A NOVEL OPPORTUNISTIC CHANNEL STATE SELECTION MECHANISM BASED ON TIME SERIES PREDICTION IN COGNITIVE RADIO NETWORKS

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By

SAUMYA SRIVASTAVA

(Enrollment No. 1170454007)

Under the Supervision of

Mr. ASHUTOSH RASTOGI

[Assistant professor, BBDU]

BBD UNIVERSITY

To the

School of Engineering

BABU BANARSI DAS UNIVERSITY

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CERTIFICATE

It is certified that the work contained in this thesis entitled **“A NOVEL OPPORTUNISTIC CHANNEL SELECTION BASED ON TIME SERIES PREDICTION IN COGNITIVE RADIO NETWORKS”**, by **SAUMYA SRIVASTAVA (Roll No 1170454007),** for the award of Master of Technology from **Babu Banarasi Das University** has been carried out under the supervision of **Mr. Ashutosh Rastogi** and that this work has not been submitted elsewhere for a degree.

Supervisor	**Head of Department**
(Mr. Ashutosh Rastogi)	**(Dr. Nitin Jain)**
(Assistant Professor)	**(Professor)**
BBD University	**BBD University**

DECLARATION

I, **(Saumya Srivastava)** declare that the thesis titled "**A Novel Opportunistic Channel State Selection Mechanism Based on time series prediction in Cognitive radio Networks**" has been composed solely by me and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely by my own.

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ABSTRACT

With the increasing demand of wireless application, the insufficiency of the electromagnetic radio spectrum is getting more and more serious. Spectrum is regulated by governmental agencies that license their use to individuals or organisations on a long-term basis, normally over huge geographical regions. The Nov. 2002 report of the FCC speaks of spectrum access in many bands as a more significant problem than the scarcity of spectrum itself, owing mainly to the restrictions imposed by the legacy command-and-control regulations over the potential spectrum users [1]. Due to this, precious resources go wasted for large-frequency regions are used very sporadically.

Cognitive radio is a wireless technology that provides solution to meet scarcity of radio spectrum. Here to find out the busy states of any spectrum unit and selection of appropriate vacant channel for communication by secondary users are two important tasks . In this paper a new technique Navien Bayes classifier based on Bayes theorem has been applied to find out the minimum busy probability of any spectrum unit. Various predictions at various steps ,their switching probability, collision probability and throughput has been taken in the series. By using historical information of the licensed spectrum, the SU chooses the channel with the lowest busy probability within its service time for data transmission. Time series prediction is employed to forecast the near future busy probabilities of the licensed spectrum units.In this we applied the time slot scheme where the secondary user tries to prefer the least busy channel, into this we have divided them into various frequencies, and for each frequency we have provided certain time frame , then the busy probability at each prediction step has been found. There also we have done the mapping between various users and channel states.

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Saumya Srivastava

Roll no. 1170454007

BBD University

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LIST OF ABBREVATIONS

RF: Radio Frequency

CR: Cognitive Radio

PU: Primary User

SU: Secondary User

BS: Base Station

QOS: Quality of service

ITU: International Telecommunication Union

FCC: Federal Communications Commission

ADC: Analog-to-Digital converter

MDL: Minimum Description length

RKRL: Radio Knowledge Representation Language

SNR: Signal to noise Ratio

ASIC: Application-specific integrated circuit

CSI: Channel state information

SDR: Software Define Technology

PCS: Personal Communication Services

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Radio frequency (RF) spectrum is a treasured but tightly regulated resource due to its particular and critical position in wi-fi communications. With the proliferation of wi-fi offerings, the needs for the RF spectrum are continuously growing, main to scarce spectrum sources. On the opposite hand, it's been stated that localized temporal and geographic spectrum utilization is extremely low [1]. Currently, new spectrum policies are being developed by means of the Federal Communications Commission (FCC) in order to allow secondary users to opportunistically get entry to a licensed band, when the primary consumer (PU) is absent. Cognitive radio has end up a promising strategy to remedy the spectrum scarcity hassle inside the subsequent technology cell networks with the aid of exploiting possibilities in time, frequency, and space domain names [2],[3]. Cognitive radio is a complicated software-defined radio that robotically detects its surrounding RF stimuli and intelligently adapts its operating parameters to network infrastructure whilst meeting consumer needs. Since cognitive radios are taken into consideration as secondary users for the use of the licensed spectrum, a essential requirement of cognitive radio networks is they have to successfully take advantage of below-utilized spectrum (denoted as spectral opportunities) with out inflicting dangerous interference to the PUs. Furthermore, PUs haven't any obligation to share and change their running parameters for sharing spectrum with cognitive radio networks.

Hence, cognitive radios have to be capable of independently locate spectral possibilities without any assistance from PUs; this capacity is referred to as spectrum sensing, that's taken into consideration as one of the maximum vital components in cognitive radio networks. Many narrowband spectrum sensing algorithms have been studied within the literature [4] and references therein, which includes matched-filtering, strength detection [5], and cyclostationary function detection. While present narrowband spectrum sensing algorithms have targeted on exploiting spectral opportunities over slender frequency range, cognitive radio networks will eventually be required to make the most spectral possibilities over wide frequency range from masses of megahertz (MHz) to several gigahertz (GHz) for achieving better opportunistic throughput. This is pushed by the famous Shannon's system that, underneath sure situations, the maximum theoretically doable bit charge is without delay proportional to the spectral bandwidth. Hence, special from narrowband spectrum sensing, wideband spectrum sensing pursuits to discover extra spectral opportunities over extensive frequency range and attain better opportunistic combination throughput in cognitive radio networks. However, conventional wideband spectrum sensing techniques based on widespread analog-to-virtual converter (ADC) could lead to unaffordably high sampling fee or implementation complexity; accordingly, progressive wideband spectrum sensing strategies end up increasingly critical.

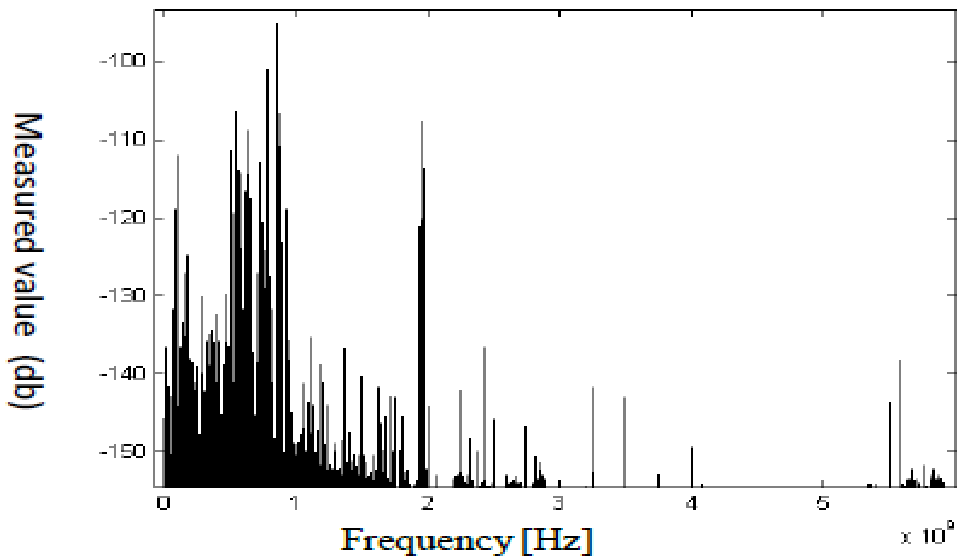

Fig 1.1 Measurement of Spectrum utilization at BWRC

In sensor array processing, it's miles important to determine the number of signals acquired by means of an antenna array from a finite set of observations or snapshots. A comparable trouble arises in line spectrum estimations. The range of assets must be determined efficaciously with a view to reap good performance for excessive-resolution course finding estimates. A lot of work has been published concerning the version order selection problem. Estimating the quantity of resources is traditionally idea of as being equal to the dedication of the number of eigen values of the covariance matrix which can be distinctive from the smallest eigen value[24]. Such an method leads to a rank discount principle that allows you to separate the noise from the sign eigen values. Anderson gave a hypothesis testing technique based totally on the self belief c language of the noise eigenvalue, in which a threshold fee must be assigned subjectively. He showed that the log-chance ratio to the range of snapshots is asymptotic to a $\chi 2$ distribution. For a small quantity of snapshots, James delivered the concept of "changed records".Chen et al. Proposed a technique primarily based on an a priori at the remark probability density characteristic that detects the number of assets gift by putting an top certain on the price of the eigenvalues. For thirty years facts theoretic standards (ITC) procedures have been broadly counseled for detection of multiple resources [6]. The excellent acknowledged of this test circle of relatives are the Akaike facts criterion (AIC) [7] and the minimum description length (MDL) [8–10]. Such criteria are composed of two phrases. The first relies upon on the facts and the second is a penalty term concerning the wide variety of unfastened parameters (parsimony). The AIC is not constant and tends to over-estimate the wide variety of assets present, even at high sign-to-noise ratio (SNR) values. While the MDL technique is regular, it tends to underneath-estimate the quantity of resources at low and slight SNR. A theoretical assessment is given of the possibility of over and under estimation of supply detection methods which include the AIC and MDL, under the assumption of asymptotical situations [11]. In an attempt to mild the conduct of the AIC and MDL techniques a changed ITC method is proposed, which makes use of the marginal p.D.F. Of the pattern eigenvalues because the log-chance characteristic [12].

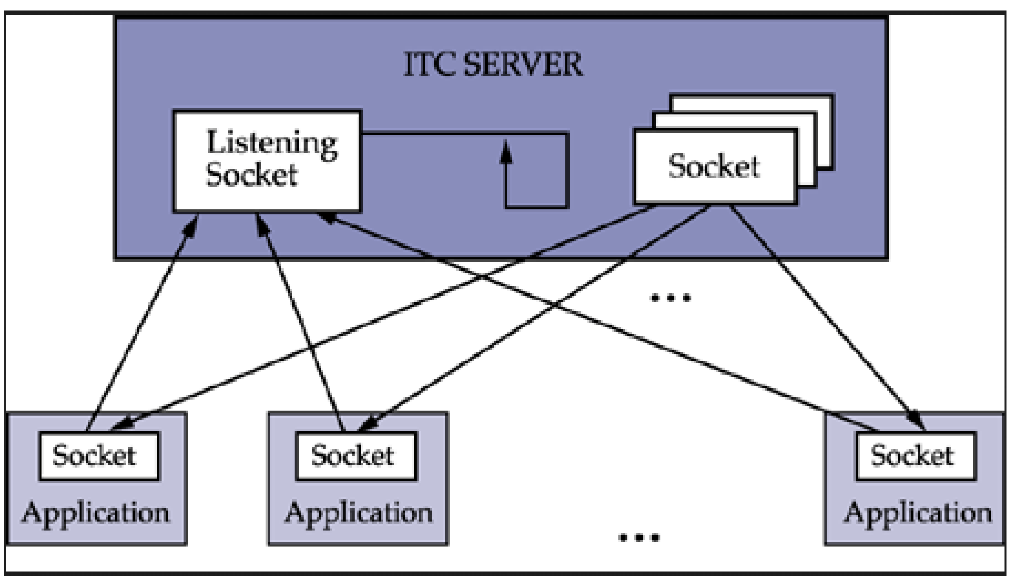

Fig 1.2 ITC Approach

A widespread ITC is proposed wherein the primary term of the criteria may be decided on from a fixed of suitable capabilities [24]. Then a parametric approach is proposed as an alternative technique of defining the primary term of this criterion [29]. Using Bayesian method, an opportunity to the AIC and MDL techniques is proposed [30] wherein the penalty towards over-parameterization changed into now not impartial of the statistics

A Global System for Mobile Communications (GSM) radio's equalizer faucets replicate the channel multipath shape. A community might need to invite a handset, "How many distinguishable multipath additives are you seeing?" Knowledge of the internal states of the equalizer may be useful due to the fact in some reception areas, there can be little or no multipath and 20 dB of extra signal-to-noise ratio (SNR). Software radio processing ability is wasted strolling a computationally in depth equalizer set of rules when no equalizer is necessary. That processing capability may be diverted to better use, or part of the processor might be placed to sleep, saving battery existence. In addition, the radio and community may want to agree to put information bits within the superfluous embedded schooling sequence, enhancing the payload data price thus.

Here wo troubles arise. First, the network has no fashionable language with which to pose a question approximately equalizer faucets. Second, the handset has the answer inside the time-area structure of its equalizer taps, however can't get entry to this records. It has no computational description of its personal shape. Thus, it does no longer "recognise what it is aware of." Standards-putting bodies have been steadily making such internal information to be had to networks through particular air interfaces, because the wishes of the era dictate. This labor-intensive method takes years to accomplish. Radio Knowledge Representation Language (RKRL), then again, offers a wellknown language inside which such unanticipated records exchanges can be defined dynamically. Why might the need for such unanticipated exchanges get up? Debugging new software radio downloads would possibly require get admission to to internal software program parameters. Creating non-public offerings that differentiate one service provider from some other might be more suitable if the provider does now not need to show new ideas to the competition in the requirements-setting method. And the time to deploy those personalised services may be decreased. Cognitive radio, via RKRL, is aware of that the natural language word equalizer taps refers to precise parameters of a tapped delay-line structure. This structure can be applied in an software-particular included circuit (ASIC), a field programmable gate array (FPGA), or an algorithm in a software radio. Since a cognitive radio has a model of its own internal shape, it can check the version to discover how the equalizer has been implemented. It then may additionally retrieve the register values from the ASIC (e.G., the use of a JTAG port) or find the taps in the proper reminiscence area of its software implementation. A radio that knows its own internal shape to this diploma does not have to look forward to a consortium, discussion board, or standards frame to outline a level H33492.X7 radio as one that can get entry to its equalizer taps. The network can pose such an unanticipated question in (a widespread) RKRL, and any RKRL-capable radio can answer it.

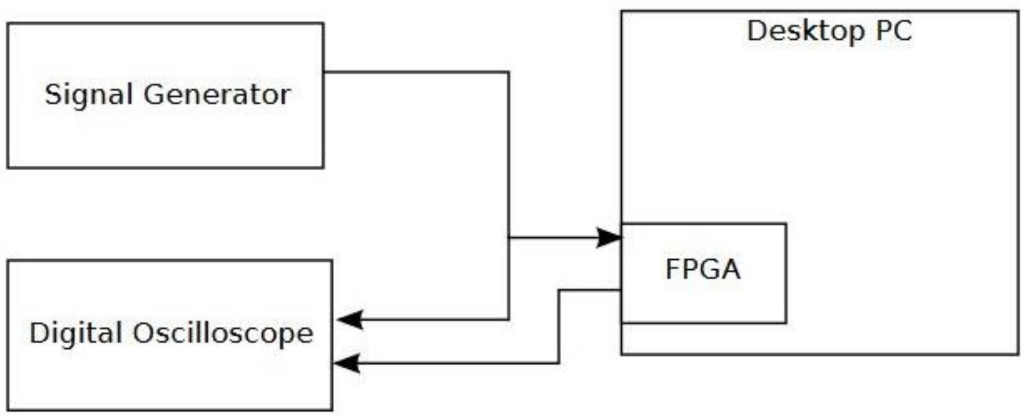

Fig. 1.3: FPGA Approach

To permit any such situation, cognitive radio has an RKRL model of itself that includes the equalizer’s structure and characteristic, as illustrated in Fig. 1.1. In this situation, the radio hardware includes the antenna,the radio frequency (RF) conversion module, the modem, and the opposite modules shown inside the hardware part of the figure. The baseband processor consists of a baseband modem and a again-give up control protocol stack. In addition, this processor includes a cognition engine and a hard and fast of computational models. The models encompass RKRL frames that describe the radio itself, inclusive of the equalizer, within the context of a complete ontology, additionally written in RKRL. Using this ontology, the radio can music the consumer’s environment through the years and area. Cognitive radio, then, matches its inner fashions to external observations to apprehend what it means to shuttle to and from paintings, take a enterprise journey to Europe, pass on excursion, and so on. Clearly, extensive memory, computational resources, and communications bandwidth are wished for cognitive radio, so this era won't be deployable for a while. In addition, a group of cognitive radios won't require human intervention to expand their own protocols. Initially, intervention will be required so that you can make certain that networks of such radios stay stable (or that we realize who in charge if this isn't always the case). Networks of such radios are complicated adaptive systems [33], the look at of that's an rising discipline involved with the nonlinear conduct of huge collections of adaptive entities which have complex interactions. Although there are many technical demanding situations, the possibilities for stronger private services encourage the development of **cognitive radio.**

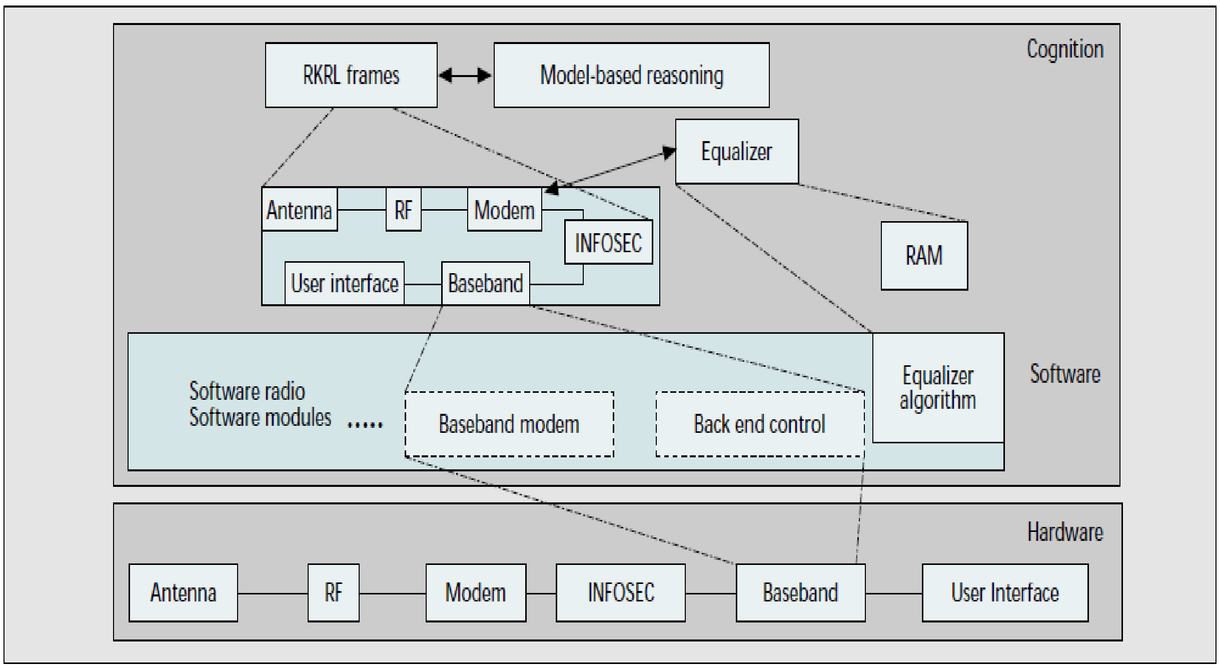

Fig. 1.4: Cognitive radio [33].

1.2 INTODUCTION

The Orient-level makes a decision at the urgency of the communications in element from those cues if you want to lessen the burden on the person. **The Plan-level** generates and evaluates options, including expressing plans to peers and/or the network to acquire advice. **The Decide stage** allocates computational and radio resources to subordinate (conventional radio) software. **The Act-stage** initiates obligations with special assets for exact quantities of time. If the primary battery has simply been removed, however, the Orient-degree might without delay invoke the Act-level to shop facts vital for a swish begin-up after shutdown. Cognitive radio also includes a few types of supervised and unsupervised gadget mastering. Cognitive radio is a aim-pushed framework wherein the radio autonomously observes the radio surroundings, infers context, assesses options, generates plans, supervises multimedia offerings, and learns from its mistakes. This have a look at-assume-act cycle is radically one-of-a-kind from these days's handsets that either blast out at the frequency set through the person, or blindly take instructions from the network. Cognitive radio technology for this reason empowers radios to study extra bendy radio etiquettes than turned into feasible inside the past.

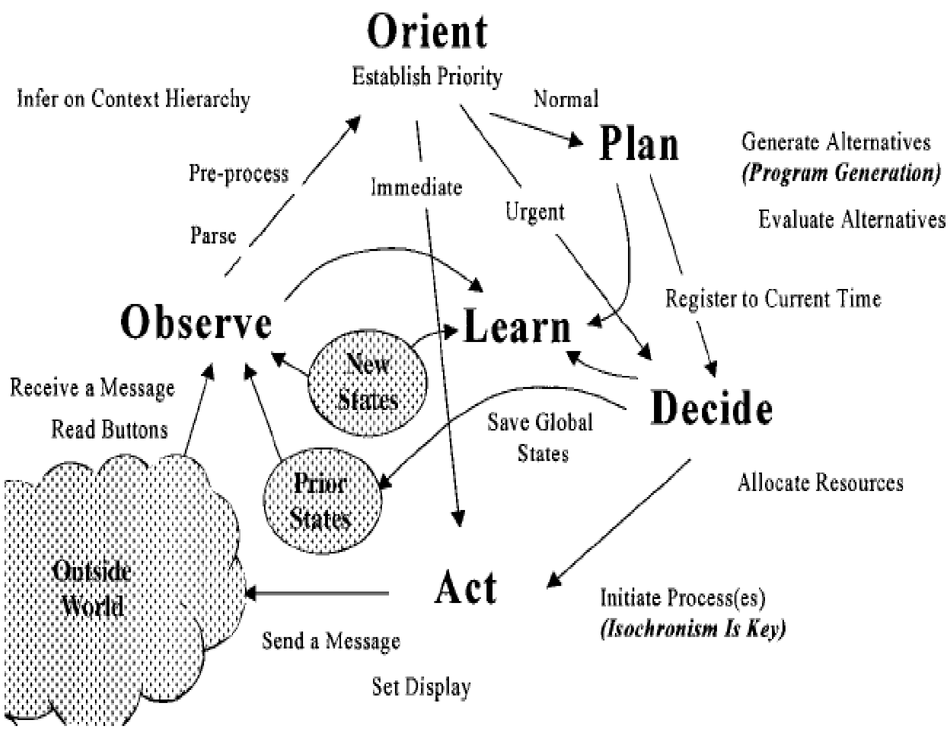

Fig 1.5: The cognition cycle [4].

1.2.1 Pooling strategy:

Present business wireless architectures are network centric and confined by spectrum allocations. Nick Negroponte [5] pointed the manner together with his spectrum management set of rules of the future: "If it actions, supply it spectrum; if it doesn't, give it fiber." A barely more achievable method on hand thru SDR and cognitive radio might be to pool mobile spectrum: "If it actions, supply it spectrum pool priority; if it doesn't, make it pay." Satellites and plane flow swiftly and/or cowl massive areas, so the bands devoted to those motors would no longer be pooled.

Spectrum pooling each increases the number of sites and integrates the multi-mode spectrum in order that the portions needed for multimedia wireless packages are extra affordable. But the cognitive radios could rent out the fast-time period locally available spectrum that isn't always instantaneously in use, establishing spot prices as a characteristic of time, bandwidth, interference tiers, radiated strength, location, and possibly other parameters. Cognitive radios could lease spectrum for a 2nd (e.G., to upload a short e-mail message), a minute (e.G., for a part of a voice call), an hour (e.G., for a video teleconference) or more. Spectrum control authorities might set up the overall etiquettes and constraints, however the marketplace might set the rate.

Cognitive radios might use their spectrum consciousness and intention-driven behavior to collectively assure conformance to etiquette, and to become aware of and document offenders to human authorities. Such a pooled spectrum method should accomplish dynamically with allotted control era what could not be pondered with these days's centralized allocation-primarily based manipulate – the fee powerful green pooling of previously scarce mobile radio spectrum for honest and equitable use when and wherein wanted.

1.2.2. Pooled Mobile Spectrum Parameters:

The legal guidelines of physics impose limits on the spectrum this is beneficial for pooled terrestrial cellular-multimedia programs. The HF bands and beneath, for instance, have constrained bandwidth (practically speakme, some tens of kHz,). HF also propagates for thousands of miles, a range that exacerbates co-channel interference. Bands above 6 GHz depend on directional antennas for reasonable statistics fees at affordable tiers. HF and higher SHF are consequently now not appropriate. The 4 spectrum swimming pools of table 1, but, are perfectly suited to cell packages. The notion of spectrum pooling was first introduced in . In this resource-sharing strategy called spectrum pooling the primary user would get the highest priority. Once a primary user appears in a frequency band all secondary users transmitting in this band would have to leave immediately, giving priority to the primary user. A cognitive radio-based spectrum pooling concept has been developed in . A COg-nitive Radio approach for Usage of Virtual Unlicensed Spectrum (CORVUS), a vision of a cognitive radio-based approach that uses allocated spectrum in a opportunistic manner to create virtual unlicensed bands.

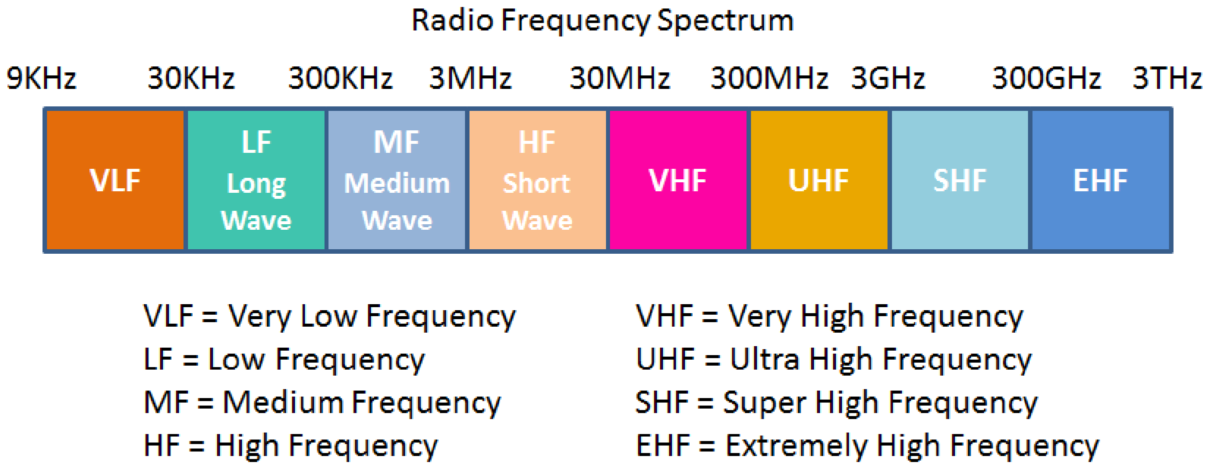

Fig 1.5 Division of the radio spectrum and radio Ranges

The **very low band** of this cell spectrum regime penetrates homes and propagates properly in rugged terrain. The **low band** has the quality propagation for excessive-velocity terrestrial mobile traffic, in element, due to the fact auto and rail traffic is supported with exceptionally low infrastructure density. The **mid band** is best for Personal Communications Services (PCS) with its better infrastructure density. In addition, the excessive band has the big coherent bandwidth for excessive statistics fee Internet and cellular video teleconference applications. 3G waveforms could be used in any of those bands, however are first-rate perfect for the low and mid bands. Wc is the entire spectrum that might participate inside the spectrum pool primarily based on an analysis of US, Canadian, and UK spectrum allocations [4]. Wc does not consist of satellite, plane, radio navigation, astronomy, or amateur bands, which are not acceptable for pooling. The pooling concept is illustrated in fig 1.Three.

A cognitive radio-get entry to community may want to evolve the working parameters shown in desk 1.2. For simplicity, the complete populace offers load (one hundred% penetration). With pooling, each cellular outdoor user would have a median of 432 kbps. This assumes today's infrastructure density and 2G-equal bandwidth efficiency (0.2 Mbps/MHz/cell). These rates are gross data fees not discounted for Quality of Service (QoS), which can lower these charges substantially if low bit blunders charges are required (e.G., for document transfers) [8]. They additionally do not include signaling overhead. On the other hand, 3G technology is supposed to obtain zero.Forty five Mbps/MHz/cell, so the fees are consultant of the range of quotes attainable with a mixture of 2G and 3G era. With spectrum pooling, then, multimedia bandwidths can be performed with out a chief increase in the variety of mobile sites. In component, the participation of public centers increases the wide variety of web sites. In addition, the pooling of spectrum is greater green than block allocations. Through cognitive radio etiquette, police, fireplace, and rescue devices participating in spectrum pooling could have priority for spectrum. They can also communicate seamlessly through the shared SDR cellular sites.

Table 1.1 Mobile Spectrum Pools

Band	RF_{min}(MHz)	RF_{max}(MHz)	W_c	Remarks
Very Low	26.9	399.9	315.21	Long range vehicular traffic
Low	404	960	533.5	Cellular
Mid	1390	2483	930	PCS
High	2483	5900	1068.5	Indoor and LANs

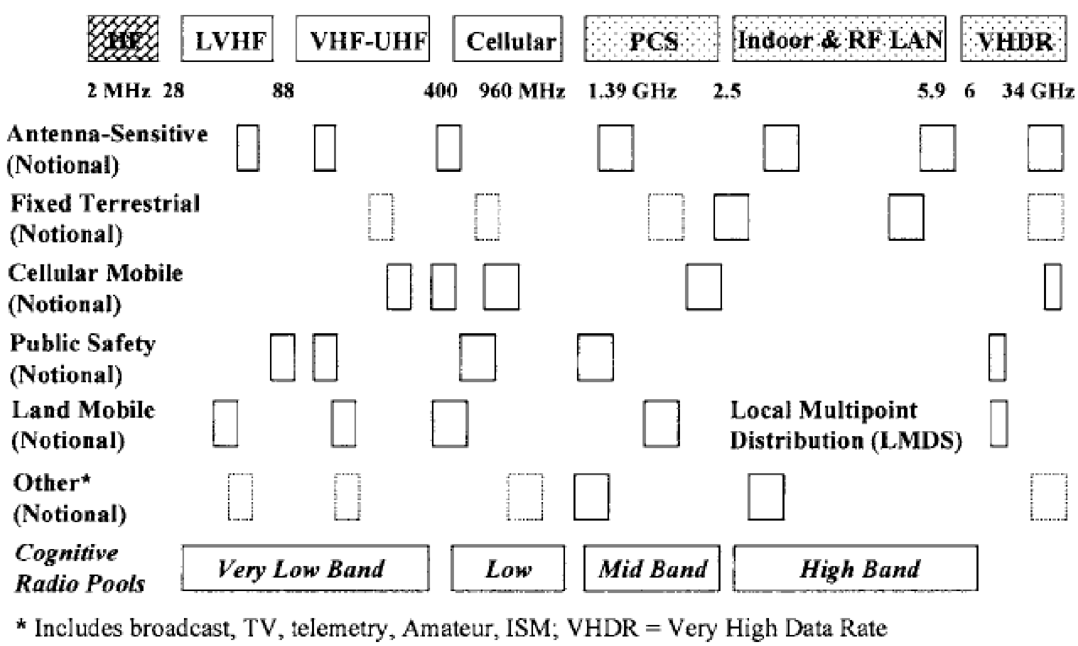

Fig. 1.6: Fixed allocations versus pooling with cognitive radio etiquette [8].

Table 1.2:Illustrative cognitively pooled radio access network parameters

Parameter	Illustrative range of values	Remarks
Total spectrum	0.4–2.5 GHz	1.463 GHz pooled
Duplexing	Frequency Domain (FDD)	Evolved from cellular services
Voice channel	8 1/3 kHz-equivalent, TDMA or CDMA	Evolved from second generation
Channels per cell	25088	Usable, including 6:1 reuse and FDD
Coverage area	4000 square kilometers	The size of Washington, DC
Number of cells	40 commercial (plus 40 public sites[a])	5.5 km average cell radius (3.9 km)
Population	609,000	The entire population of Washington, DC
Offered demand	0.1 Erlang	Multimedia level (vs. 0.02 for voice user)
Demand per cell	1522 Erlang	Drops to 761 considering public cell sites
Spectrum per user	160.7 kHz (320.4 kHz with public sites)	0.22–0.64 Mbps/user (0.4–1.28 Mbps)

1.3 MOTIVATION

With the ever developing call for for spectrum in the unlicensed consumer structures (e.G., cellular Internet), dynamic spectrum allocation techniques should be followed. Recently, the U.S. Federal Communications Commission (FCC) has accepted the opportunistic use of TV spectrum via unlicensed customers [1]. This idea may be extended to other certified person systems thru the cognitive radio (CR) era [2]. Under the CR era, a certified consumer is called the primary person even as an unlicensed consumer is called the secondary user because of the concern in accessing the licensed person spectrum. In most of the cases, the secondary customers in a cognitive radio network (CRN) logically divide the channels allotted to the primary user spectrum into slots [3]. The slots left unused by way of the number one user are referred to as spectrum holes or white spaces [2]. Within each slot the secondary person has to sense the primary user pastime for a short period and therefore accesses the slot when it's far sensed idle. The spectrum get right of entry to by using the secondary consumer must now not motive any dangerous interference to the primary consumer. To decrease the interference to the primary customers, the secondary users want a dependable spectrum sensing mechanism. Several spectrum sensing mechanisms had been proposed in literature [4--6]; in a number of which the secondary users are assumed so one can feel the entire spectrum. However, the secondary users are normally low-price battery powered nodes. Due to the hardware constraint, they could feel most effective part of the spectrum [7]. On the opposite hand, because of the power constraint, the secondary customers might not have the willingness to waste strength to sense the spectrum component which could be very likely to be busy. Hence, the key problem is to let the secondary customers efficaciously and effectively sense the channels inside the licensed spectrum without losing a good deal energy.

One manner to alleviate this hassle is, via the use of spectrum sensing guidelines [8,9]. The spectrum sensing guidelines distribute the spectrum sensing operation among specific companies of nodes. These businesses sense distinctive portions in the licensed spectrum and proportion the sensing outcomes with each other. Thus, complete knowledge of the number one user hobby inside the licensed spectrum is received. Alternately, the spectrum sensing module can be made electricity efficient by way of combining the sensing operation with a channel reputation prediction mechanism. The secondary user may additionally are expecting the status of a channel based totally on the beyond sensing effects and experience only if channel is expected to be idle in next time slot. Thereby, the secondary person can also use its sensing mechanism resourcefully. Besides, the usage of channel reputation prediction, the powerful bandwidth within the next slot can be envisioned which permits the secondary customers to regulate the facts fees in advance. The handiest way to design a channel status predictor is to use linear adaptive filters [10], which require the statistics of the licensed channel's usage (e.G., 2d order facts like autocorrelation or even higher order information). However, in most of the primary consumer systems, the channel usage information are difficult to obtain a priori (e.G., cellular band, public safety band, and microwave). Therefore, we discover the predictor layout based on two adaptive schemes which do no longer require a priori information of the facts of channel usage.

1.4. CONTIBUTION AND OUTLINE

In this work, we show the benefits of channel reputation prediction to the spectrum sensing operation in terms of enhancing the spectrum usage (SU) and saving the sensing energy (SE). Specifically, we gift two adaptive channel repute prediction schemes. For the primary scheme, we suggest a neural network technique the usage of naïve bayes classifier [11], whereas for the second one scheme,]. A qualitative evaluation of the 2 channel popularity prediction schemes is finished. We compare the accuracy of the two prediction schemes in terms of the wrong prediction chance, denoted by Pe p(Overall). Of unique hobby is the incorrect prediction probability (i.E., misdetection opportunity) given the actual channel reputation is busy, denoted with the aid of Pe p(Busy). Pe p(Busy) is an crucial degree from the number one person's point of view as it indicates the level of interference to the number one consumer. Pe p(Overall) is an critical degree from a secondary person's angle because the aim of the secondary user is to reduce the interference to the primary customers whilst maximizing its own transmission opportunities.

The rest of the work is prepared as follows:

Chapter 1: This chapter includes general instruction, background, overview of cognitive radio , motivation, and contribution of this particular work.

Chapter 2: We present the overview of cognitive radio network , most of the elements we tried to cover in this part as in basic features , cognitive radio cycle , its functions and the previous work done by other authors related to this field.

Chapter 3: We propose the channel status prediction technique using naive bays classifier In this we discuss about the bays theorem, as in the naïve bays classifier is based on it, moreover the posterior probability and prior probability.

Chapter 4: This chapter induces the simulation results for the prediction schemes and demonstrate the effect of the two channel status prediction schemes on throughput, normalized mean square error, switching and collision probability .

Chapter 5: Finally, chapter 5 concludes this work with limitations and future scope.

1.5. METHODOLOGY

The prediction of actual international behavior can be accomplished both by way of simulating the gadget or via the use of theoretical analysis. The channel choice method, besides simulation experiments, is considered to be from the main trendy methodologies within the telecommunication, laptop technological know-how and laptop engineering. Theoretical analysis method appears to be cheaper and faster answer , whereas, simulation approach can be used when the mathematical version of the gadget may be very complex. However , simulation approach is an steeply-priced and time consuming solution . On this thesis each tactics are used to analyse the proposed models. For the simulation method, the discrete event simulation MATrix LABoratory (MATLAB) package deal device is used to analyse the postpone performance measures , such s the throughput, normalized suggest rectangular error, switching and collision possibility and the others . Recently, MATLAB has been broadly used in simulating and reading communication networks and it offers proper approximations for exponentially distributions traffic. For the theoretical evaluation method, the well- regarded naive bayes classifier method is used to model the corresponding proposed models.

CHAPTER : 2

LITERATURE SURVEY

2.1 INTRODUCTION

The electromagnetic radio spectrum is a herbal aid, the use of which by using transmitters and receivers is certified by using governments. In November 2002, the Federal Communications Commission (FCC) published a record prepared by means of the Spectrum-Policy Task Force, aimed toward improving the way in which this precious aid is managed inside the United States. The venture pressure become made up of a group of high-level, multidisciplinary expert FCC body of workers—economists, engineers, and attorneys—from across the commission's bureaus and places of work. Among the challenge pressure main findings and guidelines, the second finding is as an alternative revealing inside the context of spectrum usage: "In many bands, spectrum get entry to is a extra considerable hassle than bodily shortage of spectrum, in massive component because of legacy command-and-manipulate regulation that limits the capacity of ability spectrum users to achieve such get right of entry to." Indeed, if we had been to experiment quantities of the radio spectrum including the sales-wealthy city regions, we'd locate,

- some frequency bands in the spectrum are largely unoccupied most of the time;
- some other frequency bands are only partially occupied;
- the remaining frequency bands are heavily used.

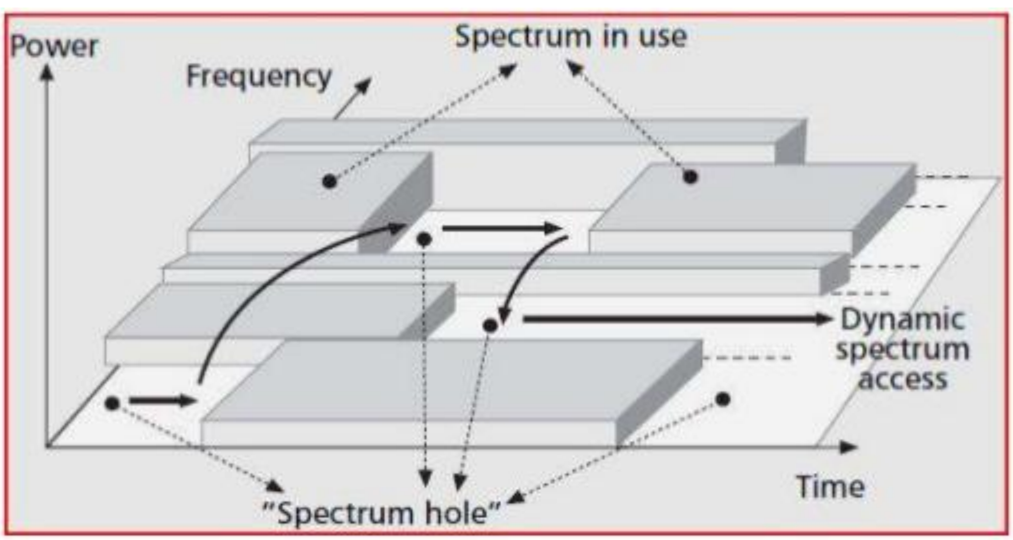

Fig 2.1 Spectrum Hole

“A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user.”

Spectrum usage can be progressed notably by using making it feasible for a secondary consumer (who is not being serviced) to access a spectrum hollow unoccupied by using the number one person at the right area and the time in query. Cognitive radio [33], such as software-described radio, has been proposed as the manner to sell the efficient use of the spectrum with the aid of exploiting the existence of spectrum holes. But, first and most important, what do we mean via cognitive radio? Before responding to this query, it's far in order that we deal with the meaning of the related time period “cognition.” According to the Encyclopedia of Computer Science, we've a three-factor computational view of cognition.

1) Mental states and processes intervene between input stimuli and output responses.

2) The mental states and processes are described by algorithms.

3) The mental states and processes lend themselves to scientific investigations.

2.2 AN OVERVIEW OF COGNITIVE RADIO

2.2.1 Introduction

CR consumer can skip sensing the ones channels which can be predicted to be busy, for this reason saving the sensing time as well as energy. Figure 2 shows the change off between spectrum sensing time and spectrum get admission to time

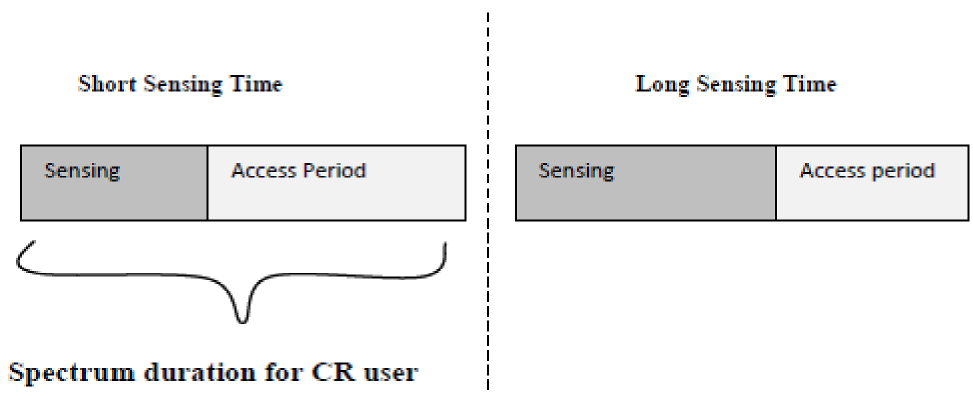

Fig 2.2. Trade-off between Spectrum Sensing Time and Access Time

For reconfigurability, a cognitive radio appears naturally to software- described radio to carry out this project. For other responsibilities of a cognitive type, the cognitive radio appears to sign-processing and gadget-gaining knowledge of techniques for their implementation. The cognitive process starts offevolved with the passive sensing of RF stimuli and culminates with movement. In this, we awareness on three on line cognitive duties:

1) Radio-scene analysis, which encompasses the following:

- estimation of interference temperature of the radio environment;
- detection of spectrum holes.

2) Channel identification, which encompasses the following:

- estimation of channel-state information (CSI);
- prediction of channel capacity for use by the transmitter

3) Transmit-power control and dynamic spectrum management.

2.2.2 Cognitive Radio

A cognitive radio (CR) is a radio that can be programmed and configured dynamically to apply the fine wi-fi channels in its area to avoid consumer interference and congestion. Such a radio automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to permit more concurrent wireless communications in a given spectrum band at one region. This manner is a form of dynamic spectrum control.

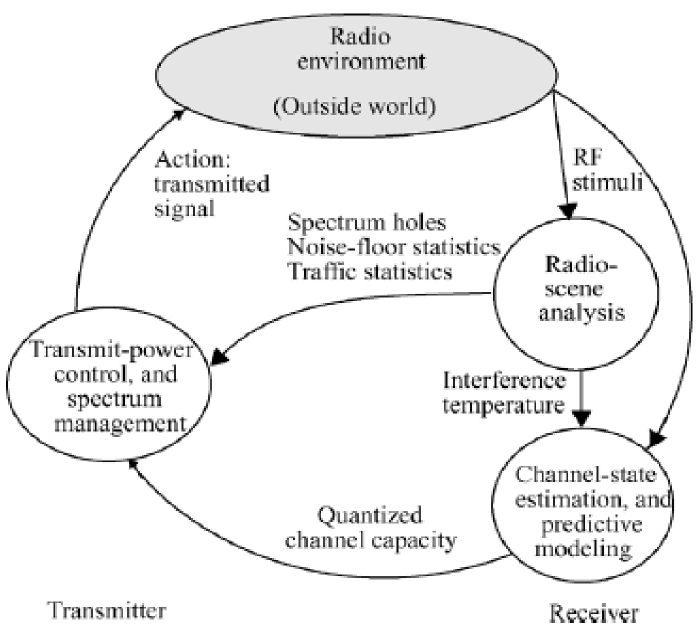

Fig 2.3 Cognitive radio environment

2.2.3 Cognitive Cycle

The interdisciplinary study of cognition is concerned with exploring widespread ideas of intelligence via a synthetic methodology termed studying by understanding. Putting those ideas collectively and bearing in mind that cognitive radio is aimed at progressed usage of the radio spectrum, we offer the subsequent definition for cognitive radio. Cognitive radio is an clever wi-fi communication machine that is privy to its surrounding environment (i.e., out of doors world), and makes use of the technique of information-by-constructing to study from the surroundings and adapt its inner states to statistical variations in the incoming RF stimuli with the aid of making corresponding changes in sure working parameters (e.g. Transmit-energy, carrier-frequency, and modulation method) in actual-time, with two number one goals in mind:

- highly reliable communications whenever and wherever needed
- efficient utilization of the radio spectrum.

Six key words stand out in this definition**: awareness, intelligence, learning, adaptivity, reliability, and efficiency**. Implementation of this far-reaching combination of capabilities is indeed feasible today, thanks to the spectacular advances in digital signal processing, networking, machine learning, computer software, and computer hardware. In addition to the cognitive capabilities just mentioned, a cognitive radio is also endowed with **reconfigurability.** This latter capability is provided by a platform known as *software-defined radio*, upon which a cognitive radio is built.

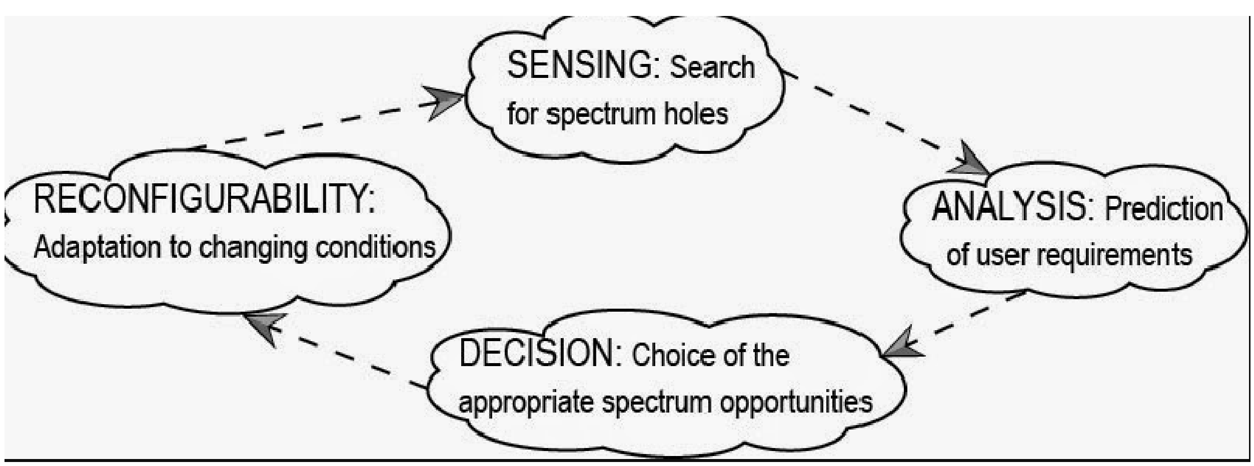

Fig.2.4. Basic cognitive cycle [33].

2.2.4 Main Challenges of CR Terminology

Despite promise of cognitive radio, there are nonetheless many technical hurdles to conquer before the generation is prepared to be carried out in a real global state of affairs. Among the many demanding situations that have yet to be solved, two of the more insidious are hidden number one users and spread spectrum number one customers, each of which lead a cognitive radio to incorrectly decide that a spectrum block is empty, leading to indicators that interfere with the licensed primary person. [6] The geometry of the hidden number one person problem is depicted in Fig. 1.

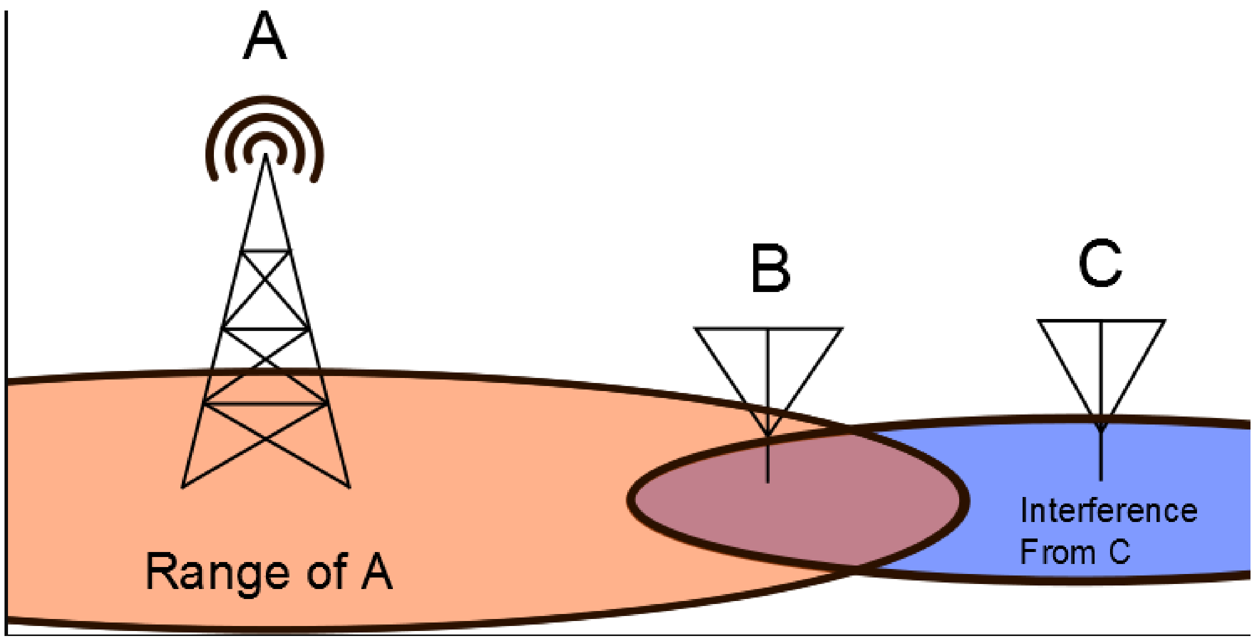

Fig. 2.5: An out-of-range secondary user C can interfere with primary spectrum users A and B.

Consider primary transmitter A, number one receiver B, and secondary user C who would love to apply the spectrum certified to be used by using A and B. Before working C measures the strength within the band and compares it to a threshold set through historical past noise which will decide if the band is in use. In the case wherein the secondary user C is just out of variety of the primary transmitter A it can conclude that there's no number one consumer inside the instant location and co-opt the spectrum. The problem arises when secondary consumer C starts offevolved to transmit. Although C is a ways faraway from A, the primary receiver B may be near sufficient to A to receive its signal. However, once C starts to transmit interference can also obstruct those transmissions preventing the certified spectrum usage between A and B. [6] .

2.2.5 Network Architecture for Cognitive Radio Network

The components of the CR network architecture,, may be categorized as two organizations: the primary network and the CR community. The primary community (or certified community) is called an existing network, in which the number one customers have a license to function in a sure spectrum band. If number one networks have an infrastructure, primary person activities are managed through primary base stations. Due to their priority in spectrum get entry to, the operations of number one customers have to not be stricken by unlicensed customers. The CR network (additionally known as the dynamic spectrum get entry to network, secondary community, or unlicensed network) does now not have a license to operate in a desired band. Hence, extra capability is required for CR users to proportion the certified spectrum band. CR networks additionally may be geared up with CR base stations that provide unmarried-hop connection to CR users. Finally, CR networks may encompass spectrum agents that play a function in distributing the spectrum resources among extraordinary CR networks.

• **Licensed band operation:** The licensed band is basically utilized by the primary community. Hence, CR networks are centered specially on the detection of number one users in this example. The channel capability relies upon at the interference at close by number one users. Furthermore, if primary customers seem in the spectrum band occupied with the aid of CR users, CR customers ought to vacate that spectrum band and circulate to to be had spectrum right now.

• **Unlicensed band operation:** In the absence of number one customers, CR users have the same right to get right of entry to the spectrum. Hence, sophisticated spectrum sharing strategies are required for CR customers to compete for the unlicensed band.

The CR customers have the opportunity to perform 3 special access sorts:

• **CR community get entry to:** CR users can get admission to their very own CR base station, on each certified and unlicensed spectrum bands. Because all interactions occur within the CR network, their spectrum sharing policy can be unbiased of that of the primary network.

• **CR ad hoc get entry to:** CR users can speak with other CR customers through an ad hoc connection on both certified and unlicensed spectrum bands.

• **Primary community get admission to:** CR customers can also get entry to the number one base station through the certified band. Unlike for different access kinds, CR users require an adaptive medium get right of entry to control (MAC) protocol, which permits roaming over a couple of primary networks with distinct get right of entry to technology.

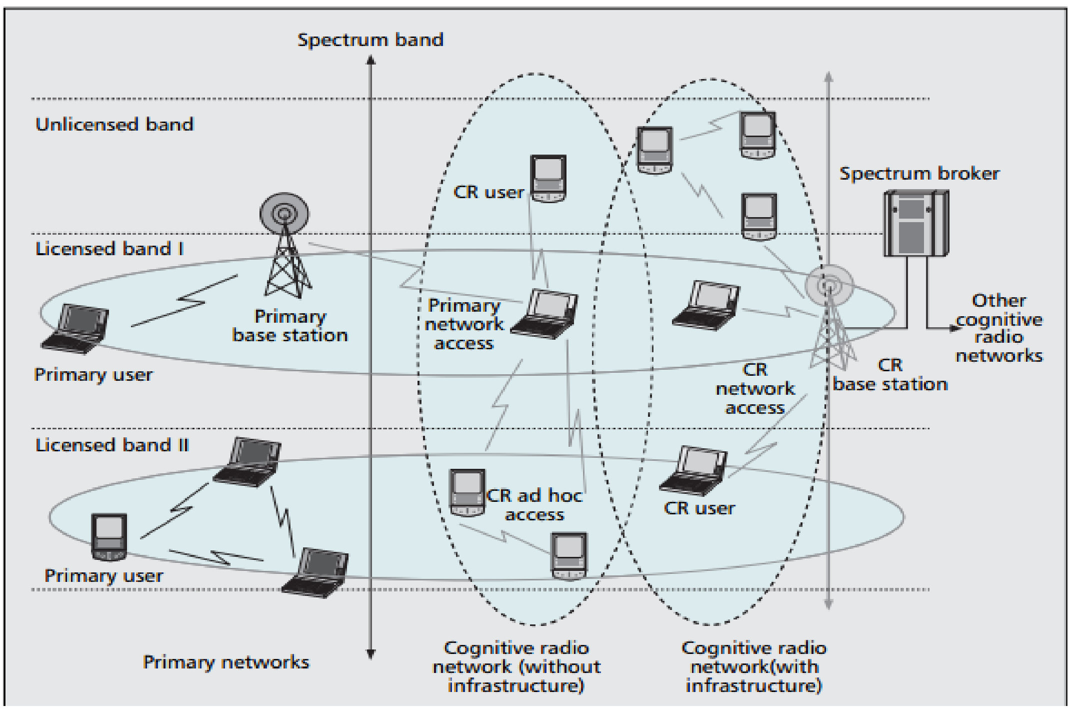

Fig2.6 : Figure specifying Cognitive Radio Architecture

Thomas et al. [2] define the CN as a community with a cognitive process that could perceive modern-day network conditions, plan, determine, act on the ones situations, examine from the consequences of its movements, all at the same time as following cease-to-cease goals. This loop, the cognition loop, senses the environment, plans movements in step with input from sensors and community rules, makes a decision which situation fits quality its end-to-stop purpose using a reasoning engine, and sooner or later acts on the selected situation as discussed within the previous phase. The device learns from the past (conditions, plans, selections, moves) and uses this know-how to improve the choices in the future.

2.2.6 Functions Performed by CR :

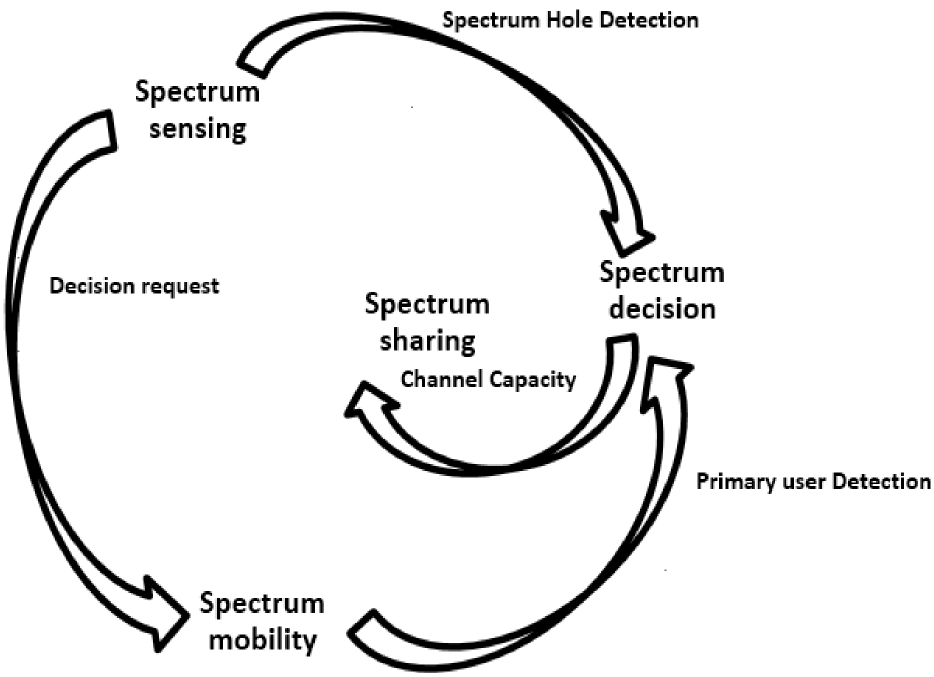

Fig.2.7 . Activities performed by CR users

2.2.6.1 Spectrum sensing

Secondary users can use only the unused portion of the spectrum which requires monitoring of the spectrum and detection of the spectrum holes.

Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. It is done across Frequency, Time, Geographical Space, Code and Phase.

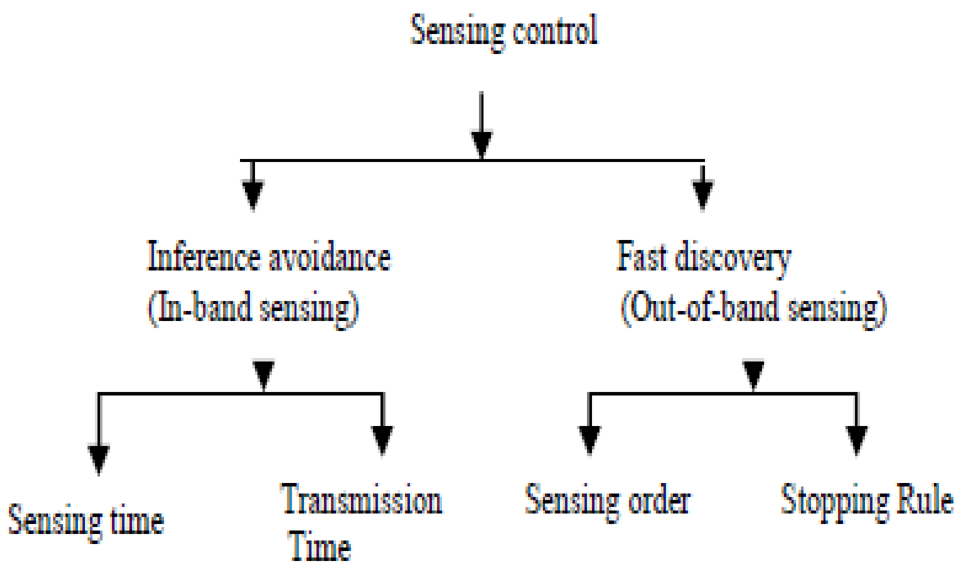

Fig. 2.8. Sensing Control

- **PU detection:** CR user monitors the environment for the presence of primary users and identifies the spectrum holes.

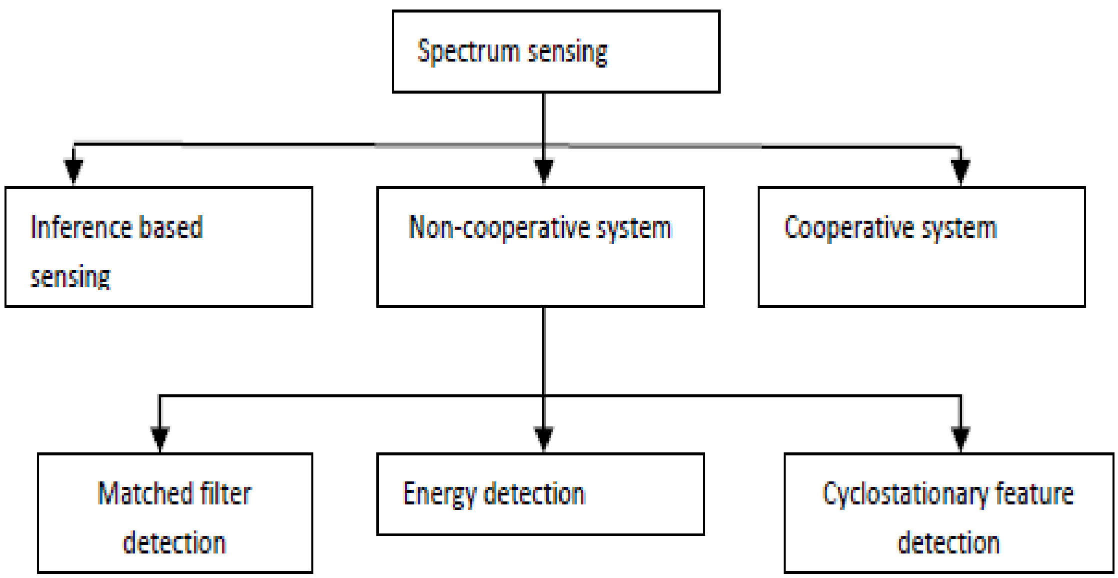

Fig. 2.9. Spectrum Sensing Classification

2.2.6.2 Spectrum decision

Spectrum decision is the capability of the secondary user to decide the best spectrum available according to the quality of service required by the application from the pool of available channels.

2.2.6.3 Spectrum sharing

The main challenge after detecting the available spectrum is sharing the spectrum among CR users. Spectrum sharing is the distribution of spectrum among the secondary users according to the requirements and cost of usage.

2.2.6.4 Spectrum mobility

If a channel currently in use by secondary user is required by the primary user, secondary user have to leave the channel and communication have to be continued in another vacant channel. This is called spectrum mobility which leads to spectrum handoff. Spectrum mobility has mainly two functionalities spectrum handoff and connection management.

2.2.6.5 Transmitter-receiver handshake

After deciding a portion of the spectrum, the receiver of this communication should also be indicated about the spectrum information.

2.2.7 Applications

Cognitive Radio (CR) can sense its environment and, with out the intervention of the consumer, can adapt to the user's communications desires at the same time as conforming to FCC policies within the United States. In idea, the amount of spectrum is endless; almost, for propagation and different reasons it is finite because of the desirability of positive spectrum quantities. Assigned spectrum is far from being absolutely applied, and efficient spectrum use is a developing concern; CR offers a approach to this hassle. A CR can intelligently locate whether any portion of the spectrum is in use, and might quickly use it without interfering with the transmissions of other users.[28] According to Bruce Fette, "Some of the radio's different cognitive competencies consist of figuring out its region, sensing spectrum use through neighboring gadgets, changing frequency, adjusting output power or even changing transmission parameters and characteristics. All of these abilities, and others but to be found out, will offer wi-fi spectrum users with the capacity to evolve to actual-time spectrum situations, imparting regulators, licenses and most people bendy, efficient and comprehensive use of the spectrum".

Examples of programs encompass:

- The application of CR networks to emergency and public safety communications by utilizing white space ·
- The potential of CR networks for executing dynamic spectrum access (DSA) .
- Application of CR networks to military action such as chemical biological radiological and nuclear attack detection and investigation, command control, obtaining information of battle damage evaluations, battlefield surveillance, intelligence assistance, and targeting

2.3 AN OVERVIEW OF SPECTRUM MOBILITY

2.3.1 Introduction

The concept of spectrum handoff/mobility in CR networks isn't like the classical handoff mechanisms in wi-fi networks. Based on priority one-of-a-kind varieties of customers are studied in Spectrum handoff/mobility. High priority person (additionally known as as Primary Users) has the proper to interrupt the transmission of the low-priority customers (also called as Secondary Users) and ask them to depart the channel even though lowpriority person has respectable sign energy. All customers in classical handoff have the same priorities and the selection of changing channels is made particularly because of the deterioration of the modern channel signal first-class.

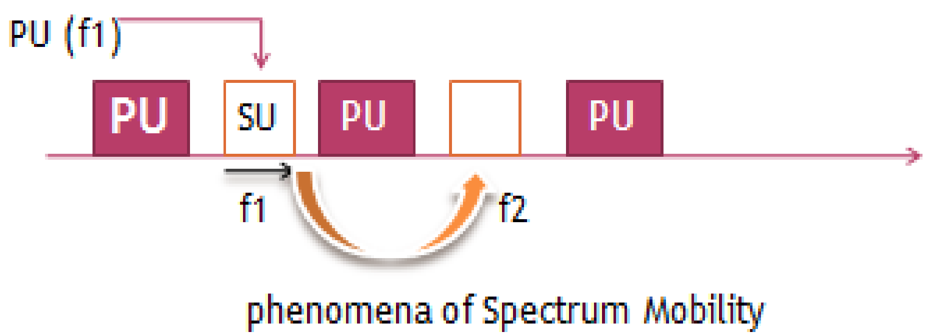

Fig. 2.10.Phenomena of Spectrum Mobility

2.3.2 Spectrum Handoff in CR

When PU arrive the channel then SU must switch to the alternative vacant channel for the seamless communication. This process is known as spectrum handoff. In the certified channel, PU is given more precedence over the SU. SU can speak within the channel whenever there may be absence of PU. It can also speak in the same channel till the SU doesn't cause interference to PU. Hence SU is frequently disrupted in the fairly dynamic environments. Thus there's a want to introduce the spectrum mobility. This allows seamless SU statistics transmission. The foremost task of the spectrum mobility in cognitive radio network (CRN) is to perform continuous channel switch over whilst maintaining performance of ongoing secondary person (SU) verbal exchange. In order to do this, spectrum mobility is classified into two tactics: spectrum handoff and connection management [1]. Spectrum handoff may be defined as a cyclic procedure. It has two phases: Evaluation phase and Link upkeep segment. In the evaluation phase, Cognitive consumer observes the situation and analyses whether handoff triggering incident shall take area or no longer. Once SU chooses to perform spectrum handoff, it enters link maintenance phase. In this phase, cognitive person quit the channel to the licensed person and continues records transmission over another available channel.

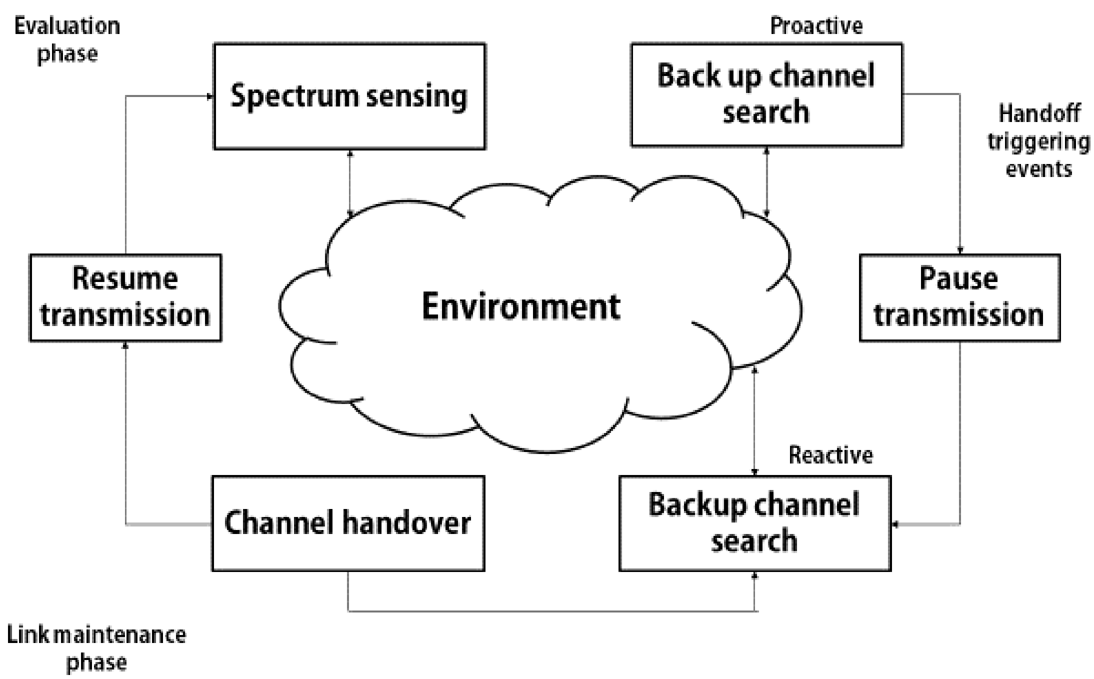

Fig. 2.11. Spectrum Handoff environment

2.3.3 Types of Spectrum handoff

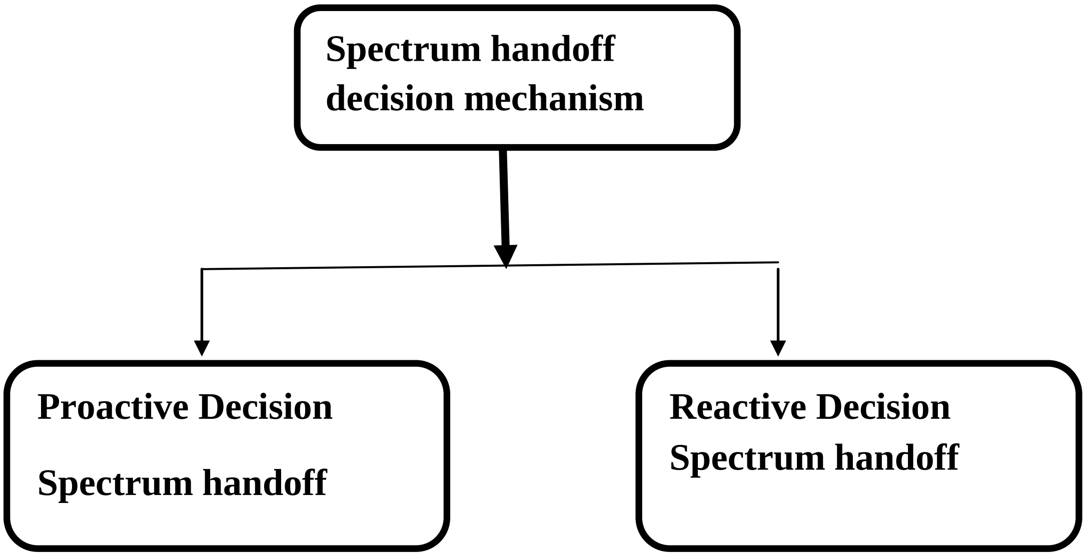

Fig. 2.12. Spectrum Handoff decisions in CRNs

Handoff in cognitive radio networks may be due to exclusive reasons; a) primary person is detected, b) secondary consumer lost its connection because of mobility c) channel in use can not meet the QoS requirements. Spectrum handoff mechanisms for choosing the goal channel to hold the verbal exchange can be of types:

2.3.3.1 Proactive spectrum handoff

Where secondary users pick out their target channel earlier than starting the transmission and carry out handoff whilst any unwanted scenario happens. In proactive spectrum handoff spectrum switching is quicker however it requires complicated algorithms since it maintains its modern-day transmission and search for the brand new band simultaneously. It is more often than not suitable for spectrum satisfactory degradation and person mobility.

2.3.3.2 Reactive spectrum handoff

Target channel isn't always selected in advance as an alternative it's far decided on while hyperlink failure occurs. Spectrum mobility is finished on an immediate basis without any guidance time. There is a great degradation in pleasant of ongoing transmission, however the algorithm is less complex. It is normally used while a primary user appears within the spectrum in use.

2.3.4 Spectrum Handoff Procedure

In CR structures, the sudden look of a PU on a band occupied by using a SU triggers the cognitive consumer to go away this band as quickly as possible. The SU might then try to regain the medium thru one of the following three actions: (i) till the PU finishes its transmission SU will live within the authentic channel and postpones its transmission, (ii) pick a channel from a list of previously sensed channels (predetermined spectrum handoff) or (iii) switching to a positive channel after on the spot sensing (sensing-primarily based spectrum handoff) and if SU fails in regaining the spectrum it's miles forced to terminate its session. In fig 1(a) secondary users SU1 and SU2 communicate on channel Ch1. When number one person seems on Ch1 SUs pause its modern verbal exchange as in fig 1(b). Now SU1 has two alternatives i) SU1 and SU2 can resume its transmission on the chosen target channel as in fig 1(c) or ii) it is able to also remain on the same channel and resume the transmission after the PU hobby is over as in fig 1(d) this situation is preferred if PU pastime is small as it will reduce the number of handoff. A body can be interrupted many times all through its transmission subsequently spectrum handoff system can be executed many times.

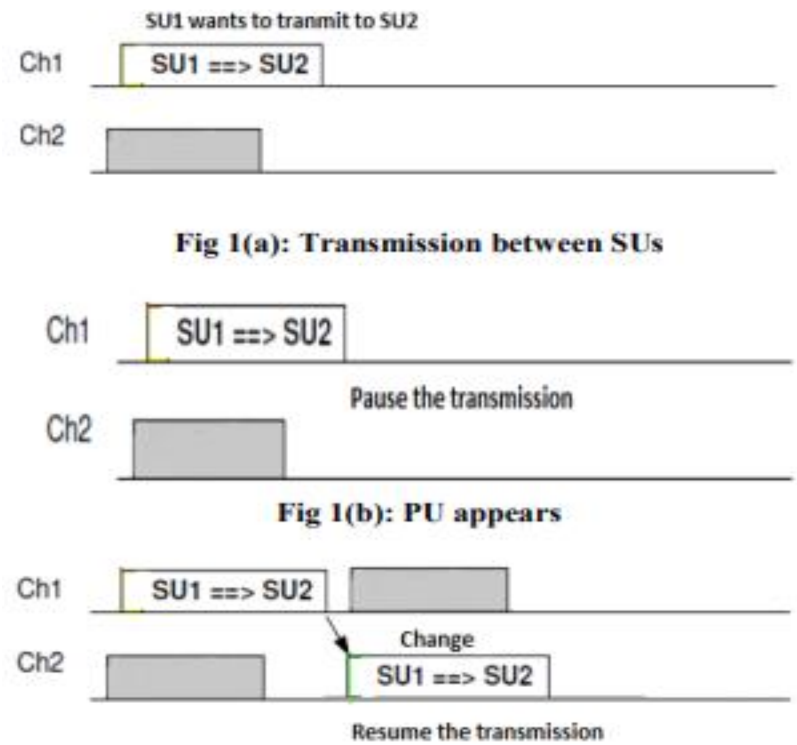

Fig 2.13(a): Resume transmission on selected channel

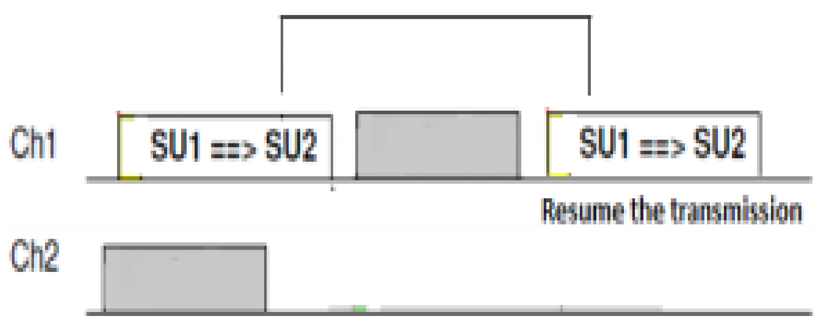

Fig 2.13(b): Resume transmission on the same channel

Spectrum handoff is an inherent operation in cognitive radio networks to help resilient and non-stop communications. The spectrum handoff manner is characterised. Its quick-time period performance and long-term conduct are thoroughly investigated with admire to 4 metrics: hyperlink upkeep probability, the quantity of spectrum handoff, switching put off and non-finishing touch possibility. Results show that the opportunistic and negotiated spectrum get entry to strategies can lead to seriously exceptional performance. The strategies as well as the results are very helpful for optimizing cognitive radio networks.

2.4 NAÏVE BAYES CLASSIFIER

It works on the principle of conditional probability as given by the bayes theorem.

2.4.1 Bayes Theorem

In probability theory and statistics, Bayes' theorem (alternatively Bayes' law or Bayes' rule) describes the probability of an event, based on prior knowledge of conditions that might be related to the event. For example, if cancer is related to age, then, using Bayes' theorem, a person's age can be used to more accurately assess the probability that they have cancer, compared to the assessment of the probability of cancer made without knowledge of the person's age.

2.4.2 Naive-Bays classifier

It assumes that the incidence of a particular function in a category is dissimilar to the presence of every other function. Bays Theorem combines previous information of the lessons with new facts accumulated from education records [9]. Extensive simulations display that the proposed channel selection policy out perform preceding solutions in phrases of switching alarm, average throughput, average mistakes, and collision opportunity of SUs.

Navie bayes classifier which essentially works directly to the precept of bayes theorem, which states that It follows really from the axioms of conditional probability, but can be used to powerfully purpose approximately a wide variety of troubles regarding notion updates. Given a hypothesis H and evidence E, Bayes theorem states that-

$$\mathrm{P(H|E)} = \frac{p(E|H)}{P(E)}\,P(H)$$

Naive Bayes classifiers assign observations to the most probable class (in other words, the maximum *a* posteriori decision rule). Explicitly, the algorithm:

1. Estimates the densities of the predictors within each class.
2. Models posterior probabilities according to Bayes rule. That is, for all $k = 1,\ldots,K$,

$$\hat{P}(Y=k|X1,..,XP) = \frac{\pi(Y=k)\prod_{j=1}^{p}(Xj|Y=k)}{\sum_{k=1}^{k}\pi(Y=k)\prod_{j=1}^{p}P(Xj|Y=k)}$$

where:

- Y is the random variable corresponding to the class index of an observation.
- $X_1,...,X_P$ are the random predictors of an observation.

2.4.3 Posterior Probability

The posterior probability is the probability that an observation belongs in a particular class, given the data. For naive Bayes, the posterior probability that a classification is k for a given observation $(x_1,...,x_P)$ is-

$$\hat{}P(Y=k|x1,..,xP)=\frac{P(X1,...,XP|y=k)\pi(Y=k)}{P(X1,...,XP)}$$

where:

- $P(X1,...,XP|y=k)$ is the conditional joint density of the predictors given they are in class k. Mdl.DistributionNames stores the distribution names of the predictors.
- $\pi(Y = k)$ is the class prior probability distribution. Mdl.Prior stores the prior distribution.
- $P(X1,..,XP)$ is the joint density of the predictors. The classes are discrete, so $P(X1,...,XP)=K\sum_k k=1P(X1,...,XP|y=k)\pi(Y=k)$.

2.3.3 PriorProbability

The prior probability is the believed relative frequency that observations from a class occur in the population for each class

2.5 RELATED WORK

Mission-oriented MANETs are characterized by implicit common group objectives which make inter-node cooperation both logical and feasible. We propose new techniques to leverage two optimizations for cognitive radio networks that are specific to such contexts: opportunistic channel selection and cooperative mobility. **Ala Al-Fuqaha,(2008) [1]** presented a new formal model for MANETs consisting of cognitive radio capable nodes that are willing to *be moved* (at a cost). We develop an effective decentralized algorithm for mobility planning, and powerful new filtering and fuzzy based techniques for both channel estimation and channel selection. Our experiments are compelling and demonstrate that the communications infrastructure—

specifically, connection bit error rates—can be significantly improved by leveraging our proposed techniques.

In addition, we find that these cooperative/ opportunistic optimization spaces do not trade-off significantly with one another, and thus can be used simultaneously to build superior hybrid schemes. The resultant algorithm improves the average connection BER almost linearly as the mobility budget increases (with constant numbers of cooperative nodes). It also improves the connection BER almost linearly as the number of cooperative nodes increases (with constant total mobility budgets). The wavelet transform and flip-flop filtering techniques are effective, predict the status of primary channels, enable lower average connection BER especially when coupled with our channel selection scheme.

The spectrum sensing problem has gained new aspects with cognitive radio and opportunistic spectrum access concepts. It is one of the most challenging issues in cognitive radio systems. In **Tevfik Y¨ucek and H¨useyin Arslan, (2009) [2]** work, a survey of spectrum sensing methodologies for cognitive radio is presented. Various aspects of spectrum sensing problem are studied from a cognitive radio perspective and multi-dimensional spectrum sensing concept is introduced. Challenges associated with spectrum sensing are given and enabling spectrum sensing methods are reviewed. The work explains the cooperative sensing concept and its various forms. External sensing algorithms and other alternative sensing methods are discussed. Furthermore, statistical modeling of network traffic and utilization of these models for prediction of primary user behavior is studied.

Cognitive radio, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. One of the important elements of cognitive radio is sensing the available spectrum opportunities. In this work, the spectrum opportunity and spectrum sensing concepts are re-evaluated by considering different dimensions of the spectrum space. The new interpretation of spectrum space creates new opportunities and challenges for spectrum sensing while solving some of the traditional problems. Various aspects of the spectrum sensing task are explained in detail. Several sensing methods are studied and collaborative sensing is considered as a solution to some common problems in spectrum sensing. Pro-active approaches are given and sensing methods employed in current wireless systems are discussed.

Vamsi Krishna Tumuluru, (2010) [3] The Cognitive Radio (CR) technology enables the unlicensed users to share the spectrum with the licensed users on a non-interfering basis. Spectrum sensing is an important function for the unlicensed users to determine availability of a channel in the licensed user's spectrum. However, spectrum sensing consumes considerable energy which can be reduced by employing predictive methods for discovering spectrum holes. Using a reliable prediction scheme, the unlicensed users will sense only those channels which are predicted to be idle. By achieving a low probability of error in predicting the idle channels, the spectrum utilization can also be improved. Since the traffic characteristics of most licensed user systems encountered in real life are not known a priori,

In **S. Senthuran, (2011) [4]** work cognitive radio networks, it is important to effectively use the under-utilized spectrum resources without affecting the primary users. In an underlay system, cognitive users are allowed to share the channel simultaneously with primary users with the restriction on interference level but not in an overlay system. In this work, we consider a system where cognitive users can switch between overlay and underlay modes of operation in order to improve their throughput. The results, based on Markov chain analysis, are satisfactorily verified using Monte- Carlo simulation. It is shown that proper selection of transmission mode can provide greater improvement in throughput for cognitive users. If a primary user occupies the channel for a longer (shorter) period, then the system should allow the cognitive users to choose underlay (overlay) mode for throughput advantage.

This work provides an up-to-date survey of spectrum decision in CR networks (CRNs) and addresses issues of spectrum characterization (including PU activity modelling), spectrum selection and CR reconfiguration. For each of these issues, we highlight key open research challenges. We also review practical implementations of spectrum decision in several CR platforms. Spectrum decision in CRNs is crucial to ensure that appropriate available spectrum bands are selected to satisfy the heterogeneous QoS requirements of the SUs. In this work, we presented the main functions related to spectrum decision in CRNs based on an extensive study of the existing literature. We explored spectrum decision based on its three key functions:

spectrum characterization, spectrum selection and CR reconfiguration. **Moshe Timothy Masonta,(2012) [5]** identified a number of open research issues related to key functions of spectrum decision. We also reviewed various ongoing research work on practical implementations of spectrum decision in CR platforms. It is worth mentioning that in CRNs, the spectrum decision capability relies on effective spectrum sensing and reliable or accurate data on primary network characteristics (e.g. from geo-location spectrum databases).

In this work, they demonstrate the advantages of channel status prediction to the spectrum sensing operation in terms of improving the spectrum utilization and saving the sensing energy. **Vamsi Krishna Tumuluru, (2012) [6]** designed the channel status predictor using two different adaptive schemes, i.e., a neural network based on multilayer perceptron (MLP) and the hidden Markov model (HMM). The advantage of the proposed channel status prediction schemes is that these schemes do not require *a priori* knowledge of the statistics of channel usage. Performance analysis of the two channel status prediction schemes is performed and the accuracy of the two prediction schemes is investigated. Copyright © 2010 John Wiley & Sons, Ltd. Channel status prediction is important to CRNs because it can greatly save the sensing energy and help the secondary users to exploit the spectrum holes more efficiently.

This article surveys the state of the art of spectrum prediction in cognitive radio networks. **Xiaoshuang Xing And Tao Jing (2013) [7]** summarized the major spectrum prediction techniques, illustrate their applications, and present the relevant open research challenges. Spectrum prediction is a promising approach for better realization of cognitive radio functions. Extensive research has been performed on various prediction techniques and applications in CR networks. However, effort is still needed to design prediction-based spectrum sharing methods, provide long-term accurate spectrum prediction, and devise PU activity map prediction schemes.

Cognitive radio, an intelligent spectrum sensing technology detects the spectrum holes or white spaces in the spectrum which reallocates this idle spectrum to unlicensed users called Secondary Users (SU) and without causing harmful interference to licensed users called Primary Users

(PU). Normally prediction-based channel sensing carried out for the efficient utilization of spectrum for the unlicensed users using different prediction models and probability theory-based algorithms available in the literature. In **P. Pavithra Roy,(2015) [8]** work, they proposed a methodology for the prediction of channel state using Hidden Markov Model (HMM). A comparative analysis is carried out between the proposed technique with that of the traditional spectrum sensing technique and the accuracy of the predictor is established through numerous simulations.

Spectrum occupancy models are very useful in cognitive radio designs. **Yunfei Chen, (2016) [9]** can be used to increase spectrum sensing accuracy for more reliable operation, to remove spectrum sensing for higher resource usage efficiency or to select channels for better opportunistic access, among other applications. In this survey, various spectrum occupancy models from measurement campaigns taken around the world are investigated. These models extract different statistical properties of the spectrum occupancy from the measured data. In addition to these models, spectrum occupancy prediction is also discussed, where the auto-regressive and/or moving-average models are used to predict the channel status at future time instants. After comparing these different methods and models, several challenges are also summarized based on this survey.

This research intends to provide a survey and a guide on the latest work on spectral prediction, examining state of the art in the inference of the spectrum in cognitive radio networks. For a better understanding of the prediction roll, the main spectrum prediction techniques were summarized, the applications were categorized, and the relevant research challenges were presented in a distributed manner. Accordingly, **Luis Miguel Tuberquia,(2018) [10]** considered a qualitative evaluation of different prediction strategies. Furthermore, this work will offer a general overview to the readers of the current development proposals for the prediction process in heterogeneous wireless networks and identifies new channels to improve the quality of the service without interruptions. spectrum inference. We conclude that the primary objective of existing and future studies on spectral prediction in CRNs is to achieve a compromise between the inconsistent aims of improving prediction accuracy, reducing their computational complexity and the memory requirement. This forms a fruitful research area.

In this work, **Syed Hashim Raza Bukhari,(2018) [11]** proposed a simulation model for cognitive radio sensor networks (CRSNs) which is an attempt to combine the useful properties of wireless sensor networks and cognitive radio networks. The ex- isting simulation models for cognitive radios cannot be extended for this purpose as they do not consider the strict energy constraint in wireless sensor networks. This module has been designed on NS2 so it is very flexible to extend for future enhancements and channel bonding block will be added as the extension of this work. It will provide the CR users a chunk of large bandwidth to utilize for multimedia applications. Other types of PR activities and energy models can also be integrated in this module. Another important future enhancement is to check the accuracy of our simulator in real world scenarios. It will provide a stronger base for the future researchers in this field of CRSN.

Hind Ali. M. Saad,(2018) [12] Cognitive radio (CR) is considered as an intelligent wireless communication system proposed to improve the utilization of the radio electromagnetic spectrum. In CR technology the secondary users take the responsibility of dynamically sensing and accessing any unused channels in the spectrum allocated to the licensed users. As spectrum sensing consumes considerable energy, predictive methods for inferring the availability of spectrum holes can reduce energy consumption of the unlicensed users to only sense those channels which are likely to be idle. It also helps to improve the spectrum utilizations. Several prediction techniques have been used to predict spectrum utilization. However, most of current approaches do not consider seasonality in spectrum workload, for example most of the channels are busy during business hours in mobile phone bands.

Hind Ali. M. Saad,(2018) [12] proposed a channel status predictor based on the multiplicative seasonal model called Holt-Winters' method. The proposed prediction method has the ability to adapt with changes in trends and seasonal patterns of the sensing observations. Performance analysis and the accuracy of the channel status prediction schemes are investigated. Since, wireless channel in Cognitive Radio networks is time varying in nature, it is extremely difficult to estimate it accurately through the conventional detection scheme with fixed threshold

To improve the utilisation efficiency of licensed spectrum in cognitive radio network, two new channel selection strategies are proposed for the secondary user (SU) in this work. **Xiaobo Tan(2013) [13]** proposed solution tries its best to reduce collision and switching probabilities of the SU during data transmission. By using historical information of the licensed spectrum, the SU chooses the channel with the lowest busy probability within its service time for data transmission. Time series prediction is employed to forecast the near future busy probabilities of the licensed spectrum units, and a novel time series prediction method named distance factor recursive least square is also presented. Simulations prove that the performances of the SU, which is measured by collision probability with primary user, switching probability during data transmission and throughput within limited time slots, are all significantly improved when compared with random channel selection method DF-RLS method

CHAPTER : 3

PROBLEM FORMULATION AND SIMULATION METHODOLOGY

3.1 OBJECTIVE

In this work, we recommend a brand new channel selection strategy to address this assignment. Combining the prediction statistics and cooperative sensing, a CR base station can obtain the sensing data for future region of every secondary person, a good way to prearrange incredible channels for secondary users a head of time. [1] Besides traditional choice elements, the new channel selection algorithm takes the channel's future availability acquired from spectrum prediction under consideration. By nicely integrating the spectrum prediction, person mobility prediction, and channel selection, the new spectrum control approach is able to allocating the spectrum useful resource extra effectively. Extensive simulations are conducted and outcomes affirm that the proposed spectrum management strategy substantially improves the machine overall performance in terms of lowering handoff instances and enhancing consumer first-class, connection reliability, and channel usage.

3.2 PROBLEM STATEMENT

The objective of this work is to implement a new channel state prediction technique to enhance the performance of cognitive radio system.

3.3BACKGROUND

To improve the usage performance of electromagnetic radio spectrum, cognitive radio (CR) turned into proposed [1]. From the description of the cognitive radio, one of the most important features is that it could facilitate swish opportunistic spectrum sharing amongst diverse radio users. The secondary customers (SUs) normally look for opportunistic access of the spectrum, that is certified to number one users (PUs) for their transmissions. In an overlay cognitive radio community, the SU would pick out the spectrum bands, which are not occupied by using PU for their diverse wireless activ- ities. But how to pick the transmission channel amongst spectrum possibilities, that could fulfill the transmission necessities of the SU, and simultaneously reduce the col- lision and switching possibilities during the transmission is still a problem.

Many of the researchers proposed solutions to this trouble. In [26], they firstly formulated the trouble of channel choice for negotiation, aiming to enhance thetransmission performance of the SU, after which the trouble become solved by using Markov Chain analysis. Some different researchers carried out reinforcement gaining knowledge of (Q-Learning) to channel choice in cognitive radio networks [7, 11]. Through trial-and-error interactions with its radio environment, the researchers believed that the SU would in the end converge to the most appropriate channel choice coverage. Other methods, consisting of fuzzy good judgment [12], sport idea [13, 15] and graph colouring [16] also are introduced. For Markov Chain evaluation techniques, the kingdom transition prob- ability of the primary channel need to be regarded before it could be implemented. In [12, 15], they studied one-of-a-kind eventualities of channel selection in cognitive radio networks, however all of the methods proposed in the literatures worked in a manner of passively reaction to the changes of surrounding radio environment. They take actions after the foreseeable adjustments have took place instead of acting beforehand of adjustments. In this example, a few dangerous influences, which includes extra collisions and switchings, will manifest all through data transmission, which could subsequently lead to a decrease of person's transmission overall performance. Reinforce gaining knowledge of hired in [7, 10] enabled the CR to research from the radio environment and alter itself to enhance transmission overall performance, but the procedure of trial-and-errors interactions with the radio environment may additionally take a long time to gain the opti- mal selection particularly whilst there are many candidate channels. And it is also required that the number one channels exchange slowly among the state of idle and the state of busy. If they trade hastily which include in a few emergency conditions, in which the number one channel stories fast busy/idle kingdom transitions within a quick time, the method might no longer react as quickly as the environment modifications. Joint go layer spectrum sensing and channel selection is a new manner to clear up the hassle of channel selection in cog- nitive radio networks. In [17], efficient sensing-series and novel channel-management approach had been proposed for instant discovery of spectrum opportunities. MAC (Multime- dia Access Control) layer sensing, which contributes plenty to find out as many spectrum opportunities as viable thru sensing-period model algorithm and premiere sensing- sequencing at channel switching, was proposed in [18]. These works display that both the spectrum sensing and the channel choice can advantage plenty from go layer layout technique.

The running environment of the SU is time various; therefore, cognitive radio ought to have the capacity to study from beyond revel in to enhance future performance rather than taking immediate records under consideration best. In [19], the authors attempted to pursue a higher destiny overall performance through making use of a predictive approach, which could forecast the busy- idle states of the primary channels. However, the method is effective simplest when the traffic patterns (which might be specially described) of primary channels are labeled effectively at first; in any other case, its performance might be reduced. If extra trendy strategies may be proposed to predict the destiny busy or idle situations of candidate primary channels earlier than choice, we believe that it would make the CR response to the modifications of radio surroundings extra actively and successfully. Therefore, in this work, we proposed general strategies for channel choice based totally on time collection pre- diction. Compared with works provided within the literatures, the proposed approach is a good deal extra suitable for sensible applications, and the proposed channel choice method executes in a proactive way on the idea of predicting the busy chances of the candidate channels, as opposed to pas- sively switching the transmission channel among candidate ones.

3.4. SPECTRUM SENSING MECHANISM

In this work, as proven in Figure 1(a) , we don't forget a cord- less situation that a cognitive mobile coexists with PUs. The cognitive mobile includes a cognitive base station (CBS) and plenty of SUs. Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. It is done across Frequency, Time, Geographical Space, Code and Phase. A number of different methods are proposed for identifying the presence of signal transmission all of which are in early development stage. In the range of cognitive cellular, the CBS can successfully trade facts with all the SUs and agenda can exchange data at a particular field. In a wireless scenario cognitive cell coexisting with PU, SU and a base station. Coexisting of SU with the PU is the biggest problem now-a-days,

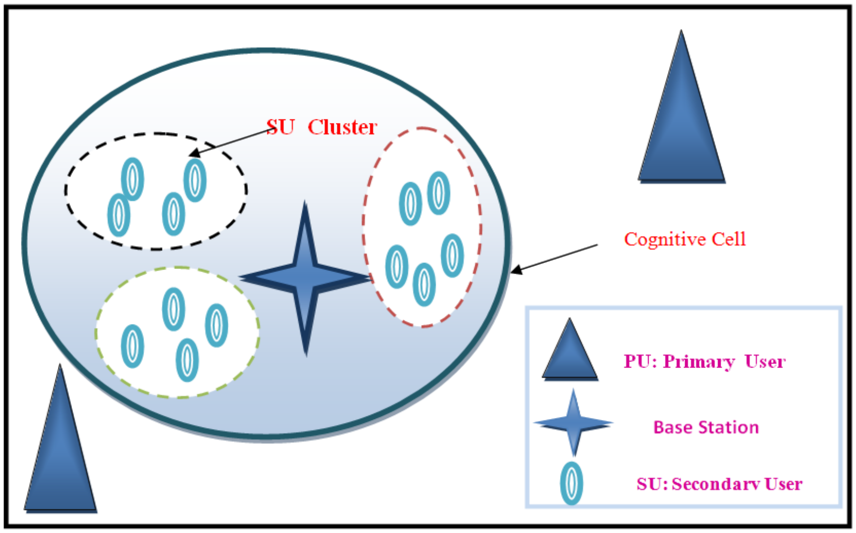

Fig. 3.1(a) Wireless scenario of CR

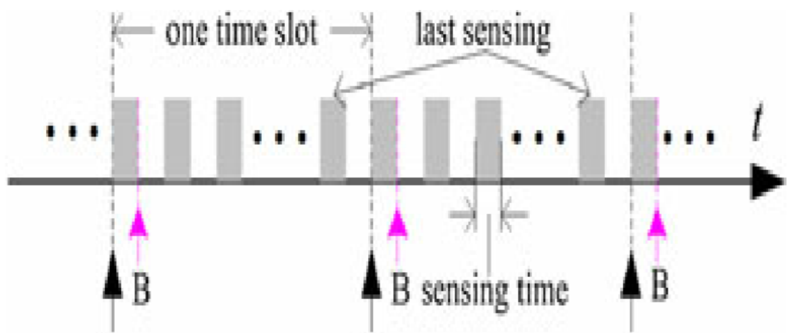

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Fig 3.1(b) Spectrum sensing mechanism in this work.

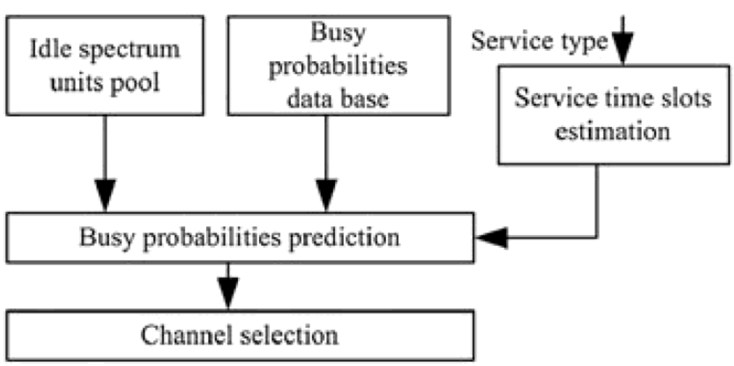


Fig 3.1 (c) Predictive transmission of the secondary user.

Figure 3.1. System model of proposed predictive transmission: (a) wireless scenario of this work (b) spectrum sensing mechanism in this work and (c) predictive transmission of the secondary user.

The SUs for collaborative spectrum sensing. In exercise, the feature of these collaborative SUs can also be imple- mented via sensor network. The overall to be had spectrum band for cognitive radio is divided into a couple of same spec- trum devices, which can be sensed and used by SUs. CBS of the cognitive cellular consists of 4 modules: fusion cen- ter, sensing mission management, busy probabilities database and idle spectrum units list. The fusion center collects sensing effects from all of the SUs and determines the states (idle/busy) of the spectrum devices. According to the output of the fusion center, idle spectrum devices are delivered to idle spectrum units list, whereas busy ones are dropped. Mean- even as, busy probabilities of all spectrum gadgets, which can be stored in the database, are updated in line with the modern sensing outcomes. Sensing venture management module controls all of the spectrum sensing behaviours of SUs via a great common manage channel.

To obtain busy probabilities of the spectrum devices in every time slot (a constrained time c program languageperiod, that's predefined), spectrum sensing ought to be completed for M(M>1) times in one time slot. If Q busy states of the spectrum unit are detected, then the busy chance of the spectrum unit can be described independently with the aid of the ratio of Q/M, as demonstrated in Figure 1(b) . We assume that the time of all SUs are synchronised; accordingly, on the quit of every time slot (moment A), the fusion center of the CBS computes the busy chances of all spectrum units on the idea of the sensing consequences said via all of the SUs. According to the consequences of remaining sensing in each time slot, idle spectrum gadgets list in the CBS is likewise up to date. All these data are broadcasted to all SUs by way of the CBS at second A and B, respectively. If one SU is transmitting data, we anticipate that only at the start of on every occasion slot (moment B), the radio will check whether the PU appears within the decided on channel.

Although targeted spectrum sensing algorithms aren't the focal point of this paintings, a few troubles of the primary assump tions still ought to be illustrated. Because the SU wishes to continuously screen the spectrum band, we count on that two antennas are ready on every SU. One is employed for ordinary transmission, and the opposite is used for spectrum sensing. The principal drawback of antennas is the sig nals transmitted through itself might be detected by its spectrum sensing module. Fortunately, this issue can be addressed by applying self sign suppression approach offered in [20]. Scanning all of the spectrum units in each sensing through one SU might be time eating particularly within the case of huge-band sensing. To improve the sensing performance of the SUs, collaborative spectrum sensing is hired. All the SUs in the cognitive mobile are divided into several SU clusters by sensing venture management module in the CBS. And every cluster is assigned to sense most effective part of the total to be had spectrum bands in preference to all of the spectrum gadgets. Therefore, time wanting for spectrum sensing can be notably decreased. In addition, new strategies together with compressive sensing [21], superior sensing mission control schemes [22, 23] and novel layout of the cognitive radio receiver [24] additionally can be implemented to enhance the sensing efficiency and accuracy in spectrum sensing packages. As proven in Figure 1(c) , idle spectrum gadgets pool and busy chances database of the SU can acquire cor- responding facts from the CBS periodically. Data desiring to be transmitted may be measured through Time slot according to spectrum unit (Tpsu). One Tpsu manner the quantity of information transmitted in a single time slot with bandwidth of 1 spec- trum unit. Service queue of the SU is a sequence of integers, and every of the integers represents the quantity of statistics to be transmitted in each transmission. If there is statistics wanting to be transmitted, contemporary idle spectrum devices are furnished to busy probabilities prediction module, and corresponding ancient busy chances of these idle spectrum devices are also loaded. Service time slots in this work denote the time wanting to transmit all the consumer statistics with band- width of one spectrum unit. It can be estimated according to present day service kind of the radio. For some forms of ser- vice, the estimation can be tough; in this context, the service time slots might be actually predefined as a hard and fast cost. Then, channel choice strategy is implemented. If PU is detected all through SU's records transmission, the SU could be backpedal right now and pick out a new channel to renew its facts transmission.

Different from traditional sensing-then-get right of entry to model, the channel choice latency of the proposed model is especially from busy chance prediction. Benefitting a lot from the continuous monitoring of the spectrum bands and ancient busy possibilities database, SUs inside the cognitive cellular usually can reap information about modern-day to be had spectrum devices from the CBS. Because the overall performance of proposed answer a whole lot is based on ancient busy probabili- ties of the spectrum gadgets, growing the instances of spectrum sensing in one time slot might be an powerful way to attain greater accurate probabilities. However, blindly increasing the sensing frequency will growth the power and time consumption. Obviously, there's a change-off between the accuracy of busy chance and the sensing overhead.Figure three.2 presents the flow chart of how records are trans- mitted on this presented version. From the determine, we will

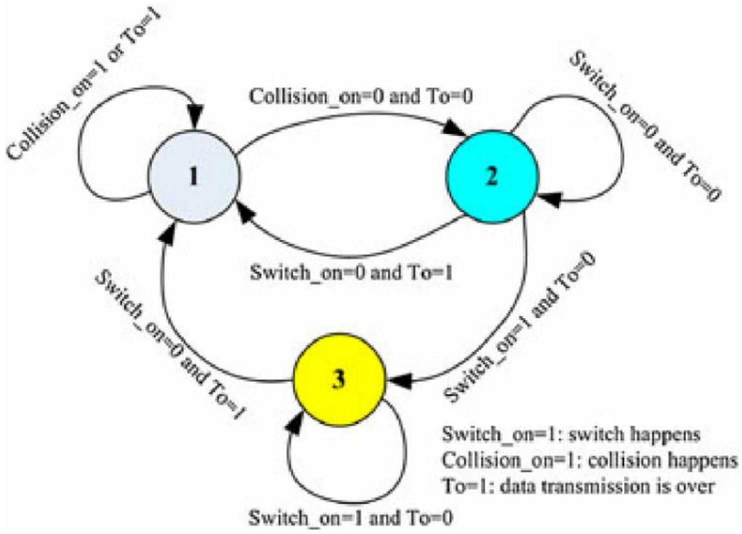


Fig 3.2. Flow chart of data transmission

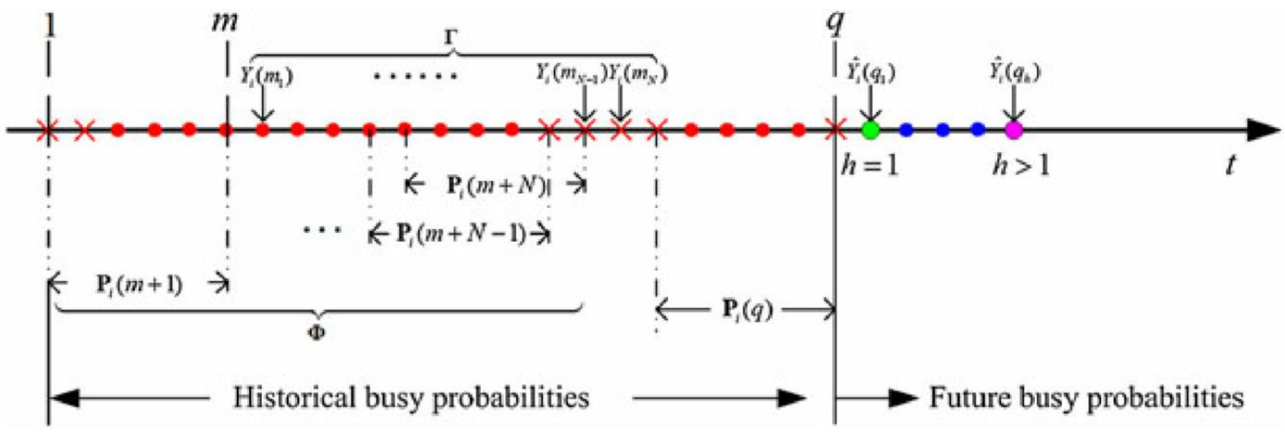


Fig 3.3. Illustration of the busy probabilities prediction

See that the entire system may be divided into three tactics, which denote extraordinary states of the SU under unique conditions:

Pl. The SU chooses the transmission channel consistent with channel selection strategy and then assessments whether or not the PU appears in the decided on channel. If the PU is detected, one collision happens, and the facts transmission is blocked; then, it's going to repeat Pl to renew its transmission. Otherwise, one Tpsu of consumer statistics is transmitted, and if the transmission remains not completed, it goes to P2.

P2. Data transmission of the SU keeps in selected channel till the PU is detected or all the records is transmitted. If the PU is detected for the duration of statistics trans- challenge, switching happens, the transmission of the SU is blocked, and it goes to P3. If the transmission is over, it goes to Pl and waits the new transmission.

P3. When the PU appears at some point of information transmission, switch occurs, and the SU has to pick a new chan- nel to resume its transmission. Otherwise, transmis- sion goes on till all the user information are transmitted.

3.5. BUSY PROBABILITIES PREDICTION

We will present the proposed method of predicting busy probabilities of candidate spectrum units. The method enables the SU to choose appropriate channel to reduce the probabilities of collision and switching during data transmission.

The historical busy probability of the i th spectrum unit at time slot t can be expressed as $\{p_i(t), i = 1,2, \cdots\}$. Let $P_j(t) = [p_i(t-1), \cdots, p_i(t-m)]^T$, $Y_i(t_h) = p_i(t+h)$, where m is the embedding dimension, h is the prediction step and $y_i(t_h)$ is the busy probability of the i th spectrum unit after h time slots. If there is a mapping F between Φ and Γ, which can be written as $F\colon \Phi \to \Gamma$, with

$$\Phi = \{P_i(m+1), P_i(m+2), \cdots, P_j(m+N)\}$$

$$= \begin{pmatrix} p_i(m) & p_i(m+1) & p_i(m+N-1) \\ p_i(m-1) & p_i(m) & p_i(m+N-2) \\ \vdots & \vdots & \vdots \\ p_i(l) & p_i(2) & p_i(N) \end{pmatrix}$$

and $\Gamma = \{Y_i(m_1), Y_i(m_2), \cdots, Y_i(m_N)\}$; thus, the problem of time series prediction can be formulated as mapping reconstruction on the basis of (Φ, Γ) . And the (Φ, Γ) are known as the training examples. After the map- ping reconstruction is completed, for a historical busy probabilities vector $P_j(q)$, we always can compute the pre- diction value of $y_i(qh)$ by applying the equation given as follow:

$$\hat{Y}(qh) = F(P_i(q)) \quad (1)$$

When $h = 1$, the prediction is defined as one-step pre- diction, whereas when $h > 1$, the prediction is defined as multistep prediction. The illustration of the prediction is presented in Figure 3.3

Actually, many prediction methods have been proposed for time series prediction, such as recursive least square (RLS) [25] and lazy learning (LL) [26]. Autoregressive model, moving average model and autoregressive moving average model are the main models of time series anal- ysis. According to the conclusion in [27], autoregressive model (simultaneously its order also can be determined) is employed. Thus, the prediction of the busy probability can be described by the equation as follows:

$$\hat{Y}(m_k) = \Theta P_i(m+k) + e(k) \quad (2)$$

where $1 \leq k \leq N$, $e(k)$ is prediction error between $\hat{Y}(m_k)$ and $Y_i(m_k)$, which can be written as $e(k) = Y_i(m_k) - \hat{Y}(m_k)$. And θ is defined as prediction coeffi- cient vector with $\Theta = [\theta_{1;}\theta_{2;} \cdots ; \theta_m]$. We notice that the key to find the mapping F is the estimation of Θ. In con- ventional RLS method, the cost function used to estimate Θ can be denoted as

$$J(\theta) = \sum_{k=1}^{N} e^2\,(k) \quad (3)$$

Compared with conventional RLS method, the main improvement of the DF-RLS proposed in this work is the similarity measurement of time series, which defined as

distance factor between the $P_i(q)$ and the training exam- ples $P_i(m+k)$. The cost function of DF-RLS can be modified as

$$J(\theta) = \sum_{k=1}^{N} \beta_i\,(k) e^2(k) \quad (4)$$

And $\beta_i(k)$ is the distance factor, which is defined as

$$\beta_i(k) = \frac{1}{|P_i(q) - P_i(m+k)|^2} \quad (5)$$

where $|.|^2$ is a two-norm operator. From the equation, we can find the Euclidean distance between the two time series is employed as similarity measurement. It indicates that the more similar of the two busy probability series $P_i(q)$ and $P_i(m+k)$, the more it contributes to the cost func- tion. Thus, the prediction coefficients can be computed by applying the following equation:

$$\Theta(k+1) = \Theta(k) + \beta_i(k+1)(k+1)e(k+1) \text{ (6)}$$

with

$$e(k+1) = Y(m_{k+1}) - \Theta(k)P_i(m+k+1)_; \quad (7)$$

$$(k+1) = g(k+1)P_i(m+k+1)_; \quad (8)$$

$$g(k+1) = g(k) -$$

$$\frac{\beta_i(k+1)g(k)P_i(m+k)P_i(m+k)^T g(k)}{\beta_i(k+1) + P_i(m+k)^T g(k) P_i(m+k)} \quad (9)$$

After a series of iterations, the prediction coefficients are obtained. Thus, the predicted busy probability $\hat{Y}(q_h)$ can be computed by

$$\hat{Y}(q_h) = \Theta P_i(q) \quad (10)$$

Because the derivations of the proposed method follow the same way as conventional RLS method, only the main iterative process of DF-RLS is presented in this work, as shown in algorithm 1.

If there are N training examples, only one time of iter- ation is needed for conventional RLS method in each pre- diction, but for the proposed DF-RLS method, N times of iteration are required. Despite the computation complexity of the proposed method is increased, whereas the following simulation results demonstrate that the accuracy of predic- tion results of the proposed is improved when compared with the conventional RLS method.

To improve the utilisation efficiency of licensed spectrum in cognitive radio network, two new channel selection strategies are proposed for the secondary user (SU) in this work. The proposed solution tries its best to reduce collision and switching probabilities of the SU during data transmission. By using historical information of the licensed spectrum, the SU chooses the channel with the lowest busy probability within its service time for data transmission. Time series prediction is employed to forecast the near future busy probabilities of the licensed spectrum units, and a novel time series prediction method named distance factor recursive least square is also presented. Simulations prove that the performances of the SU, which is measured by collision probability with primary user, switching probability during data transmission and throughput within limited time slots, are all significantly improved when compared with random channel selection method. Higher prediction accuracy than the conventional recursive least square and lazy learning methods is achieved by proposed time series prediction algorithm when tested by voice traffic data and Lorenz time series.

Algorithm 1 Main iterative process of DF-RLS algorithm

1: Initialisation: $\Theta(0) = [0,0,\cdots 0]_{1\times m}$,

2: for $k = 1; k \leq N; k++$; do

3: Compute $\beta_i(k)$ by using Equation (5);

4: $\hat{Y}(m_k) = \Theta(k-1)P_i(m+k)$;

5: Compute $e(k)$ by using Equation (7);

6: Update $\Theta(k)$ by using Equations (6), (8) and (9);

7: end for

8: $\hat{Y}(q) = \Theta P_i(q)$

3.6 CHANNEL SELECTION ALGORITHM

According to the system model and assumptions, Figure 4 shows that the total available spectrum is divided into s spectrum units and an exclusive ID is assigned to each of them. The total spectrum units can be denoted as aspectrum set S, with $S = \{u_{1;} u_{2;} \cdots ; u_s\}$. If more than one spectrum units are idle at the same time, how the SU chooses transmission channel to improve its trans- mission performance is a crucial problem. Two strategies are proposed for channel selection based on the estimated probabilities.

Strategy A: If the service time slots are ρ *Tpsu*, according to the sensing information from the spectrum sensing mod- ule, $d(1 \leq d \leq s)$ spectrum units are idle at t, which can be denoted as an idle spectrum units set U, with $Usubseteq$ S. Then, the busy probabilities prediction module forecasts the busy probabilities of $u_\alpha(u_\alpha \in U_; 1 \leq \alpha \leq d)$ in the following ρ time slots, which can be denoted as

$$\hat{p} = [\hat{p}(t+1)_; \hat{p}(t+2)_; \cdots ; \hat{p}(t+\rho)] \quad (11)$$

Thus, the selected channel is

$$C_{sl} = \arg\ \min \{\frac{1}{\rho} \sum_{i=1}^{\rho} \hat{p}\,(t+i)\} \quad (12)$$

The channel selection strategy A is summarised in algorithm 2.

Strategy B: The SU would occupy only one spectrum unit with strategy A. Although the selected spectrum unit has the minimum mean busy probability among the can- didate spectrum units, its busy probability cannot always maintain at low level during data transmission, such as

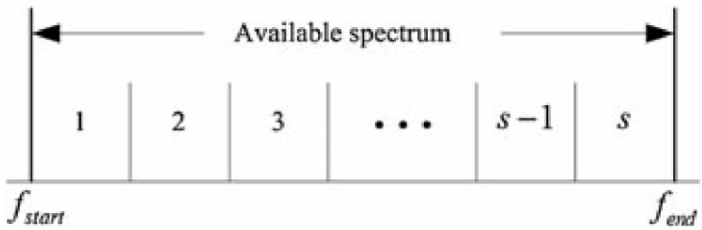


Figure 3.4. Division of the available spectrum

$\boldsymbol{Algorithm2}$ $Channelselectionalgorithm: strategy$A

1: Updates the information of idle spectrum units U;

2: if $U \neq \varphi$ then

3: Load the historical busy probabilities of d spectrum units;

4: $for\alpha = 1; \alpha \leq d; \alpha + +; do$

5: Generates the αth training examples $(\Phi, \Gamma)_\alpha$; 6;

6: for $j = 1; j \leq \rho; j + +$; do

7: DF-RLS: $\Theta_\alpha \leftarrow F : (\Phi \leftarrow \Gamma)_\alpha$;

8: $\hat{p}(1_, j) \leftarrow \hat{p}(t + j) \leftarrow \Theta_\alpha P_\alpha(t + j)$;

9: end for

10: end for

11: Select channel according to Equation (12);

12: end if

---

its busy probability periodically increases and decreases rapidly within a limited time slots. Therefore, the trans- mission of SU may be interrupted if the data transmission cannot be completed during the interval. Meanwhile, other idle spectrum units, which would provide the SU wider transmission bandwidth, are not utilised. In this case, throughput of the SU will be decreased because of the increase of switching times and the bandwidth limitation of the transmission channel. If the SU can occupy more spectrum units and transmit all the data with fewer time slots, the transmission performance of the SU would be improved.

When service time slots of the SU are ρ *Tpsu*, U is the idle spectrum units set at t. The SU checks whether there are adjacent spectrum units in U at first. If there is no adjacent spectrum unit, strategy A is applied for channel selection; otherwise, the available spectrum units are divided into several spectrum groups. Spectrum group is defined as a series of adjacent spectrum units. For example, when $U = \{u_{1;}u_{2;}u_{4;}u_{6;}u_{7;}u_8\}$, the idle spectrum units would be divided into three spectrum groups; they are $G_1 = \{u_{1;}u_2\}$, $G_2 = \{u_4\}$ and $G_3 = \{u_{6;}u_{7;}u_8\}$. We assume that there are η spectrum groups, and one spectrum group $G_v(1 \leq v \leq \eta)$ consists of σv spectrum units. The candidate channels are consisted of $\chi(1 \leq \chi \leq \sigma v)$ adjacent spectrum units in G_v; thus, the actual time slots of the SU needing to transmit all the user data are reduced to ρ_{ac}, which is defined as

$$\rho_{ac} = \lceil \rho/_{\chi} \rceil \quad (13)$$

where dl is an operator, which rounds · to the nearest integer greater than or equal to ·. So, the busy probability of the $\tau th(1 \leq \tau \leq n)$ candidate channel (consists of χ_τ adjacent spectrum units) in G_v during the following ρ_{ac} time slots can be computed by

$$\hat{P}v\tau = \frac{1}{\chi_\tau}:\sum_{j=1}^{\chi_\tau}[\frac{1}{\rho_{ac}}\sum_{i=1}^{\rho_{oc}}\hat{p}\,(t+i)]\} \quad (14)$$

where $\hat{p}(t+i)$ is the prediction busy probability of the j th spectrum unit in the candidate channel at the following ith time slot. After the busy probabilities of all candidate channels in G_v

are calculated, the minimum busy prob- ability $\hat{p} = \min\{\hat{p}1 \leq \tau \leq n\}$ and the correspond- ing candidate channels C_v are stored. Then, the selected channel is

$$C_{sl} = C_v(v = \arg\min \ldots\{\hat{p}\}) \quad (15)$$

When the service time slot of the SU is small and a channel consisted of χ spectrum units is selected for data transmission, according to Equation (13), despite the ρ/χ is small, at least one time slot would be assigned to the SU for data transmission. Hence, during this time slot, lots of idle spectrum units would be occupied by one SU to transmit small amount of user data, whereas the other SUs can not access these spectrum units anymore. In this case, the spectrum efficiency of the cognitive radio network would be significantly decreased. To avoid this problem, a spectrum efficiency threshold σ_{se} is defined to guarantee that the SU would occupy suitable number of spectrum units for data transmission. The threshold indicates that the number of spectrum units in one spectrum group is constrained; that is,

$$\chi = \{\chi = 1, 2 \cdots \sigma v; \text{ and } \frac{\rho}{\chi} \geq \sigma_{se}\} \quad (16)$$

Thus, the channel selection strategy B is summarised in algorithm 3.

In strategy A, only one spectrum unit would be occupied for data transmission. Therefore, if strategy A is employed as channel selection method in the cognitive cell, data transmission rate of the SU would be limited as its bandwidth can be utilised for data transmission is fixed. By contrast, strategy B is much more flexible. If there are many idle spectrum units, the number of spectrum units occupied for data transmission can be adjusted according to the user's requirements. Thus, the SU employed with strategy B can vary its transmission rate at a larger range than the one with strategy A. This ability is important especially when transmission rate adaptation is required by the user.

To collect busy probability information, the SU needs to sense the spectrum units several times in one time slot. Thus, determining a proper sensing frequency would be an important factor to consider. If the sensing frequency is too low, it would bring large observation errors to observed busy probability. In this case, because of the inaccurate prediction, the proposed solution may miss the transmission opportunity with lower busy probability. The following simulations demonstrate that the busy probabilities are accurate enough if they can represent the basic busy/idle situation of spectrum unit. Blindly increasing the sensing frequency can not bring much benefit because of high sensing overhead, such as the consumption of energy and time.

Algorithm3 $Channelselectionalgorithm: strategyB$

1: Updates the information of idle spectrum units U;

2: Load the historical busy probabilities of d spectrum units;

3: if $U \neq \varphi$ and there are adjacent spectrum units in U then

4: Find η spectrum groups: $\{G_{1;}G_2 \cdots G_\eta\}$;

5: for $v = 1; v \leq \eta; v + +do$

6: χ is selected according to Equation (16);

7: n candidate channels are searched;

8: for $\tau = 1; \tau \leq n; \tau + +do$

9: for $j = 1; j \leq \chi_\tau; j + +do$

10: Generates the jth training examples

$(\Phi, \Gamma)_j$;

11: $DF - RLS:_{ji} \leftarrow F : (\Phi \leftarrow \Gamma)_{ji}$, i from 1 to ρ_{ac};

12: $\hat{P}v\tau \leftarrow \frac{1}{\chi_\tau}\hat{p} \leftarrow \frac{1}{\rho_{0C}}\sum_{i=1}^{\rho_{ac}} \theta_{ji} P_{ji}(t + i)$;

13: end for

14: end for

15: $\hat{p} =$ min $\{\hat{p}1 \leq \tau \leq n\}$;

16: end for

17: Select channel according to Equation (15);

```
else
Strategy A is applied;
end if
```

The channel selection latency of the proposed solution can be further reduced with the aid of channel sensing sequence management. Meanwhile, searching all the candidate channels to find the one with the lowest busy probability would consume a lot of time. To reduce the time consumption, once the future busy probability of one channel is below a predefined threshold, the searching operation stops. These are the two possible ways to reduce the channel selection latency.

CHAPTER: 4

SIMULATIONS AND RESULT ANALYSIS

4.1 SYSTEM ARCHITECTURE

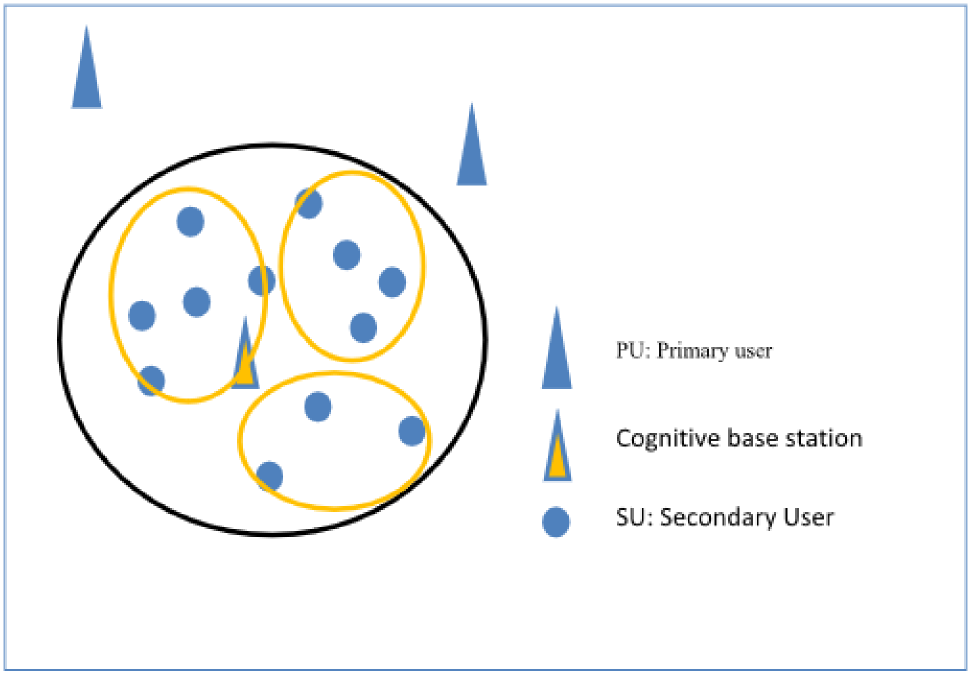


Fig 4.1. Assumed CR network scenario

The total available spectrum band for cognitive radio is divided into multiple equal spectrumunits, which can be sensed and used by SUs. CBS of the cognitive cell consists of four modules: fusion center, sensing task management, busy probabilities database and idle spectrum units list. The fusion center collects sensing results from all the SUs and determines the states (idle/busy) of the spectrum units. According to the output of the fusion center, idle spectrum units are added to idle spectrum units list, whereas busy ones are dropped. Meanwhile, busy probabilities of all spectrum units, which are stored in the database, are updated according to the latest sensing results. Sensing task management module controls all the spectrum sensing behaviours of SUs via a perfect common control channel.

To obtain busy probabilities of the spectrum units in each time slot (a limited time interval, which is predefined), spectrum sensing must be carried out for M .M >1/ times in one time slot.

If Q busy states of the spectrum unit are detected, then the busy probability of the spectrum unit can be described independently by the ratio of Q/M ,as demonstrated in . We assume that the time of all SUs are synchronized ; thus, at the end of each time slot (moment A), the fusion center of the CBS computes the busy probabilities of all spectrum units on the basis of the sensing results reported by all the SUs. According to the results of last sensing in each time slot, idle spectrum units list in the CBS is also updated.

4.2 SIMULATION PARAMETERS

Area	**(100 * 100) meters**
Base Station near the center	**[40, 20]**
No. of Primary Users	**2**
No. of Secondary Users	**15**
No. of bands	**9**

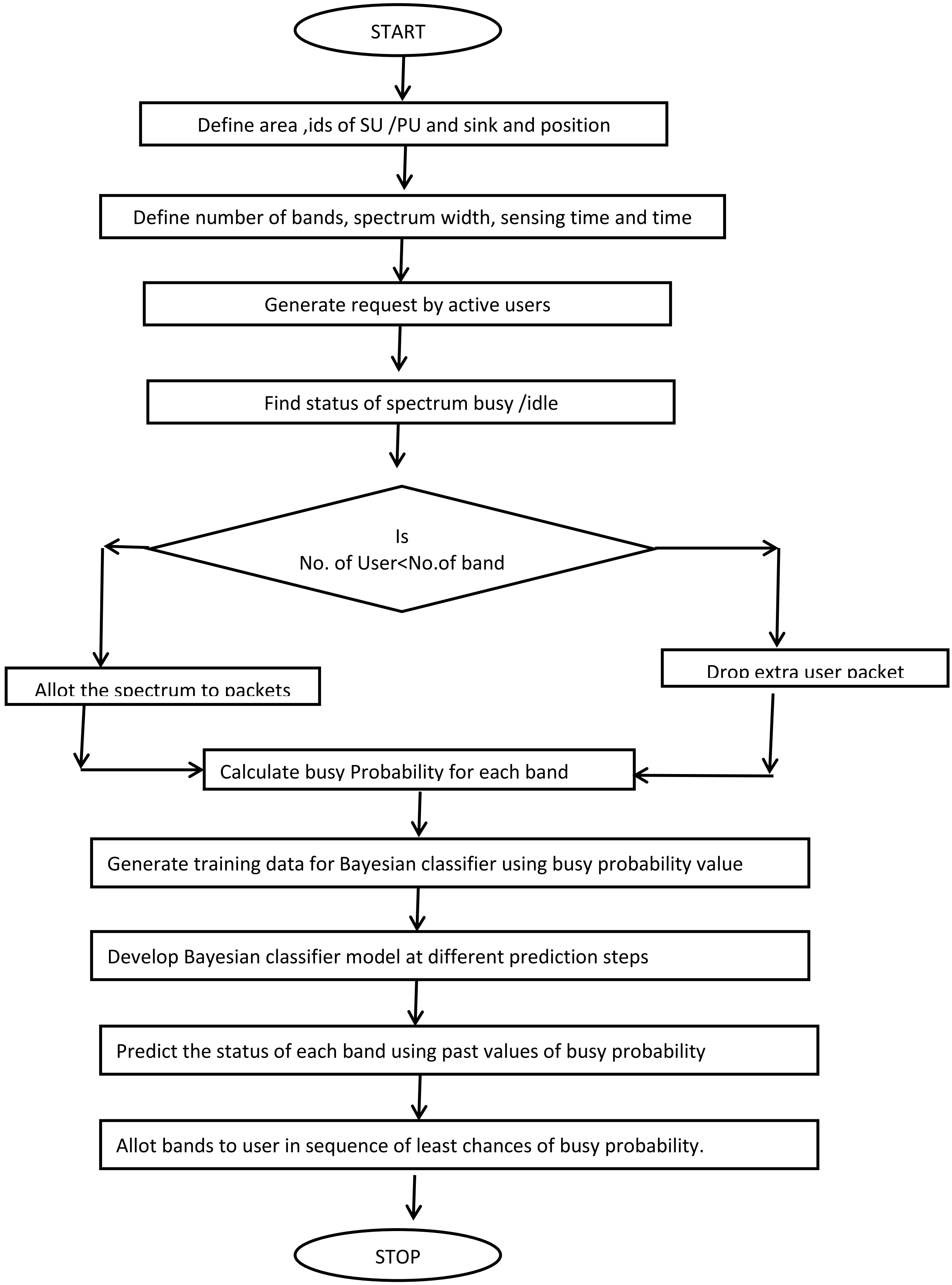
In this section, we present numerical simulation results to evaluate and compare the performances of the channel selection strategies. Random channel selection method is also introduced, which means the SU randomly selects one spectrum unit at each transmission (also when collision or switch happens) and accesses this spectrum unit for data transmission, without any prior information about the busy probability of the idle spectrum unit.

4.3 SIMULATION TOOL

At present, modeling & simulation is the only paradigm which allows the simulation of complex behavior in a given environment's cognitive radio networks. Network simulators like OPNET, NetSim, MATLAB and ns2 can be used to simulate a cognitive radio network. CogNS is an open-source NS2-based simulation framework for cognitive radio networks.

For performance evaluation, we use MATLAB Software which is similar to C language where the code is executed line by line.

4.4 DATA FLOW FOR CHANNEL SELECTION PROCEDURE



4.5 SIMULATION RESULT

In this chapter the results and analytical observations are described in details regarding the response generated by our approach for explaining the response that are generated by development of algorithm for improved prediction strategy of ideal and busy channels in a WSN network using Bayesian prediction process.

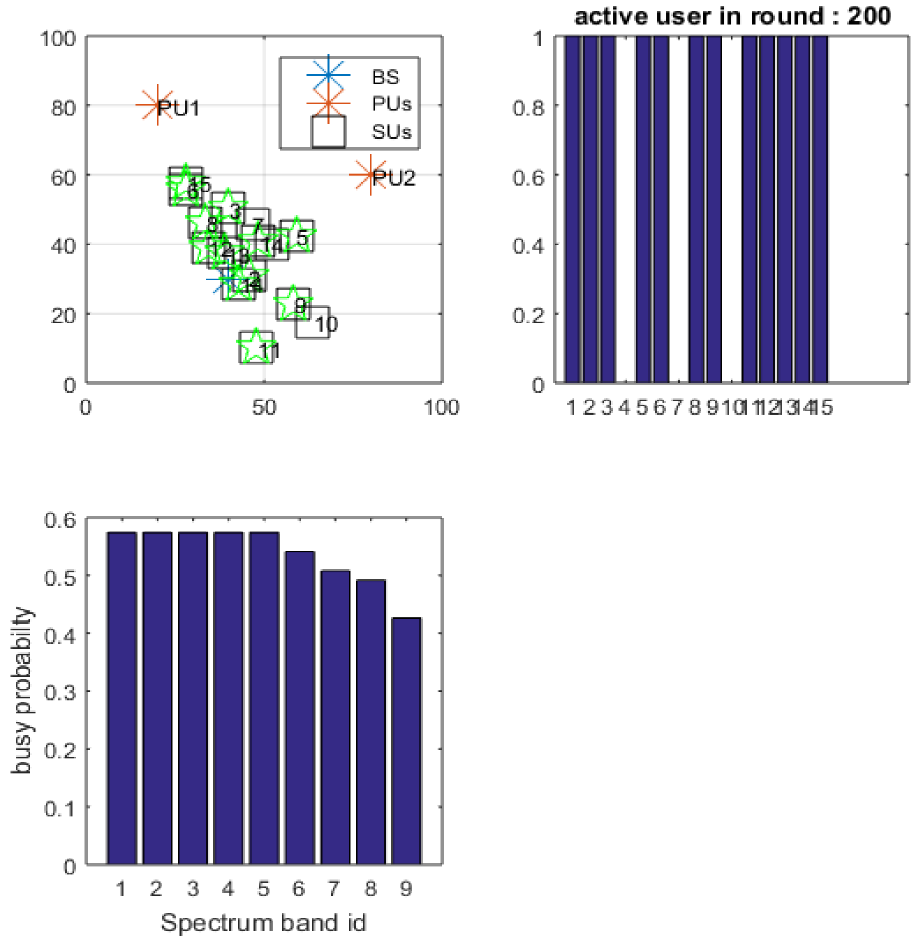


Figure 4.2: (a) WSN network with different users.(Top left) (b) Active user at round r=200 (top right) (c) busy probability(bottom left)

In the figure 4.2 it has been shown that in a network area of 100 x 100 meter there are several users some are behaving as primary user and some are secondary user. They are communicating to each other.in a given cognitive cell environment.

Figure 4.2 (b) demonstrates the number of active users in a round that are ready to send packet. It can be seen that it has 15 users all total and some of them have zero and most of them have 1one status. In such a way the number and ids of active users varies. Figure 4.2 (c) displays the status of spectrum band. In this figure it can be seen that y axis is the busy probability of each band and x axis is the band id varying from 1 to 9 (total 9 bands).The number of bands are less than the number of users. If active users are less than the number of bands then some bands will remain ideal and if active users are equivalent to number bands then all the bands will be busy and if active users are more than the bands then packet drop will occur.

In the proposed work multi step prediction is applied to estimate the status of all the bands prior to channel allotment autonomously by the network head. The busy probability in upcoming round is predicted by using the Bayesian Prediction model. The data used to predict is initially generated for 60 to 100 rounds.Then using last busy probability values 31 to 10 steps back the upcoming instance busy probability of all bands is predicted by Bayesian model.

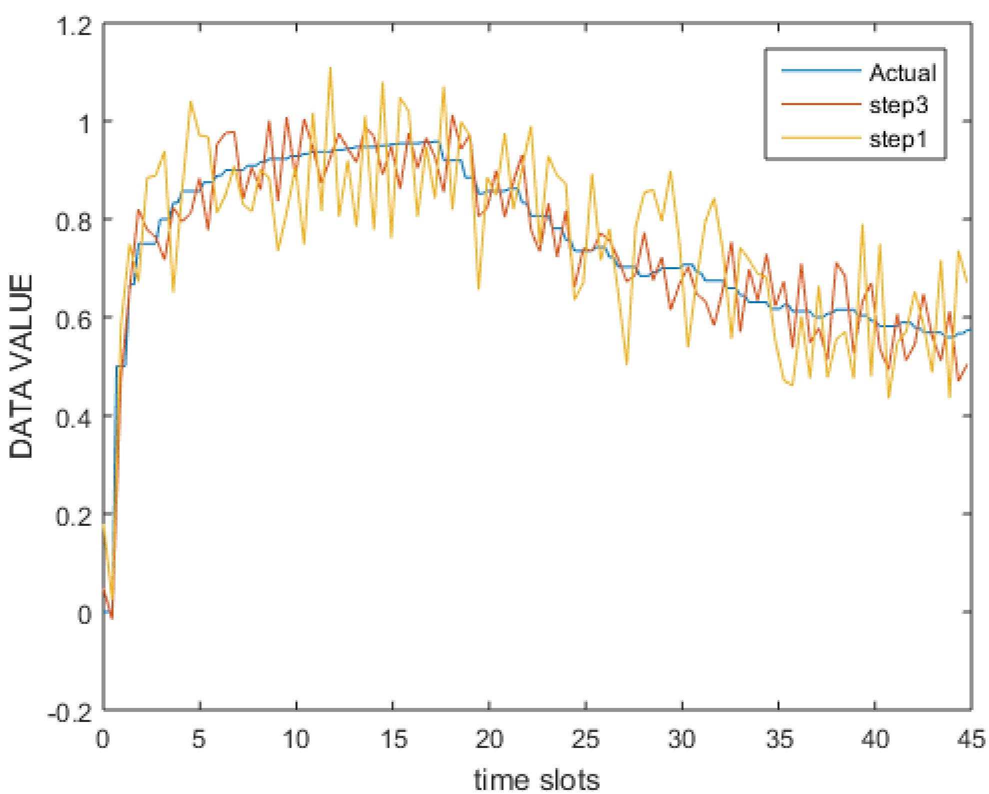


Figure 4.3: Representations of the actual and estimated busy probability.

Figure 4.3 represents the data value that are predicted and the actual data value.at different time slots.x axis is the time slots from 0 to 45 seconds and the data value is varying from 0 to 1 in actual data and the predicted value using one step and 3 step prediction are also shown along with actual data value. They are also following the similar approximate curve and hence fits the predicted curves to the actual curve.

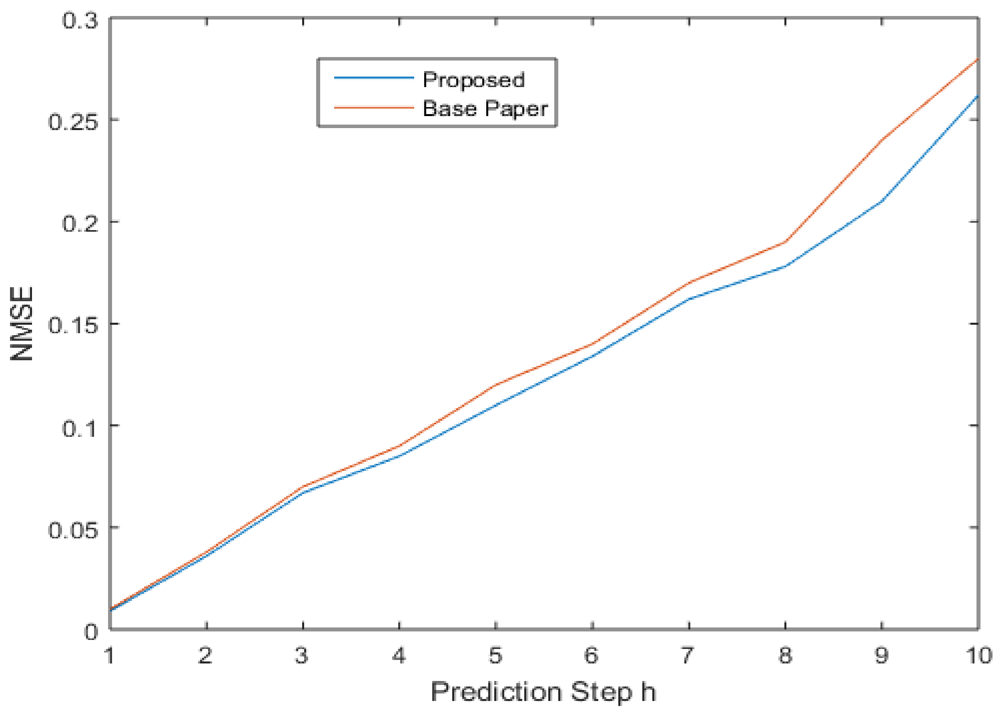


Figure 4.4Error (NMSE) in proposed model and base work.

Figure 4.4 displays the normalized mean square error in prediction of busy probability at different prediction steps as the prediction steps are increased the errors are increased. The maximum error observed here is 0.3.Figure 4.5 displays the switching probability of the bands from ideal state to busy state and vice versa. In proposed work switching probability is higher than the base work. It observed that this switching probability s consistent and in between 0.5 to 0.6. Normalized mean square error is nothing but a deviation between measured value and absolute value. Is is defined by –

$$M' = \frac{1}{N} \sum_i Mi$$

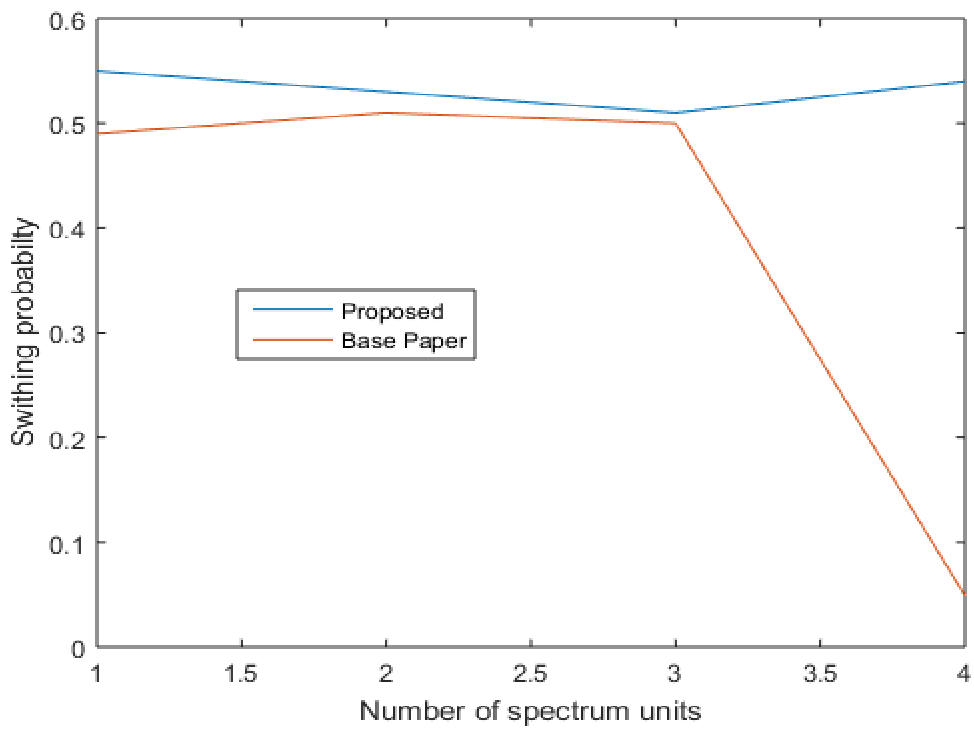


Figure 4.5: Switching Probability vs. number of spectrum units.

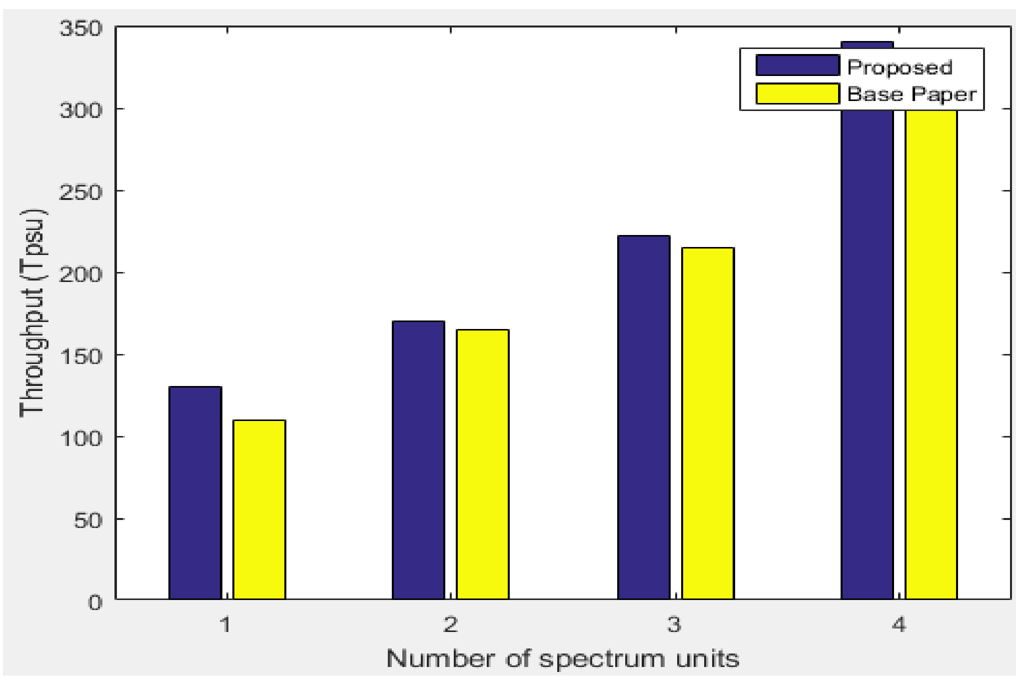


Figure 4.6 : Throughput at different spectrum units.

Figure 4.6 shows the overall network throughput at different values of spectrum units. The spectrum units are varied from 1 to 4 and thereafter the data throughput is generated and the plot for this value represents that as the spectrum units are increased the throughput increases and the through put maximum goes to the 340 approx. and for all spectrum units value the proposed work throughput is found to be higher than the base work.

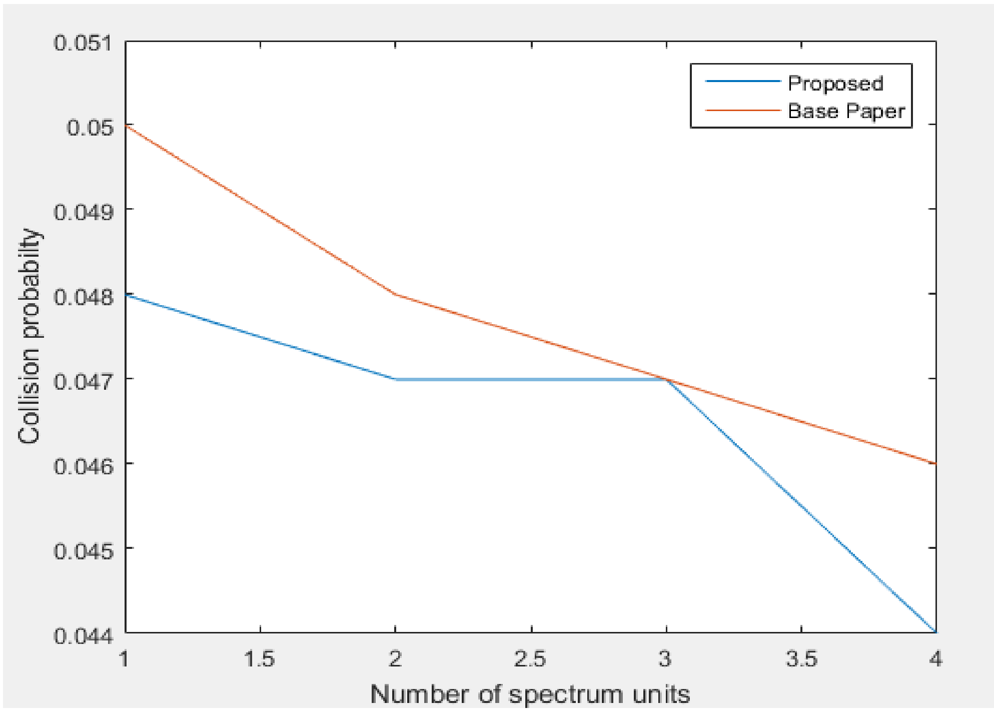


Figure 4.7: Collision Probability vs. number of spectrum units.

Figure 4.7 displays the collision probability of the bands from ideal state to busy state and vice versa. In proposed work collision probability is lower than the base work. As much as the collision probability will be low, the more and more system will be better. So, it's good for any system that its collision probability is low which is fully satisfying our objective.

CHAPTER: 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

Cognitive radio, which will become a fundamental part of the *Internet of Everything* (Io E), has been identified as a promising solution for the spectrum scarcity. In a multi-SU and multi-PU cognitive radio network, selecting channels is a fundamental problem due to the channel competition among secondary users (SUs) and packet collision between SUs and primary users (PUs).

In this thesis, we adopt cooperative sensing method to avoid the packet collision between SUs and PUs and focus on how to collect the spectrum sensing data of SUs for cooperative sensing. In order to reduce the channel competition among SUs, we first consider the transmission model for a SU that can opportunistically access both channels operating either the busy or the *ideal state* model and the busy channels by using the channel priority algorithm technology. Then we propose a predictive set based channel selection policy using Bayesian Classification algorithm for multi-SU where all SUs competing for data transmission or energy harvesting in the same channel will form a dedicated set. Extensive simulations show that the proposed cooperative sensing method and the channel selection policy out perform previous solutions in terms of switching alarm, average throughput, average error, and collision probability of SUs.

In this work, aiming at solving the problem of spectrum scarcity in wireless environment, we consider a multi-SU and multi-PU cognitive radio network in which the SUs are equipped with the RF energy harvesting capability. In this network, the crucial issues are the channel allotment among SUs and the packet collision between SUs and PUs. We adopt the Bayesian classifier based cooperative spectrum sensing method to reduce the probability of sensing errors and alleviate the interference to PUs. In order to solve the problem of channel competition among SUs each SU can either implement data transmission in an idle channel or energy harvesting from a busy channel given its data queue and energy queue state and sensing result. Additionally, we present a channel selection policy for multi SU based on competitive set. Our proposed policy can achieve higher throughput compared with the conventional random policy with lower collision probability because of very low prediction error. Furthermore, the collision will never be detected by themselves and may last for a quite long time when several SUs collide with each other in the conventional random policy. Hence, the channel competition among SUs will largely limit the performance of conventional random policy. In future we can include that while SUs detect the collision in the initial phase and stop transmission in the next phase to avoid longer in effective transmission in our future scopes policy. Such simulations may show that the proposed cooperative sensing method and channel selection policy outperform previous solutions in terms of probability of false alarm, average throughput ,average waiting time, and energy harvesting efficiency of SUs.

5.2 FUTURE SCOPE

We note that, however, when there are many SUs and they are sharing the same band of spectrum, interference occurs when more than two SUs access the same spectrum unit at the same time. Thereby, it is necessary to build coordination mechanisms to avoid interferences among them. In addition, energy efficient cognitive radio would be more attractive. We believe that effective sensing task management algorithm can significantly reduce the energy consumption, simultaneously guaranteeing the sensing accuracy. In future, the proposed schemes in this thesis can be extend to a more practical scenario.

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LIST OF PUBLICATION

1. Saumya Srivastava, , “Study on Spectrum Mobility occurs in Cognitive Radio Networks”, International Journal of Advance Engineering and Research Development (IJAERD),Volume 6, Issue 03,March-2019

2. Saumya Srivastava, , “A Novel Opportunistic Channel Selection Based on time series prediction in Cognitive Radio Networks”, International Journal of Advance Engineering and Research Development (IJAERD),Volume 6, Issue 05, March-2019

PLAGIARISM REPORT

Student Name **:** Saumya Srivastava

Roll No **:** 1170454007

Thesis Title **:** A Novel Opportunistic Channel State Selection Mechanism based On time series prediction in Cognitive Radio Networks

Guide **:** Assistant Professor Ashutosh Rastogi

Babu Banarasi Das University, Lucknow

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5. Faculty of the University to which the thesis is submitted

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7. Specifications regarding thesis format have been closely followed. YES / NO

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(Signature of the Candidate)

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Roll No …………………………………

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5. School (of the University to which the thesis is submitted)

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6. Thesis Preparation Guide was referred to for preparing the thesis. YES / NO

7. Specifications regarding thesis format have been closely followed. YES / NO

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9. The thesis has been prepared without resorting to plagiarism. YES / NO

10. All sources used have been cited appropriately. YES / NO

11. The thesis has not been submitted elsewhere for a degree. YES / NO

12. All the corrections have been incorporated. YES / NO

13. Submitted 4 hard bound copies plus one CD.

(Signature(s) of the Supervisor(s)) **(Signature of the Candidate)**

Name(s):……………...………………… **Name:……………...…………………….**

Roll No ………………………………...

CURRICULUM VITAE

SAUMYA SRIVASTAVA
Mobile:7905590077
Email:swamisrivastava555@gmail.com
Address: 305/12, Near Chitragupt Tempel,
In front of Reliance Tower,
Katra-Banda,
UP-210001

CAREER OBJECTIVE:-

I would like to pursue my career in an organization where I can utilize my efforts along with knowledge, perseverance and intelligence so as to contribute to organizations growth and goal. Having a flare to achieve excellence, I always look forward to enrich my knowledge and want to be valuable and viable part of the organization.

EDUCATION QUALIFICATION:-

INSTITUTION	COURSE/STREAM	YEAR OF PASSING	MARKS
Babu Banarsai Das University, Lucknow	M.tech (Electronics & Communications)	Joined in – 2017 (Waiting for Resutls)	CGPA- 8.57 (Up to 3rd Semester)
Babu Banarasi Das University, Lucknow.	B. Tech (Electronics & Communication)	2017	74.21%
Govt. Girls Inter College, Banda.	Class XII, PCM Physical Education, U.P. Board	2013	81.33%
Arya kanya Inter College, Banda.	Class X, U.P. Board	2011	74.16%

INDUSTRIAL TRAINING:-

- 4 weeks Industrial Training from Bharat Sanchar Nigam Limited (BSNL), Banda in 2016.

ACADEMIC PROJECTS:-

- **Spectrum Handoff in Cognitive radio Networks.**
- **Fabrication of PCB Board and Designing circuit.**
- **Simulation of Various modulation techniques in one system.**
- **ECD Project:** Laser security alarm circuit.

- **Major Project:** GPS & GSM Based Vehicle Tracking System.

SUBJECTS OF INTEREST:-

- Wireless communication & Cognitive Radio Networks

TECHNICAL SKILLS:-

- Knowledge of programming language C & C++.
- Programming 8085 Microprocessor using assembly language.

PERSONAL SKILLS:-

- Good communication skill.
- Ability to work in a team.
- Willingness to learn.

EXTRA CURRICULARS:-

- Participated in Inter House Dance Competition in the years 2007-2010.
- Attended the seminar on "EMPOWER: Be your own Boss".
- Participated in UTKARSH which is annual fest of the college, in 2014.
- Participated in Sanskarshala compition organized by Dainik Jagran.
- Awarded by 1st position in the Technical Fest.

PUBLISHED PAPERS : -

- Saumya Srivastava, ," **Study on Spectrum Mobility occurs in Cognitive Radio Networks",** International Journal of Advance Engineering and Research Development **(IJAERD),Volume 6, Issue 03,March-2019**
- Saumya Srivastava, ,**A Novel Opportunistic Channel Selection Based on Time Series Prediction in Cognitive Radio Networks** ", International Journal of Advance Engineering and Research Development **(IJAERD),Volume 6, Issue 05, March-2019**

PERSONAL DETAILS:-

Name	**:**	Saumya Srivastava.
Father's name	**:**	Mr. Om Prakash Srivastava.
Date of Birth	**:**	22-03- 1996.
Hobbies	**:**	Writing Articles, Dancing, Listening music.

Declaration

I Saumya Srivastava, hereby declare that the information furnished above is true to the best of my knowledge and belief.

Place: Lucknow **(Saumya Srivastava)**