Performance Analysis of Spectrum Sharing Techniques Using ARQ retransmission based on Bayesian Spectrum Sensing in Cognitive Radio Networks

DISSERTATION-II

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(April 2015)

CERTIFICATE

This is to certify that the Dissertation-II titled "**Performance analysis of Spectrum Sharing Techniques Using ARQ retransmission based on Bayesian spectrum sensing in Cognitive Radio Networks**" that is being submitted by **P. Sujith Kumar** in partial fulfillment of the requirements for the award of MASTER OF TECHNOLOGY, is a record of bonafide work done under my guidance. The contents of this Dissertation-II, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

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Objective of the Dissertation-II is satisfactory / unsatisfactory

Examiner I   Examiner II

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I also extend my sincere thanks to all other faculty members of Electronics and Communication Department and my friends for their support and encouragement.

P. SUJITH KUMAR

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CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the report, entitled "**Performance analysis of Spectrum Sharing Techniques Using ARQ retransmission based on Bayesian spectrum sensing in Cognitive Radio Networks"**, in partial fulfilment of the requirement for the award of the Degree of **Master of Technology** and submitted to the Department of Electronics and communication Engineering of Lovely Professional University, Punjab, institution is an authentic record of my own work carried out during the period *january-2015* to *april-2015* under the supervision of **Mr. Surjeet Kumar**. I also cited the reference about the text(s)/figure(s)/table(s) from where they have been taken.

The matter presented in this thesis has not been submitted elsewhere for the award of any other degree of diploma from any Institutions.

Date: Signature of the Candidate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: Signature of the Research Supervisor

ABSTRACT

In the recent years, the spectrum sensing methods using the ARQ Retransmission technique in the context of cognitive radio become a significant method and in my research, I have worked with the standard detection method using the Bayesian approach and compared with the ARQ retransmission methods and drawing the inferences using the obtained results.

Two different types of spectrum sharing methods are taken into consideration namely conservative and aggressive and compared with legacy and as well as the proposed Bayesian approaches. And two of them do not introduce any relative breakdown regarding to the primary users who are using the spectrum and the main difference regarding both of them is that the conservative does not interrupt the primary operations and whenever primary needs spectrum it will provide, but in aggressive, sometimes it may not allow the spectrum to primary user until the secondary user releases the spectrum which decreases the throughput of primary.

The results have been obtained regarding the throughput comparison of the spectrum sharing techniques mentioned above with the standard energy detection technique called Bayesian energy detection technique which has become significant in the recent days and the related inferences are taken and represented in the conclusion section.

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LIST OF ABBREVIATIONS

ARQ	Automatic Repeat Request
CSI	Channel Side Information
DMT	Discrete Multi Tone
DSA	Dynamic Spectrum Access
AWGN	Additive White Gaussian Noise
ACK	Acknowledgement
BIC	Backward Interference Cancellation
CR	Cognitive Radio
PU	Primary User
SU	Secondary User
SHARP	Spectrum Harvesting through ARQ Retransmissions and Probing
OFDM	Orthogonal Frequency Division Multiplexing
BPSK	Binary phase shift keying
FCC	Federal Communications Commission
IEEE	Institute of Electrical and Electronics Engineers
LTE	Long Term Evolution
WiMax	Worldwide Interoperability for Microwave access
GSM	Global System for Mobile communications
ICI	Inter Carrier Interference
ISI	Inter Symbol Interference
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
PAPR	Peak to Average Power Ratio
MAN	Metro-politian Area Network
NACK	Negative Acknowledgement
UWB	Ultra Wide Band
DMT	Discrete Multi Tone
BER	Bit Error Rate
PIC	Perfect Interference Cancellation

ICI	Inter Carrier Interference
SBIC	Single Block Interference Cancellation
SNR	Signal to Noise Ratio
SIR	Signal to Interference Ratio

CHAPTER – 01

Introduction

1.1 Introduction

This chapter deals with the basic introduction and as well as the terminology that is necessary and also about the research organization.

The cognitive radio based research work regarding the "Performance analysis of Spectrum Sharing Techniques Using ARQ retransmission based on Bayesian spectrum based sensing in Cognitive Radio based wireless Networks" basics which are necessarily needed and are used for the efficiently usage of the spectrum based channel by identifying or discovering the spectrum holes or unused subcarriers or idle channels and allotting or allocating the respective primary channel or licensed subcarriers to the secondary consumer or the unlicensed consumer in a dynamic spectrum sharing order method over using an underlay cognitive radio approach.

1.2 Cognitive Radio

Cognitive Radio offers a historical solution or obtained answers to suppress or to reduce the under utilization problem by letting an opportunistic usage of allocating or reserving bandwidth resources. This is proof from the definition of cognitive radio that has followed or used by the famous spectrum allotting organisation Federal Communications Commission (FCC).

1.2.1 Basic Terminology

Basic and fundamental terminology or definitions that are related to and regarding the respective cognitive radio functionalities regarding the implementation of cognitive radio are given below:

1. ***Spectrum*** is defined as the band of respective frequencies or subcarriers that are being allocated for the particular consumers in a particular region and it also can be reused in different regions. For e.g., 900 MHz, 1800 MHz
2. ***Spectrum hole*** is defined as the unused frequency regions which are detected by the cognitive radio.

3. ***Primary*** consumer***s*** are considered as the respective consumers who can use the resources of the spectrum whenever they want and they have no restrictions imposed on them and are called as licensed consumers in terms of wireless communication and these are the rightful consumers of the spectrum or network.
4. Similarly, ***Secondary*** consumer***s*** are the consumers who can use only when the spectrum is free and returns the spectrum channels when primary consumer needs and also called as unlicensed consumers.
5. ***Cognitive Radio*** is the reasoning based adaptive multipurpose software based defined radio that is used to monitor its surroundings continuously and varies its parameters accordingly to allot the unused primary spectrum channels to the secondary consumers when needed.
6. ***Underlay Cognitive radio*** is called only if the unlicensed consumer transmits in the allotted spectrum of a primary consumer exclusive of degrading or disturbing the relative performance of the respective primary consumer.
7. ***Overlay Cognitive radio*** is also defined as only; the secondary consumer transmits in the allocated spectrum related to a licensed consumer which may cause degrading performance to the licensed consumer.
8. ***Ad-hoc network*** is the wireless based network where mobile nodes are connected with each other without any centralized infrastructure as in wireless mobile communication.
9. ***Licensed-Band based Cognitive Radio***, defined as a radio which is able to use the respective bands allotted to the concerned licensed consumers. The standard IEEE 802.22 working organization is working to improve the standard of the wireless regional area based network (WRAN), which already proved to operate and employ on the unused respective television channels.
10. ***Unlicensed-Band based Cognitive Radio***, Defined as a radio in which the cognitive based consumers may only be able to use the unlicensed region parts of the respective radio frequency (RF) spectrum. One of the systems which are given in the IEEE 802.15 Group 2 specifications, which is entirely focus on the coexistence of IEEE 802.11 and as well as the Bluetooth.
11. ***Spectrum mobility***: Mechanism by which a respective cognitive radio consumer used to change its related frequency of its operation when moving from one location to other. Cognitive- radio based wireless networks aimed to use the respective spectrum in a dynamic fashion by only allowing the respective radio terminals to be operated in

the very best available related frequency bandwidth, which is used for maintaining excellent seamless way or means of the related communication requirements during respective transitions to make the available spectrum in a better manner.

12. ***Spectrum sharing based cognitive radio***: It allows the respective cognitive radio consumers to share the available spectrum bands of the licensed- band consumers. Moreover, the Cognitive Radio consumers have to control their concerned transmitted power so that the respective interference caused to the needed licensed- band consumers is kept below a required certain threshold.

1.2.2 History of Cognitive Radio

From the invention of the cognitive radio by the researcher Dr. Mitola which has made a revolution in the history of the wireless communication and later on many researchers worked on the various techniques that are regarding the implementation of the cognitive radio and their research passed elsewhere to solve the problems regarding aspects for the spectrum bandwidth and have found out some solutions to get better spectrum band width exploitation and have categorized into mainly two research ideas such as spectrum based sensing , as well as spectrum based sharing.

In context to the related numerous wireless communication based networks, it has always become the fastest growing advanced numerous competitive modern technologies and also building the several imposed challenges that are regarding to its existence and also considering several problems that are related to the respective communication field which is regarding to the spectrum effective reuse, spectrum restrictions, as well as the speed, coverage area, voltage consumption, maintenance of the block issues and also the cost of laying the infrastructure etc.

In the era of the wireless communication networks, we will be only having the less available spectrum which has been allocated or allotted by the FCC as well as the TRAI in India and the right and correct way of using the spectrum is well needed and this has been motivated me to get the solution for this problem which can be mitigated or solved by the usage or implementation of the Cognitive Radio based functionality.

With the advent coming of sustainable and as well as the astonishing growth of the wireless communication in the presence of well known numerous wireless operating systems and the wireless services or applications operating around the world, the accessibility of the quality based wireless spectrum has also become less severe fixed. Moreover, an actual related findings or discoveries made at the various countries around the world gives or reveal us that the majority of the radio Frequency bandwidth that are available is ineffectively used and accessed by means of the spectrum utilization factor mostly in the series of 5%-50% only.

Thus, the real hurdle or problem regarding to this is not only the spectrum inadequateness but also the amount of scarcity that is having but also the ineffective spectrum usage which has coming from the constant or fixed spectrum allocations or reservations made by the famous spectrum allocating government agencies such as TRAI in India, inflexible conditions that has been laid by the FCC, fixed radio functions, and also the less determined coordination among or between the available wireless based networks.

From the invention of cognitive radio by the well known researcher Dr. Mitola, many researchers are attempting or trying to work on the topic cognitive radio related to spectrum based issues in terms of the related concerned sub topics of the cognitive radio which are spectrum sensing, spectrum sharing and as well as the type of channel that is used such as the Rayleigh, Rician, AWGN, Nagakami etc.

In [1], they have studied extensively on the spectrum sensing and as well as the sharing methods and developed an related ARQ model and proposed the spectrum sharing types such as the conservative, aggressive and have been compared the throughputs of the duo by varying the secondary power as well as the SIR(signal to interference ratio) , nominal spectral efficiency.

In [12], they have worked on the energy detection technique i.e., Bayesian energy detection technique in which some of the sampled part of the energy is taken and have been calculated iteratively and also they have compared all the energy detection techniques.

In this report, as an extension to [1], I have compared the results of [1] with the Bayesian energy detector and the related concerned inferences have been drawn.

Coming to my topic, first of all I have implemented the base paper [1] and thanks to the authors for doing a great job and I have tried to find some of the extension or modification to that paper, since cognitive radio is an vast topic and I have tried to compare the results of the ARQ retransmission technique in cognitive radio [1] with the standard and also the most efficient powerful technique for finding energy in the signal which is called the Bayesian energy detection method [12].

Examples of the licensed or rightful consumer technology are global system for mobile communications (GSM), worldwide interoperability for the microwave access (WiMax), and as well as the long term evolution (LTE), which is being the one of the emerging technology such as the 4G while the examples of legacy technology are such as the microphone and as well as the wireless based local area network (WLAN).

On the other side, an unlicensed based cognitive consumer with less priority is stated as the secondary consumers (SUs). A SU are only allowed to access the spectral resources of a PU when the PU's are not using them according to the above mentioned definition. Moreover the SU should have to release the allotted frequency band, as early as the PU becomes energetic or when the primary consumer needs the spectrum.

So that the minimum insignificant (or no) interference is caused to the respective PU. This type of relative opportunistic mean of access in terms of the PU resources by the SUs is called as the dynamic spectrum access.

In the sensing-based spectrum sharing, cognitive radio based consumer's first pay attention to the respective spectrum or channels allotted to the licensed consumers to detect the relative status of the licensed consumers.

A SU can only opportunistically get utilizing the different spectrum holes present in the available spectrum which are detected by the cognitive radio equivalent to the different available respective PUs in command to assure its own bandwidth need without cause the related interference to the respective PUs as given in the Figure. 1.1

Concept of spectrum sharing: identifying spectrum holes.

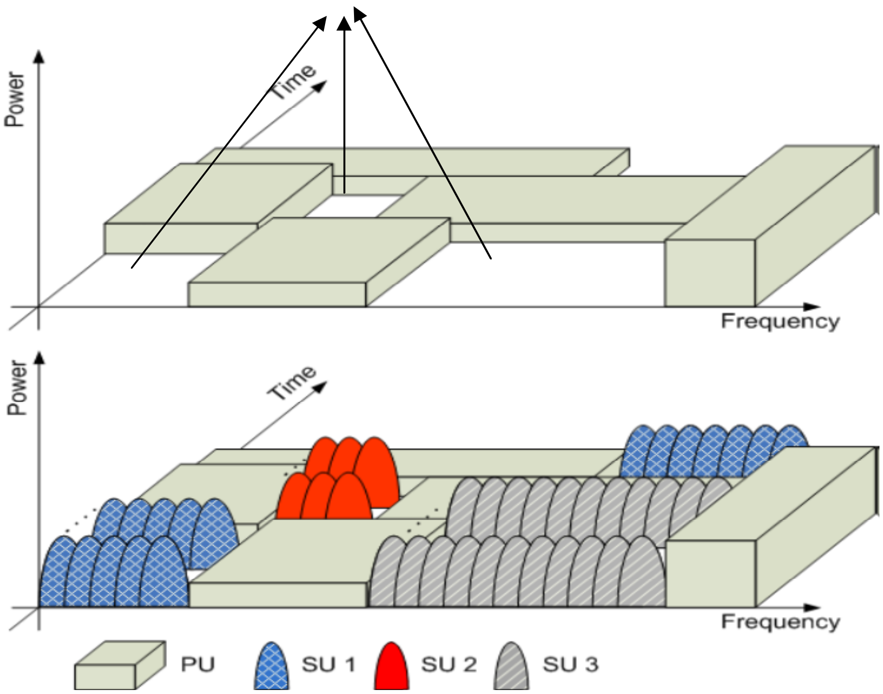


Figure 1.1 Spectrum hole concept

Considering all the required necessities and also the wanted requirements of the cognitive radio mentioned above, and also to embed it into the existing Wireless Sensor Networks applications, a cross layer has to be legitimately adapted or used to sense, share, reconfigure, update and as well as to maintain the QOS management etc.

Each layer has corresponding to its own related functions and methodology to tackle with the handoff problems occurred during the establishment, delay losses in the information regarding the data message, link layer delay, and spectrum sharing mechanism routine etc. and all the functions has been correlated with in the ISO OSI (Open system interface) reference transparency model as shown in the fig 1.2.

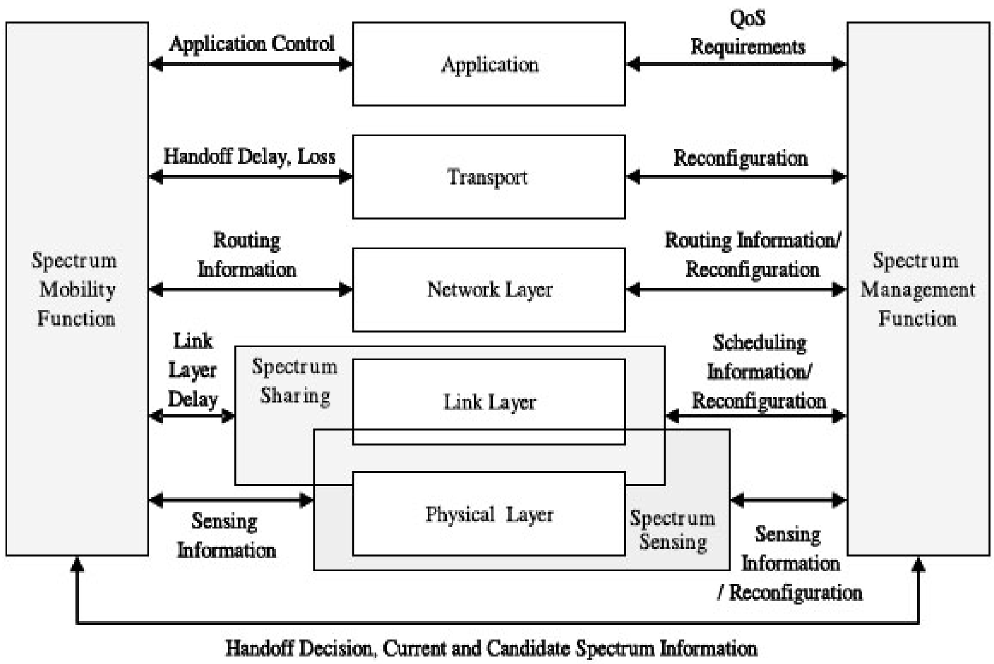
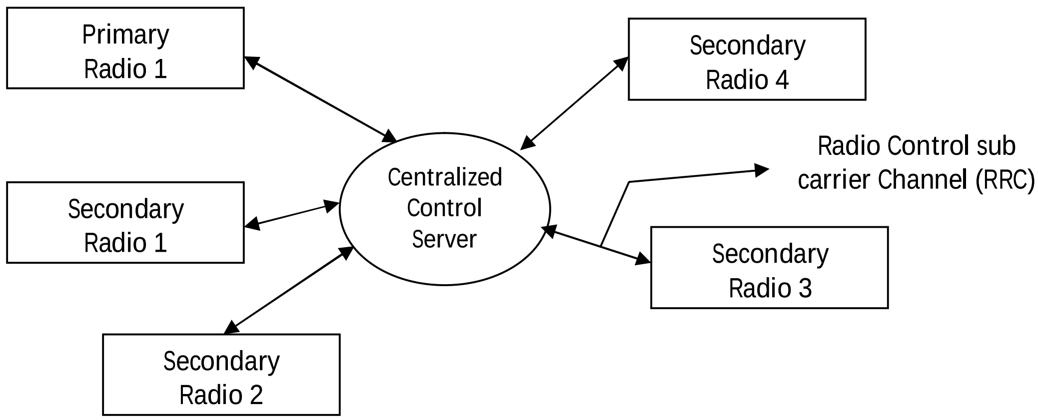


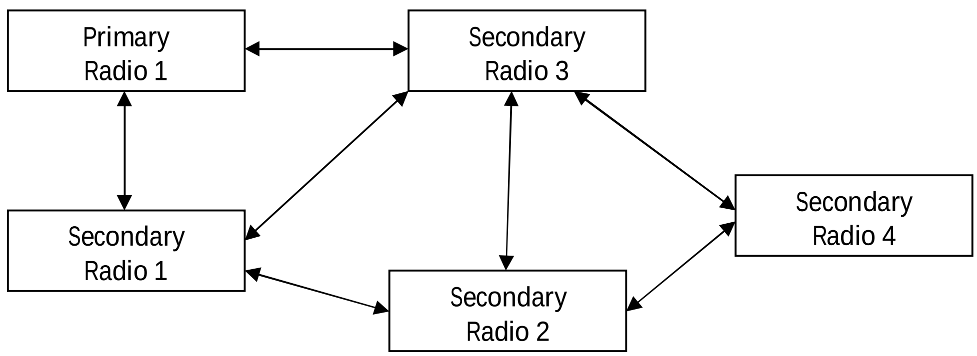
Figure 1.2 Cross layered Cognitive radio functionalities

The cognitive radio can be implemented in the wireless networks of the communication either in the mechanism of using a centralized control server or can be by using the distributed mechanism where the available respective primary consumers as well as the secondary consumers use the available necessary bandwidth channel that has been allocated as shown in the respected below figure 1.3.

As shown in the figure 1.2 which tells us about the different layers of the cognitive radio and my topic is related to one of the functionalities of the cognitive radio and I have worked on the physical layer and as well as the link layer which is used to sense and as well as to share the respective available spectrum.



(a): Centralized mechanism



(b): Distributed mechanism

Figure 1.3 Centralized and Distributed Spectrum Sharing Approaches of CR

In the distributed based networks, the respective available radio consumers are used to share the available spectrum in a distributed manner, where the primary and the secondary consumers are used to depend on each other to share the spectrum and there will not be any centralized control to provide the channel to the consumers.

But in the view of the centralized mechanism, the respective consumers are controlled by the centralized server to access the channel which may be the cognitive radio or the base station. Distributed mechanism is widely used in the internet LAN connections or the WLAN connections as well as the ad-hoc networks and the centralized mechanism is used in the wireless networks of the communication where the respective available spectrum is limited.

Both the mechanisms do not cause the obstructions to the existing infrastructure and do not cause any or impose any type of restrictions or limitations to the existing networks, and they are mean to improve the spectrum that is available to the concerned consumers who are needed.

1.2.3 Advantages of the Cognitive Radio

1. It has the superior spectral efficiency than the other standard double side band modulation schemes such as the known digital modulation techniques such as m-ary PSK, ASK, BPSK, QPSK, as well as the respective direct sequence spread spectrum techniques etc.
2. It can also be easily susceptible to the severe or many channel conditions or restrictions without the usage of complex time- domain equalization.
3. It is much robust or rich dominant resistant against the narrow- band interference methods such as the co- channel interference.
4. It is also robust and less susceptible against the relative inter-symbol based interference (ISI) and also their respective fading losses occurred by the imposed multipath based transmission.
5. It can also be efficiently placed or implemented or embedded using the Fast Fourier Transform (FFT) algorithm.
6. Less prone or change and less sensitivity to the time synchronization errors occurred in the processed signals.
7. It doesn’t require ant bulk infrastructure and can easily embed into the existing available network.
8. It is a self learning mechanism which has no boss to give orders and reduces the base station overhead.
9. It can be easily implemented in TV signals, internet available bandwidth and as well as for wireless networks.

1.2.4 Demerits of the Cognitive Radio

1. It is sensitively or more prone to change with the Doppler shift phenomenon.
2. It is also sensitive and more susceptible to the frequency synchronization problems.
3. It also has the high relative peak- to- average- power ratio (PAPR), requiring linear transmitter based circuits to operate which will be causing more weight to the entire system, which also tends to suffer from the poor power spectral efficiency.

4. Loss or degradation of the efficiency caused by the cyclic prefix/guard intervals that has been used in OFDM.

1.3 Motivation

In the recent twenty first century, Wireless communication has become the one of the fastest growing as well as the most well known successful technology in the context of modern advanced technology of the communication field where it can be whether in terms of the respective speed, coverage, number of consumers using the allotted bandwidth etc and also cost of maintenance is also tending to decrease even though with the rigorous limitations on the available spectrum laid or imposed by the government boards who are controlling the spectrum regulations which are FCC, TRAI in India.

In the field or context of the wireless communication networks, since the available related spectrum or bandwidth that is provided is much less limited that is in which is allotted and decided by the FCC and also the only efficient way and key management of using the given available spectrum is always needed because the available spectrum is very precious to the vendors who has obtained in the bidding made by the government agencies such as Telephone Regulatory Authority of India, Federal Commission for Communication and this has set the required goal for me to get the appropriate solution for this problem or hurdle which can be mitigated or suppressed by using the implementation of the Cognitive Radio functionality and embed into the existing real wireless network. Until the completion of my goal I will continue my research work.

1.4 Organization of the Thesis

This section describes about the comparison of spectrum sensing methods between the ARQ Retransmission technique in the context of cognitive radio with the standard detection method using the Bayesian approach and drawing the inferences using the obtained results. Two different types of spectrum sharing methods are taken into consideration namely conservative and aggressive and compared with legacy and as well as Bayesian approaches. And two of them do not introduce any relative breakdown regarding to the primary consumers who are using the spectrum and the main difference regarding both of them is that the conservative does not interrupt the primary operations and whenever primary needs spectrum it will provide, but in aggressive, sometimes it may not allow the spectrum to primary consumer until the secondary consumer releases the spectrum which decreases the throughput of primary.

The results have been obtained regarding the throughput comparison of the spectrum sharing techniques mentioned above with the standard energy detection technique called Bayesian energy detection technique and the related inferences are taken and represented in the conclusion section.

This thesis gives the overview of some of the known existing techniques through the investigation and compared with the known technique called Bayesian detector. Detailed simulation based study and its related assessments have done to validate their respective applications. This report then suggests some extension to [1] with using Bayesian.

This thesis has been broadly categorized as follows:

In Chapter 1 provides the complete detail as well as the basic introduction, objectives and some of the basic information that related to the thesis. In the Chapter 2 provides the related literature which is derived on using some of the published papers taken from the organization such as IEEE.

In the Chapter 3 , describes the methodology and planning for implementation of the research based topic as taken from the base paper [1] starting from the ARQ model, defining flow charts for two techniques conservative as well as aggressive SHARP and its mathematical analysis which determines the throughput, and as well as the probabilities of channel in different regions.

In the Chapter 4, the various results of the thesis methodology have been placed which are implemented and validated using the software Mat lab. Mat lab is consumer friendly software in which the entire inputs and outputs are taken in the form of matrices. In the Chapter 5, I have given the conclusion about my thesis which compares the various spectrum sharing techniques.

The related design cycle has been given below as shown in the below figure 1.4 which tells about the brief idea of the research process and how the idea has been implemented and reveals the structure of the thesis. The flow chart of the entire thesis has been described in the design cycle.

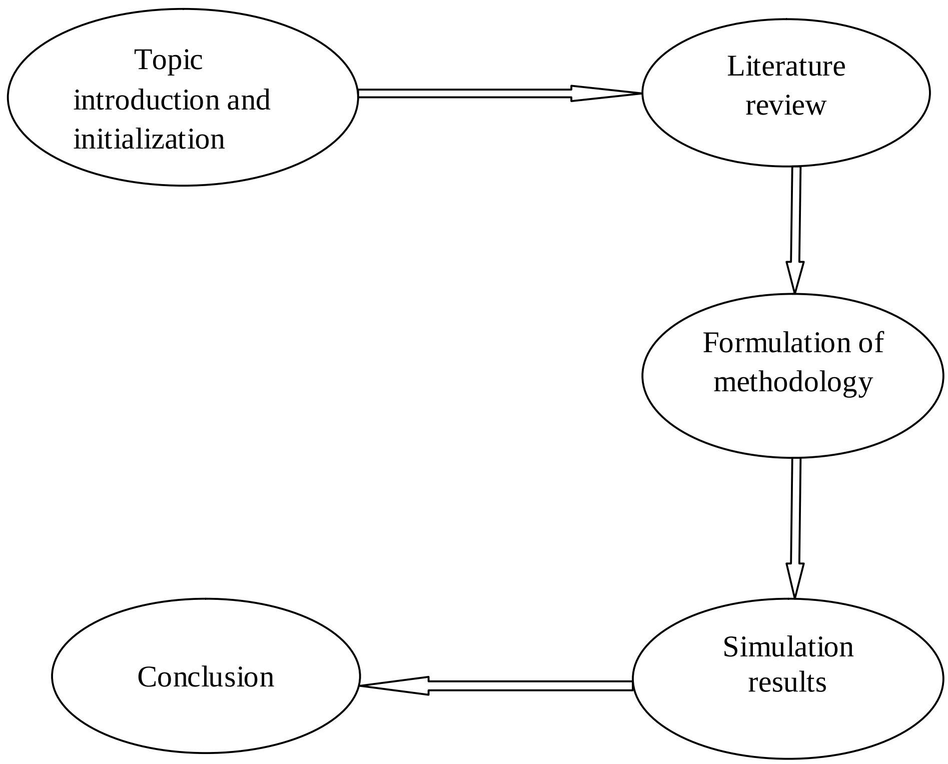


Figure 1.4 Flow chart of research

Chapter - 2
LITERATURE SURVEY

2.1. Introduction

The total entire literature regarding concerned topic is derived from the following papers taken from the published papers.

2.2. Review of the Research Papers

The following papers tell about the ideas and as well as the different methods that have been employed by the different authors and also the respective views and approaches that are considered by them.

(a) Spectrum utilization with the help of ARQ Retransmission and as well as searching the unused subcarriers in Cognitive Radio [1]

This paper proposes and explains about an artificial transmission scheme which may be vulnerable to the interference causing because of sharing the entire available spectrum, known as SHARP, where the concerned secondary cognitive consumer try to co-existing with the primary system using the ARQ based transmission and mechanism. Depending on the received ACK/NAK packet messages from the respected primary consumer only, the proposed concepts of the SHARP schemes used to utilize the several probing time divisions for obtaining a normal perspective regarding the respective primary owned channel conditions, and used to run consequently to the desirable respective transmission modes.

They have analyzed the proposed schemes and formalized through with using the prescribed Monte Carlo simulations. Moreover, it has been concluded that the proposed aggressive SHARP technique can achieve a best throughput for the secondary consumers than the respective conservative scheme with the small negligible primary loss in the throughput. Whereas the proposed respective conservative SHARP technique doesn’t make any negative effect on the respective primary system, and used to work and execute better than the respective legacy based systems in terms to the throughput of the primary consumer.

Two of the proposed SHARP techniques doesn’t try to generate any unnecessary breakdowns to the respective primary system, and as well as they are capable to give the efficient throughput based gains to the respective secondary consumer exclusive of any complete well known CSI at the transmitter side.

(b) On the Capacity improvement with the underlying Receive and as well as the Spatial Spectrum-Sharing Conditions [2]

In this paper, they have submitted and partly resolved the unknown capacity problems and hurdles under the severe constraints or restrictions imposed on the respective received signals, and abstractions thereof, for the various respective multiple access and passing relay problems.

Their respective considerations or circumstances are motivated by the spatial spectrum sharing method based mechanism, in which it is an environment based friendly scenario in which an license spectrum is allotted for a certain respective frequency band is provided under the reservation that the reliable network that is using this respective frequency band does not produce or generate an interfering power of more than a rated threshold level outside of an respective predefined spatial spectrum area. He showed that this condition may used to significantly vary the structure of the facing problem, which leads to a number of many simple and easy capacity expressions and terminology.

(c) Fundamental or basic Limitations of the Spectrum-Sharing methods in the respective Fading Environments [3]

They have stated that the cognitive radio functionalities uses the respective dynamic spectrum sharing mechanism and has become one of the recent rising technologies and also as a new abstract paradigm for the well efficient access scheme for the spectrum. They have reformed or redefined the well known existing established policy to enact the adoption of this method that can enhance or improve the spectrum utilization factor across the pre defined licensed allotted spectrum, hence thereby paving the way for the introduction of a new approach to the respective various digital wireless applications and the respective service based applications.

Regarding with the available conventional well known regulatory conditions on the transmitted power being either relaxed or removed, a constraint on the respected received-interference seems to be more suitable. Phrasing using this above mentioned arguments, they have tried to investigate on the capacity of the respective fading channels that are subjected to the imposed constraints on the power received by the respective third-party (primary) receiver. Their results indicates that as far as in many several cases significant capacity gains can be achieved if the respective channels are varying or changing due effect of fading.

(d) Cooperative sharing based wireless Communications for the Cognitive Radio Networks [4]

According to them, implementation of the Cognitive radio is refreshing technologies that can be used for possibly improve the effective utilization efficiency ratio of the radio bandwidth available spectrum. Cooperative sharing based wireless communications can also perform an important key function in the development as well as enhancement of the Cognitive Radio based networks. In their respective journal, they have considered by taking one of the applications of such type of communications method to the respected cooperative spectrum sensing and as well as the cooperative spectrum type of sharing. The traditional spectrum sensing based methods were firstly included, and their advantages or merits and as well as disadvantages or demerits have been discussed. According to them, upon all their all respective investigations Cooperative spectrum sensing was then be considered and has shown to be a efficient powerful method in revealing with the hidden terminal problem that exists in ad-hoc networks. Moreover, under such type of realistic environment, in which the reporting subcarriers or channels are subjected to be in fading and/or shadowing, the usual performance of the cooperative spectrum sensing can be severely lesser extent defined.

To get the solution for the mentioned above problems and as well as to address this and also for the other pre-existing challenges of the cooperative spectrum sensing, various types of the potential solutions have been focussed. They have also suggested that the dynamic spectrum method can be then fully utilized by implementing a numerous cognitive relay nodes. The well predefined so called cognitive wireless relay network can also well support to the uninterrupted wireless data service for the respective cognitive consumers meanwhile leading to no or zero interference on the respected primary systems.

(e) Cooperative based Relay transmission to enhance the Diversity of the Cognitive Radio Networks [5]

Cooperative based retransmission has been seems to be a assuring and as well as the promising approach for the enhancement of the overall throughput of the respective secondary nodes by raising the required spatial diversity and as well as also the spectrum diversity.

In their article, they have tried to give the overall brief summary regarding some of the well known most significant views of the connection of the cooperation transmission and as well as the well known cognitive radio technologies. Looking to the challenges that has been made by the heterogeneity (many forms) in the available spectrum and as well as also the traffic that has needed by the secondary consumers, they have tried to explore the usage of an cooperative relay node method in order to use and as well as to serve the retransmission of CRNs and also to improve the spectrum efficiency.

(f) The effective Throughput possible Potential of the Cognitive Radio: A Theoretical approach based Perspective model [6]

They have made a suggestive brief summary of the several techniques based on the cognitive radio types which are the underlay, overlay and interweave secondary retransmissions with the respective primary consumer's signals. Different models for the implementation of the cognitive radio links which are depended on these above mentioned methods or techniques have been studied extensively.

The obtained Numerical and simulation results have been compared with the respective throughputs of the various cognitive radio network models which reveals that the respective overlay mentioned technique may raise the overall throughput of the secondary communications transmission significantly over the mentioned interweave technique. This enhancement has moreover, has been much dependent on the availability of the respective knowledge on the interference obtained at the respective secondary transmitter and as well as also rapidly vanishes as the respective distance between the primary and as well as the secondary transmitters increases.

(g) Collapsing the Spectrum Gridlock with Cognitive Radios: An Information Theoretic approach based Perspective [7]

Cognitive Radio networks has made an overall tremendous reforms and keeps assurance to withdraw the spectral gridlock by using the respected advanced modern radio designs, and also the powerful encoding schemes and as well as the received signal-processing methods, and their respective related coexistence based Protocols. Cognitive radios may improve or enhance their capacity by using the information or data about the activity of channels (Channel State Information), and as well as the prescribed coding techniques and also the related messages from the other wireless network nodes which are used to share the same available radio spectrum.

There are also multiple many scenarios that are associated with the available cognitive radio based functionalities, and also the most known common methods which are the underlay, overlay, and interweave networks. These mechanisms are united in their usage of cognitive radios to detect their related environment and as well as to tap the network side information obtained from this sensing which are needed to improve the related spectral efficiency and also the performance for all the consumers.

(h) Bits through the ARQ based models: Spectrum sharing with a Primary Packet System [8]

They have studied and tried to work on a real time problem which is based on and motivated them by the implementation of the cognitive radio in which the primary consumer is a packet system that uses the advanced ARQ feedback method which is familiar in ad-hoc networks.

A secondary transmission system is only allowed to transmit or send using the same allotted frequency band or spectrum made available in which, it can ensures that the respective primary consumer used to get an assigned target rate. This is, the secondary consumers have a certain “interference budget." and the behaviour of such a problem is that the secondary does not even knows how much amount of interference it can imposes on the primary and as well as therefore hence it is ignored of its relevant interference budget.

By considering some type of assumptions, they have shown us that there has exists an optimal tradeoff in the rate-Interference budget (RIB). They have also compared how far the fixed constant strategies are made from this RIB Function by changing the interference budget. Furthermore, they have also presented a strategy which is more optimum beyond the threshold maximum interference budget and also stated that within 1 bit per primary packet otherwise.

(i) Cognitive radio based relative Interference Management mechanism in the Retransmission-Based Wireless Networks [9]

In the extension made to the much important work done on the cognitive networks, in their paper they have worked on a scenario based environment where the secondary consumer is made to superimpose its respective transmissions over the source of the primary consumer. The secondary will not only tries to increase or raise its own respective throughput, meanwhile also guarantees a performance loss for the primary consumer source.

They have also derived the better transmission mechanism for the secondary consumer while the respective primary consumer uses an adaptive retransmission based error control method. If the related decoding probability made at the secondary consumer receiver is not raised by the primary source consumer transmissions, and thus the obtained related optimal strategy mechanism of the secondary consumer has a unique type of structure. In detail, the respective optimal throughput is also achieved by the secondary consumer by concentrating in its interference made to the respective primary consumer in the first initial transmissions of a packet data. This is the first step towards or regarding the better understanding of interference control strategic methods in the well known dynamic wireless network systems.

(j) On the maximum Peak against the Average Interference Power (AIP) Constraints for Protecting the Primary Consumers in Cognitive Radio based Networks [10]

This paper deals with the information and as well as the theoretic restrictions imposed in the wireless spectrum bandwidth sharing of the primary CR network where the respective corresponding CR applies the interference-power/interference-temperature constraint at the Primary Radio consumer receiver system as a practical sustainable means to defend the Primary Radio transmission only. The paper made by them has showed that the respective AIP condition made can be in the many several cases is much beneficial over the PIP that is used for reducing the obtained resultant capacity losses of the Primary Radio consumers fading channel. This is furthermore mainly concentrated on an interesting concern on the interference diversity phenomenon which is one of the discoveries made in this paper.

This paper also assumes that the CSI is maintained on the interference channel from the CR transmitter to the PR receiver and is made easily available at the CR transmitter for each of the fading state.

(k) Cognitive Radio Protocols Based on Exploiting the Hybrid ARQ Retransmissions [11]

This work proposes and also involves in several many protocols which allows the coexistence of primary and as well as the secondary pairs of the available wireless nodes which are under the imposed fading conditions. The well defined structure of the primary ARQ transmissions has been investigated to provide the necessary nontrivial rate for the respective secondary consumers while reducing the negative impact on the respective primary radio.

The proposed well known protocols in their paper make the usage of relaying, power control, and interference cancellation and also as well as the multi-consumer diversity mechanisms. The protocols have been thoroughly analyzed and their performance is numerically validated. The proposed protocols used to produce the attractive results even though without imposing any overlay restrictive assumptions on the respective predefined system. They have made suggestions for the further more practical advantage or benefits of using the well-known and as well as the well understood system level components.

(l) Spectrum based Sensing for the digitally equipped Primary consumer Signals in the Cognitive Radio based networks: A type of Bayesian detector based Approach for improving the available Spectrum bandwidth Utilization [12]

Having the well knowledge of the respective primary radio consumer is most likely to be idle and unchangeable and also the primary radio signals which are used to be digitally modulated, they have proposed a technique which is based upon the well known Bayesian energy detector for the spectrum based sensing to get more spectrum utilization factor regarding to the well known cognitive radio based networks.

They have tried to work on the mentioned detector and are successful to derive the well defined detector structure for the MPSK modulated based primary consumer signals with the expected order over an AWGN type of channels and also given the respective suboptimal based detectors in which both of the low and as well as high SNR (Signal-to-Noise Ratio) regions. Through the various approximations made by them, it has been discovered that, in the low SNR region, for the MPSK modulated when (M >2) consumer signals, the well known used detector is the energy detector, whereas for the BPSK based modulated consumer signals the best fit detector is the energy detection which is on the real part of the signal. In the high SNR region, it has been shown that, for the BPSK modulated consumer signals; the test based statistics gives the sum of the consumer signal magnitude components; however it also utilizes the real component of the respective phase-shifted consumer signals as the input parameter.

They have given the detailed performance based analysis of the mentioned detectors with respect to the various probabilities of the detection and as well as false alarm, and also the choosing of the right detection threshold and the number of samples that has to be used. The simulation results that has shown indicates that the mentioned Bayesian energy detector has a performance which is as likely to the energy detector that has used in the low SNR region, but moreover has the better efficient performance in the respective high SNR region regarding the spectrum utilization factor and as well as the secondary radio consumer throughput.

CHAPTER - 03

Spectrum Sharing Techniques

3.1 Introduction

This chapter describes the enhanced methodology for the implementation of the research thesis topic mechanism which is used to start from the ad-hoc ARQ based system model. Based on the system model, spectrum sharing techniques have been derived and also related respective flow charts are mentioned for the respective two spectrum sharing based techniques such as the well known techniques in this communication field called as the conservative and as well as aggressive techniques and regarding their respective relational mathematical and as well as the desired theoretical analysis are given which is used for determining the required amount of throughput, the respective related probabilities of the concerned bandwidth spectrum channel in the different many regions which have been categorized depending on the primary and as well as the secondary operations.

Hence as an extension to the [1], compared the throughput versus SNR based comparison of the mentioned spectrum sharing techniques with the well known energy detection technique which is acting here as a spectrum sharing technique which is called as the Bayesian energy detector.

3.2 Spectrum Sharing Techniques

According to [1], spectrum sharing techniques are defined as the respective bandwidth that is allocated is shared among the relative consumers and are broadly classified into two different types which are given below.

1. **Conservative Sharing:** Defined as the technique, available primary spectrum provided to the secondary users without causing any outage to the primary users and whenever the primary needs the channel, it breaks the secondary communication allegedly even though transmission will be halted.
2. **Aggressive sharing:** Defined as the technique, available primary spectrum provided to the secondary users causing some waiting to the primary users and whenever the primary needs the channel, it will wait until the completion of the secondary communication and the released channel will be allocated to the primary.

3.3 ARQ based System Model

The system model that has described below is entirely depends and based on the famous well known networks called as the ad-hoc networks and this respective related model is mainly used to or applicable to the mobile devices that are which have been extremely used in a stationary or static surroundings for example taking an ad-hoc environment surroundings such as the college, the office etc. I have taken an assumption that the respected available channel is undergoing slow fading mechanism which is extending through various many transmissions time intervals.

We know that about the respective CSI- channel state information, which is used to give us about the related features of the bandwidth channel, whether it is unoccupied or not and using that information, we can easily allot the channels to the primary or secondary consumers.

But in my research I have known that without using CSI, also we can know whether the respective channel is busy or not and I have implemented the sharing techniques without using CSI.

The channel gains of the respective channels are shown by 'g_{ij}' from transmitter i to receiver j, where, 'i' denotes or refers the primary and 'j' denotes or refers to the secondary. Channel gains will obey or accept the respective exponential based distribution with the related mean referred as 'λ'. The system model that has proposed has been given in figure.1.

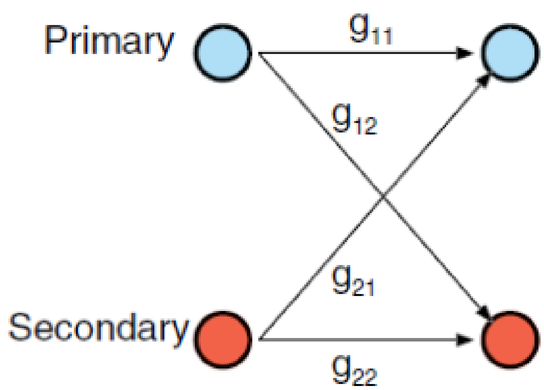


Fig.3.1 System Model [1]

In this research paper, I have simply taken a simple ad-hoc based network where an ARQ based spectrum sharing have been taking place without using the CSI (channel state information) at the secondary transmitter. ARQ means automatic repeat request and the mechanism used in the process is whenever the source node transmits a message to the destination consumer, if the message received successfully by the destination then it sends ACK-acknowledgement signals back to the sender such that the sender used to assume that the message has reached successfully.

If at all message doesn't reached the destination, then it will send a NACK-negative acknowledgement signal to the sender such that sender assumes that message should be retransmitted.

Let us now considering two additional things in this process cycle [1]:

(1) Each of the respective primaries ARQ mechanism will used to carries the respective information regarding the obtained channel gains that has been taking place in the multiple intervals of time.

(2) Each of the respective secondary transmission now creates the concerned interference on the respective primary consumer that are using in the network; therefore the following ARQ mechanism will now carries further information back to the secondary regarding the relative strength of the primary and values of the cross channel coefficients.

In the aggressive based sharing, the secondary will used to or allowed to only transmit whenever it has possible to do so without sending the primary into breakdown, even though it will somewhat degrade the performance of the primary throughput but not let the primary to be in outage.

In the Conservative sharing, the secondary will only allowed to transmit when there has been no additional negative effect on the respective primary throughput. We can now determine or obtain the respective probing or searching process and as well as the discovery mechanism. The probing of the system have determined by the secondary transmission decisions only [1].

3.4 Terminology regarding methodology

For our clarity, let us use the following concerned notations that will used to or related to combine the transmission modes of the primary consumer and as well as the secondary cognitive consumer.

T0 = {primary consumer transmits the brand new packet; whereas the respective secondary will keeps idle}

T1 = {primary will repeats the respective older concerned packet; secondary will keeps idle}

T2 = {primary transmits the another new brand packet; secondary also allowed to transmits}

T3 = {primary repeats the concerned older packet; secondary transmits}.

Using the above given notations, the related discovery process mechanism for the respective secondary consumer is as relatively simple as possible and is easy to grab quickly to understand, and has been shown in the flowcharts of the respective below given Figures 3.2 and 3.3.

The algorithmic rule will then be started or initialized from the source root or base origin of the tree, and proceeds to a leaf side or edge. Right the way through this whole process, the secondary consumer will then make the transmission decisions and observes and analyzes the ACK/NACK from the primary, until it will determine which of the six regions it should be operated.

The related searching and as well as the channel detection for each of the six operating regions are outlined and mentioned below:

Region (S1) is discovered by getting only one type of ACK, searching the respective primary based channel (T2). This will show that the primary channel can only supports the rate in only one transmission despite with any interference.

Region (S2) is discovered by getting the first ACK, then the secondary probing in two successive back to back intervals (T2, T3) and also reaching an NACK pursue by an ACK. This indicates that the primary channel will support its rate in only one interference-free transmission, but in the presence of interference it may need only two transmissions to succeed.

Region (S3) is discovered by getting an ACK, then probing will done in two such successive intervals (T2, T3) and receiving the two NACKs. This will indicate that the primary channel can supports the rate in only one interference-free transmission, but in the presence of interference it will be in the outage even with the retransmission of the packet.

Region (S4) is discovered when the following sequence happens: getting an initial NACK (which, can recall that, was under no related focussed interference), and the secondary will be used to keep on quiet or idle and will get or receive an ACK (now we know that the primary will get through in two transmissions if left unaccompanied). On the subsequently transmission the respective secondary consumer also stay quiet or idle but listen's an NACK (as usual), the next time the secondary transmits (T3) and hears an ACK. This tells us that the primary channel can only support the rate in two (but not one) interference-free transmissions; it can also be succeeded in two reliable transmissions as long as only one of the transmissions will be subjected to the interference.

Region (S5) is discovered by going through the same sequence as the case described above, but however, in the last stage Instead of an ACK a NACK will be received, showing or indicating us that despite with all the care the secondary consumer cannot be transmit in the prescribed channel. This however will also tells us that the respective primary channel can only supports the rate in two (but not one) interference-free reliable transmissions, and that it cannot support its rate with interference (even on one of its two transmissions).

Region (S6) is discovered by the secondary staying idle for the two reliable transmission type of intervals. When the two successive amounts of back to back NACKs are received by the respective primary, it is known us that the respective primary consumer will be in breakdown even with the absence of secondary [1].

3.5 Mechanism of spectrum sharing techniques

The detection of the opera table region for the aggressive can be described as a systematic mode as shown in the Figure 3.2. Starting from the root or origin of the given tree below, the secondary used to stay at rest in quiet mode for the first initial transmission and also observes the primary ACK/NACK. Each of the six detection cases mentioned above fetches a route from the root of the tree to one of the six leaves or edges of the tree.The flow charts for the aggressive as well as the conservative spectrum sharing have been given in the following figures 3.2 and 3.3.

The outcomes S2, S3 from the aggressive sharing which has been resulted in the primary throughput degradation are now changed into a single outcome S2' in conservative sharing as shown the in figure 3, where no secondary transmission is allowed to access the channel.
It has to be noted that either the spectrum sharing techniques such as aggressive or conservative does not produces any primary breakdown. The main difference between them is that the aggressive may occasionally will used to slow down the primary throughput by forcing it to use two time slots instead of one transmission interval.

This is a slightly different form of dreadful conditions, where the respective primary consumer is slightly degraded in its throughput because the secondary may enforces on the primary (a small amount of) additional breakdown.

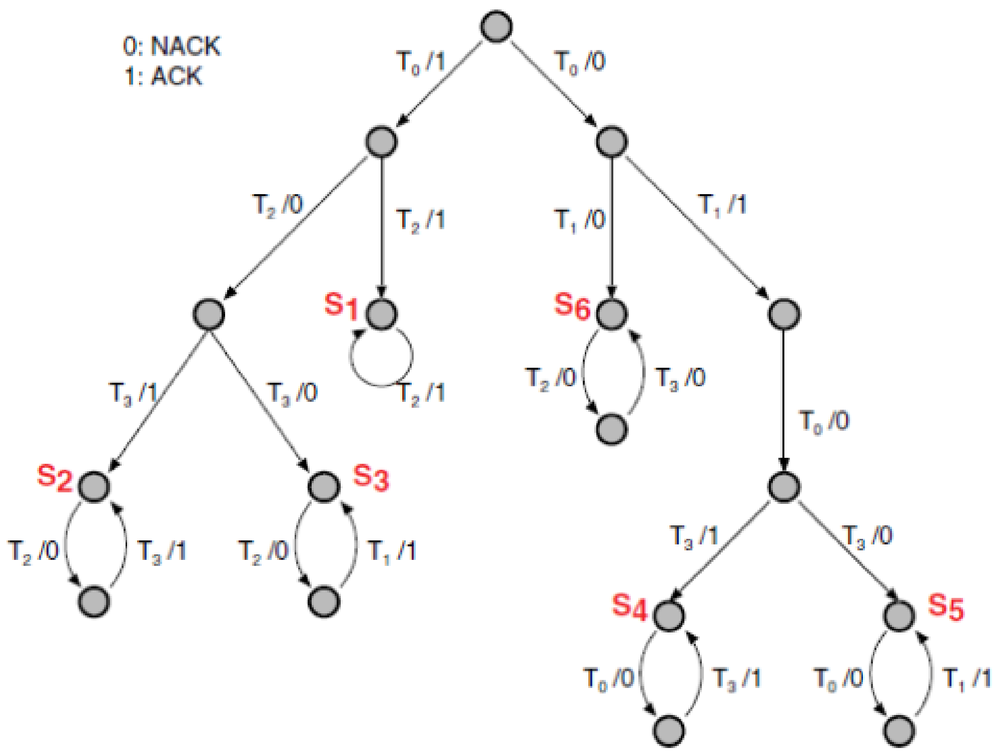


Fig. 3.2 Flow chart for the aggressive spectrum sharing [1]

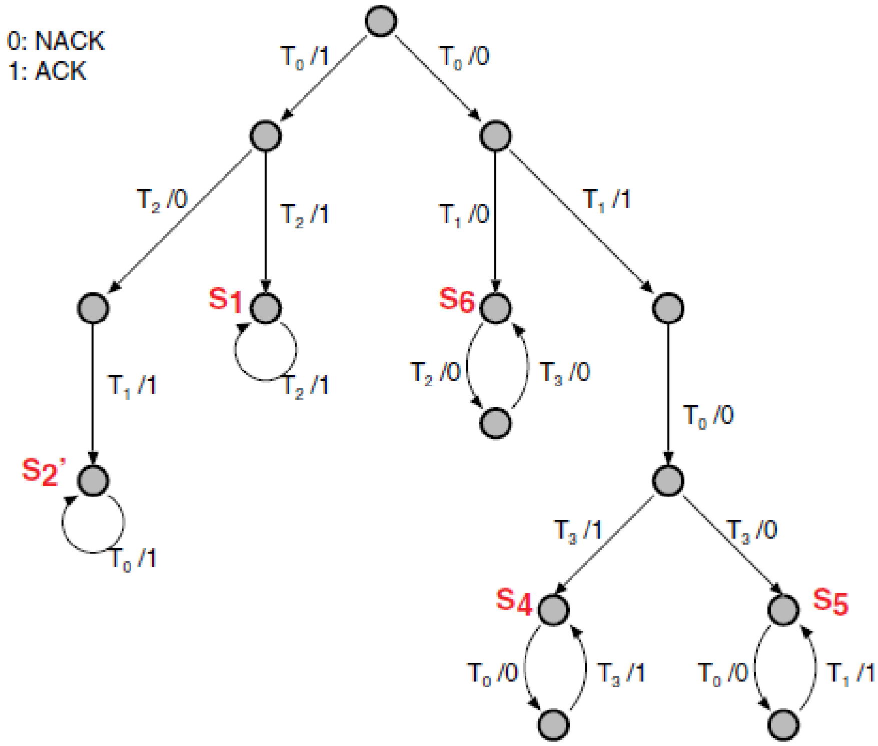


Fig.3.3 Flow chart for the conservative spectrum sharing [11]

The probabilities of the respective channel gains that reside in each of the six operating regions have been formulated and are given below:

$P(S_n)$- Probability of the channel gains in n^{th} region.

$$P\{S1\} = P\left\{\frac{g_{11}Pp}{1 + g_{21}Ps} \geq \gamma_p\right\} = \frac{\lambda_{11}Ppe^{-\frac{\gamma_p}{\lambda_{11}Pp}}}{\lambda_{21}Ps\,\gamma_p + \lambda_{11}Pp}$$

……………………..3.1

Where, g_{11}, g_{21}, g_{22}, g_{12} are the respective channel gains

Ps- secondary transmitted power.

Pp- primary transmitted power.

We use the following related considerations for our understandings and the flexibility,

$\gamma_p \triangleq 2^{Rp} - 1$ and $\gamma_s \triangleq 2^{Rs} - 1$

And Rp- the related Nominal spectral efficiency of the respective primary consumer in bits/sec/Hz,

Rs- The related Nominal spectral efficiency of the respective secondary consumer in bits/sec/Hz.

$\lambda_{11}, \lambda_{21}$ – are the respective mean of the channel propagation gains.

Probability of the channel gain in region S2 is given by

$$P\{S2\} = P\left\{\frac{g_{11}Pp}{1+g_{21}Ps} < \gamma_p, g_{11}Pp \geq \gamma_p \frac{g_{11}Pp}{1+g_{21}Ps} \geq \gamma_p/2\right\}$$

$$= \frac{\lambda_{21}Ps\gamma_p e^{-\frac{\gamma_p}{\lambda_{11}Pp}}}{\lambda_{21}Ps\,\gamma_p + \lambda_{11}Pp} - \frac{\lambda_{21}Ps\gamma_p e^{-\left(\frac{\gamma_p}{\lambda_{11}Pp}+\frac{1}{\lambda_{21}Ps}\right)}}{\lambda_{21}Ps\gamma_p + 2\lambda_{11}Pp}$$

……..……………………3.2

Probability of the channel gain in region S3 is given by

$$P\{S3\} = P\left\{g_{11}Pp \geq \gamma_p, \frac{g_{11}Pp}{1+g_{21}Ps} < \frac{\gamma_p}{2}\right\}$$

$$= \frac{\lambda_{21}Ps\gamma_p e^{-\left(\frac{\gamma_p}{\lambda_{11}Pp}+\frac{1}{\lambda_{21}Ps}\right)}}{\lambda_{21}Ps\,\gamma_p + 2\lambda_{11}Pp}$$

……..……………………3.3

Probability of the channel gain in region S4 is given by

$$P\{S4\} = P\left\{g_{11}Pp + \frac{g_{11}Pp}{1+g_{21}Ps} \geq \gamma_p, g_{11}Pp < \gamma_p\right\}$$

$$= e^{-\frac{\gamma_p}{\lambda_{11}Pp}\left(\varphi\left(\lambda_{21}Ps, \frac{\lambda_{11}Pp}{\gamma_p}\right)-1\right)}$$

……..……………………3.4

Probability of the channel gain in region S5 is given by

$$P\{S5\} = P\left\{g_{11}Pp \geq \frac{\gamma_p}{2}, g_{11}Pp + \frac{g_{11}Pp}{1+g_{21}Ps} < \gamma_p\right\}$$

$$= e^{-\frac{\gamma_p}{2\lambda_{11}Pp}} - e^{-\frac{\gamma_p}{\lambda_{11}Pp}\left(\varphi\left(\lambda_{21}Ps, \frac{\lambda_{11}Pp}{\gamma_p}\right)\right)}$$

……..……………………3.5

Probability of the channel gain in region S6 is given by

$$P\{S6\} = P\{g_{11}Pp < \gamma_p/2\} = 1 - e^{-\frac{\gamma_p}{2\lambda_{11}Pp}}$$

Where, $\varphi(y,z) \triangleq \int_0^{+\infty} e^{\frac{1}{(2+yt)z}-t} dt.$

……..……………………3.6

The inference between aggressive and conservative SHARP is that whether the secondary consumer is allowed to delay the primary's transmission cycle or not. In the conservative scheme, Region S2 and S3 are combined to 'S_2^1' with and the secondary consumer has not been allowed to transmit in this concerned related region. [11]

$$P\{s_2^1\} = P\left\{\frac{g_{11}Pp}{1 + g_{21}Ps} < \gamma_p, g_{11}Pp \geq \gamma_p\right\}$$

$$= \frac{\lambda_{21}Ps\gamma_p e^{-\left(\frac{\gamma_p}{\lambda_{11}Pp}\right)}}{\lambda_{21}Ps\,\gamma_p + \lambda_{11}Pp}$$

……..……………………3.7

3.6 Throughput and the respective Outage Probability Analysis

The primary packet is sent by only one transmission cycle in the Region S1 and two cycles in the other mentioned SNR regions. Except in Region S6, the packet is the only successfully decoded at the primary receiver. As a result, the throughput for the primary consumer in the aggressive SHARP is given as

$$G_p^A = RpP\{S1\} + \frac{Rp}{2}\sum_{i=2}^{5} P\{Si\}$$

……..……………………3.8

Where, the 'A' denotes the aggressive and $R_p/2$ is taken due to the fact that it consumes two consecutive transmission cycles.

Accordingly, the throughput of the secondary consumer in aggressive sharing can also be derived and given as,

$$G_s^A = \begin{pmatrix} R_s(P\{S1\} + P\{S2\} + P\{S6\}) \\ + \frac{Rs}{2}(P\{S3\} + P\{S4\}) \end{pmatrix}\{1 - P^{OS}\}$$

……..……………………3.9

Apart from exploiting and digging the transmission opportunities for the secondary in the regions S1 and S4 which makes no harmful effect to the existing primary operating system, the secondary consumer may slows down the primary by forcing it to use two transmission cycles instead of one in the Regions S2 and S3. In addition to these, the secondary is allowed to transmit when there is two interference-free transmissions are not good enough to support the primary consumer in the Region S6.

The conservative sharing aims to avoid any negative adverse effect on the primary consumer by allowing the secondary to transmit only when the channel is good enough to support simultaneous communication for both the primary as well as the secondary [1].

The conservative scheme also precludes the transmission in the region S_2^1 (i.e., S2 ∪ S3), and leaves the primary operation alone. Consequently, the throughput of the primary as well as the secondary in the conservative sharing are given by

$$G_p^C = Rp(P\{S1\} + P\{S_2^1\}) + \frac{Rp}{2}(P\{S4\} + P\{S5\})$$

……..……………………3.10

$$G_s^C = \left(R_s\left(P\{S1\} + \frac{1}{2}P\{S4\} + P\{S6\}\right)\right)\{1 - P^{OS}\}$$

……..……………………3.11

Bayesian energy detection can be used for the mathematical basic function of cognitive radio, and according to the Bayesian the power that has been detected related to SNR and noise power is given by [12]

$$p_d = Q\{\log(e_{thresh}) - 2N(SNR^{2)}|SNR\sqrt{N(2 + 8SNR)}\}$$

……..……………………3.12

Where, $e_{thresh=}{}^{p_{r0}}/_{p_{r1}}$ and $p_{r0,=0.85,}p_{r1=0.15}$ are the assumed received powers.

SNR- signal to noise ratio, N-noise power and assumed to be a constant value '10'.

Where, 'Q(x)' function is given as

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\propto} \exp\,({}^{-t^2}/_2)dt$$

……..……………………3.13

The throughput for the Bayesian detection sharing related to the Bayesian detected power is given by [12]

$$g_b = \log(1 + p_d SNR)/_{SNR}$$

……..……………………3.14

On varying or changing the P^{OS} in the below equations given, we can calculate for the different interference cancellation schemes such as PIC (perfect interference cancellation), SBIC (single block interference cancellation), and BIC (block interference cancellation) regions for both aggressive and conservative sharing.

The secondary consumer will only allow transmitting only when the interference from the primary is perfectly or absolutely cancelled at the secondary receiver [1]. The corresponding obtained outage probability for the secondary has been given as

$$P^{OS} = P^{OS}_{PIC} = 1 - e^{-\frac{\gamma_s}{\lambda_{22} P_s}}$$

……..……………………3.15

Where, the superscript indicates the 'Outage for Secondary' and the subscript 'PIC' denote 'Perfect Interference Cancellation.

3.7 Secondary outage probability regarding different interference cancellation schemes

We have to now take the interference as into the consideration, and allowed the secondary to coexist with the interference from the primary consumer. Specifically, the secondary tries to equalize the interference from primary in the first place. If the received signal-to-interference-plus-noise ratio (SINR) is greater than γp, the interference is considered to be equalized from the received signal. Otherwise, the secondary will simply treats the interference as the additional background noise. In this method the secondary receiver attempts to cancel the interference signals using only the information received in only one block, hence this approach has been denoted as single-block interference cancellation [1].

Then the outage probability of the secondary is then given as for single-block interference cancellation.

$$P^{OS} = P^{OS}_{SBIC} = P\left\{\frac{g_{11}Pp}{1 + g_{22}Ps} \geq \gamma_p, g_{22}Ps < \gamma_s\right\}$$
$$+P\left\{\frac{g_{12}Pp}{1 + g_{22}Ps} < \gamma_p, \frac{g_{22}Ps}{1 + g_{12}Pp} < \gamma_s\right\}$$

……..……………………3.16

It has been noticed in that the secondary receiver is able to buffer the initially received packet and attempts to equalize the interference came from the primary as a whole when both duplicate copies in the two transmission slots are received, i.e. can be called as Backward Interference Cancellation (BIC).

In this type of manner, the throughput of the secondary consumer can also be improved further. The difference lies in the fact that BIC requires the secondary receiver to eavesdrop (silently listening) on the ARQ feedbacks that has came from the primary receiver so that the decoder can also recognize whether the interference from the primary is the repeating duplicate copy or a totally new packet. If this ARQ information is made available at the secondary receiver, then the outage probability for the secondary consumer can also be further can be improved as follows:

$$P^{OS} = \begin{cases} P^{OS}_{SBIC} & S1 \\ P^{OS}_{BIC1} & S2 \text{ AND } S6 \\ P^{OS}_{BIC2} & S3 \text{ AND } S4 \\ \frac{N}{A} & S5 \text{ AND } S^{1}_{2} \end{cases}$$

……..……………………3.17

Where, the detailed wanted explanations for the above given equation are given below:

- When in the operating region $S1$, the primary packet has been sent only once from the primary transmitter.
- When in operating region $S2$ and $S6$, the primary packet will be going to be repeated, and the secondary can able to buffer in the primary message and tries to decode it only after receiving the two duplicate copies of the same transmitted message. In the

meanwhile, the secondary transmitter sends packets (information) in both slots. The outage probability of this BIC scheme has been given below:

$$P_{BIC2}^{OS} = P\left\{g_{12}Pp + \frac{g_{12}Pp}{1 + g_{22}Ps} \geq \gamma_p, g_{22}Ps < \gamma_s\right\}$$
$$+P\left\{g_{12}Pp + \frac{g_{12}Pp}{1 + g_{22}Ps} < \gamma_p, \frac{g_{22}Ps}{1 + g_{12}Pp} < \gamma_s\right\}$$

……..……………………3.18

- When in the operating regions *S*3 and *S*4, the primary packet will sent twice, but the secondary consumer utilizes the transmission slot only once (either the first as in *S*3 or the second as in *S*4). Therefore, the corresponding outage probability with the BIC can be obtained as given below:

$$P_{BIC2}^{OS} = P\left\{g_{12}Pp + \frac{g_{12}Pp}{1 + g_{22}Ps} \geq \gamma_p, g_{22}Ps < \gamma_s\right\}$$
$$+P\left\{g_{12}Pp + \frac{g_{12}Pp}{1 + g_{22}Ps} < \gamma_p, \frac{g_{22}Ps}{1 + g_{12}Pp} < \gamma_s\right\}$$

……..……………………3.19

- When in the operating regions *S*5 and S_2^1 (for *conservative* SHARP), the secondary transmitter will used to be remains silent or idle.

Chapter 04

Results and Discussions

4.1 Introduction

In this chapter, the respective various results of the methodology have been placed which are implemented in the software Mat lab.

In this section, the results of the various schemes that have been described above has been validated and compared the spectrum sharing schemes such as aggressive, conservative, legacy with the standard energy efficient technique called as Bayesian detector and the inferences has been drawn by taking the obtained simulation results.

4.2 Probabilities of the mentioned regions against secondary transmit power

The probabilities of the above six regions that have mentioned in the above system based model in the chapter 3 has been compared graphically against the secondary transmit power (in decibels). As shown in the below figure, maximum probability of the regions is nearly equal to unity (nearly equal to 1).

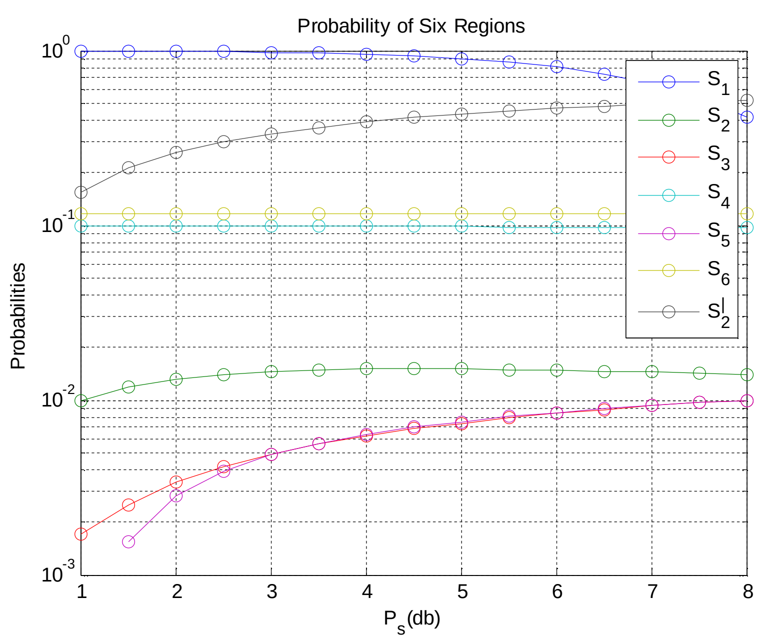


Fig.4.1 Probabilities of six regions against secondary transmit power

Where, Ps- secondary transmitted power.

Pp- primary transmitted power.

s1, s2, s3, s4, s5, s6 are the operating regions.

The probability of the Region *S*6 is a constant due to the fact that it is independent of secondary transmit power *Ps*. Moreover, it can be seen that the probabilities of Region *S*1 and *S*4 both decrease as *Ps* increases. The below figure 4.1 shows that the change in probability has been shown against the secondary transmit power in the possibly different regions that are mentioned in chapter 3.

4.3 Secondary consumer throughputs against SNR in different spectrum sharing techniques

The mentioned below respective figure compares the related throughput of the different mentioned spectrum sharing based techniques using the derived mathematical equations that are mentioned in the chapter 3,such as the aggressive, conservative and legacy schemes.

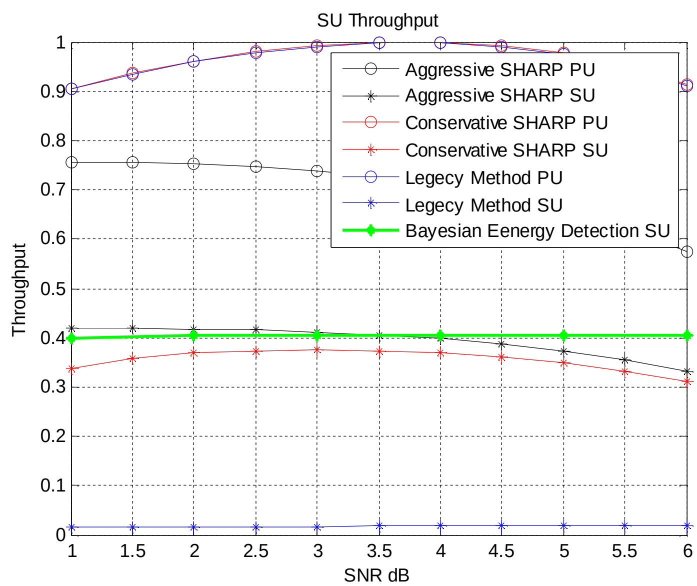


Fig.4.2 Throughput of secondary against SNR corresponding to all spectrum sharing techniques

The results has been compared graphically in mat lab by varying the SNR (signal to noise ratio) values which has been depicted from [1] and has been compared with the mentioned with the described spectrum sharing based techniques such as Bayesian energy detection techniques [12] as shown in the above figure.

4.4 Secondary throughputs against nominal spectral efficiency in different cancellation schemes

The secondary consumer throughput results with the three interference cancellation schemes mentioned are given below.

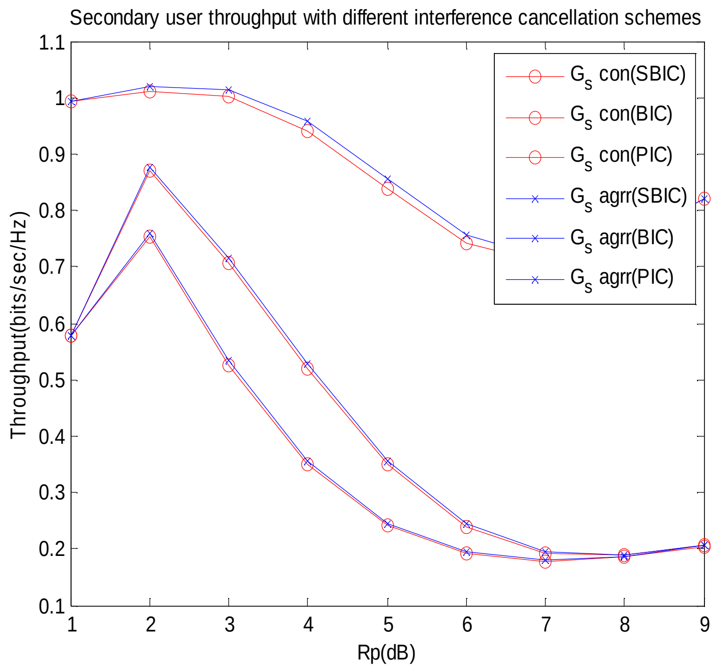


Fig.4.3 secondary consumer throughput against Rp in different cancellation schemes

Where, Rp- the related Nominal spectral efficiency of the respective primary consumer in bits/sec/Hz,

Rs- The related Nominal spectral efficiency of the respective secondary consumer in bits/sec/Hz.

Gs- Throughput of the secondary.

SBIC- Single block interference cancellation

PIC- perfect interference cancellation

BIC- Backward interference cancellation

Con- conservative

Agrr- aggressive

We vary the rate outage threshold for the primary and observe that all three schemes are similar to each other in terms of the secondary consumer throughput when the rate threshold *Rp (nominal spectral efficiency of the primary)* is low, but the single-block interference cancellation scheme has some difficulties when the requirement for the decoding gets higher.

Chapter - 5

Conclusion and Future Work

5.1 Introduction

In this chapter, the various inferences of the research are given based on the results that have been given in the chapter 4 which have been derived from the chapter 3 and also mentioned the related future work that can be done in future regarding the concerned research work.

5.2 Conclusion

The key contribution of this paper was about the research process which is centred on the spectrum sharing techniques such as aggressive, conservative and legacy which are considered from [11] and throughputs of the considered techniques has been compared with the proposed Bayesian energy detection . Before the throughput calculation, first of all we have divided the all possible regions into six regions as mentioned in the system model and the respected probabilities of those regions has been calculated. Then depending on these probabilities, we have calculated the throughputs of the secondary as well as primary with respect to the mentioned spectrum sharing techniques has been calculated, and also throughputs of the different interference cancellation schemes mentioned in section III has also been calculated. Finally results are obtained for the throughputs comparison of the different mentioned techniques.

5.3 Future Work

In order to continue the further research about the spectrum sharing and the spectrum sensing techniques of cognitive radio. The research can be further enhanced by either comparing the results with other energy detection techniques or by working on the spectrum sensing techniques. The scope of the research process is never ended process since the scope of the cognitive radio is unpredictable and it will have numerous ways of continuing research work in many aspects and can relate to many fields.

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