Clustering Based Cooperative Spectrum Sensing for Cognitive Radio Sensor Networks

Dissertation submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

By

SUYASH MEHRA (131023)

AMAR KUMAR JYOTI (131024)

TUSHAR KAUSHIK (131029)

Under the Supervision of

MR. ALOK KUMAR

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,WAKNAGHAT

May, 2017

TABLE OF CONTENTS

DECLARATION BY THE SCHOLAR

We hereby declare that the work reported in the B-Tech thesis entitled **"Clustering Based Cooperative Spectrum Sensing for Cognitive Radio Sensor Networks"** submitted at **Jaypee University of Information Technology,Waknaghat India,** is an authentic record of our work carried out under the supervision of **Mr Alok Kumar** .We have not submitted this work elsewhere for any other degree or diploma.

Suyash Mehra (131023)

Amar Kumar Jyoti (131024)

Tushar Kaushik (131029)

Department of Electronics and Communication

Jaypee University of Information Technology, Waknaghat , India

Date :

SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the B-Tech. thesis entitled **"Clustering Based Cooperative Spectrum Sensing for Cognitive Radio Sensor Networks"**, submitted by **Suyash Mehra , Amar Kumar Jyoti , Tushar Kaushik** at **Jaypee University of Information Technology, Waknaghat** , **India,** is a bonafide record of their original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

Mr. Alok Kumar

Date :

ACKNOWLEDGEMENT

We would like to express our gratitude to all those who helped us to complete this project.

We would specially like to thank our final year project guide, **Mr. Alok Kumar**, who introduced us to this intriguing research field. We would also like to thank my friends who made several constructive suggestions to improve the project.

Furthermore we would also like to appreciate the crucial role played by the lab staff by providing us with the necessary equipment's essential for project completion.

LIST OF ACRONYMS & ABBREVIATIONS

RF	Radio Frequency
SPTF	Spectrum Policy Task Force
FCC	Federal Communications Commission
NTSC	National Television System Committee
SDR	Software-Defined Radio
LAN	Local Area Network
WLAN	Wireless Area Network
MAC	Medium Access Control
ISM	Industrial, Scientific and Medical
P_d	Probability Of Correct Detection
P_f	Probability Of False Alarm
P_m	Probability Of Miss
CR	Cognitive Radio
PU	Primary User
SU	Secondary User
QoS	Quality of Service
PU TX	Primary User Transmitter
PU RX	Primary User Receiver
AWGN	Additive White Gaussian Noise
ROC	Receiver Operating Characteristic
BS	Base Station
RSS	Received Signal Strength
WSN	Wireless Sensor Network
CRSN	Cognitive Radio Sensor Network
MEMS	Micro Electronics Mechanical System
DSAC	Distributed Spectrum Aware Clustering
PCH	Primary Cluster Head
SCH	Secondary Cluster Head

LIST OF FIGURES AND TABLES

ABSTRACT

Cognitive radio has emerged as promising new technology in the field of wireless communication for the efficient utilization of the spectrum resources. A cognitive radio sensor network (CRSN) is a wireless sensor network that is equipped with cognitive radio capability. Clustering is a grouping technique that can be applied to wireless sensor networks. Therefore, with the aim of increasing network lifetime, energy efficiency and network stability this project implements a energy efficient clustering based on cooperative spectrum sensing (ECS) for CRSNs. The ECS scheme uses the concept of pairing among sensor nodes and shifts between Sleep and Awake modes.

CHAPTER 1

INTRODUCTION

Communication via wireless medium has become an essential component in the current culture. Various devices such as car lock openers, television remote control, cellphones, security systems and TV receivers are the result of wireless technology .In the past few years there has been an exponential growth in the field of communication technology. As a result communication through constitutes the major part of overall transmission coverage. This has enabled better quality of services in wireless communication.

Cognitive radio (CR) is the new technological development which would enhance the utilization of the available spectrum resources. There has been a rapid increase in the wireless technologies that require frequency spectrum which has eventually led to the shortage of the spectrum. According to research conducted by FCC(Federal Communications Commission) some of the frequency band are heavily utilized by the licensed user at a particular time and at a particular location , but there are few bands that are largely unutilized[1]. For an instance, the spectrum bands given to the cellular technology in India are largely occupied during the peak hours (i.e working hours) but are unutilized during the night.

The spectrum licensing scheme is the major reason for the inefficient use of the available spectrum. In the conventional spectrum allocation scheme, the basic concept was to prevent an unlicensed user from accessing the spectrum that is allocated to the licensed user. This led to the poor utilization of the spectrum bands. Even if the spectrum is not being utilized by a licensed user , a cognitive user cannot access the spectrum for transmitting the information.

The factors that define the right to access the spectrum are frequency , space , transmit power , type of usage , duration of license and the licensee. Once a user is licensed a spectrum , certain parameters such as maximum determined transmit power , location of the fusion center etc. must be taken into account . In case of present licensing scheme the spectrum owner cannot transfer the right to access the spectrum to other licensee or change the type of service for which the spectrum had been allocated to the licensee.

The current licensing scheme has led to evolution of the concept of spectrum holes. Spectrum Holes or spectrum opportunities can be defined as spectrum bands which are allocated to the licensed user but at a particular location or at a particular time these are not utilized by them , therefore it could be utilized by an unlicensed user.

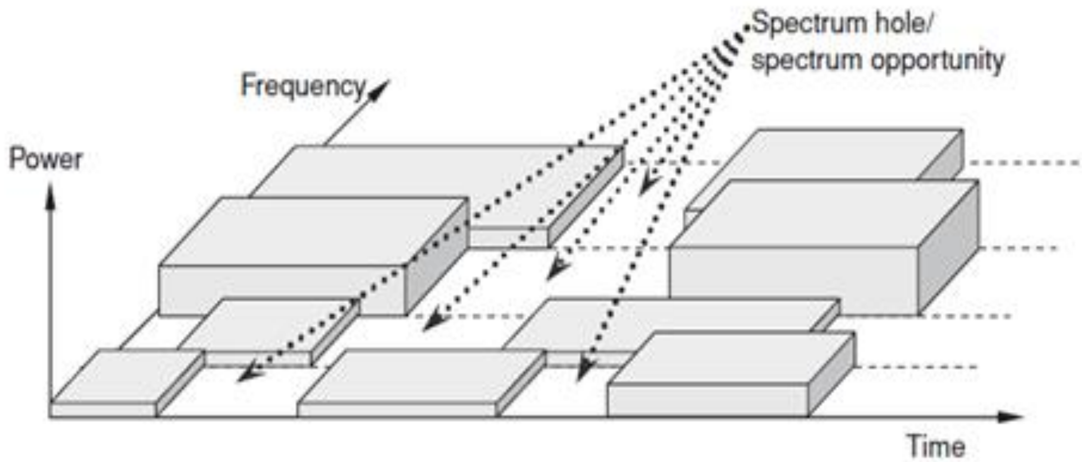

Figure 1.1 : Spectrum hole (or spectrum opportunity).

The various limitations of the static spectrum licensing scheme are:

- Spectrum usage of a fixed type: The type of spectrum usage cannot be changed under the static licensing scheme. A spectrum allocated for a particular technology cannot be used by another wireless technology. For instance, spectrum allocated to analog TV broadcast cannot be used by broadband or digital TV broadcast [1].

- Licensed for large area: A particular spectrum is usually licensed for a large area .However , the service provider to get greater return on investment may utilize this spectrum only in the areas where the number of subscribers is large. In other regions, the allocated spectrum is unutilized.

- Large part of licensed spectrum band: Generally a large portion of radio spectrum band(50MHz) is licensed to the wireless network provider . It may not be possible for the wireless service provider to obtain a spectrum band of small size to be used in a specific region for a short duration of time.

- Prohibit unlicensed user from accessing the frequency band: In the static spectrum allocation scheme, the radio spectrum can only be accessed by a licensed user and an unlicensed user is prohibited from using the spectrum band allocated to the primary users. For an instance , in a Cellular network, there are certain regions in the cell without any licensed users. In this circumstance, the unlicensed user would not be allowed to access the spectrum, even when the short –range transmission by the unlicensed user would not interfere with the cellular users.

\

CHAPTER 2

CONCEPTS OF COGNITIVE RADIO

A Software – Defined Radio (SDR) is a wireless communication system that can be reconfigured by dynamically controlling the transmission parameters.[1-3]. The software – operated signal –processing algorithms help to achieve the adjustability function.

SDR is an essential component in implementing cognitive radio . The major utilities of Software Defined Radio are as follows:

- Operation in multiple bands : With the help of SDR data can be transmitted over various frequency spectrum used by different access systems . For Example: ISM band , cellular band ¸TV band etc.

- Multi standard support : Different standards are supported by SDR (For Example : GSM , WCDMA , cdma2000, WIMAX , WiFi) . SDR also supports various air interfaces within the same standard (For Example: IEEE 802.11g, 802.11a, 802.11b or 802.11n in WiFi standard).

- Multiservice support : SDR also supports various types of services . For Example : broadband wireless Internet access or Cellular telephony.

- Multichannel support : SDR can simultaneously transmit and receive (i.e operate) on multiple frequency bands.

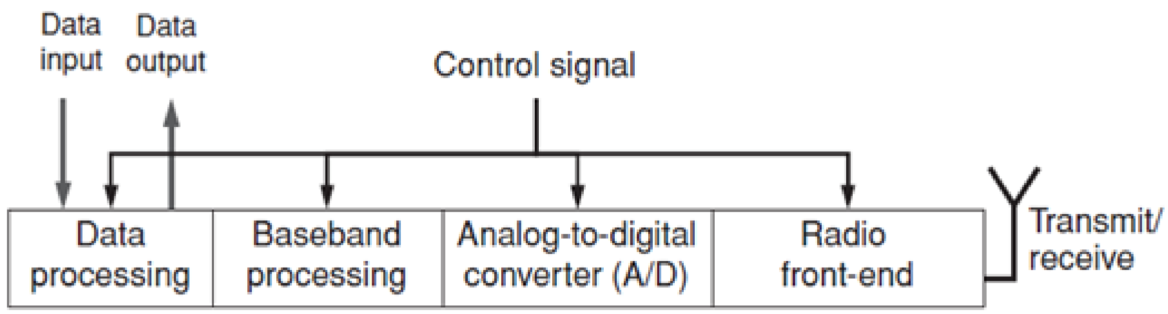

Figure 2.1: SDR transceiver.

.There is a lot of similarity in the components of the traditional transceivers and the components in SDR (i.e data processing , analog –to- digital converter , and baseband processing) , the major difference is that each component in SDR can be controlled by the upper layer protocols or can be reconfigure with the help of cognitive radio module.

In a SDR , the analog signals are received from antenna by the radio front-end .The desired frequency signal is obtained by filtering the analog signal with the help of a band pass filter. The signal is then amplified and processed to obtain an in-phase component (I) and a quadrature-phase component (Q) .The I and Q signals are then converted into digital signals by an analog- to- digital converter . The Nyquist Sampling Theorem should be taken into consideration while choosing the sampling rate of the A/d converter .Also , to reduce the signal processing overhead the sampling rate should be minimized[1] . Reconfiguration of the sampling rate , parameters of the analog and digital filters and signal –processing algorithm can be done on the basics of operating frequency and wireless air technology used.

2.1 Cognitive radio architecture

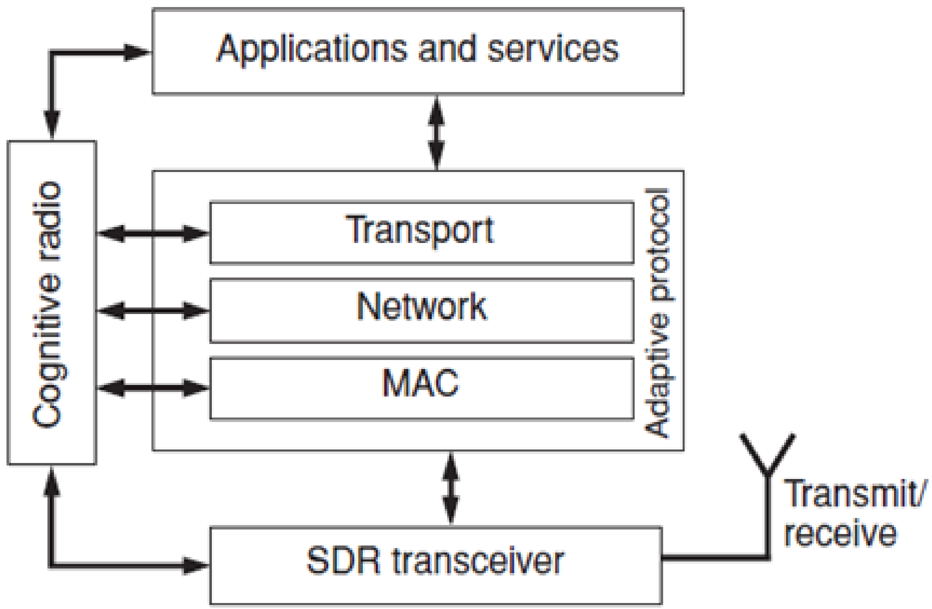

Figure 2.2 : Cognitive radio protocol stack

The RF front-end is implemented based on the SDR (Software–Defined Radio) in the physical layer. Awareness of the variations in the cognitive radio environment is achieved with the help of the flexible protocols in various layers of the cognitive radio protocol stack.The transmission requirements for the secondary user , traffic activities of the primary user ,variations in the channel quality etc are some things that should be considered by the adaptive protocols[1-2].

The cognitive radio establishes interfaces among adaptive protocols , SDR transceiver , and wireless applications and services so that these modules can be linked .The data from the physical layer is processed by the CR module using efficient algorithms . The CR module then controls the various parameters of the protocols in different layers based on transmission information received from applications.

2.2 Functions of cognitive radio

The cognitive radio supports the dynamic and intelligent spectrum access with the following main functions:

- Spectrum Sensing : The activity of the licensed user and the status of the spectrum is periodically sensed during spectrum sensing. This is achieved by sensing the target frequency band .

  There are two types of spectrum sensing :

  1. Centralized Spectrum Sensing : In this method the base station senses the target frequency and the gathered information is transmitted to all other nodes in the network. The major drawback of this method is that it suffers from diversity based on location. As an example in a situation where the unlicensed user is present at the edge of the cell then the base station that is the sensing controller can't detect it.

  2. Distributed Spectrum Sensing: In this technique , the frequency band is individually sensed by each unlicensed user and that data thus obtained can be shared among the users or can be used for individually by a CR.

- Spectrum Analysis: A schedule and plan to access the spectrum needs to be prepared with the help of the information from the spectrum sensing phase .In spectrum analysis the information gained from sensing the spectrum like spectrum hole (i.e interference estimation, probability of collision with licensed user due to sensing errors , interference estimation) is properly analyzed to gain knowledge. Then by taking in consideration the desired objective (e.g interference caused to the licensed user should be less than a threshold) a decision to access the spectrum is taken.
- Spectrum Access :The spectrum holes are accessed after a decision is made on the basis of the spectrum analysis. The various MAC protocol is then used to access the spectrum. Thus the chances of collision between the licensed and the unlicensed user is avoided.
- Spectrum Mobility: When a licensed user starts accessing a radio channel currently used by an unlicensed user the unlicensed user should switch to another spectrum band that is idle This change in the spectrum band is referred to as spectrum mobility [1].

2.3 Components of cognitive radio

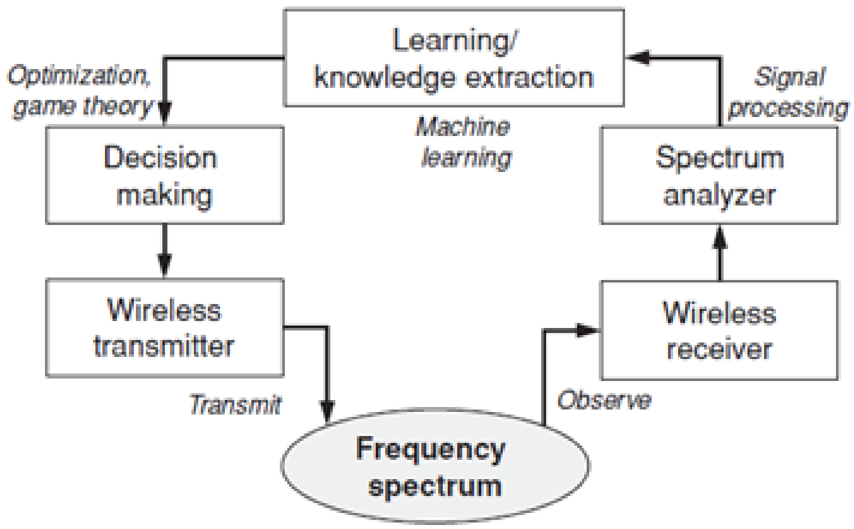

Figure 2.3 : Components in a cognitive radio node

- Transmitter /Receiver : The data signal transmission and reception is achieved with the help of a software –defined radio based wireless transceiver .Also , the wireless receivers are used to sense target frequency spectrum (i.e. sense activity on the spectrum)[1].The higher layer protocols can dynamically change the transceiver parameters in a cognitive radio node.

- Spectrum analyzer : The spectrum analyzer is used to detect the signal of the licensed user and to find the spectrum holes that can be accessed by the unlicensed user . It ensures that an unlicensed user transmission should not interfere with the transmission of the licensed user. Spectrum usage information is obtained by using various signal processing techniques.

- Knowledge extraction / learning : The knowledge and extraction component uses the spectrum usage information to understand the conduct of the licensed user .This helps to understand the ambient radio frequency environment[1] .To obtain the desired objectives under various constraints a knowledge base of spectrum access environment is built and maintained which helps to optimize and adopt the transmission parameters. To optimize the transmission parameters, a knowledge base is built and maintained.

- Decision Making : It is the ambient environment that decides the optimal decision .Therefore an optimal decision depends on the behavior of unlicensed users (i.e. competitive or cooperative behavior of the unlicensed users).For Example: when system comprises of multiple entities each with its own objective game theory can be used .While if system consists of single entity with single objective optimization theory can be used.

2.4 Spectrum sensing

The spectrum sensing can be divided into three major types , namely ,non cooperative sensing ,cooperative sensing and interference – based sensing.

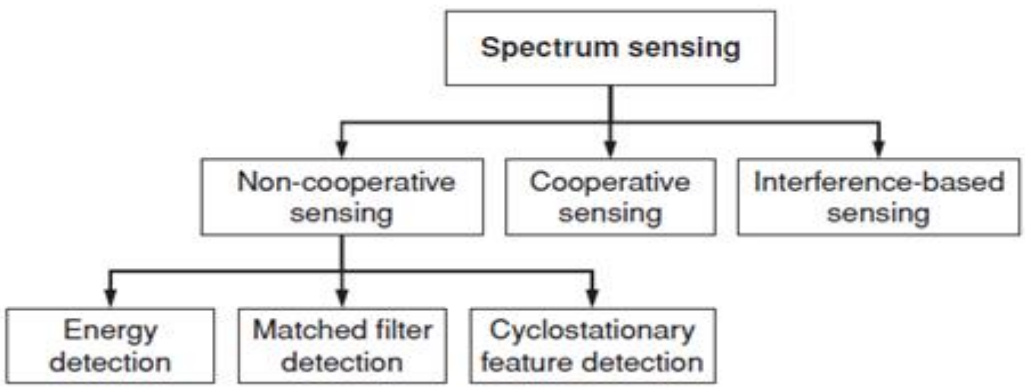

Figure 2.4 : Different types of spectrum sensing in the physical layer.

2.4.1 Non-cooperative sensing

This form of spectrum sensing, occurs when a cognitive radio acts in an individual manner and performs local sensing .The local sensing data obtained is then used to take the decision on whether licensed user is present or not .

The model for detection of signal at a particular time t can be given as :

$$z(t) = \begin{Bmatrix} k(t), & H_o \\ b.a(t) + k(t), & H_1 \end{Bmatrix} \tag{2.1}$$

Where z(t) defines the signal that is received at the Cognitive user,

a(t) is the transmitted signal of Primary User,

b is the channel gain through which unlicensed users are sensing the licensed user.

k(t) is the zero-mean additive white Gaussian noise (AWGN),

H_0 and H_1 represent the hypothesis of the absence and the presence, respectively of the PU signal in the concerned frequency band.

The different methods in non cooperative sensing are :

- Matched filter detection or coherent detection : Matched filter technique compares the input signal with a known signal (i.e. template).Matched filter is the best detection technique in stationary Gaussian noise if the details about the signal from licensed user are known (e.g. packet format and modulation). Small amount of time is required by matched filter to operate if template is used for signal detection. However, its performance degrades if template is incorrect or not available[1] .

- Transmitter energy detection : When the information about the signal from the licensed is not available energy detection technique is used .In the case of energy detection, the output signal from a bandpass filter is squared and integrated over the observation interval. A decision algorithm compares the integrator output with a threshold to decide whether a licensed user exists or not.

- Cyclostationary feature detection : The transmitted signal of the licensed user has a periodicity which is known as cyclostationarity.This can be used to sense the presence of licensed users . If the autocorrelation of a signal is periodic then that signal is cyclostationary(in wide sense).Due to the periodicity the licensed user signal can be distinguished from the noise, which is wide sense stationary[1]..

2.4.2 Cooperative Sensing

Many a times secondary user is not able to detect primary user's signal due to geographic constraints and as transmitted signal can travel from transmitter to receiver over multiple reflective paths, this results in fluctuations in amplitude, phase and angle of received signal. This problem is called the hidden terminal problem.

To deal with the problem cooperation among cognitive users can be done. In this sensing group of cognitive radio users(i.e. secondary users) share the information they sense, thus any cognitive radio user who is not able to detect the primary users can take the result of other secondary user who is successful in identifying the primary user, thereby probability of detection is increased leading to the efficient spectrum usage. The cooperative sensing can be classified as: distributed and centralized .Though the cooperative sensing is better than non cooperative sensing it comes with some disadvantages like much more computations are involved and greater communication overhead.

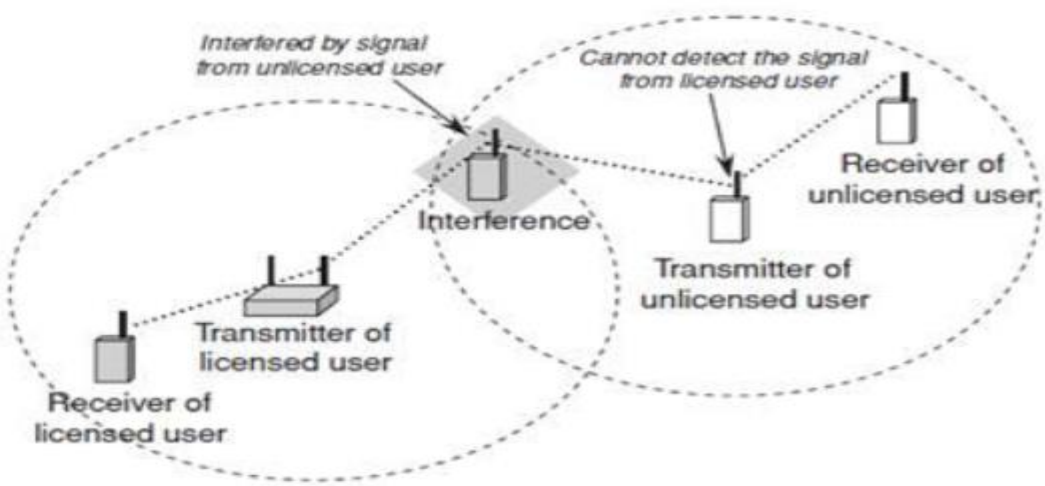

Figure 2.5: Hidden node problem

2.4.3 Interference-based Sensing

In this case, at the receiver of the licensed user noise level are measured with the help of various sensing algorithms. Spectrum access schedule is created by the unlicensed user with the help of this information by taking in consideration the interference temperature limit . Also to gather the knowledge of interference limit , a cognitive user may perceive the signal from a licensed receiver.

2.5 Spectrum analysis

Spectrum analysis is required to get the know various aspects of different spectrum bands. The aspects such as operating frequency,bandwidth,activity of primary user, channel capacity, degree of interference. The analysis can be based on the spectrum usage history or current spectrum sensing results.

Spectrum analysis can be done both at the individual level and through the cooperation also. In case of individual level each user scans the spectrum and keeps track of the parameters. In this case there are chances that results can be erroneous also leading to the degraded performance[1-2].To solve the above issue Cooperation technique is used where even if one user has correct data, it can share it to the other users which can lead to the improved spectrum usage.

CHAPTER 3
COOPERATIVE SPECTRUM SENSING

With the continuous growth of various applications involving wireless communication in both the unlicensed and licensed frequency bands, there has been shortage of spectrum which is primarily due to the fixed spectrum division policy enforced by FCC(Federal Communications Commission).To solve this problem cognitive radio(CR)[2] is being considered as the most appropriate solution. It basically allows the access of untenanted spectrum bands by the unlicensed users in so doing it increases the spectrum efficiency. The basic motivation behind spectrum sensing are: firstly ,unlicensed user should constantly keep a check on the interference it causes to the licensed users and, secondly, The spectrum holes should be continuously identified and exploited by an unlicensed user for attaining the required quality of service(QoS) [2-5].The performance of both the CR users and the licensed user largely depends on the outcomes of the spectrum sensing mechanism .

The two metrics that govern the performance of the spectrum sensing are : probability of false alarm, which defines the probability of a unlicensed user stating that a licensed user is present when the spectrum is actually not occupied , and probability of detection, which defines the probability of an unlicensed user affirming that a licensed is present when the spectrum is used by the licensed user. Also a failure in the detection will cause the intervention with a licensed user and spectral efficiency will be reduced by the false alarm, it is generally considered for best detection performance that the detection probability is made as large as possible with respect to the restriction of the false alarm probability.

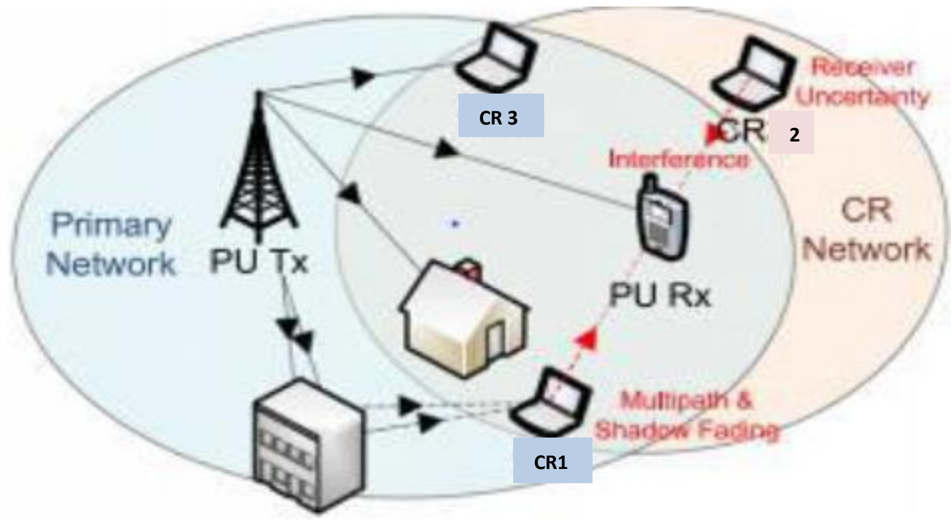

Figure 3.1: Multipath/shadow fading and receiver uncertainty

Many causes in practice such as shadowing, multipath fading, and the receiver uncertainty problem[2] might considerably effect the performance of detection in spectrum sensing. In Figure. 3.1, these effects are represented. As depicted in the figure, CR3 and CR1 are present inside the transmission range of primary transmitter (PU TX) while CR2 is not in the range. Because to various diminished PU signal copies and the obstruction by a home, CR1 undergoes multipath and shadow fading in such a way that the licensed signal may not be appropriately sensed. Additionally, CR2 is affected by the receiver uncertainty problem as it is uninformed of the licensed user transmission of signal and the presence of receiver of the licensed user (PU RX). Therefore , CR2 transmission may obstruct with the primary transmitter's signal reception at PU RX. Yet, because of 3-D diversity, there are no chances for all spatially spread cognitive users in a CR network to concurrently experience the receiver uncertainty problem or fading. If unlicensed users, large number of which experience a strong Primary User signal like CR3 in the figure, can cooperate with one another as well as share the results of spectrum sensing with other users, the collective decision resulted from the various observations that were collected can overcome the paucity of observations individually collected at each CR user[6].This would improve the performance to a great extent . This is reason for cooperative spectrum sensing to be considered as a striking and effective approach to contest shadowing and multipath fading and reduce the receiver uncertainty problem.

3.1 Parameters for detection of primary signal

Cooperative spectrum sensing begins with the sensing of the target spectrum performed at each individual Cognitive user. This method is called local sensing. Normally, local sensing for detection of the primary signal can be expressed as binary hypothesis problem as follows

$$z(t) = \begin{cases} k(t), & H_o \\ b.a(t) + k(t), & H_1 \end{cases} \tag{3.1}$$

Where z(t) defines the signal that is received at the Cognitive user, a(t) is the transmitted signal of Primary User, b is the channel gain through which unlicensed users are sensing the licensed user., k(t) is the zero-mean additive white Gaussian noise (AWGN), H_0 and H_1 represent the hypothesis of the absence and the presence, respectively of the PU signal in the concerned frequency band. For checking the performance, the detection probability Pd and false alarm probability Pf are defined as

$$P_d = P\{decision = H_1 \mid H_1\} = P\{Y > \lambda \mid H_1\} \tag{3.2}$$

$$P_f = P\{decision = H_1 \mid H_0\} = P\{Y > \lambda \mid H_0\} \tag{3.3}$$

Where Y is the decision statistic and λ is the decision threshold.The value of λ is set depending upon the requirements of detection performance. Similarly probability of miss or miss detection is defined as Pm=1-Pd. The plot that shows Pd vs Pf is called the ROC(reciever operating characteristic) curve. The accuracy of the spectrum sensing by CR user is determined with the help of the ROC curve.

3.2 Cooperative Spectrum Sensing Classification

Cooperative spectrum sensing can be broadly classified into three types based on how cooperative Cognitive users share the gathered data in the network:

a) Centralised

b) Distributed

c) Relay-assisted

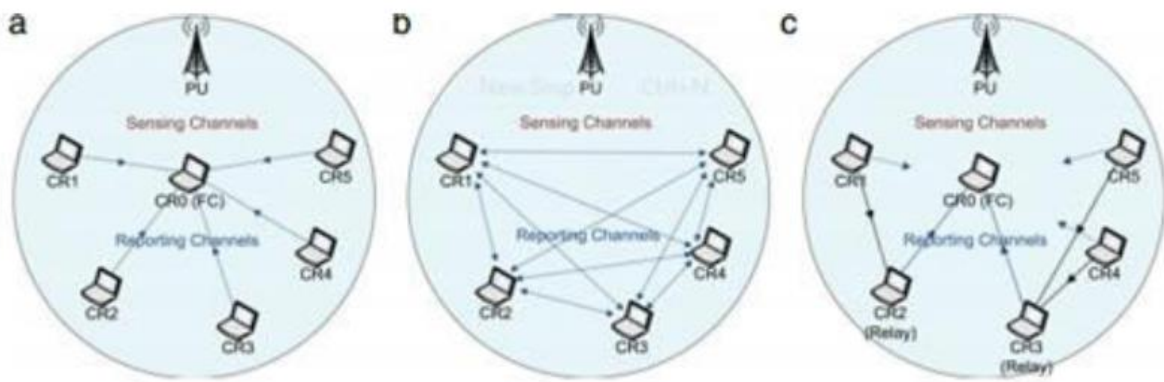

Figure 3.2: a) Centralised b) Distributed c) Relay-assisted

a) Centralised:-

In case of centralized sensing, a central point device called FC (fusion center) is responsible for the coordination of the various steps involved in the cooperative sensing mechanism (three –step process) . Firstly, the different CR users perform local spectrum sensing on the spectrum band decided by the FC (fusion center) [7,8,9]. Secondly, the cognitive user cooperating with each other use control channels to report the sensing results .The Fusion center aggregates the sensing outcomes and takes a decision on whether the licensed user is present or not . This result is then disseminated back to the CR users. As shown in Fig. 3.2(a), CR0 is the Fusion center and CR1-CR5 are Cognitive users that are cooperating , performing local spectrum sensing and reporting the outcomes back to FC (fusion center). For local sensing, all CR users are tuned to the selected licensed channel called the sensing channel (which is a point-to –point connection between CR User and the FC). For reporting of the data , all Cognitive users are supposed to report their respective data through a link between CR user and FC, that link is called reporting channel.

b) Distributed:-

In this type of sensing a decision on the presence or absence of the licensed user is determined with the help of a unified decision that is taken via iterations by the communication among the CR users in cooperation. Fig. 3.2(b) depicts the cooperation in the distributed manner[10]. After local sensing, the local sensing statistics are shared with other users within the transmission range . Each CR user determines the presence or absence of the PU by testing it against the local conditions. This is done by the cognitive user by sending its local sensing statistics to other users as well as combing the received statistics with the measured statistics to come to a conclusion . If the condition fails, CR users iteratively send their combined results to other users unless the algorithm converges and a conclusion is attained .

c) Relay-assisted:-

There are instances when both the sensing and report channels are not ideal i.e. one cr user is having a strong reporting channel and a weak sensing channel while the other cr user is having a weak reporting channel and a strong sensing channel, in that scenario cr user can supplement and improve the performance of cooperative sensing by cooperating with one another [11,12,13].In Fig. 3.2(c) CR4, CR1, and CR5, detect strong Primary User signals, may have reporting channels that are weak .CR3 and CR2, that have a reporting channel which is strong, can forward the sensing results from CR4, CR1, and CR5 to the FC by serving as a relay.

3.3 Cooperative spectrum sensing elements

Cooperative sensing can performed in three phases : local sensing phase, reporting phase, and data fusion phase .The seven key elements of the process of cooperative sensing are :

- Models for cooperation,
- various techniques of sensing,
- control channel and reporting,
- data fusion ,
- testing of hypothesis ,
- selection of user, and
- knowledge base

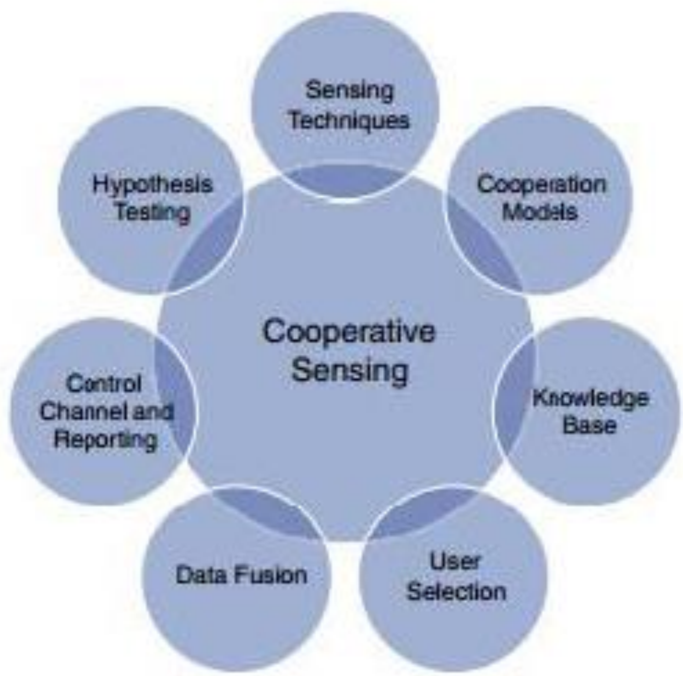

Figure 3.3: Elements of cooperative sensing

• Cooperation models explains the different cooperation method adopted by the cognitive users while sensing the spectrum . There are two types of cooperation models : game theoretical model and parallel fusion model .

• Sensing techniques are used to detect the presence of PU or the spectrum holes .These techniques involves processing of signal to extract information essential for spectrum access The selection of the sensing technique has the profound effect on cooperation of CR users .

• Hypothesis testing is a statistical test to determine the absence or presence of a PU. This test can be performed either at individual CR node or at the FC . In this test $H_{1,}$ denotes presence of PU and $H_{0,}$ absence of the PU.

• Control channel and reporting defines on how the data gathered by local sensing at each CR user can be transmitted to the FC and other CR users in an efficient and reliable manner. This can be done by utilizing the channel with minimum bandwidth and susceptible minimum fading .

• Data fusion is process of making a cooperative decision by aggregating the results collected from different CR users .

• User selection deals aims at reducing the cooperation overhead and increasing the cooperative gain by using the optimal criteria for selection of CR user that are cooperating and determining the cooperation range.

• Knowledge base is the storage space that contains the information of users such as Primary user and cognitive user locations, licensed user movement models and RSS(Received signal strength) profiles. This information assists the sensing process and improves the detection performance.

CHAPTER 4
CLUSTERING IN COOPERATIVE SPECTRUM SENSING

4.1 WSNs (Wireless sensor networks)

A WSNs is a randomly distributed network composed of multiple low power sensors called nodes[14]. These networks are deployed to monitor the physical and environmental conditions such as temperature, pressure, sound and humidity. With recent advancement in MEMs technology (Micro Electronics Mechanical system), there has been vast growth in the field of wireless sensor networks.

WSNs can be broadly classified as: unstructured WSNs and structured WSNs. In case of unstructured WSN the sensor nodes are randomly distributed in the field. Once positioned, the network is left unattended to achieve monitoring and reporting functions. The issue with the unstructured WSN is that it is difficult to do managing work such as detecting failure, maintenance work, as there is vast number of nodes and they are randomly deployed. In case of structured WSN, the sensor nodes(all or some) are arranged in an organized manner which gives an advantage of low maintenance and management cost.

Various issues in WSNs are:

a) Communication protocol: The TCP/IP protocol suite comprises of five layers : application layer, transport layer, network layer, data-link layer, and physical layer.
b) Sensor technology: energy consumption, storage and processing capability of sensors.
c) Systems: This mainly consists of operating system, storage and performance evaluation.
d) Services: data aggregation, synchronization, security, cross layer optimization.
e) Application: the application of WSN can be shown as in fig below

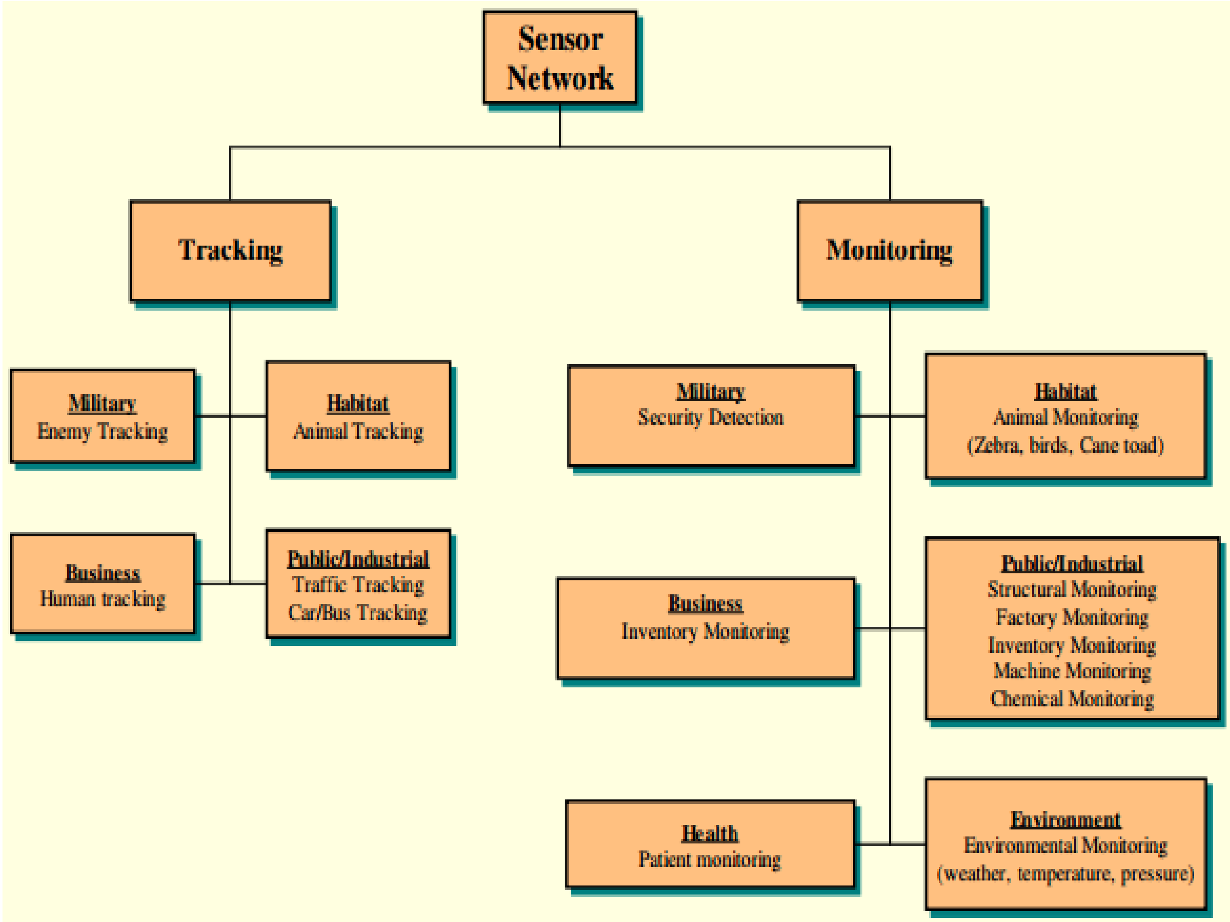

Figure 4.1: Application of WSN

Clustering is an important technique used in wireless sensor environment [15]. These sensor nodes then transfer data to a sink node or the base station. The exponential growth in wireless sensor networks (WSNs) has lead to spectrum congestion and inefficient spectrum usage. As explained, cognitive radio helps to utilize the unused licensed band. But then it suffers from uncertainty due to fading and shadowing and hidden primary terminal problem. For this cooperative spectrum sensing has grown as liable spectrum sensing technique, giving more protection to primary user and allowing more efficient spectrum sensing.[16][17]

The combination of these two, called the Cognitive radio sensor network has grown as more liable option these days[18]. Clustering in wireless sensor network refers to grouping a set of nodes in such a way that forms a cluster (group). The nodes in a cluster are more similar to each other than nodes in other cluster. The clusters that are distributed all over the environment collects data and sends it to the base station or the fusion center. In a CRSN,a cluster head is liable for all the tasks involving management of spectrum , such as obtaining the sensor data from the nodes in the cluster and sending it to the fusion center. This decreases the total consumption of energy .

Clustering in a wireless sensor network reduces the energy in accumulating the environment information and increases the lifetime of the network. There are certain clustering algorithms such as the LEACH (low-energy adaptive clustering hierarchy) method [19] and the DEEC (distributed energy-efficient clustering) method [20], both have attained a sensible degree of success at enhancing the performance of a network. The conventional centralized algorithms require comprehensive knowledge of all the nodes in the network, so in case of failure of any critical node the whole protocol fails. On the other hand, in the distributed algorithms we can prevent the failure caused by any single critical node since it is executed locally within partial nodes. Most of these protocols can't be used for CRSNs because they have supposed a channel assignment that is fixed and hence spectrum cannot be accessed in a dynamic manner.

Another scheme called DSAC (distributed spectrum aware clustering) is suggested in [21, 22]. This technique merge two nearby nodes that share the similar available channel. The probability that two nodes will merge depends on the local minimum distance obtained from the data exchanged between two nodes that are located close to one another. This process of formation of the cluster is continued till we get optimal number of clusters. In DSAC, both the nodes are active for sensing the environment and they communicate with the cluster head, adding to energy consumed. Using this idea of spectrum aware constrained clustering we have implemented a energy efficient clustering scheme created on cooperative spectrum sensing (ECS) for CRSNs. In the ECS scheme , energy is conserved as the nodes that are paired can be switched between sleep and awake mode . Also, this method operates in a self-organized way, prolonging the network's lifespan, with more stability and an optimum cluster-head selection process. Also we have implemented an algorithm to configure the awake and sleep modes for coupled CRSN network.

4.2 Energy-efficient clustering-Based Cooperative Spectrum Sensing (ECS) Scheme

Assumptions and objectives that are used in this scheme are :

a) The nodes deployed are random and dense.
b) Nodes belonging to the same cluster should have at least one shared channel and this channel should not be currently occupied by a neighbouring primary user.
c) Each node is capable of cognitive radio characteristics, such as dynamic spectrum access, spectrum sensing and transmission-parameter configurability.
d) The MAC protocol being used is built on a time-division multiple-access (TDMA) method.
e) There exists a cluster head for every cluster in the network. The data collected by different nodes in cooperation in a cluster should be combined first in cluster head and after that it should be transmitted to the fusion-center. This is efficient application oriented source sensing.
f) The location of a node, randomly installed in a region is calculated with a global positioning system (GPS) that pass on its location, along with the type of application and the node-id, to the fusion center.

Steps involved in ECS scheme explained below :-

a) Spectrum-Aware pairwise coupling: Coupling in ECS scheme is somewhat similar to distributed spectrum-aware clustering (DSAC) scheme[21](as explained above). Our target in ECS is to lessen the energy used by the CSRN to improve the stability and the life time of the network. In Figure 1, Nodes A and B can be paired together, only if they have at least one channel in common. So Nodes A and B can be coupled together, because they have Channel1 in common. However, on other side of the figure, Nodes A and B do not have a channel in common. So they cannot be coupled together. The numbers put on Nodes A and B represent the available channels.

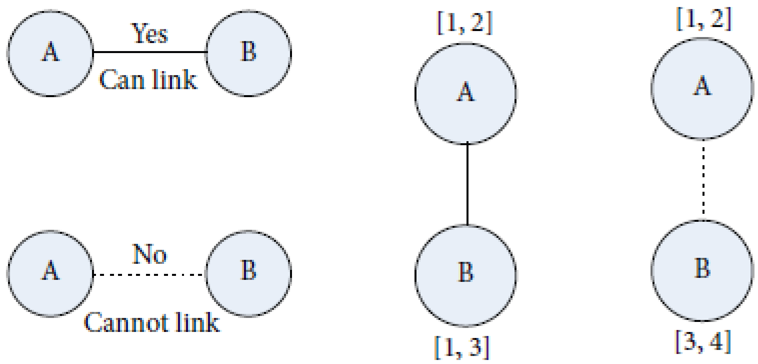

Figure 4.2: Spectrum-aware pairwise coupling

The fusion center then calculates the mutual distance between the nodes based on the information received by it about, type of application, and node-id for every node installed in the considered region. The fusion center then guides the pairing of the nodes that are of the same application type, that are at a minimum distance from each other within their intra cluster transmission range and have at least one channel in common. This is called spectrum aware pairwise coupling. However, during this pair-wise coupling process, some nodes are still unpaired, because they do not fall within the intra cluster communication range of any other node. To make each node aware of its pairing the fusion center broadcasts the pairing data to all CRSN nodes in the network. For energy efficiency the coupled nodes can switch between the awake and sleep node during a single communication interval. The distance of the node from the fusion center and the coupled node is calculated and if the distance of this node from the fusion center is less than that of the coupled node then it switches to Awake state. The node in Awake mode senses the channel status and sends this data to the cluster heads. The other node in the pair switches to Sleep mode and it neither senses the channel status nor communicates with the cluster head. In the following iteration, the Awake node switches to Sleep mode and the other node in the pair becomes active. This alternate awake and switch mode reduces the energy consumed as the node in sleep mode doesn’t have to sense the channel and talk with the cluster head.

b) Creation of cluster head and Clustering: according to the LEACH protocol nodes transfer information to the cluster heads, and then they combine and compress this data before sending it to the fusion center. In this process the decision for becoming a cluster head for that round is taken by each node using a algorithm based on random probability distribution. If P is the desired percentage of cluster heads, then probability of each node becoming cluster head in a round is $1/P$ i.e the nodes that have already been cluster heads cannot become cluster head again for P rounds. Each node that is not the cluster head, joins the closest cluster. Now it is the duty of cluster head to plan a schedule for each node in its cluster to transmit its data. The cluster head will die immediately, if the measured energy of a cluster head is less as compared to other CRSN nodes, because of a heavy energy burden.

In this scheme, only nodes in awake mode engage in the cluster-head selection process. Thus the communication cost is reduced. The cluster heads selected after the first round are determined based on the residual energy with each node. In the first iteration, when the energy level of all the nodes is E_0, then using probability from a distributed algorithm the active node will choose itself as cluster head. During this each node that is Awake uses a threshold value $T_h(n)$ and then selects a random number between 0 and 1. After this it compares that random number to the threshold value, which is calculated as follows:

$$T_h(n) = \begin{cases} \dfrac{P}{1 - P\left((first\ round\ ) mod\ \left(\frac{1}{P}\right)\right)}, & \forall\, n \in A \\ 0 \quad , & otherwise \end{cases} \tag{4.1}$$

where A is the set of active nodes in first round.

A node will elect itself as a cluster head, i.e. as the primary cluster head(PCH), if the random number chosen by a CRSN node in Awake mode is less than the threshold $Th(n)$. When a node has been selected as the PCH, the entire network is made aware about this, through an advertisement message send by PCH. These messages from different PCHs are received only by the awake nodes, based on the RSSI they select their PCH for formation of a cluster. Awake-mode CRSN node uses CSMA/CA to link to the .This is done to avoid collision with the link requests of other active nodes. Other than the link request to their respective PCHs, information regarding their energy and distance is also transmitted by the Awake nodes. The PCH then selects a secondary cluster head (SCH) that will act as cluster head in the next round, based on the remaining energy of each Awake node in a cluster. In case the nodes have the same level of energy, the node that is nearest to the PCH is selected as the SCH. The procedural flow for the cluster formation and the cluster-head selection is shown in Figure 4.3.

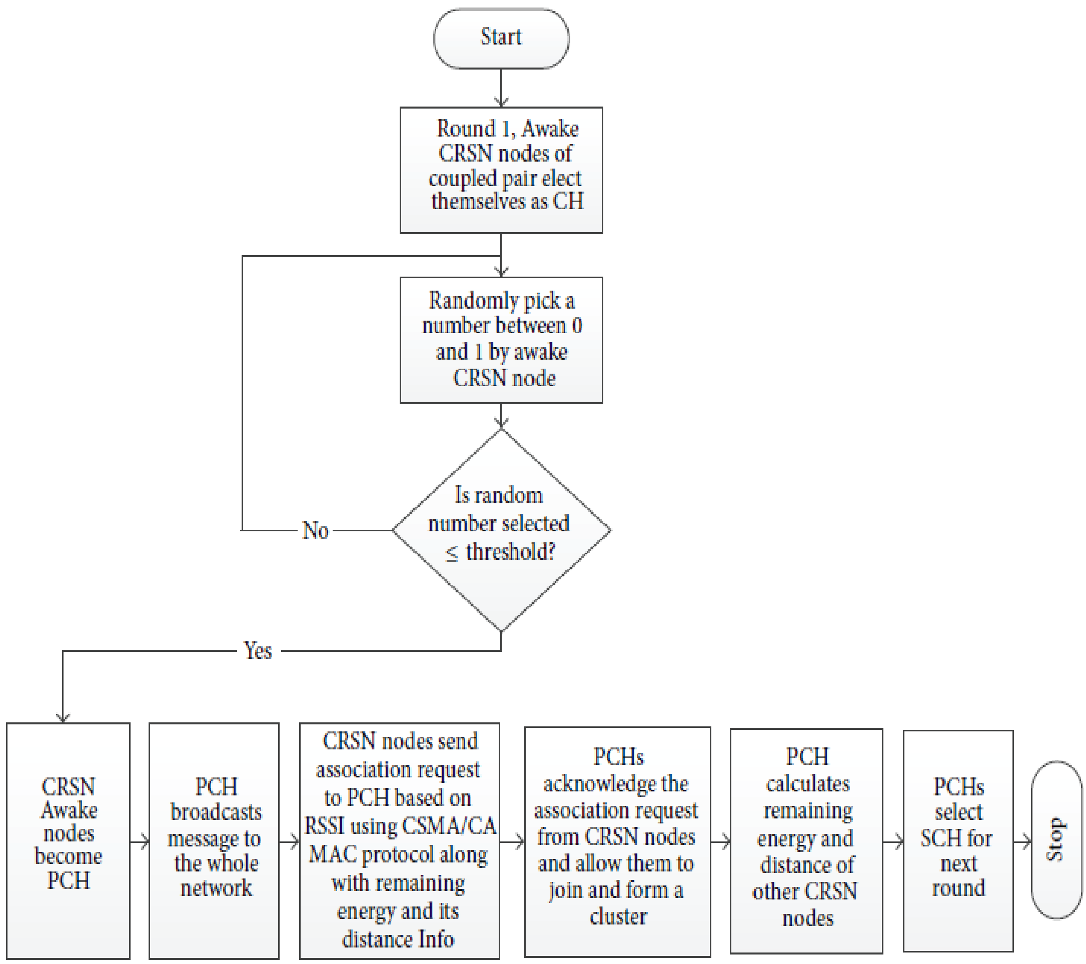

Figure 4.3: Flow Diagram of formation of a cluster and cluster head selection

i) Sleep-Awake Mode Configuration for Coupled CRSN Nodes: Once the pairwise coupling, clustering, and cluster-head selection is achieved, each node organizes its corresponding Awake and Sleep modes for the next round. After each round, turn switching between Awake and Sleep mode occurs in spectrum aware coupled pairs. The necessary condition for the nodes that are selected to be the cluster head in the next round i.e becoming SCH is that it must be Awake in during the current round. This condition leads to conflict between the paired nodes in terms of interchanging between Awake and Sleep modes. For resolving this we implemented an algorithm for configuring Awake and Sleep modes in the coupled nodes in ECS scheme. In Algorithm1, the node will first see if spectrum aware coupling has been done. Now if the node is coupled, then one of the nodes in the pair will check whether it is in awake mode and whether it is flagged as the SCH for the next round. The node will be in awake mode or not, depends on value of the SCH flag, if it is "ON" in next round it will be awake mode else inactive or sleep. If the SCH next-round flag is "ON" then that node will be in Awake mode during the next round and the other node will stay in sleep. But if the node is in awake mode and its SCH next-round flag is "OFF" then the current node will go into Sleep mode and other node will take its turn in Awake mode node for the next round. This process is continued for all other Sleep-mode nodes.

ii) Data Transmission and Reporting in a CRSN : Transmission of data from nodes to the respective heads take place on TDMA basis. The active nodes during their individual TDMA time slot sends data to their respective cluster heads. But it is only the active nodes that take place in transmission of data and not the nodes in the sleep mode. The cluster head then collects the data from different nodes and sends it to the fusion center for the decision making process. So in order to decrease the energy consumption of the network we need to apply some technique to compress the amount of data. If there are N total nodes and K is the optimal number of cluster heads, then the average number of nodes in each cluster will be :-

$$(\frac{N}{k} - 1) \tag{4.2}$$

The processes in which the energy is consumed in the data transmission process are a) data sent to the cluster head by the node, b) data collected by the cluster head, c) combining data by the cluster head, d) sending combined data to the fusion center.

Energy dissipated by the node is given by:-

$$E_{node} = \left(\frac{N}{K} - 1\right)\left(E_T * D_C * E_{amp} * D_C * d_{toCH}^2\right) \tag{4.3}$$

where E_{node} is energy dissipated by the node. d_{toCH}^2 is the distance between the cluster head and the node, D_C is message bit that is to be transmitted from the node to the cluster head, E_T is the energy to run the transmission circuitry at the node, E_{amp} is the energy in amplifier to reach the desired SNR for transmitting the data.

Energy dissipated in the cluster head E_{Rec} is given by

$$E_{Rec} = E_R * D_C \left(\frac{N}{K} - 1\right) \tag{4.4}$$

where E_{Rec} is the energy dissipated at the cluster head for receiving the data from the nodes

If E_{AD} is the energy dissipated at the cluster head to aggregate the data from one node then total energy dissipated at the cluster head for aggregating the data D_C received from the nodes is given by E_{aggE}

$$E_{aggE} = E_{AD} * D_C \left(\frac{N}{K} - 1\right) \tag{4.5}$$

The energy dissipated in sending the aggregated data from the cluster head to the fusion center is represented by E_{Total}

$$E_{Total} = E_T * D_A * E_{amp} * D_A * d_{toFC}^2 \tag{4.6}$$

Where d_{toCH}^2 is the distance measured between the cluster head and fusion center, D_A denotes aggregated data.

Hence from the above equation the total dissipated energy from the head of the cluster in each round can be given by:

$$E_{TCH} = E_{Rec} + E_{AggE} + E_{Total} \tag{4.7}$$

4.3 Performance evaluation of the ECS scheme

We have used the following metrics to evaluate the performance of the ECS scheme:

a) the number of cluster heads: this is the number of cluster heads that is created in each round.
b) packet to fusion center (FC): This is the rate at which the data is successfully delivered to the fusion center from the cluster head,
c) network lifetime: duration of the CRSN is performing from its initialization to the last node is active,
d) stability period: time duration from initialization until the first node dies out,
e) instability period: time duration from initialization of CRSN until the last node dies out.
f) Based on the above metrics and using MATLAB simulations we have analyzed the performance of ECS scheme.IN the simulation we have used 100 * 100 meters area and randomly deployed 100 nodes with fusion center being located at 50,50. The initial energy of the nodes is supposed to be E_o. The various simulations parameter are given in the table below:

Table 4.1: Parameters used in Simulation

Parameter	Value
Network size	100 m * 100 m
Initial energy	0.5 J
P_d	0.1
Data aggregation energy cost	50 pj/bit j
Number of nodes	100
Packet size	4000 bit
E_T	50 nJ/bit
E_R	50 nJ/bit
E_{amp}	0.0013 pJ/bit/m^4

CHAPTER 5

RESULTS

a) Random deployment of node : In all simulations, we randomly deployed 100 CRSN nodes in a 100 ∗ 100 meter area with initial energy of E_0.

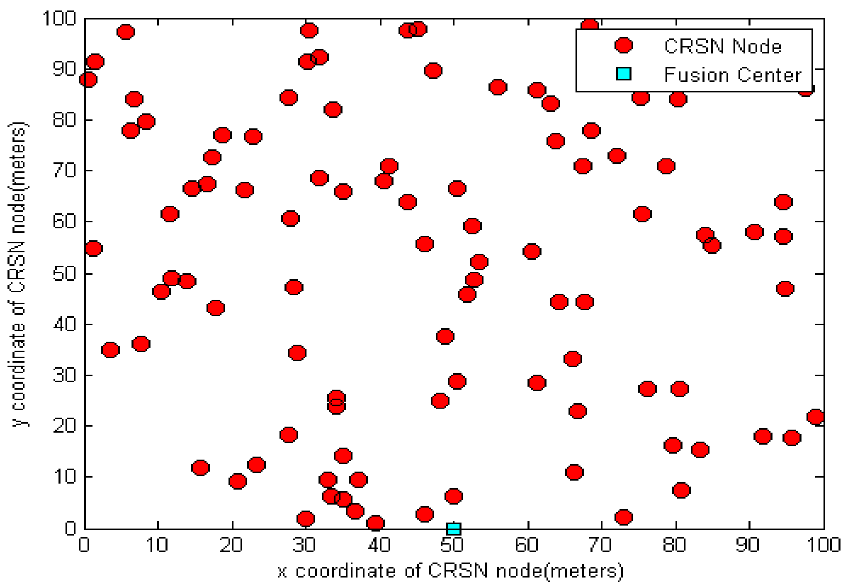

Figure 5.1: Random deployment of node

b) Cluster head display : In the figure below cluster head is selected and it is represented by the colour pink .

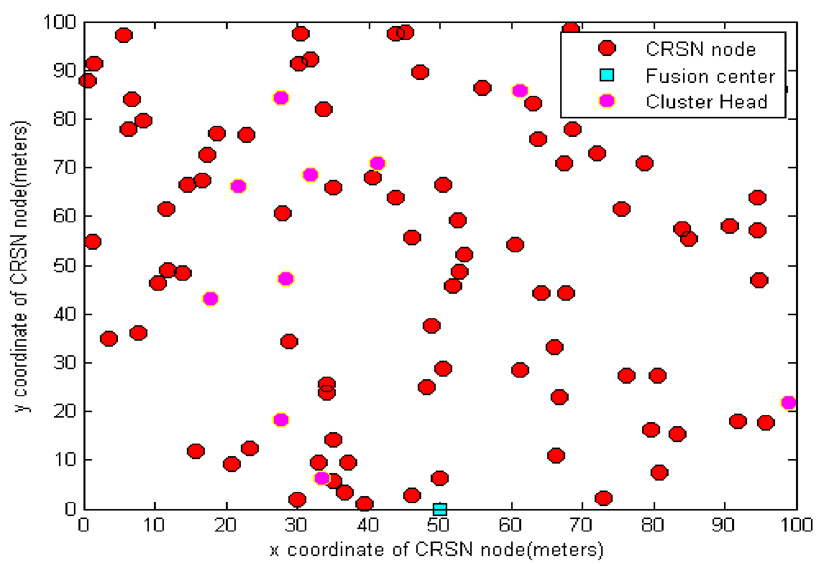

Figure 5.2: Cluster Head Display

c) Data Transmission from cluster head to fusion center : The figure below represents spectrum-aware pairwise coupling of different CRSN nodes and the transfer of data from cluster head to the fusion center.

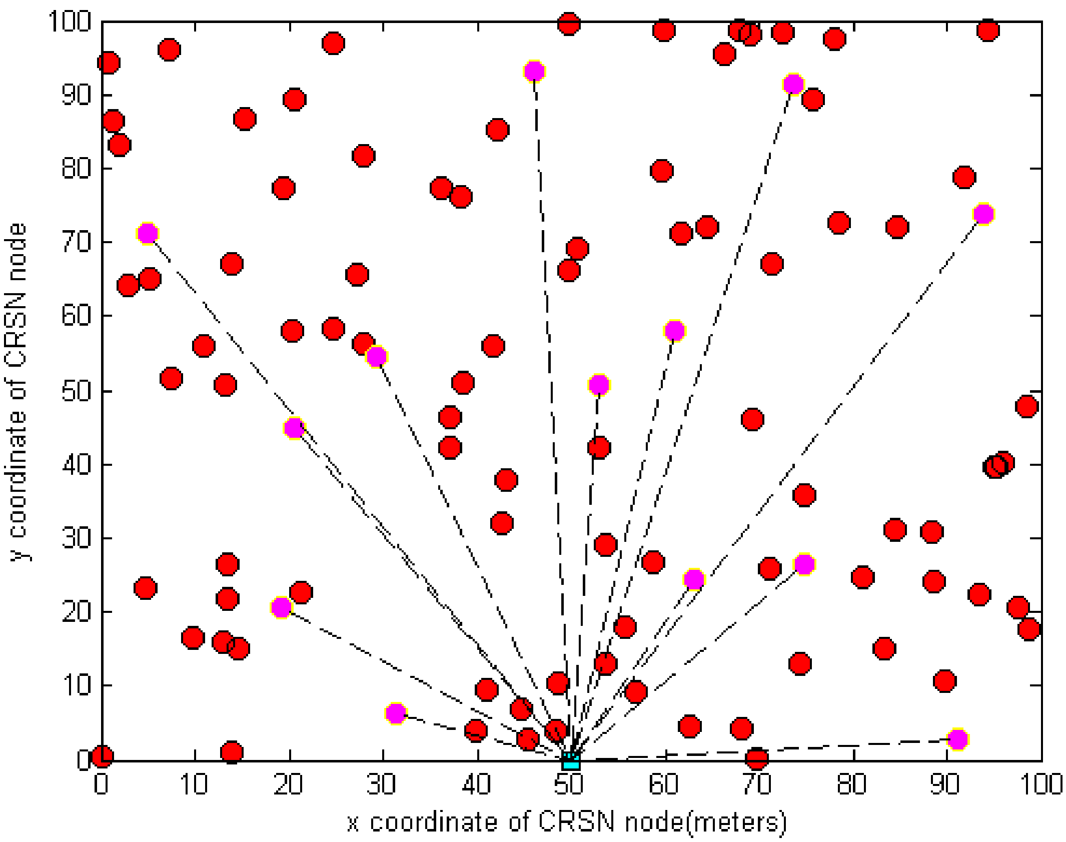

Figure 5.3: Data Transmission from cluster head to fusion center

d) Clustering using PSO scheme : This figure represents the formation of clusters using particle swarm optimization scheme .

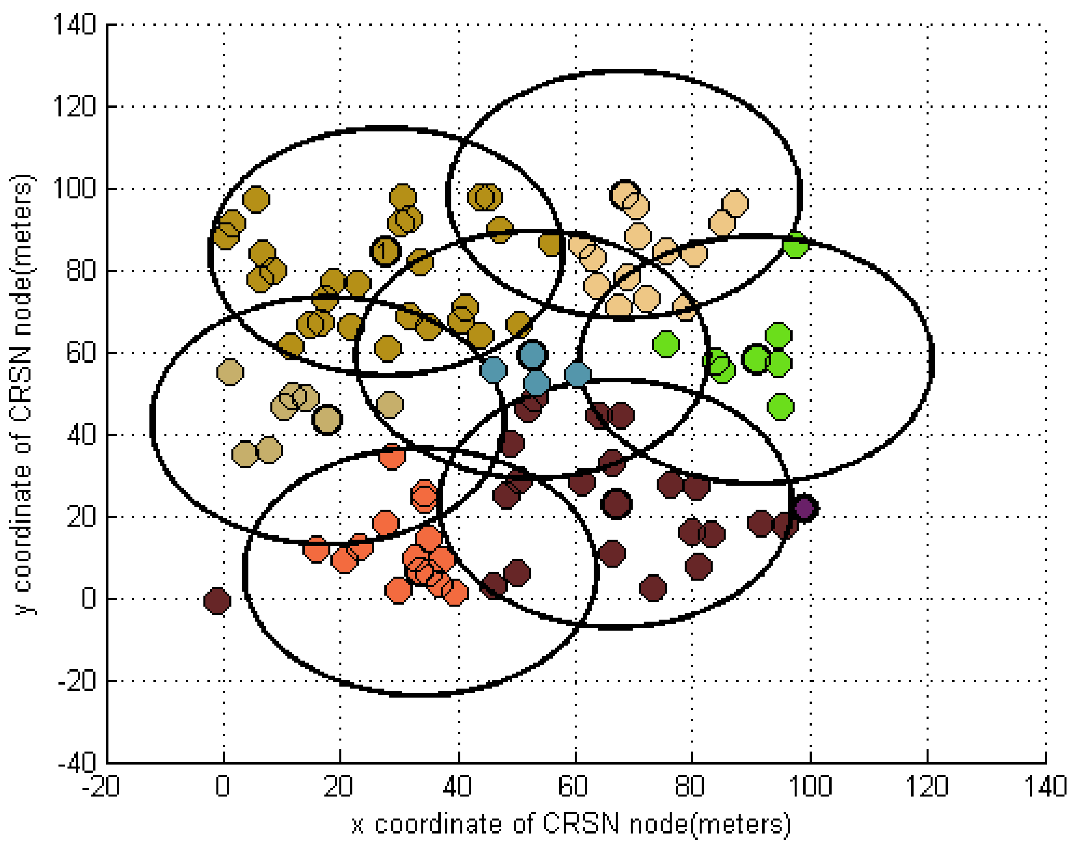

Figure 5.4: Clustering using PSO scheme

e) Comparison between PSO scheme and proposed scheme

The figure below provides a graph of the number of dead CSRN nodes against the number of rounds. This shows that the ECS scheme has a longer stability period than the PSO scheme. Under the ECS scheme, the 22 nodes died in 300 rounds, whereas the 47 nodes died in 300 rounds under the PSO scheme.

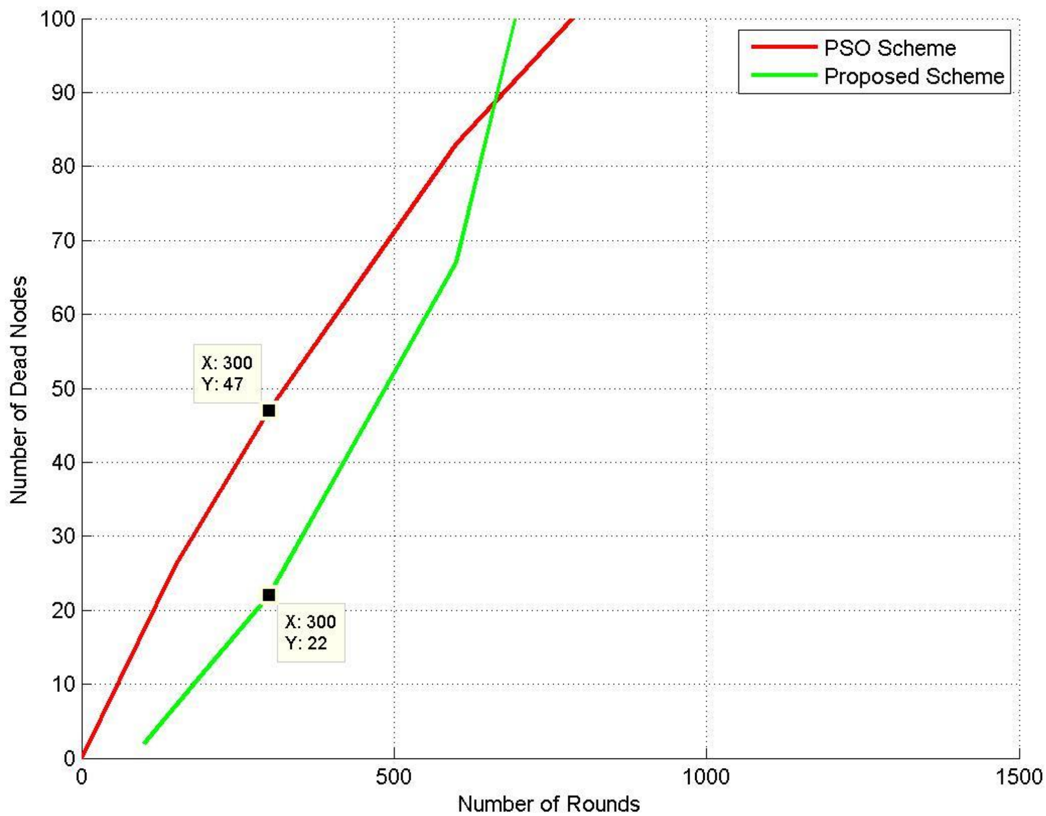

Figure 5.5: Number of Dead Nodes vs Number of Rounds

Initially all nodes are alive. In the Figure below, we can see that, out of 100 alive nodes, 85 nodes are alive after 300 rounds in the ECS scheme and 50 nodes are alive after 300 rounds in PSO scheme.

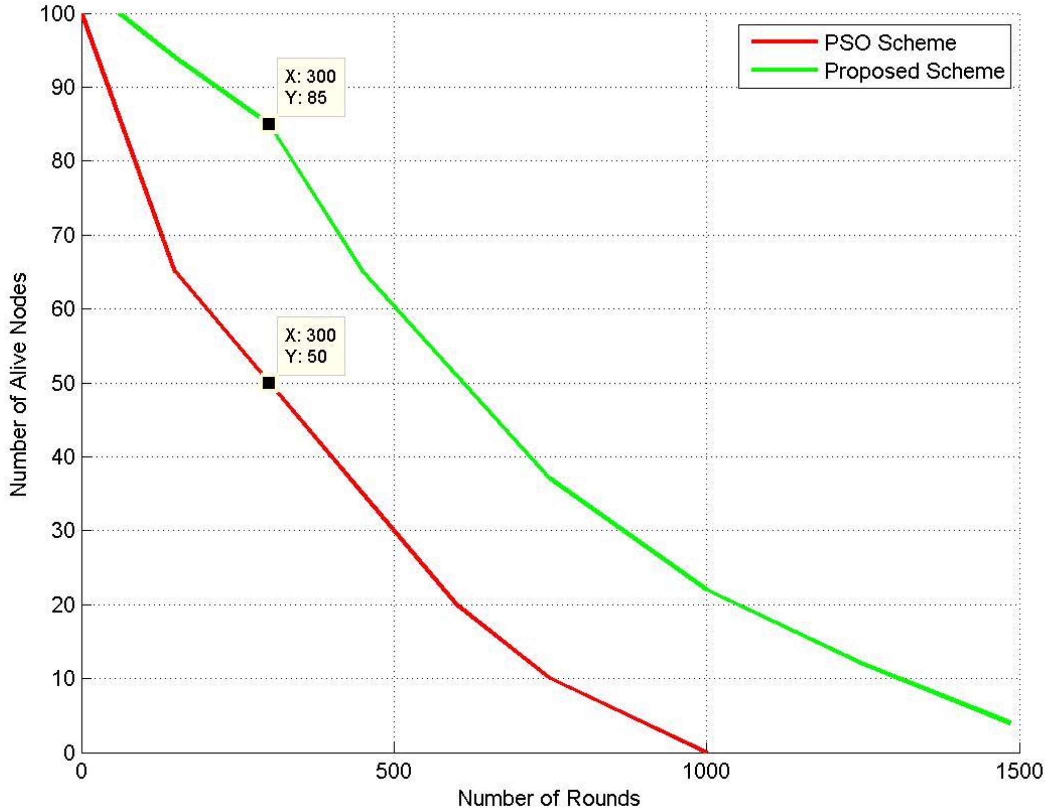

Figure 5.6: Number of Alive Nodes vs Number of Rounds

The figure below shows the data transmission to the fusion center against the number of rounds. Owing to the Sleep and Awake modes with our ECS scheme, there was less data transmitted to the fusion center compared to the PSO scheme. Under the PSO scheme, all nodes take part in data transmission.

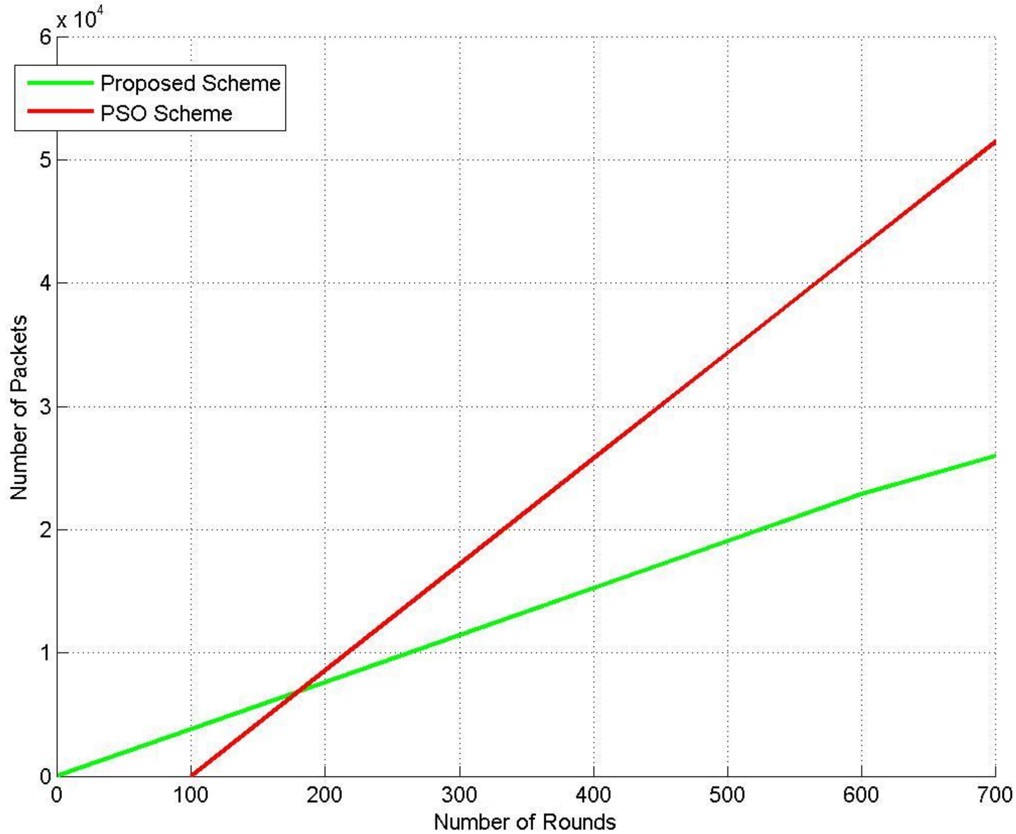

Figure 5.7: Number of Packets vs Number of Rounds

The figure below shows that the energy of the nodes becomes equal to zero after 1000 rounds in PSO scheme while in the proposed scheme does not become equal to zero even after 2000 rounds. Therefore this leads to greater network lifetime.

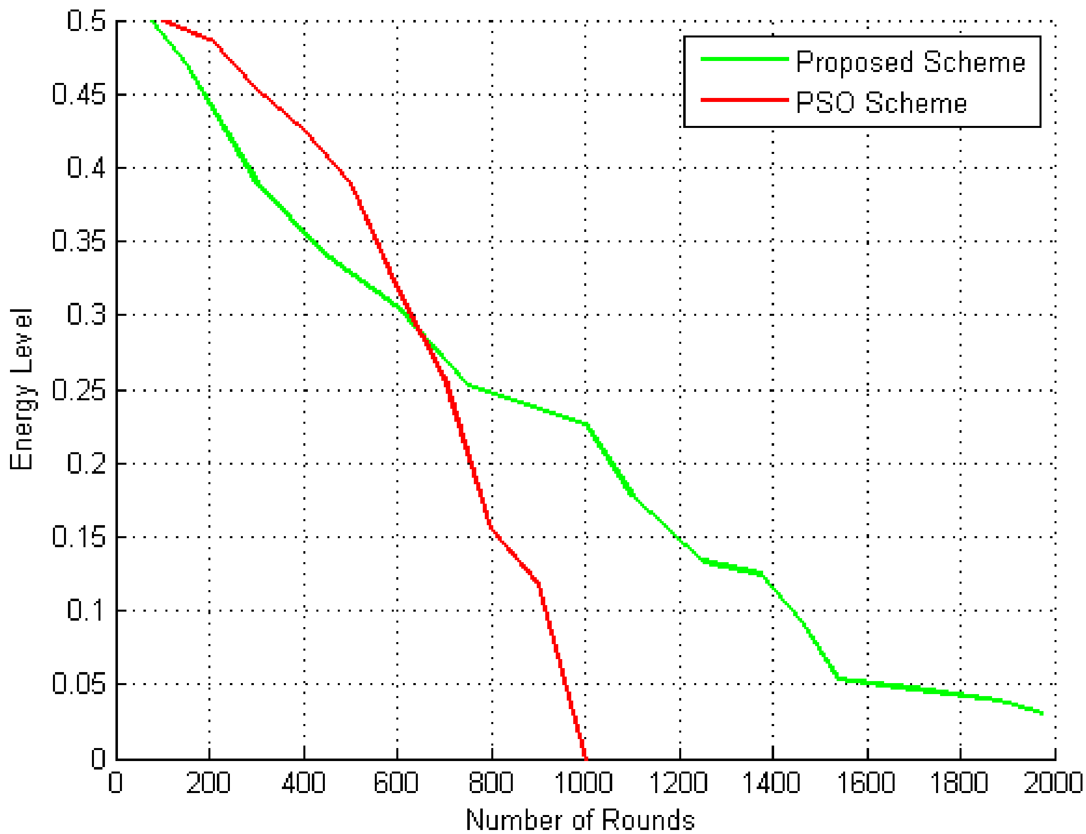

Figure 5.8: Energy Level vs Number of Rounds

CONCLUSION

The aim of our project was to enhance the energy efficiency of the cognitive radio networks so that the network lifetime and stability can be increased . Therefore in the ECS scheme , the spectrum aware pairwise coupling for sensor nodes was used. In order to minimize the consumed energy and lifetime of the network the coupled nodes alternate between sleep and awake modes. With the help of simulations , we have also demonstrated an improvement in lifetime and stability of the cognitive sensor networks.

REFERENCES

[1] E Hossain, D Niyato, Z Han, ”*Introduction to cognitive radio*,” in Dynamic Spectrum Access and Management in Cognitive Radio Networks, New York: Cambridge Univ. Press, 2009, pp. 39-53.

[2] I.F. Akyildiz, W.-Y. Lee, M.C. Vuran, S. Mohanty, “*NeXt generation/ dynamic spectrum access/cognitive radio wireless networks: a survey*”, Computer Networks, vol. 50,pp. 2127–2159, Sep. 2000..

[3] I.F. Akyildiz, W.-Y. Lee, K.R. Chowdhury, “*CRAHNs: cognitive radio ad hoc networks”*, Ad Hoc Networks, vol. 23, pp. 810–836, Aug. 2009.

[4] J. Ma, G. Li, B.H. Juang, “*Signal processing in cognitive radio*”, Proc. of the IEEE 97 , Atlanta, GA, vol.97, pp. 805–823, Apr. 2009.

[5] T. Yucek, H. Arslan, “*A survey of spectrum sensing algorithms for cognitive radio applications*”, IEEE Communications Surveys Tutorials, vol.11, pp.116–130, Mar. 2009.

[6] D. Cabric, S. Mishra, R. Brodersen, “*Implementation issues in spectrum sensing for cognitive radios*”, Proc. of Asilomar Conf. on Signals, Systems, and Computers, Pacific Grove, CA, vol. 1, pp. 772–776, Nov. 2004.

[7] E. Visotsky, S. Kuffner, R. Peterson, “*On collaborative detection of tv transmissions in support of dynamic spectrum sharing*”, Proc. of IEEE DySPAN ‘05, Baltimore, MD, pp. 338–345, Nov. 2005.

[8] A. Ghasemi, E. Sousa, “*Collaborative spectrum sensing for opportunistic access in fading environments*”, Proc. of IEEE DySPAN ‘05, Toronto Univ., Toronto, pp. 131–136, Nov. 2005.

[9] J. Unnikrishnan, V.V. Veeravalli, “*Cooperative sensing for primary detection in cognitive radio*”, IEEE Journal of Selected Topics in Signal Processing, vol. 2, pp. 18-27, Feb. 2008.

[10] Z. Li, F. Yu, M. Huang, “*A cooperative spectrum sensing consensus scheme in cognitive radios*”, Proc. of IEEE Infocom ‘09, Rio de Janeiro, Brazil, pp. 2546–2550, Apr. 2009.

[11] G. Ganesan, Y.G. Li, “*Cooperative spectrum sensing in cognitive radio—part I: two user networks*”, IEEE Transactions on Wireless Communications, vol.6, pp. 2204–2213, June. 2007.

[12] G. Ganesan, Y.G. Li, “*Cooperative spectrum sensing in cognitive radio—part II: multiuser networks*”, IEEE Transactions on Wireless Communications, vol.6, pp. 2204-2213, June. 2007.

[13] W. Zhang, K. Letaief, "*Cooperative spectrum sensing with transmit and relay diversity in cognitive radio networks*", IEEE Transactions on Wireless Communications, vol.7, pp. 4761–4766, Dec. 2008.

[14]J. Yick, B. Mukherjee, and D.Ghosal, "*Wireless sensor network survey*", Computer Networks, vol. 52, pp. 2292–2330, Aug. 2008.

[15] A. A. Abbasi and M. Younis, "*A survey on clustering algorithms for wireless sensor networks*", Computer Communications, vol. 30, pp. 2826–2841, 2007.

[16] G. Ganesan and Y. Li, "*Cooperative spectrum sensing in cognitive radio, part II: multiuser networks*", IEEE Transactions on Wireless Communications, vol. 6, pp. 2214–2222, June. 2007.

[17] S. M. Mishra, A. Sahai, and R. W. Brodersen, "*Cooperative sensing among cognitive radios*", Proc. of the IEEE International Conference on Communications (ICC '06), Istanbul, Turkey, pp. 1658–1663, Jul. 2006.

[18] O. B. Akan, O. B. Karli, and O. Ergul, "*Cognitive radio sensor networks*", IEEE Network, vol. 23, pp. 34–40, Aug. 2009.

[19] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "*Energy-efficient communication protocol for wireless microsensor networks*", Proc. of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, pp. 10, Jan. 2000.

[20] L.Qing, Q. Zhu, and M.Wang, "*Design of a distributed energyefficient clustering algorithm for heterogeneous wireless sensor networks*", Computer Communications, vol. 29, pp. 2230– 2237, 2006.

[21] H. Zhang, Z. Zhang, H. Dai, R. Yin, and X. Chen, "*Distributed spectrum-aware clustering in cognitive radio sensor networks*", Proc. Of the IEEE Global Telecommunications Conference (GLOBECOM '11), Houston, Tex, USA, pp. 1–6, Dec. 2011.

[22] H. Z. Zhang, Z. Y. Zhang, and C. Yuen, "*Energy-efficient spectrum-aware clustering for cognitive radio sensor networks*", Chinese Science Bulletin, vol. 57, pp. 3731–3739, 2012.