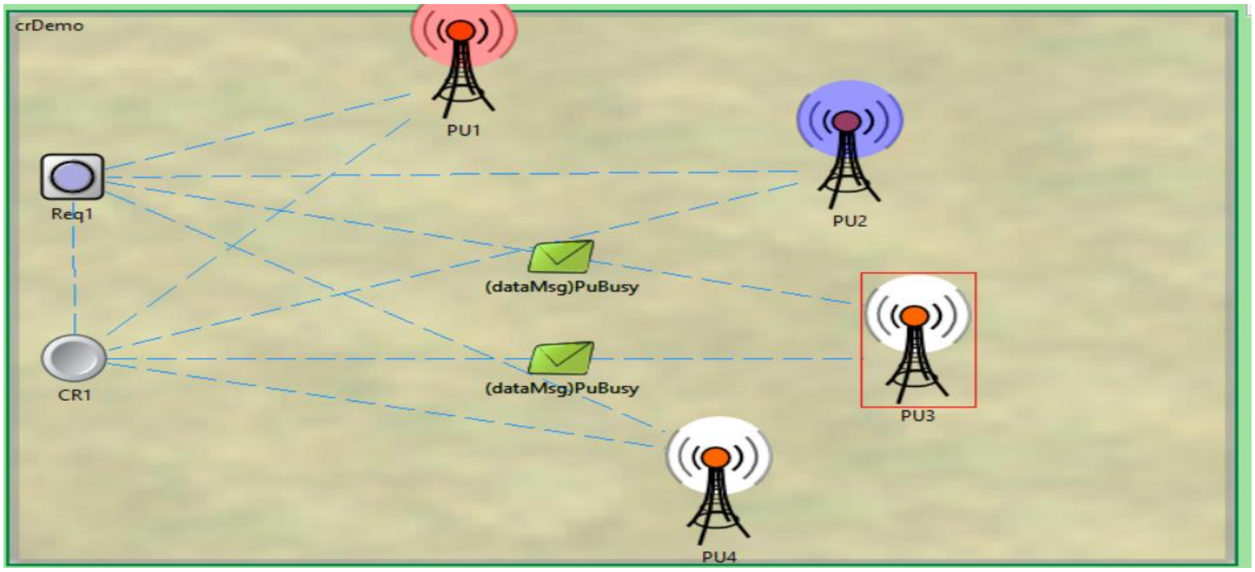


Figure 2.4 The case of 2 Cognitive Radio Nodes

4.2.2 The 2nd case study

The first state of the 4 CR nodes simulated with 8 PU and the evaluation parameters based on the different variables. The sensing signals details shown in Table 4.10.

Table 4.10: the Sensing signals details of the 4 CR nodes.

No. of Sensing signal		Size of each signal	Total size	Total Average
CR1	85	256 Bytes	21760	18496 Bytes
CR2	69		17664	
CR3	72		18432	
CR4	63		16128	

While the data signals details shown in Table 4.11.

Table 4.11: the data signals with total size in Bytes.

No. of Data signal		**Size of each signal in Bytes**	**Total size**	**Total Average**
CR1	61	60	3660	4345 Bytes
CR2	57	60	3420	
CR3	54	100	5400	
CR4	49	100	4900	

Besides, the Acknowledgement signals shown in Table 4.12.

Table 4.12: The Ack signals of the 4 CR nodes.

No. of Ack signal		**Size of each signal**	**Total size**	**Total Average**
CR1	45	32 Bytes	1440	1304 Bytes
CR2	42		1344	
CR3	40		1280	
CR4	36		1152	

Table 4. 8 is shown the total sensing, data, ACK signals with the summation and total size in Kbps.

Table 4.13: Summation and total size for 4 CR signals.

Active CR Nodes	**Total Sensing signal with size**	**Total Data signal with size**	**Total Ack signal with size**	**Summation In Byte**	**Total size in Kbps**
CR1	21760	3660	1440	26860	26.23047
CR2	17664	3420	1344	22428	21.90234
CR3	18432	5400	1280	25112	24.52344
CR4	16128	4900	1152	22180	21.66016

Table 4.14: Throughput for the data signals of 4 CR nodes.

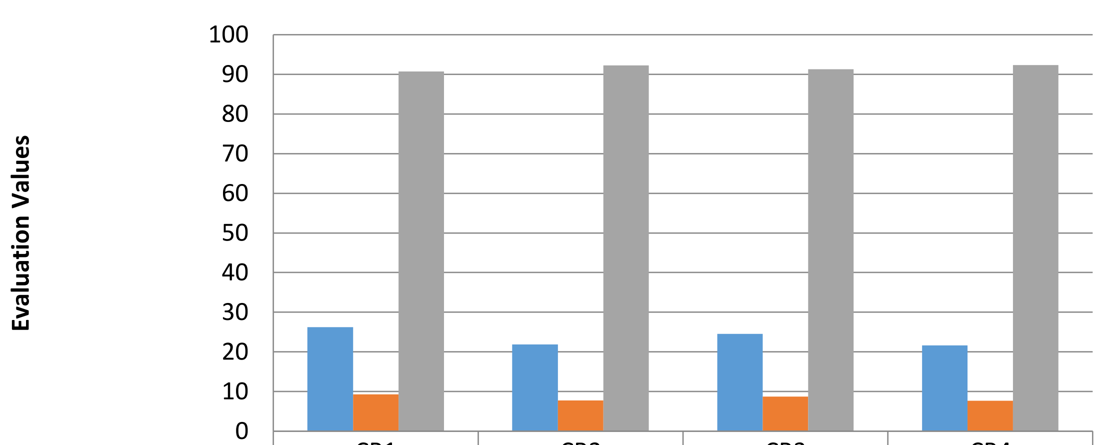
Active CR Nodes	**Total Data signal with size**	**Total size in Kbps**	**Throughput in Kbps**
CR1	3660	3.574219	0.011914
CR2	3420	3.339844	0.011133
CR3	5400	5.273438	0.017578
CR4	4900	4.785156	0.015951
Total Throughput in Kbps	**0.056576 Kbps = 56.576 Bps**		

Besides, Table 4.15, and Figure 4.3 is showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.15: Power Consumption and CR Life Time of 4 CR case.

Active CR Nodes	**Total size in Kbps**	**Power Consumption**	**CR Life Time**
CR1	26.23047	9.311817	90.68818
CR2	21.90234	7.775331	92.22467
CR3	24.52344	8.705821	91.29418
CR4	21.66016	7.689357	92.31064

As a result of the total size calculation (data, sensing and acknowledge) for 4 CR and recognize the power consumption and CR life time the figure 4.3 shows explanation chart of these results.



	CR1	CR2	CR3	CR4
Total size in Kbps	26.23047	21.90234	24.52344	21.66016
Power Consumption	9.311817	7.775331	8.705821	7.689357
CR Life Time	90.68818	92.22467	91.29418	92.31064

Figure 4.3: Power Consumption and CR Life Time of 4 CR nodes.

The implementation process of this case in Omnet++ shown in Figure 4.4.

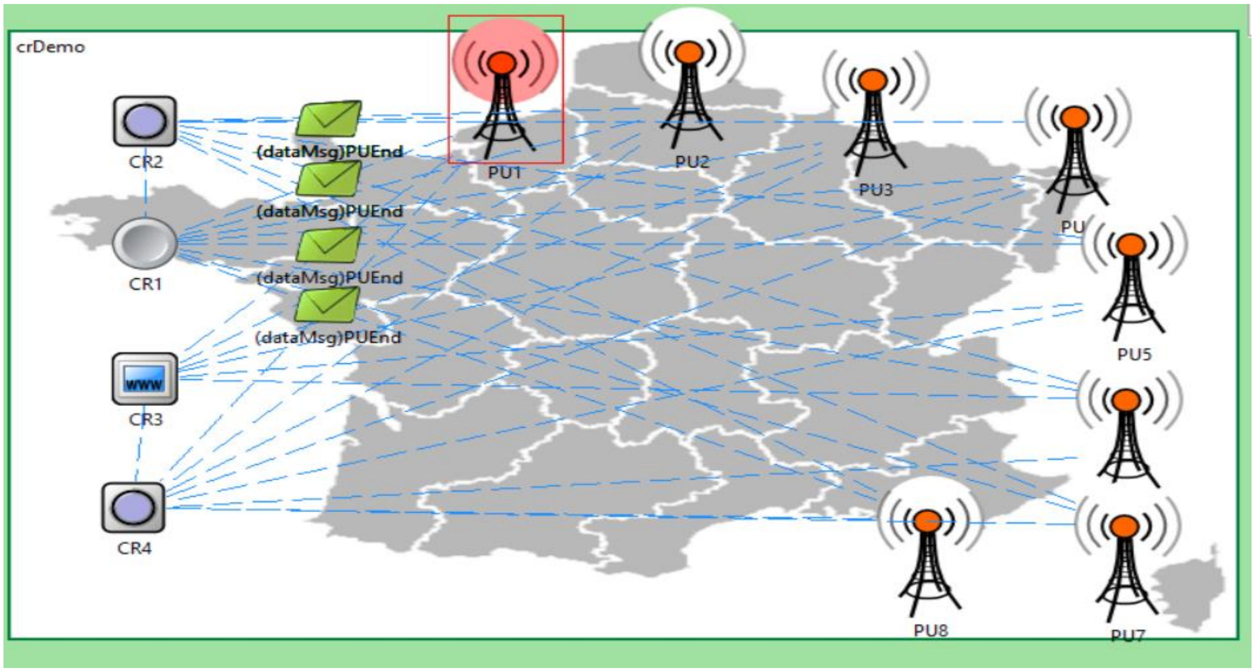


Figure 4.4 The case of 4 Cognitive Radio Nodes.

4.2.3 The 3rd case study

The third state of the 6 CR nodes simulated with 12 PU and the evaluation parameters based on the different variables, as the sensing signals details shown in Table 4.16.

Table 4.16: the Sensing signals details of the 6 CR nodes.

<table>
<tr><th colspan="2">No. of Sensing signal</th><th>Size of each signal</th><th>Total size</th><th>Total Average</th></tr>
<tr><td>CR1</td><td>63</td><td rowspan="6">256 Bytes</td><td>16128</td><td rowspan="6">7594.667
Bytes</td></tr>
<tr><td>CR2</td><td>27</td><td>6912</td></tr>
<tr><td>CR3</td><td>22</td><td>5632</td></tr>
<tr><td>CR4</td><td>16</td><td>4096</td></tr>
<tr><td>CR5</td><td>14</td><td>3584</td></tr>
<tr><td>CR6</td><td>36</td><td>9216</td></tr>
</table>

While the data signals details shown in Table 4.17.

Table 4.17: the data signals with total size in Bytes.

No. of Data signal		Size of each signal	Total size	Total Average
CR1	33	60 Bytes	1980	1453.333 Bytes
CR2	21		1260	
CR3	20		1200	
CR4	13		780	
CR5	11	100 bytes	1100	
CR6	24		2400	

Besides, the Acknowledgement signals shown in Table 4.18.

Table 4.18: The Ack signals of the 6 CR nodes.

No. of Ack signal		Size of each signal	Total size	Total Average
CR1	28	32 Bytes	896	949.3333 Bytes
CR2	19		608	
CR3	17		544	
CR4	11		352	
CR5	9		288	
CR6	20		640	

Table 4. 19 is showing the total sensing, data, Ack signals with the summation and total size in Kbps.

Table 4.19: Summation and total size for 6 CR signals.

Active CR Nodes	Total Sensing signal with size	Total Data signal with size	Total Ack signal with size	Summation	Total size in Kbps
CR1	16128	1980	896	19004	18.55859
CR2	6912	1260	608	8780	8.574219
CR3	5632	1200	544	7376	7.203125
CR4	4096	780	352	5228	5.105469
CR5	3584	1100	288	4972	4.855469
CR6	9216	2400	640	12256	11.96875

While table 4.20 is showing the data signals converted from Bytes to Kilobits and find throughput.

Table 4.20: Throughput for the data signals of 6 CR nodes.

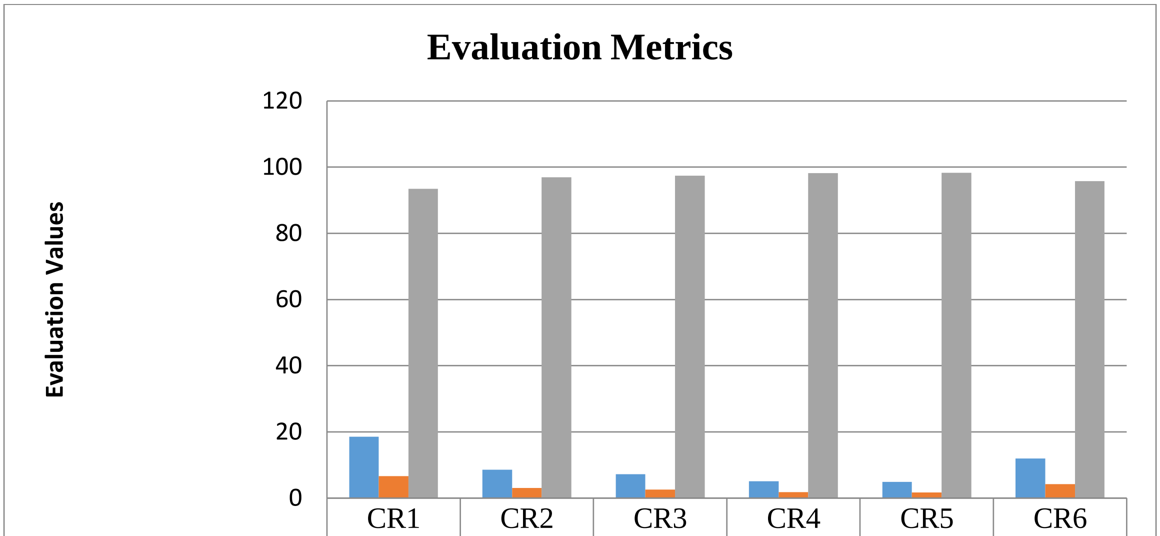
Active CR Nodes	Total Data signal with size	Total size in Kbps	Throughput in Kbps
CR1	1980	1.933594	0.006445
CR2	1260	1.230469	0.004102
CR3	1200	1.171875	0.003906
CR4	780	0.761719	0.002539
CR5	1100	1.074219	0.003581
CR6	2400	2.34375	0.007813
Total Throughput in Kbps	**0.028385 in Kbps = 29.06667 Bps**		

Besides, Table 4.21, and Figure 4.5 is showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.21: Power Consumption and CR Life Time of 6 CR case.

Active CR Nodes	**Total size in Kbps**	**Power Consumption**	**CR Life Time**
CR1	18.55859	6.588299	93.4117
CR2	8.574219	3.043848	96.95615
CR3	7.203125	2.557109	97.44289
CR4	5.105469	1.812441	98.18756
CR5	4.855469	1.723691	98.27631
CR6	11.96875	4.248906	95.75109

As a result of the total size calculation (data, sensing and acknowledge) for 6 CR and recognize the power consumption and CR life time the figure 4.5 shows explanation chart of these results.



	CR1	CR2	CR3	CR4	CR5	CR6
Total size in Kbps	18.55859	8.574219	7.203125	5.105469	4.855469	11.96875
Power Consumption	6.588299	3.043848	2.557109	1.812441	1.723691	4.248906
CR Life Time	93.4117	96.95615	97.44289	98.18756	98.27631	95.75109

Figure 4.5: Power Consumption and CR Life Time of 6 CR nodes.

The topology implementation of this case shown in Figure 4.6.

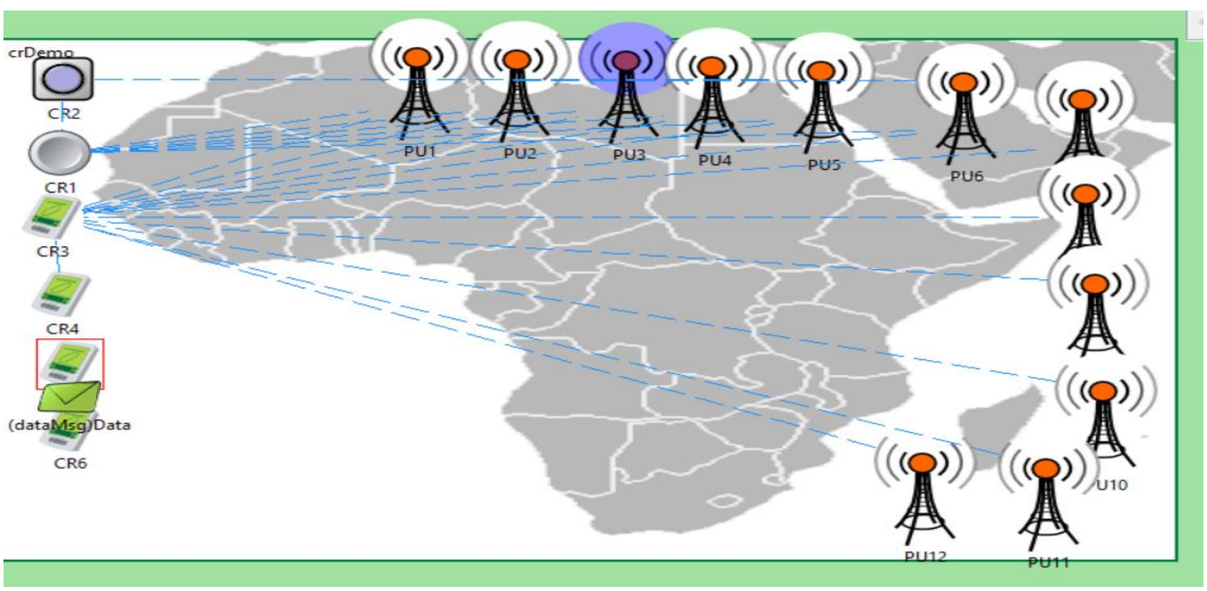


Figure 4.6 The case of 6 Cognitive Radio Nodes.

4.2.4 The 4th case study

The fourth state of the 8 CR nodes simulated with 16 PU and the evaluation parameters based on the different variables, as the topology shown in Appendix C. The sensing signals details shown in Table 4.22.

Table 4.22: the Sensing signals details of the 8 CR nodes.

No. of Sensing signal		Size of each signal	Total size	Total Average
CR1	37	256 Bytes	9472	4416 Bytes
CR2	18		4608	
CR3	15		3840	
CR4	11		2816	
CR5	9		2304	
CR6	20		5120	
CR7	11		2816	
CR8	17		4352	

While the data signals details shown in Table 4.23.

Table 4.23: the data signals with total size in Bytes.

No. of Data signal		**Size of each signal**	**Total size**	**Total Average**
CR1	25	60 Bytes	1500	990 Bytes
CR2	14		840	
CR3	11		660	
CR4	12		720	
CR5	8	100 bytes	800	
CR6	14		1400	
CR7	9		900	
CR8	11		1100	

Besides, the Acknowledgement signals shown in Table 4.24.

Table 4.24: The Ack signals of the 8 CR nodes.

No. of Ack signal		Size of each signal	Total size	Total Average
CR1	18	32 Bytes	576	332 Bytes
CR2	11		352	
CR3	9		288	
CR4	10		320	
CR5	7		224	
CR6	11		352	
CR7	8		256	
CR8	9		288	

Table 4. 25 is showing the total sensing, data, Ack signals with the summation and total size in Kbps.

Table 4.25: Summation and total size for 8 CR signals.

Active CR Nodes	**Total Sensing signal with size**	**Total Data signal with size**	**Total Ack signal with size**	**Summation In Byte**	**Total size in Kbps**
CR1	9472	1500	576	11548	11.27734
CR2	4608	840	352	5800	5.664063
CR3	3840	660	288	4788	4.675781
CR4	2816	720	320	3856	3.765625
CR5	2304	800	224	3328	3.25
CR6	5120	1400	352	6872	6.710938
CR7	2816	900	256	3972	3.878906
CR8	4352	1100	288	5740	5.605469

While table 4.26 is showing the data signals convert from Byte to Kilobits and find throughput.

Table 4.26: Throughput for the data signals of 8 CR nodes.

Active CR Nodes	**Total Data signal with size**	**Total size in Kbps**	**Throughput in Kbps**
CR1	1500	1.464844	0.004883
CR2	840	0.820313	0.002734
CR3	660	0.644531	0.002148
CR4	720	0.703125	0.002344
CR5	800	0.78125	0.002604
CR6	1400	1.367188	0.004557
CR7	900	0.878906	0.00293
CR8	1100	1.074219	0.003581
Throughput in Kbps	**0.025781 Kbps = 26.4 Bps**		

Besides, Table 4.27, and Figure 4.7 are showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.27: Power Consumption and CR Life Time of 8 CR case.

Active CR Nodes	Total size in Kbps	Power Consumption	CR Life Time
CR1	11.27734	4.003456	95.99654
CR2	5.664063	2.010742	97.98926
CR3	4.675781	1.659902	98.3401
CR4	3.765625	1.336797	98.6632
CR5	3.25	1.15375	98.84625
CR6	6.710938	2.382383	97.61762
CR7	3.878906	1.377012	98.62299
CR8	5.605469	1.989941	98.01006

As a result of the total size calculation (data, sensing and acknowledge) for 8 CR and recognize the power consumption and CR life time the figure 4.7 shows explanation chart of these results.

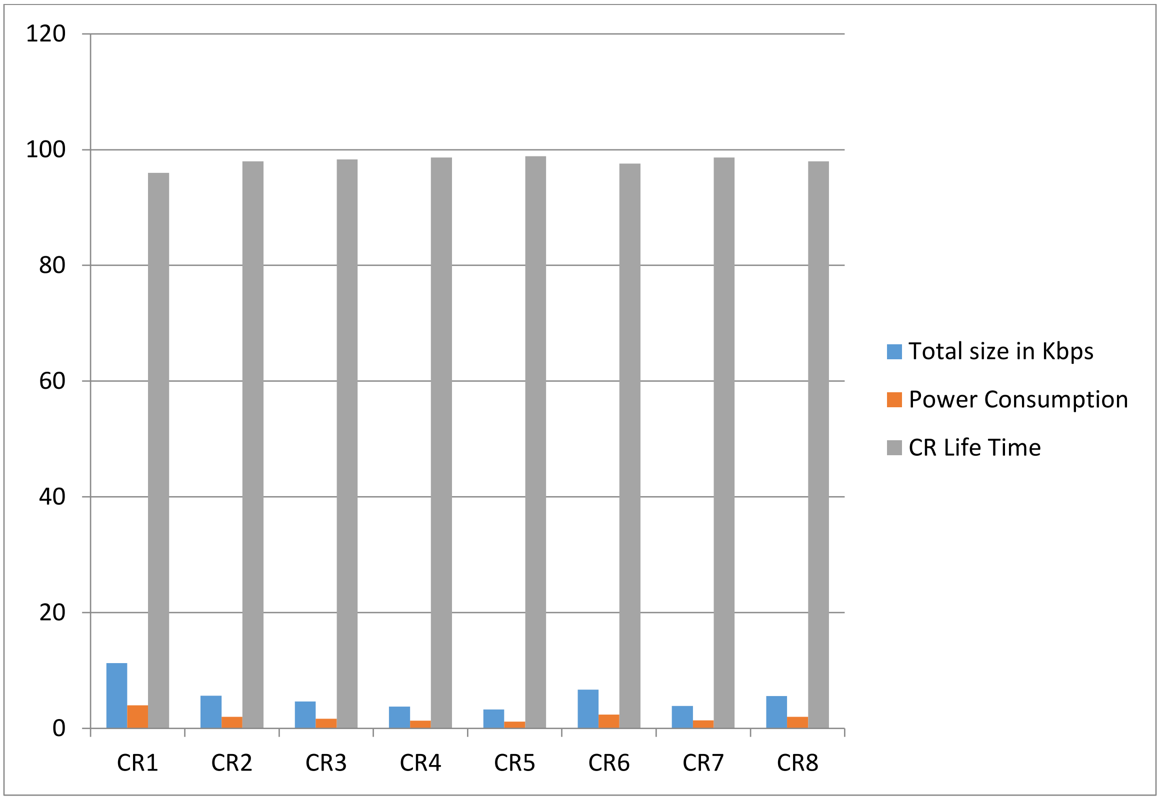


Figure 4.7: Power Consumption and CR Life Time of 8 CR nodes.

Topology implementations of 8 CR displayed in Figure 4.8.

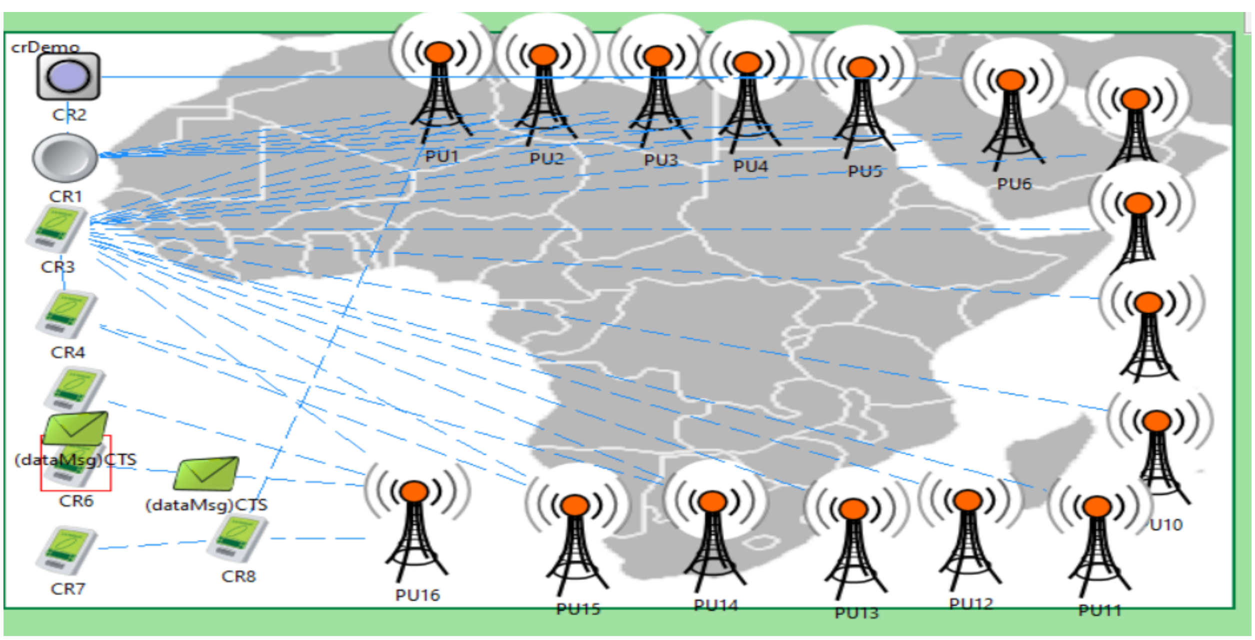


Figure 4.8 The case of 8 Cognitive Radio Nodes

4.3 Hybrid spectrum sensing approach with Fusion Center (FC)

4.3.1 The 1st case study

The first state of the 2 CR nodes simulated with 4 PU with fusion center and the evaluation parameters based on the different variables. The sensing signals details shown in Table 4.28.

Table 4.28: the Sensing signals details of the 4 CR nodes.

No. of Sensing signal		**Size of each signal**	**Total size**	**Total Average**
CR1	134	256 Bytes	34304	32640 Bytes
CR2	121		30976	

While the data signals details showed in Table 4.29.

Table 4.29: the data signals with total size in Bytes.

No. of Data signal		**Size of each signal in Bytes**	**Total size**	**Total Average**
CR1	257	100	25700	20740 Bytes
CR2	263	60	15780	

Besides, the Acknowledgement signals shown in Table 4.30.

Table 4.30: The Ack signals of the 4 CR nodes.

No. of Ack signal		**Size of each signal**	**Total size**	**Total Average**
CR1	245	32 Bytes	7840	8048 Bytes
CR2	258		8256	

Table 4. 31 is showing the total sensing, data, ACK signals with the summation and total size in Kbps, as shown the sample of statistics from OMNET++ in Appendix D.

Table 4.31: Summation and total size for 6 CR signals.

Active CR Nodes	**Total Sensing signal with size**	**Total Data signal with size**	**Total Ack signal with size**	**Summation In Byte**	**Total size in Kbps**
CR1	34304	25700	7840	67844	66.25391
CR2	30976	15780	8256	55012	53.72266

Table 4.32: Throughput for the data signals of 4 CR nodes.

Active CR Nodes	**Total Data signal with size**	**Total size in Kbps**	**Throughput in Kbps**
CR1	25700	25.09766	0.083659
CR2	15780	15.41016	0.051367
Total Throughput in Kbps	0.135026 **Kbps =** 135.026 **Bps**		

Besides, Table 4.33, and Figure 4.9 are showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.33: Power Consumption and CR Life Time of 4 CR case.

Active CR Nodes	Total size in Kbps	Power Consumption	CR Life Time
CR1	66.25391	23.52014	76.47986
CR2	53.72266	19.07154	80.92846

As a result of the total size calculation (data, sensing and acknowledge) for 2 CR and recognize the power consumption and CR life time the figure 4.9 shows explanation chart of these results.

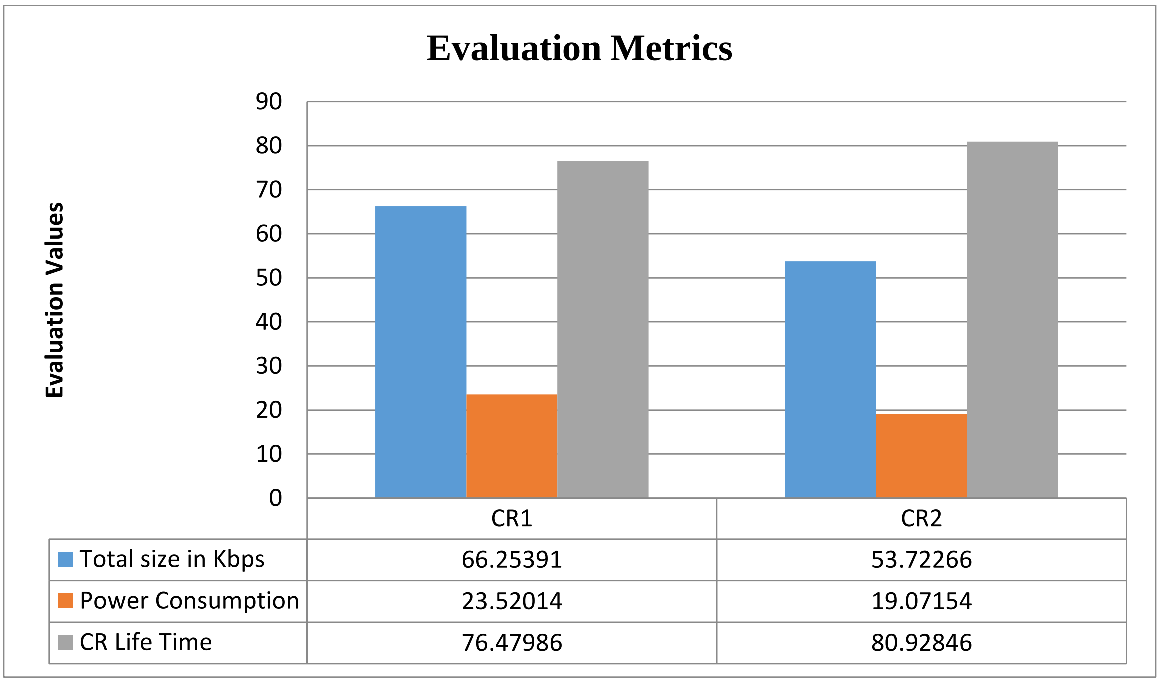


Figure 4.9: Power Consumption and CR Life Time of 2 CR nodes (FC).

And the achievement of this case shown in Figure 4.10.

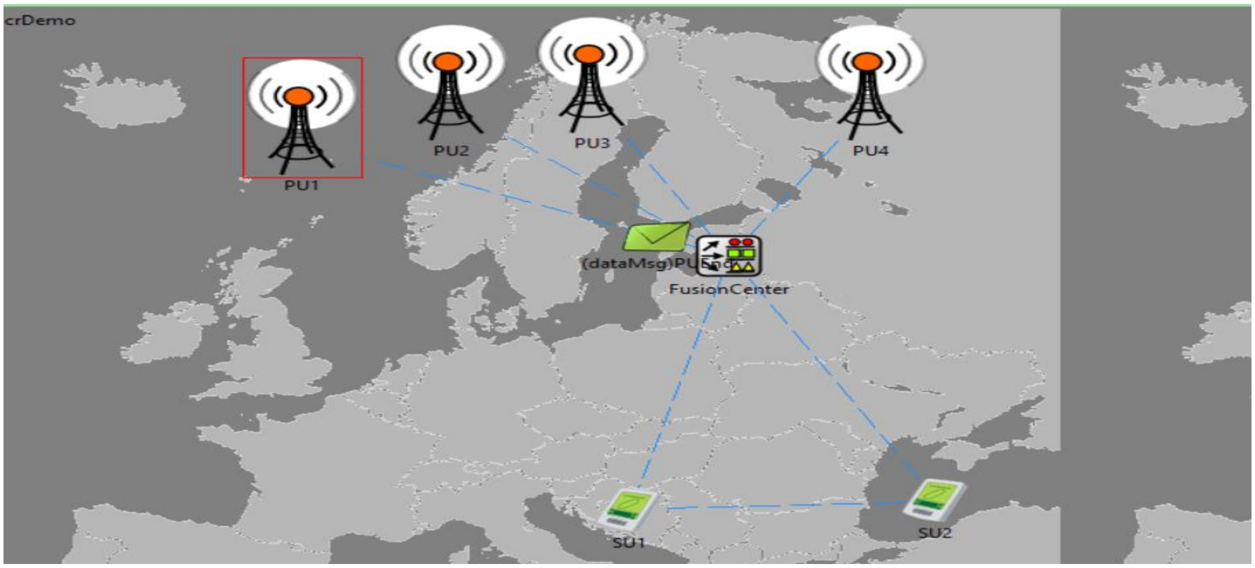


Figure 4.10 The case of 2 Cognitive Radio Nodes with FC.

4.3.2 The 2nd case study

The second state of the 4 CR nodes simulated with 8 PU and the evaluation parameters based on the different variables. The sensing signals details shown in Table 4.34.

Table 4.34: the Sensing signals details of the 4 CR nodes.

No. of Sensing signal		Size of each signal	Total size	Total Average
CR1	59	256 Bytes	15104	12864 Bytes
CR2	48		12288	
CR3	50		12800	
CR4	44		11264	

While the data signals details shown in Table 4.35.

Table 4.35: the data signals with total size in Bytes.

No. of Data signal		Size of each signal in Bytes	Total size	Total Average
CR1	73	60	4380	5640 Bytes
CR2	68	60	4080	
CR3	64	100	7300	
CR4	58	100	6800	

Besides, the Acknowledgement signals shown in Table 4.36.

Table 4.36: The Ack signals of the 4 CR nodes.

No. of Ack signal		Size of each signal	Total size	Total Average
CR1	33	32 Bytes	1056	968 Bytes
CR2	31		992	
CR3	30		960	
CR4	27		864	

Table 4. 37 is showing in the total sensing, data, ACK signals with the summation and total size in Kbps.

Table 4.37: Summation and total size for 6 CR signals.

Active CR Nodes	Total Sensing signal with size	Total Data signal with size	Total Ack signal with size	Summation In Byte	Total size in Kbps
CR1	15104	4380	1056	20540	20.05859
CR2	12288	4080	992	17360	16.95313
CR3	12800	7300	960	21060	20.56641
CR4	11264	6800	864	18928	18.48438

Table 4.38: Throughput for the data signals of 4 CR nodes.

Active CR Nodes	Total Data signal with size	Total size in Kbps	Throughput in Kbps
CR1	4380	4.277344	0.014258
CR2	4080	3.984375	0.013281
CR3	7300	7.128906	0.023763
CR4	6800	6.640625	0.022135
Total Throughput in Kbps	**0.073438 Kbps = 75.2 Bps**		

Besides, Table 4.39, and Figure 4.11 are showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.39: Power Consumption and CR Life Time of 4 CR case.

Active CR Nodes	Total size in Kbps	Power Consumption	CR Life Time
CR1	20.05859	7.120799	92.8792
CR2	16.95313	6.018361	93.98164
CR3	20.56641	7.301076	92.69892
CR4	18.48438	6.561955	93.43805

As a result of the total size calculation (data, sensing and acknowledge) for 4 CR and recognize the power consumption and CR life time the figure 4.11 shows explanation chart of these results.

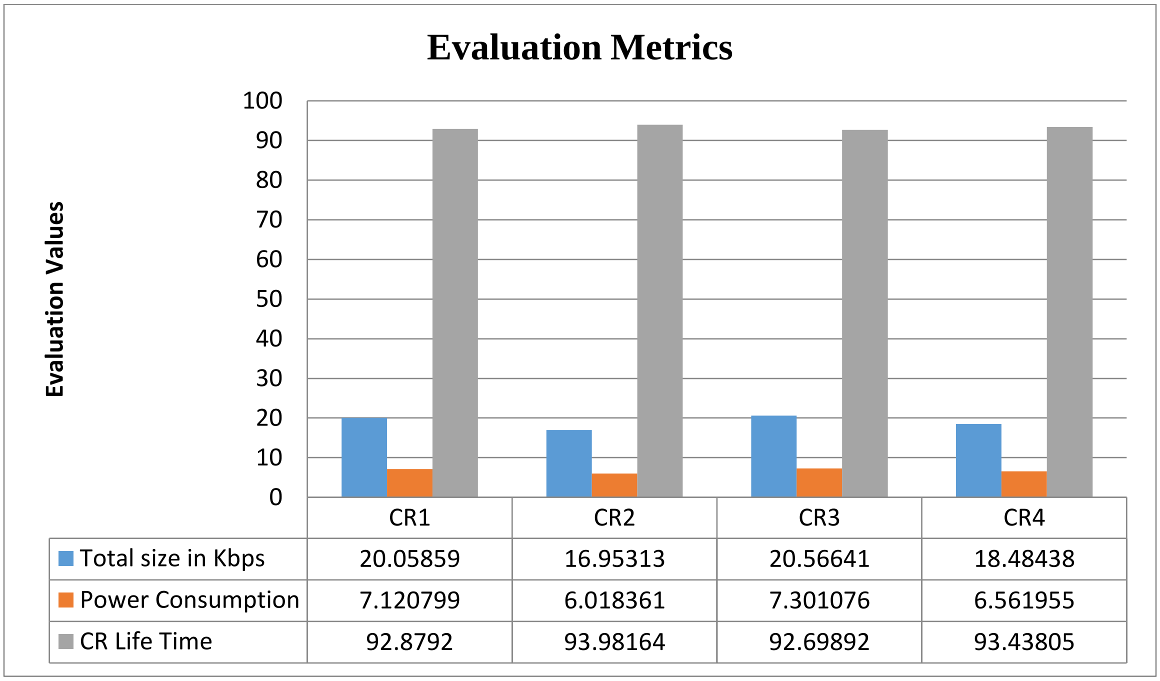


Figure 4.11: Power Consumption and CR Life Time of 4 CR nodes (FC).

The topology implementation of 4 CR nodes displayed in Figure 4.12.

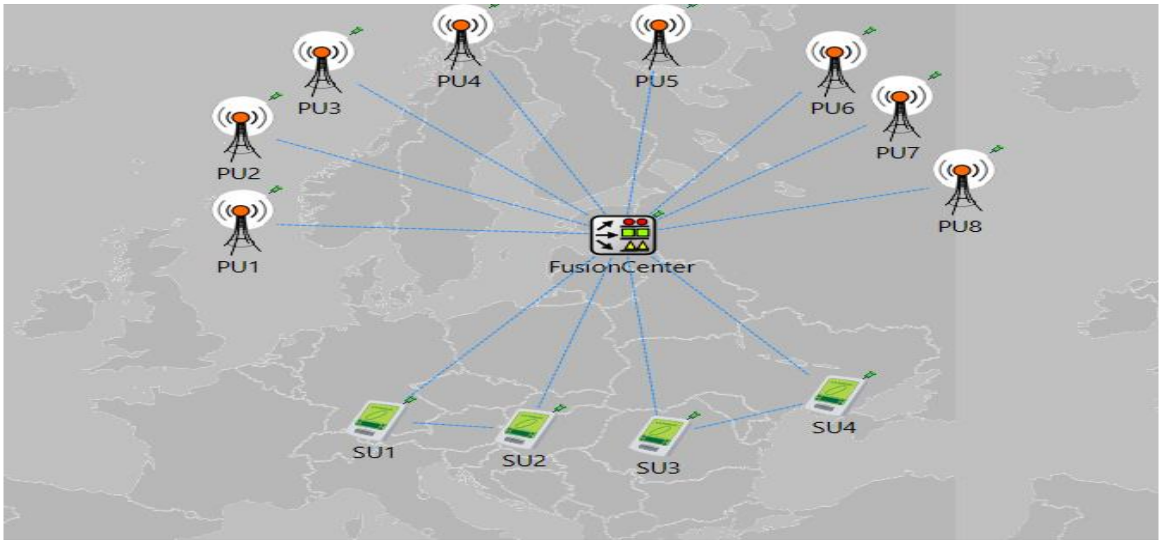


Figure 4.12 The case of 4 Cognitive Radio Nodes with FC.

4.3.3 The 3rd case study

The third state of the 6 CR nodes simulated with 12 PU and the evaluation parameters based on the different variables, as the topology shown in Appendix B. The sensing signals details shown in Table 4.40.

Table 4.40: the Sensing signals details of the 6 CR nodes.

No. of Sensing signal		**Size of each signal**	**Total size**	**Total Average**
CR1	45	256 Bytes	11520	5333.333 Bytes
CR2	19		4864	
CR3	15		3840	
CR4	11		2816	
CR5	10		2560	
CR6	25		6400	

While the data signals details shown in Table 4.41.

Table 4.41: the data signals with total size in Bytes.

No. of Data signal		Size of each signal	Total size	Total Average
CR1	39	60 Bytes	2340	1744 Bytes
CR2	25		1500	
CR3	24		1440	
CR4	15		900	
CR5	13	100 bytes	1300	
CR6	28		2800	

Besides, the Acknowledgement signals shown in Table 4.42.

Table 4.42: The Ack signals of the 6 CR nodes.

No. of Ack signal		Size of each signal	Total size	Total Average
CR1	21	32 Bytes	672	448 Bytes
CR2	16		512	
CR3	14		448	
CR4	9		288	
CR5	7		224	
CR6	17		544	

Table 4. 43 is showing the total sensing, data, Ack signals with the summation and total size in Kbps.

Table 4.43: Summation and total size for 6 CR signals.

Active CR Nodes	**Total Sensing signal with size**	**Total Data signal with size**	**Total Ack signal with size**	**Summation**	**Total size in Kbps**
CR1	11520	2340	672	14532	14.19141
CR2	4864	1500	512	6876	6.714844
CR3	3840	1440	448	5728	5.59375
CR4	2816	900	288	4004	3.910156
CR5	2560	1300	224	4084	3.988281
CR6	6400	2800	544	9744	9.515625

While table 4.44 is showing the data signals convert from Byte to Kilobits and find throughput.

Table 4.44: Throughput for the data signals of 6 CR nodes.

Active CR Nodes	**Total Data signal with size**	**Total size in Kbps**	**Throughput in Kbps**
CR1	2340	2.285156	0.007617
CR2	1500	1.464844	0.004883
CR3	1440	1.40625	0.004688
CR4	900	0.878906	0.00293
CR5	1300	1.269531	0.004232
CR6	2800	2.734375	0.009115
Total Throughput in Kbps	**0.033464 in Kbps = 34.26667 Bps**		

Besides, Table 4.45, and Figure 4.13 are showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.45: Power Consumption and CR Life Time of 6 CR case.

Active CR Nodes	Total size in Kbps	Power Consumption	CR Life Time
CR1	14.19141	5.037951	94.96205
CR2	6.714844	2.38377	97.61623
CR3	5.59375	1.985781	98.01422
CR4	3.910156	1.388105	98.61189
CR5	3.988281	1.41584	98.58416
CR6	9.515625	3.378047	96.62195

As a result of the total size calculation (data, sensing and acknowledge) for 6 CR and recognize the power consumption and CR life time the figure 4.13 shows explanation chart of these results.

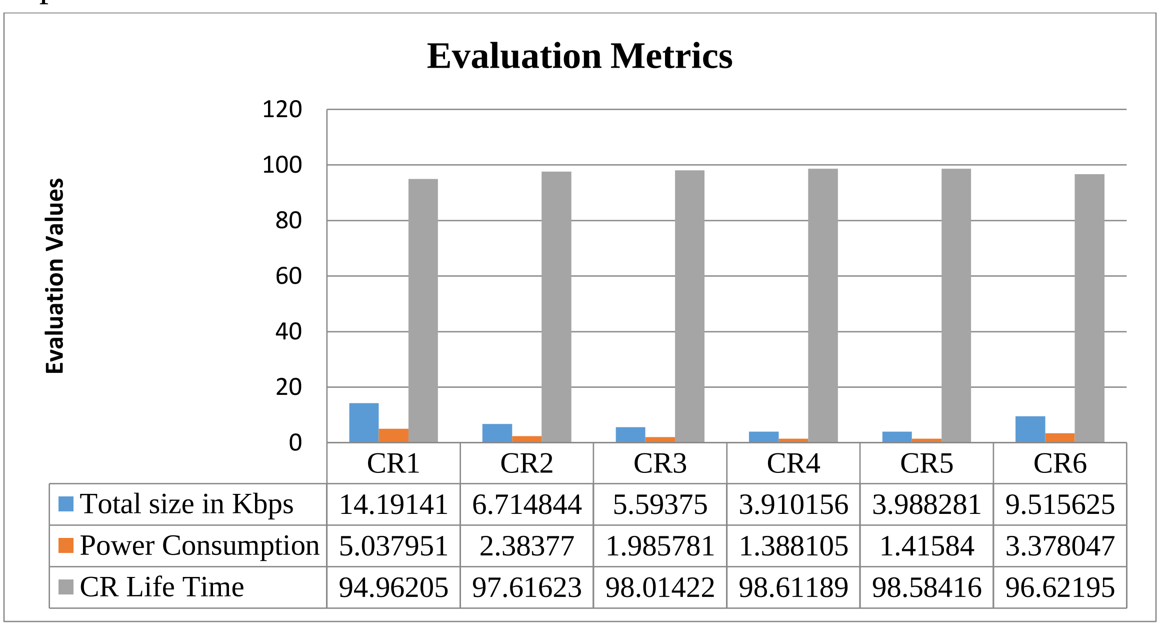


Figure 4.13: Power Consumption and CR Life Time of 6 CR nodes (FC).

And more explication about this case shown in topology implementation in Figure 4.14.

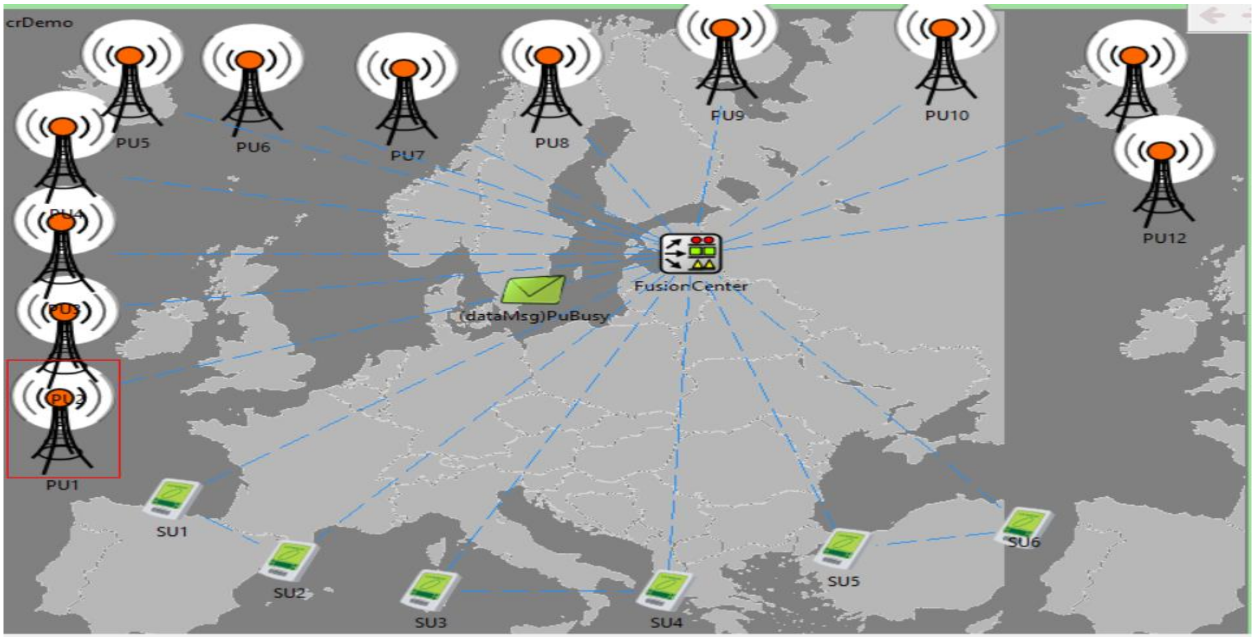


Figure 4.14 The case of 6 Cognitive Radio Nodes with FC.

4.3.4 The 4th case study

The fourth state of the 8 CR nodes simulated with 16 PU and the evaluation parameters based on the different variables, as the topology shown in Appendix C. The sensing signals details showed in Table 4.46.

Table 4.46: the Sensing signals details of the 8 CR nodes.

No. of Sensing signal		Size of each signal	Total size	Total Average
CR1	27	256 Bytes	6912	3200 Bytes
CR2	13		3328	
CR3	11		2816	
CR4	8		2048	
CR5	6		1536	
CR6	15		3840	
CR7	8		2048	
CR8	12		3072	

While the data signals details shown in Table 4.47.

Table 4.47: the data signals with total size in Bytes.

No. of Data signal		Size of each signal	Total size	Total Average
CR1	30	60 Bytes	1800	1147.5 Bytes
CR2	16		960	
CR3	13		780	
CR4	14		840	
CR5	9	100 bytes	900	
CR6	16		1600	
CR7	10		1000	
CR8	13		1300	

Besides, the Acknowledgement signals shown in Table 4.48.

Table 4.48: The Ack signals of the 8 CR nodes.

No. of Ack signal		Size of each signal	Total size	Total Average
CR1	12	32 Bytes	384	220 Bytes
CR2	7		224	
CR3	6		192	
CR4	7		224	
CR5	5		160	
CR6	7		224	
CR7	5		160	
CR8	6		192	

Table 4. 49 shown the total sensing, data, Ack signals with the summation and total size in Kbps.

Table 4.49: Summation and total size for 8 CR signals.

Active CR Nodes	**Total Sensing signal with size**	**Total Data signal with size**	**Total Ack signal with size**	**Summation In Byte**	**Total size in Kbps**
CR1	6912	1800	384	9096	8.882813
CR2	3328	960	224	4512	4.40625
CR3	2816	780	192	3788	3.699219
CR4	2048	840	224	3112	3.039063
CR5	1536	900	160	2596	2.535156
CR6	3840	1600	224	5664	5.53125
CR7	2048	1000	160	3208	3.132813
CR8	3072	1300	192	4564	4.457031

While table 4.50 is showing the data signals convert from Byte to Kilobits and find throughput.

Table 4.50: Throughput for the data signals of 8 CR nodes.

Active CR Nodes	Total Data signal with size	Total size in Kbps	Throughput in Kbps
CR1	1800	1.757813	0.005859
CR2	960	0.9375	0.003125
CR3	780	0.761719	0.002539
SCR4	840	0.820313	0.002734
CR5	900	0.878906	0.00293
CR6	1600	1.5625	0.005208
CR7	1000	0.976563	0.003255
CR8	1300	1.269531	0.004232
Throughput in Kbps	**0.029883 Kbps = 30.6 Bps**		

Besides, Table 4.51, and Figure 4.15 are showing Power Consumption and CR Life Time based on the total signals (Sensing, Data, Ack)

Table 4.51: Power Consumption and CR Life Time of 8 CR case.

Active CR Nodes	Total size in Kbps	Power Consumption	CR Life Time
CR1	8.882813	3.153399	96.8466
CR2	4.40625	1.564219	98.43578
CR3	3.699219	1.313223	98.68678
CR4	3.039063	1.078867	98.92113

CR5	2.535156	0.89998	99.10002
CR6	5.53125	1.963594	98.03641
CR7	3.132813	1.112149	98.88785
CR8	4.457031	1.582246	98.41775

As a result of the total size calculation (data, sensing and acknowledge) for 8 CR and recognize the power consumption and CR life time the figure 4.15 shows explanation chart of these results.

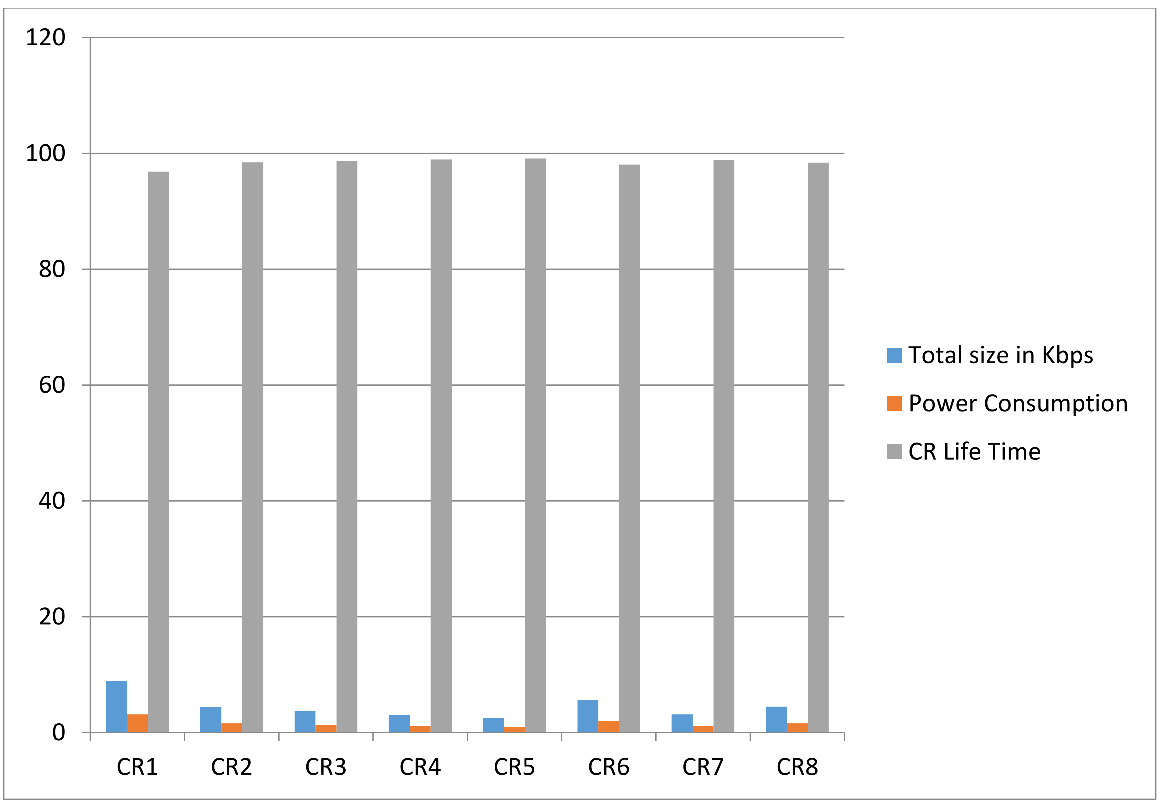


Figure 4.15: Power Consumption and CR Life Time of 8 CR nodes (FC).

Topology implementation of 8CR nodes it presents in Figure 4.16.

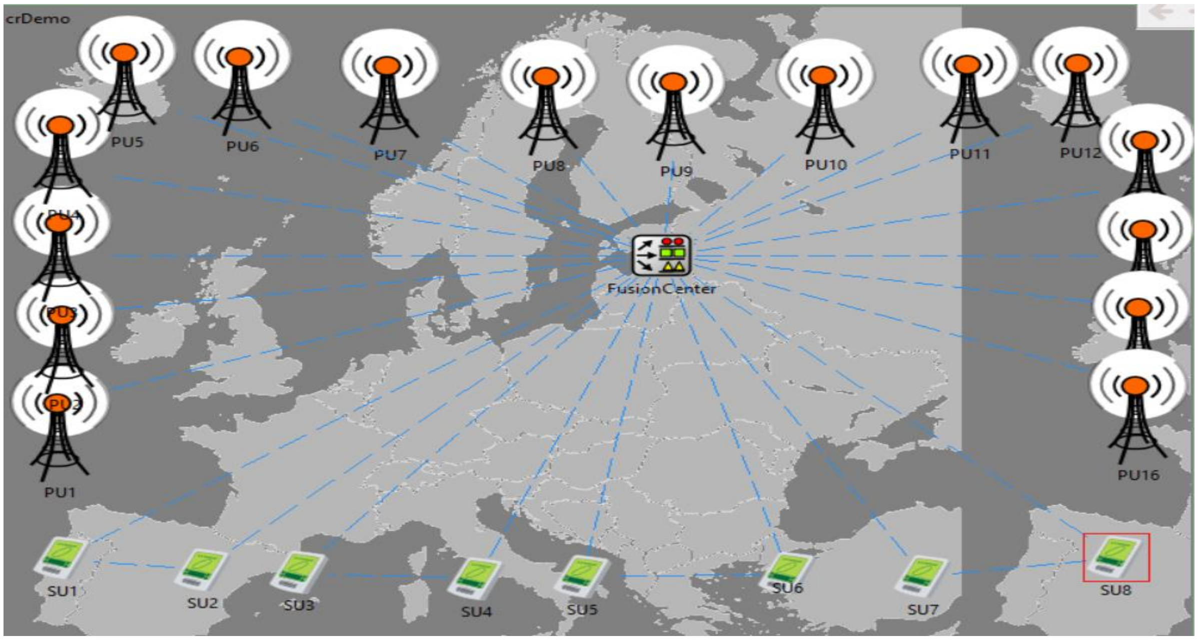


Figure 4.16 The case of 8 Cognitive Radio Nodes with FC.

The chart in Figure 4.17 represents comparative result of all four cases without FC.

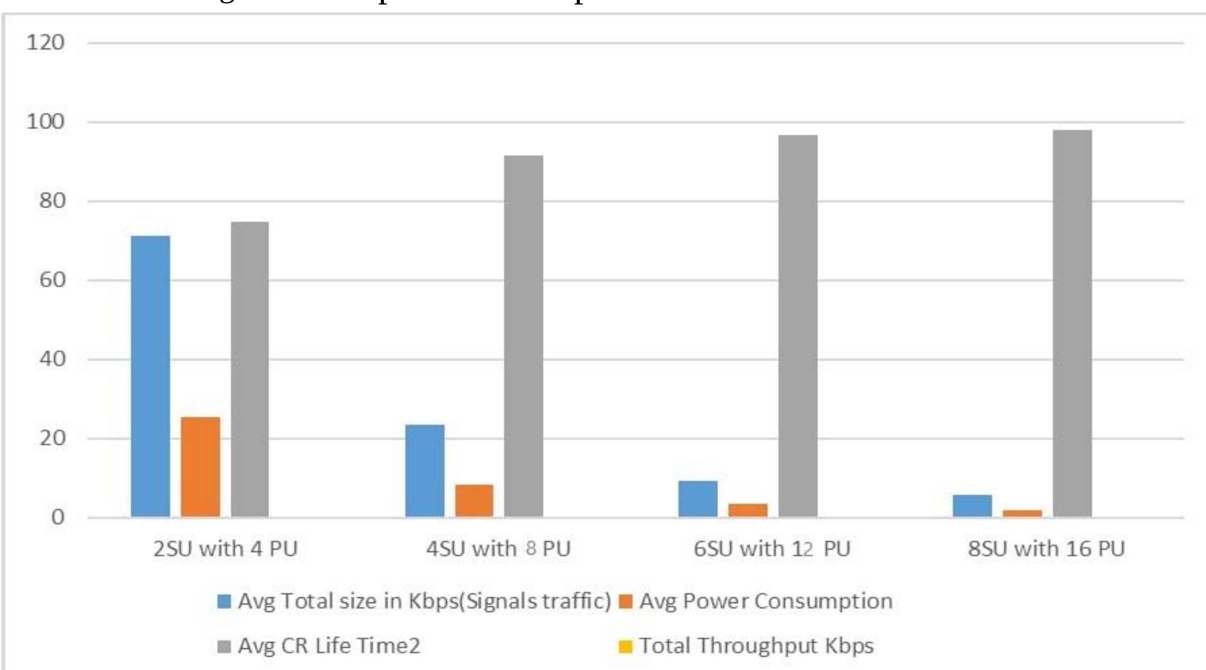


Figure 4.17: Avg Total size, Avg Power Consumption, Avg CR Life Time, Total Throughput of the 1st case study without (FC).

As showing in table 4.52 and 4.53 we reduced the average power consumption in all cases we considered and enhanced the CR life time this led to the ability to sensing and detection more time.

Table 4.52: The 1st case study Cooperative spectrum sensing without Fusion Center with (2, 4, 6,8) CR nodes.

Without FC				
CR Node	Avg Total size in Kbps (Signals traffic)	Avg Power Consumption	Avg CR Life Time2	Total Throughput Kbps
2SU with 4 PU	71.29688	25.3104	74.68961	0.083333
4SU with 8 PU	23.5791	8.370582	91.6294175	0.056576
6SU with 12 PU	9.377604	3.329049	96.67095	0.028385
8SU with 16 PU	5.603515	1.989248	98.01075	0.025781

Table 4.53: The 2nd case study Hybrid spectrum sensing approach with Fusion Center with (2, 4, 6,8) CR nodes.

With FC				
CR Node	Avg Total size in Kbps (Signals traffic)	Avg Power Consumption	Avg CR Life Time2	Total Throughput Kbps
2SU with 4 PU	59.98829	21.29584	78.70416	0.135026
4SU with 8 PU	19.01563	6.750548	93.24945	0.073438
6SU with 12 PU	7.319011	2.598249	97.40175	0.033464
8SU with 16 PU	4.460449	1.58346	98.41654	0.029883

The chart in Figure 4.18 represents comparative result of all four cases with FC.

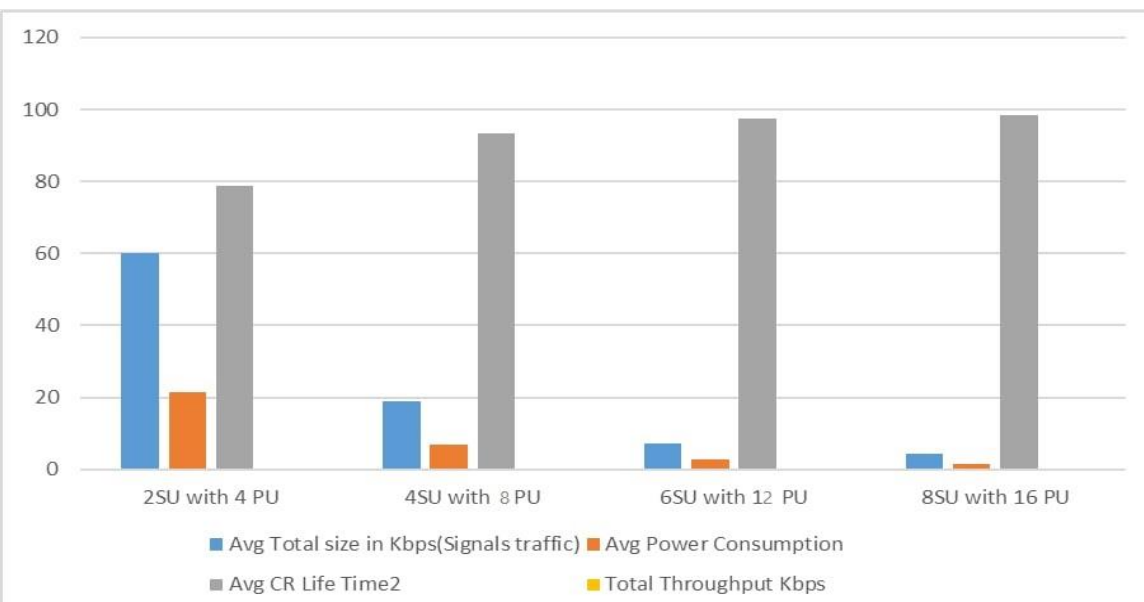


Figure 4.18: Avg Total size, Avg Power Consumption, Avg CR Life Time, Total Throughput of the 2nd case study with (FC).

4.4 System Comparison

The proposed system compared with other related works as shown in table 4.54. As explained the ACK power consumed equals to 0.33% this result shows reduction in power consumption compared to other system that's equal (2.64%) and (1.78%)

Table 4.54: The results of proposed system with the compared systems.

Ref.No	Year	No. of nodes, Signals	Environment	Method	Avg Power Consumption
[28]	2020	4 nodes, False Alarm	Monte Carlo, MATLAB	weighted-eigenvalue detection (WEVD)	2.64 %
[90]	2021	5 nodes, False Alarm	Monte Carlo, MATLAB	Extreme Learning Machine (ELM)	1.78 %
Proposed-system Total Ack signal	2023	4 nodes	OMNET ++	Eigenvalue Energy Detection (EVED)	0.33 %

Chapter Five

Conclusions and Future Works

5.1 Conclusions

This chapter explains the recommended system conclusions and the key principles for future efforts they are best defined as:

1) A nations development depends on wireless communication. However, because there is a limited amount of spectrum, wireless communication systems are facing problems such spectrum sensing accurate, diminished signal quality, and transmission delays as a result of the expansion of wireless applications and the astronomically rising number of users.
2) Spectrum sensing in cognitive radio (CR) is used to solve the problem of radio frequency interference. It is an intelligent and dynamically sense.
3) The simulations support the suggested hybrid spectrum sensing in the cognitive radio (CR) framework: Throughput, energy usage, and CR full lifetime.
4) When compared to the scenario without FC, the suggested hybrid sensing module of FC increased throughput by 135.026% for two nodes, 75.2% for four nodes, 34.26667% for six nodes, and 30.6% for eight nodes.
5) For better outcomes, the power used reduced by 25.3104%, 8.370582%,3.329049 % and 1.989248%, in the cases of 2 CR, 4 CR, 6CR, and 8 CR respectively.
6) The increase in CR life time for higher results is 74.68961%, 91.62942%,95.75109 and 98.01075 % In the scenarios of 2 CR nodes, 4 CR,6 CR and 8 CR, respectively.

5.2 Future works

1) Building a very large-scale integration (VLSI) architecture of spatialign cyclic-correlation detector for spectrum sensing consumes the least hardware computation processes.
2) A spectral sensor for cognitive radio technology based onCFD that uses less hardware and has a faster response time.
3) Applying an IoV cluster-based hybrid optimization technique with adaptive congestion-aware modeling for dynamic high-mobility vehicular networks in an urban metropolis setting.
4) Proposed new sensing methods, like match filter detection.
5) Using the suggested method with additional kinds of data, like audio, video, and compression files in another type of applications.
6) Utilize cognitive radio in 5G and Beyond(B5G) networks in order to maximize frequency efficiency and spectrum utilization.
7) Apply both (overlay/underlay) modes of spectrum sharing.
8) Apply two FC

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Appendix

Appendix A

Cognitive Radio network Layers

A- Application layer

Proposed Application Layer Steps
Phase 1 : Initialize case represented by: 1- Determine start a new communication case. 2- Getting the neighbors list. 3- Building Statistics.
Phase 2 : **start Handlers functions** 4- starting a new communication. 5- sending a request for lower layer to ultimately send RTS packet. 6- Controlling Information exchanges. 7- calling to start a communication. 8- handling received signal message data module. 9- handling acknowledge packets. 10- forwarding sensing message for lower layers. 11- forwarding DATA message for lower layers

Figure (3.4) the proposed Application layer Steps

B- Network layer

Proposed Network Layer Steps
Phase 1 : Initialize case represented by: Getting the neighbors list.
Phase 2 : **start Handlers functions** 1- Redirect signals as control signals from lower/upper layers and data messages (frames) from Lower/Upper layers with specific interface.

Figure (3.5) the used Network layer

C- CR MAC Layer :

Proposed CR-MAC Layer algorithm
Input/output : lower layer(Sensing, DATA), upper layer (Sensing, DATA)

Appendix

Phase 1 : Initialize case the number of total Frames, current Destination, current Data Channel, proposed Channel

Phase 2 : **start Handlers functions**
Handle RTS : if (rtsSent & isTransmitting & isReceiving = true)
{ delete msg } else { I am idle, sense the proposed channel }
Handle CTS : clear an RTS trigger to bring node to idle state by :
get Proposed Channel and then begin send Data.
Handle Data : if(ackEnabled == true && currentDataChannel != 0)
{ pass values for source, destination, Number Of Packets ,Proposed Channel
begin send(ack, dataLower) } else { delete msg}
Handle Ack : clear ACK timeout timer and reset frame send attempts for next packet
if (currentDataChannel == 0) { channel is lost Dont send next packet} else {
Send the next packet}
Handle Nack : sending RTS on another channel through sensing free channel proposed
 	
Handle PU : handle pu msg as (PU START and PU END) through
if(isTransmitting == true){ I was transmit and enter with two case :
case 1: if(ackEnabled == true) {cancel the ack timer, handover channel for PU then prepare to start RTS/CTS for a new channel through senseRequest(SenseFreeCHANNEL)}
else { Stop sending the acknowledgment to complete licensed users transmission}}
case 2: else {received getIdle, handover channel for licensed users}
*/ Functions that depend on Handlers
Sense Request : function used for Sense Proposed Channel as idle channel in handle RTS, Sense Data Channel through handle Ack and sense any free channel request through handle PU messages.
Get Idle : check three states with
State 1 : rtsTimer(if not null it will cancel and delete request)
State 2: ackTimer(if not null it will cancel and delete request)
State 3: get currentDataChannel to make it as idle channel

*/Timers *Set RTS timer* : is called when RTS is sent. *clear RTS timer* : clear an RTS trigger to bring node to idle state.

set Ack Time Out : called when message arrive and Channel is free to prepare for next message during send Data function.
Phase 3 : **Send Functions** send RTS : if (rtsAttempts >= 1) { success RTS Attempts so send RTS on a free channel from spectrum sensing with given parameters (source, Destination, ProposedChannel) then if no response is received, send another RTS if multiple RTS are enabled through rtsAttempts parameter} else {failed RTS Attempts ,Inform app layer by sending a nack and re-initialize rtsAttempts parameter to the number of RTS attempts for next session and send nack through ctrlUpper to application layer } send CTS : send CTS with current parameters(Source, Destination, ProposedChannel) and make isReceiving = true to begin send data. send Data : send data process with three cases : case 1: if (currentDataChannel = 1 or 2 or 3) then set Display icon. case 1: if ackEnabled == true (Send the next packet only after receiving ACK) with 2 steps : step 1: if currentDataChannel !=0 then Frame sending step 2: else get proposed Idle function (getIdle) send Nack : send this msg through transmitting and receiving unstable case for instance problem in data lower and ctrl upper.
End Algorithm

Proposed CR-MAC Layer algorithm

D- Physical Layer

Proposed Physical Layer algorithm
Input/output: address, ctrlUpper, dataUpper, ssInterface
Phase 1: Initialize case to get which address suppose dynamically to begin transmission to another node represent destination node through address value =1 Tx , address =2 Rx. myAddress = getParentModule()->par("address");
Phase 2: Channel allocation by fusion center with : Eigen value calculation for each primary user with Equation: H0: $x(n) = \eta(n)$ (2.1) H1: $x(n) = s(n) + \eta(n)$ (2.2)

Appendix

Phase 3 : **start handleMessage**

case 1: if Ctrl msg from MAC

msg->arrivedOn("**ctrlUpper$i**")

*\ arrivedOn : Boolean method return true if match value for any vector gate.

Case 2: case 2: if Data msg from MAC

send it to des node through data rate spectrum

msg->arrivedOn("dataUpper$i")

dataMsg *recMsg = check_and_cast<dataMsg *>(msg);

broadcast(recMsg);

\ A check_and_cast<> that accepts pointers other than cObject, too. For compatibility; OMNeT++ 5.0 and later already contain this.

Case 3: sensing information arrived through Spectrum sensing interface msg deliver to datarateSpectrum

msg->arrivedOn("ssInterface$i)

case 4 : msg from outside world as incoming data through receiver mode

if message as data message with object for data then send through:

(dataMsg *recMsg = check_and_cast<dataMsg *>(msg);)

Then (recMsg, "dataUpper$o");

Else if ctrl message and determine that with ctrl class then send it for sensing process :

send(copy, "ssInterface$o");

Phase 5: channel sharing

- Send idle channel to all cognitive radio node by fusion center with cooperative spectrum sensing.
- Channel selection dynamically with:
    - List of available channel as primary users.

End Algorithm

Proposed Physical Layer algorithm

Appendix B
Supporting Model

A- PU phases

Proposed PU phases
Phase 1 : Initialize case represented by: 1- Log file recording process 2- Initializing state for application layer timer with channels(PU1, PU2, PUN) 3- Assumption of idle/busy Duration for each PU: PU 1 to PU N : idle Duration: start durations busy Duration: end durations
Phase 2 : **start Handlers functions** 4- Begin broadcasting into each connected device through data rate. 5- Indicating transmission state. 6- End of transmission PU END finish PU transmission with specific known signal. 7- Indicating finish transmission

the proposed Primary users phases.

B- RFSpectrum

Proposed RFSpectrum cooperative Module for Data rates links
Phase 1 : **determines whether the channel is a transmission channel by**: 1- Setting duration field of packets. 2- Setting simulation time of the sender will finish (or has finished) transmitting to find out when the channel becomes available. 3- Sum of all previous propagation delays
Phase 2 : **Process Messages** 4- Setting propagation delay 5- Setting transmission duration. 6- Check cases of the channel has lost the message. 7- Determination of data rate value we assume as 2.4Mbps
Phase 3: sharing channel

8- Channel sharing with share method 9- Check the best idle channel from PU by Fusion center 10- Channel mobility from PU channel list

the proposed Radio Frequency spectrum for data rate links.

C- Proposed signaling & Communication Link

Proposed signaling & Communication Link (SCL) Module
Behaviors : **start Handlers functions** 1- Message checking from input spectrum sensing interface. 2- Creating objects for Control Messages 3- Collecting sensing signals and direct them to DRM module.

the proposed Signaling & Communication Link (SCL).

D- Spectrum Sensor

Spectrum Sensor Steps
Phase 1: initialize state with parameters that effect describe channel state [channels Array, sensing Duration, my Address(src), freeSenseTimer(timers for sensing free or data channels), sensed Channel, proposed Channel, currentDataChannel, sensing Signal]. - Set all channels to be free at the beginning. Looping for all total Channels.
Phase 2 : Sense Channel with three cases : Case 1 : Sense Free CHANNEL : sense any free channel 1- The currently sensed channels is either busy of occupied by PU 2- The sense channel is free. Notify MAC Layer and give the channel ID Case 2 : Sense Data CHANNEL : sense the state of SU channel 1- data channel is still free. 2- Lost data channel to PU. Case 3 : Sense Proposed CHANNEL : sense the idle channel
Phase 3 : Sensing management Case 1 : Sense Free CHANNEL: sense any free channel. sense timer 1 Schedule At(simulation Time(Returns the current simulation time)+sensing Duration, free Sense Timer); Case 2 : Sense Data CHANNEL: sense the operating channel. sense timer 2

Appendix

```
Schedule At(simulation Time()+sensing Duration, data Sense Timer);
Case 3 : Sense Proposed CHANNEL:
Schedule At (simulation Time()+ sensing Duration, proposed Sense Timer);
default: nothing to schedule
 break;
```

the proposed Spectrum Sensor Steps.

Appendix C

Conferences > 2022 Muthanna International C...

Hybrid Spectrum Sensing: Status, Open Problem And Future Trends

Publisher: IEEE Cite This PDF

Rajaa Mahmood Kareem ; Sattar B. Sadkhan **All Authors**

Abstract
Authors
Figures
References
Keywords
Metrics

Abstract:
Data transfer rates must be faster and more efficient as internet applications and wireless communications grow exponentially. As a result, a correct and effective spectrum is a must. As the demand for spectrum grow the number of bands accessible to send and receive data decreases. One of the time-consuming duties is maximizing the utilization of these bands. Various spectrum sensing approaches come up with a literature review and elements of hybrid spectrum sensing techniques as well as several cognitive radio optimizations, are discussed in this article. The search will stop at several points, including challenges, status and Future Trend.

Published in: 2022 Muthanna International Conference on Engineering Science and Technology (MICEST)

The first published paper

Appendix D

CSCTIT Conf. External Inbox x

المؤتمر العلمي العاشر لعلوم الحاسوب <csticm@uomustansiriyah.edu.iq> Nov 24, 2022, 4:51 AM (2 days ago)

to me

Dear Rajaa mahmood kareem

We are pleased to inform you that your article entitled

"Enhancement cooperative Spectrum Sensing In Cognative Radio Network based"

has been approved for presented in the 5th COLLEGE OF SCIENCE INTERNATIONAL CONFERENCE ON RECENT TRENDS IN INFORMATION TECHNOLOGY (CSCIT 2022). You are invited to present your paper at the conference, which will be held in Baghdad, Iraq, from 27th to 28th November 2022, at Mustansiriyah University, College of Science, Department of Computer Science.

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جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل كلية تكنولوجيا المعلومات

قسم شبكات المعلومات

طريقة هجينة مقترحة لتحسس الطيف في الشبكات الراديوية الإدراكية

رسالة مقدمة إلى

مجلس كلية تكنولوجيا المعلومات- جامعة بابل كجزء من متطلبات نيل درجة الماجستير في تكنولوجيا المعلومات/شبكات المعلومات

للطالبة

رجاء محمود كريم جادر

أشراف

أ.د. ستار بدر سدخان خشن

٢٠٢٣م ١٤٤٤هـ

الخلاصة بالعربي

في شبكات الراديو الادراكي (CR) ، يعد استشعار الطيف (SS) أمرًا بالغ الأهمية لتحديد مدى توفر موارد الطيف الترددي. من خلال توفير التوظيف الانتهازي لنطاقات التردد التي لا يشغلها المستخدمون المرخص لهم على نطاق واسع ، يقدم الراديو الادراكي حلاً لمسألة الازدحام الطيفي. بسبب مواقع الأجهزة ، لا يمكن اكتشاف إشارة المستخدم الرئيسي ، مما يجعل استشعار الطيف أمرًا بالغ الأهمية في الراديو الادراكي كونه المستخدم المرخص باستخدام الطيف , استخدمت طرق الاستشعار الهجين لمنع الاصطدام مع المستخدم الرئيسي ولزيادة كفاءة استخدام الطيف المسموح به. العديد من المستخدمون الثانويون في CRN يمكنهم مشاركة بيانات الاستشعار عبر شبكة راديو ادراكية تعاونية هجينة ، مما يحسن جودة تحديد تواجد المستخدم الرئيسي. في هذه الأطروحة ، يتم تناول قضية استهلاك الطاقة ، وتحسين استراتيجية الاستشعار باستخدام مركز الاندماج (FC) لتنفيذ تقنية استشعار الطيف.

يحاكي النظام المقترح أنواع مختلفة من البيانات منها (ملف) و (ملف الصورة) في بيئة شبكة الراديو الادراكية. بالإضافة إلى ذلك ، تم تنفيذ النظام المقترح باستخدام أداة المحاكاة .++ OMNET نظام الاستشعار الهجين المقترح لمركز Fusion (FC) حيث تم تحسين الإنتاجية بنسبة 135.026٪ للعقدتين ، و 75.2٪ لـ 4 عقد ، و 34.26667٪ لـ 6 عقدة و 30.6٪ لـ 8 عقد مقارنة بالحالة التي لا تحتوي على .FC ، تم تقليل الطاقة المستخدمة بنسبة 25.3104٪ و 8.370582٪ و 3.329049٪ و 1.989248٪ في حالات 2 CRو CR 4 و CR 6و CR 8 على التوالي. اضافة الى زيادة في عمر CR للحصول على نتائج أعلى هي 74.68961٪ و 91.62942٪ و 95.75109 و 98.01075٪ في سيناريوهات عقدتين CR و CR 4 و 6 CRو CR 8 على التوالي.

الانتاجية تقل نسبة لزيادة عدد العقد بسبب زيادة وقت تحسس الاشارات وبالتالي تطبيق الاستشعار التعاوني يزيد من وقت الانتظار للحصول على القناة الخاملة لارسال البيانات