PERFORMANCE ANALYSIS OF OPTIMUM COMBINING AND CO-CHANNEL INTERFERENCE WITH COOPERATIVE RELAYING SYSTEM IN COGNITIVE RADIO NETWORK

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

In

Wireless Communication

Submitted By

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JULY, 2017

DECLARATION

I, Neha Sharma hereby, declare that the work presented in this thesis entitled **"Performance analysis of optimum combining and co-channel interference with cooperative relaying system in cognitive radio network"** in fulfillment of the requirement for the award of degree of Master of Engineering submitted at, Electronics and Communication Engineering, Thapar University, Patiala is an authentic record of work carried out under supervision of Dr. Surbhi Sharma (Assistant Professor, Electronics and Communication Engineering Department) from July 2015 to July 2017. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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CERTIFICATE

It is certified that the work contained in the thesis titled **"Performance analysis of optimum combining and co-channel interference with cooperative relaying system in cognitive radio network"** by Neha Sharma [801563017] has been carried out under my supervision and that this work has not been submitted elsewhere for any other degree.

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The study has indeed helped me to explore knowledge and avenues related to my topic and I am sure it will help me in my future.

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ABSTRACT

Cooperative cognitive radio network (CCRNs) with optimum combining has been analyzed which comprised two components: a primary network and a secondary network. CRNs system is constrained by interference temperature limit (Q) at primary destination (PD), which degrades the performance of throughput hence peak power (Pp) is set to be less than Q in primary network. In secondary networks, when co-channel interference (CCI) is present at both the destination and relays this radio network consists of source-destination, multiple relays and interferers. A new closed form expression is derived from cumulative distribution function (CDF) and probability density function (PDF) for best relay is selected amongst Ri which is obtained by order statistics selection scheme. Based on these, expression for average bit error rate using hyper-geometric function and ergodic capacity have been derived. Analytical results for CCRN-OC system are obtained through Wolfram Mathematica and Matlab software. Based on the achieved results, performance of bit error rate with different interference and relays can be evaluated. With a significant decrease in the average bit error rate of the system and the capacity of the system increases; this is when the interferers in the system increases. Similarly, when the relays increase for the system the bit error rate decreases which lead to an increase in the capacity of the system. This is helpful in the present scenario where the number of users and the demand for the radio spectrum is increasing simultaneously.

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LIST OF ABBREVIATIONS

CR	Cognitive Radio
CRN	Cooperative Relaying Network
CCRN	Cooperative Cognitive Relaying Network
AAF	Amplify And Forward
DAF	Decode And Forward
SU	Secondary User
PU	Primary User
PD	Primary Destination
PT	Primary Transmitter
SD	Secondary Destination
ST	Secondary Transmitter
SR	Secondary Relays
SNR	Signal to Noise Ratio
SINR	Signal to Interference plus Noise Ratio
CCI	Co-Channel Interference
CSI	Channel State Interference
QoS	Quality of Service
ARQ	Automatic Repeat request
MAC	Media Access Control
FCC	Federal Communications Commission
WCDMA	Wideband Code Division Multiple Access
LTE	Long Term Evolution
WLAN	Wireless Local Area Network
DARPA	Defence Advanced Research Projects Agency
WNaN	Wireless Network after Next

ISI	Inter-Symbol Interference
SC	Selection Combining
MRC	Maximal Ratio Combining
EGC	Equal Gain Combining
OC	Optimum Combining
CDF	Cumulative Distribution Function
PDF	Probability Distribution Function
PSD	Power Spectral Density
BER	Bit Error Rate
MPSK	Multi-Phase Shift Keying
BPSK	Binary Phase Shift Keying
SISO	Single Input Single Output
MIMO	Multiple Input Multiple Output

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CHAPTER 1
INTRODUCTION

1.1 Wireless Communications

Wireless Communications has been making tremendous growth over the last few decades and it is anticipated to move forward in the future. The applications in view of wireless system have been expanding as per the demands of user [1]. Services, for example, mobile multi-media and sound, live video streaming; on-demand service requires high data rate, speed and reliability. Then again, transmission of signal from source to destination in wireless condition experiences fading of signal because of multipath propagation which brings about variety in amplitude, phase and delay of the got signal at the receiver. Space diversity can be achieved by using multiple antennas, but in some applications implementation of many antennas are not all the time feasible or the destination is distant to get good signal quality.

To cope up with this, an ad-hoc network is build up with the help of relay station to take the benefits of diversity. Such a model is known as Cooperative Relaying Network (CRN). The capacity and coverage of cellular networks can be extended using relays without increasing mobile transmits power or demanding extra bandwidth. To provide better reliability in case of multipath fading, cooperative relaying communication has been deployed. Diversity additionally upgrades the reliability of signal transmitted [2]. It gives more than one duplicates of signal at destination in such a way that signals are not correlated [3]. It gives better signal quality with ease [5]. Diversity can be characterized into various classes: temporal, frequency and spatial diversity [4]. Multi-Input Multi-Output (MIMO) innovation has advanced incredible consideration for remote condition which productively yields in high information rate, low power utilization and system reliability. Because of size of cell phones, cost and equipment execution makes it hard for MIMO innovation to be connected in small handheld gadgets. So as to remunerate this limitation the idea of cooperative diversity has been presented where portable users share their antennas with others users keeping in mind the end destination to have space diversity pick up at goal by making a virtual gathering of receiving antenna [6]. In agreeable condition a few duplicates of the source data signals brings about change of performance of system, robustness and power [7]. In cooperative communication network, diversity is acknowledged by utilizing a third station as a hand-off. AF and DF are two relaying protocols of cooperative communication network [1]. Cooperative communication serves various advantages like power efficiency and spectral efficiency increases to improve the coverage area of the network and outage probability reduces at the same time [4]. Different cooperative diversity techniques studied in [10]. To enhance the robustness and reliability of wireless networks, conventional QoS mechanisms is integrated by the cooperative protocols such as automatic repeat request (ARQ) protocol [8], [12]. In case of cognitive network the spectrum is managed with careful planning so the number of users present in the spectrum is maximized [13]. The regulatory framework is used for assignment and allocation purpose. AF has less complexity in designing and accomplishes space diversity which brings about expanding system reliability. In DF technique, relay decode the signal transmitted by source and forward it to the destination.

1.2 Cooperative Communication

There are a few procedures to convey differences in a wireless environment. Different antennas can be utilized to accomplish space diversity. In any case, in a few applications usage of different antennas are not generally practical or the goal is extremely far away to get great signal quality.

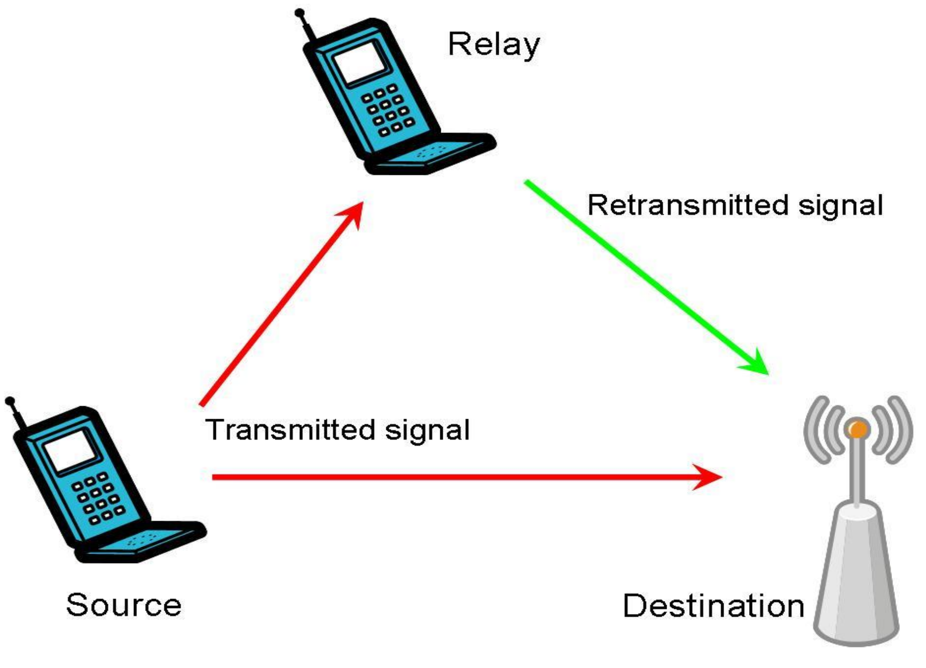

Figure 1.1: Cooperative Communication [5]

So as to appreciate the advantages of diversity, a specially appointed system i.e. ad-hoc network is develop with the assistance of relay station. The model of such a network is portrayed in figure 1.1. Information is transfer from source node, S to destination node, D and additionally relay station, R in first level of the transmission and in second level relay transfer the information and transmit to the destination, where the two signals that is obtained by the antenna are joined at the destination. In Cooperative Communication diverse users improves the nature of administration by sharing of data in the wireless condition. Orthogonal channels are utilized for the two transmissions. Time division multiplexing is utilized as a part of request to transmit signal to destination.

1.3 Cooperative Transmission Protocol

Contingent on the protocol utilized at relay station, co-operative communication can be extensively characterized into two major categories: Amplify and Forward (AF) and Decode and Forward (DF). These conventions portray the behaviour of relay station and tell what activities are performed at relay station before the transmission of information to the destination.

1.3.1 Amplify and Forward

Amplify and Forward convention is utilized when the relay node has limited power and time-frame or in-order to maintain a strategic distance from deferral happened at relay station while utilizing decode and forward protocol. Essential approach behind this convention is very straight forward. As the signal gotten at the relay station was debilitated and it is required to be enhanced before it is transmitted to the destination. At the same time the commotion display in the signal is additionally getting increased, that is the fundamental confinement of this convention. Co-operative communication process utilizing Amplify and Forward convention can be isolated into two stages. In the main stage, information is transmitted to the relay station and destination. In another stage i.e. second stage, signal got the noisy form of transmitted signal from the source and further retransmits it to the destination after enhancement. The approaching signal is enhanced block wise as shown in figure 1.2.

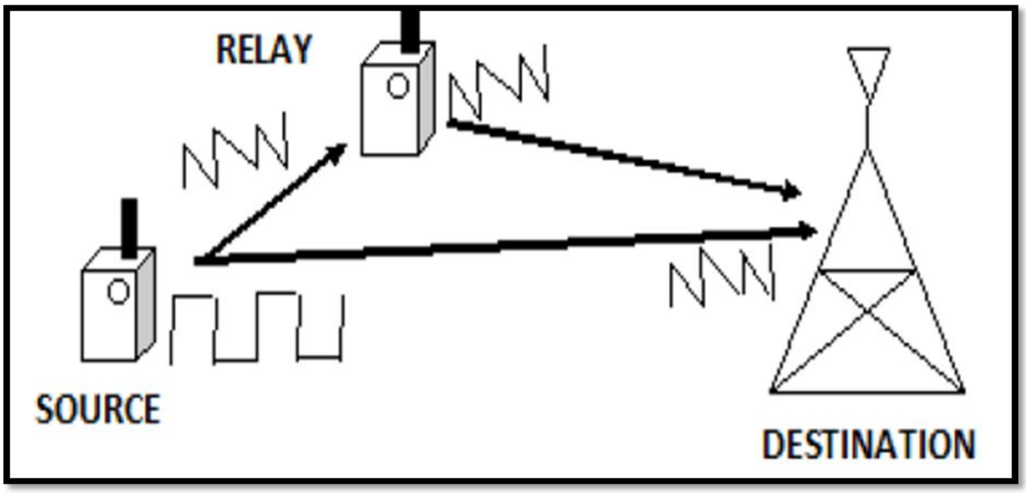

Figure 1.2: Amplify and Forward Protocol [20]

1.3.1.1 Advantages of Amplify and Forward Protocol

- Required less registering power.
- No delay happens for this case**.**
- It is extremely easy to execute and financially economical.
- For the two-user case, this strategy accomplishes diversity order of two, which is the most ideal result at high SNR**.**
- Base station gets two separately faded variants of the signal and can settle on better choices on the recognition of information**.**

1.3.1.2 Disadvantage of Amplify and Forward Protocol

- Major disadvantage of this convention is noise amplification happens at transfer. At relay along with signal, commotion additionally get enhanced which is not attractive**.**

1.3.2 Decode and Forward

Fundamental framework model and transmission system is same as on account of Amplify and Forward convention. The main contrast lies in the working of relay station. Relay station, essentially decode the received signal and then re-encode the information which is sent to the destination as given in figure 1.3. This convention is favoured when relay has expansive registering time and power. Error correcting procedures are utilized as a part of order to accomplish correct information at the destination. In the event that the received information is not correct then it is disposed of. There is no issue of noise enhancement as on account of Amplify and Forward convention.

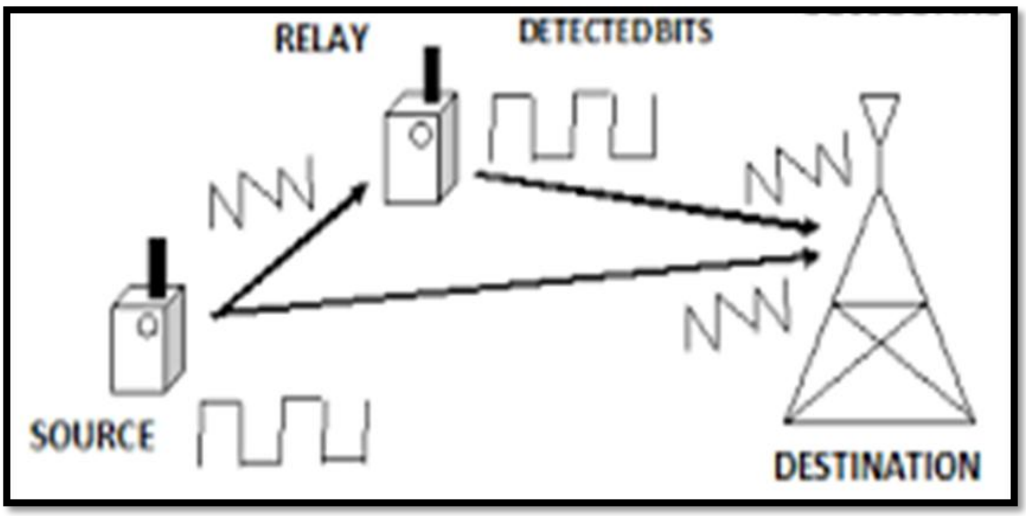

Figure 1.3: Decode and Forward Protocol [20]

1.3.2.1 Advantages of Decode and Forward Protocol

- There is no issue of noise enhancement as this happens in amplify and forward convention.
- Correct signal is gotten at received as channel coding is utilized as a part of order to identify errors.

1.3.2.2 Disadvantages of Decode and Forward Protocol

- Problem of delay happens in system**.**
- Complexity of the network increments for this situation**.**
- If the source to relay connection is poor then there is probability of not getting the signal at the destination of the system**.**

1.4 Application of Cooperative Communication

a) Wireless ad-hoc network

Ad hoc system is a self sorting out system with no incorporated infrastructure. In this network, disseminated hubs shape an impermanent practical system and bolster consistent abandon or combining of hubs. Such system is conveyed for military communication, regular citizen applications together with business and academic utilize and so forth.

b) Wireless sensor network

Wireless sensor system can be expanded by conveying cooperative relaying thus, energy utilization in sensor hubs got decreased. We know that, communication through channels that are weaker, requires enormous energy when contrasted with generally solid channels. Along these lines, careful incorporation of coordinating relaying hubs into directing procedure can choose better communication joins and valuable battery power can be spared.

c) Virtual antenna array

The virtual array is the field of high information rate, reliable wireless communication and apparitional effective, is as of now getting much consideration. The utilization of MIMO antenna system enhances the diversity pick up of wireless systems. Be that as it may, multiple antenna procedure is not appealing for small wireless hubs because of constrained equipment and signal handling ability. Diversity can be accomplished through user of cooperation; where as versatile clients divide their physical assets to make a virtual cluster, which consequently, evacuates the weight of various antennas on wireless communication terminals.

d) Cooperative sensing in cognitive radio

In cognitive radio system, SU can use the resources which are utilized for authorized PU. At the point when primary users (PU) need to utilize their authorized resources, secondary users (SU) need to empty those resources. Hence, SU need to always detect the nearness of PU. Likelihood of false alarming can be decreased with the assistance of spatially appropriated hubs, which consequently enhance the channel detecting unwavering quality by dividing the data.

1.5 Cognitive Radio Network

The Cognitive radio idea, first discovered by the Mitola [3], which say a smart radio can intelligently detect the outer electromagnetic condition and adjust the transmission parameters corresponding to the present condition of the environment. Following to the amount, reliability, kind of information accessible to a Cognitive radio framework, three types of distinctive spectrum sharing paradigms [9] can be received. Cognitive radios can be intended to get to parts of the primary user (PU) range for their information transmission, gave that they make insignificant obstruction the PUs in that band. This process can be accomplished in a few ways. For instance, overlay approach is the one of the ideal model and generally referred to the writing, cognitive can detect the signal range and recognized the unused slots in the primary section when the slot is empty and no one occupy that slot .In second model i.e. underlay approach, CRs can exist together at the same time with the PUs, and notice that they work under a specific impedance level as forced by a regulatory agency [25]. Restriction on the received nodes interference level at the essential recipient can be forced with a short term top or long term normal constraint. System capacity examination is very helpful in perception as far as possible and therefore, the potential uses of CR frameworks. A few interesting outcomes on the limit, outage probability, and throughput of cognitive frameworks have as of late developed.

1.6 Cognitive Radio Characteristics

a) Operating environment detecting

CRs work in a multi-dimensional condition which can incorporate agreeable or non-cooperative producers that can flip on and off, adjusting to nearby changes and in addition traffic loads which fluctuate quickly. In order to perform its assignment legitimately, a CR must change in accordance to the changing condition and it ought to have the capacity to inform different gadgets in the network in regards to the changed configuration [6].

b) Operational state dialect

Operational state dialects are utilized for information sharing in a CR network. As said above CR ought to inform its states and perceptions to different nodes in its network. The dialect that CRs use for this reason for existing is called operational state dialect. The information that a CR sends may be a list of all producers that it as of late detected.

c) Distributed Resource Management

The radio range is a distributed resource. Therefore utilization of a range band at one area makes it inaccessible somewhere else. Therefore the designation of range resource must be done in an adjusted manner. Different algorithms have been created to handle the portion and dealing with the conveyed range and resources in view of activity load.

1.7 Paradigms of Cognitive Radio Network

A cognitive radio is a wireless specialized gadget so that brilliantly uses some accessible side information about the movement, encoding procedures, channel conditions or transmitted information groupings of essential clients which share the spectrum [25]. In light of the kind of accessible network side information alongside the regulatory requirements, secondary users look to underlay, overlay, or join their signals with those of primary users without fundamentally affecting these users. Three main cognitive radio network paradigms are:

a) Underlay
b) Overlay
c) Interweave

a) Underlay Paradigm

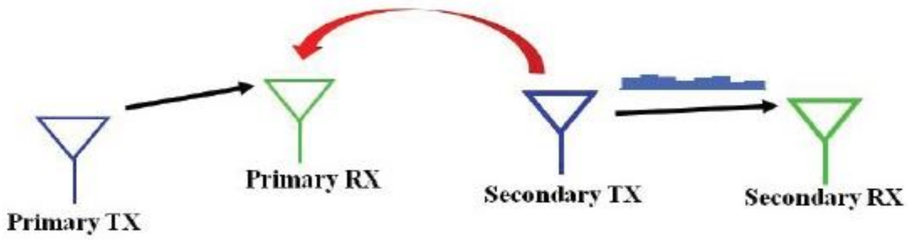

Figure 1.4: The underlay paradigm-wideband signalling [14]

The underlay paradigm mandates that simultaneous primary and secondary transmissions may happen just if the obstruction produced by the secondary transmitters at the primary recipients is beneath some satisfactory threshold. As opposed to deciding the correct impedance it causes, a secondary user can spread its signal over a wide bandwidth with the end goal that the obstruction control unearthly thickness is underneath the commotion floor at any primary user area. These spread signs are then dispread at each of their proposed auxiliary beneficiaries. On the other hand, the transmitter can be exceptionally preservationist in its yield energy to guarantee that its signal stays below the recommended interference edge. This interference imperative in underlay frameworks restricts the optional users to short range communications. Both spreading and serious confinement of transmit power avoid correct count of secondary user interference at primary receivers, rather utilizing a traditionalist outline whereby the aggregate impedance of every single secondary transmission is small all over the place. This aggregate interference, sometimes called the interference temperature [25].

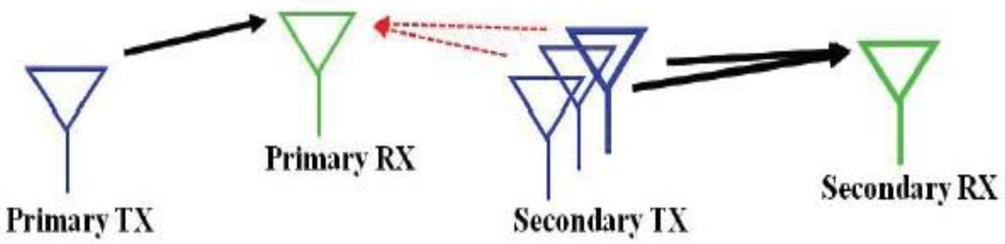

Figure 1.5: The underlay paradigm: transmit antenna array secondary [14]

Determining the correct interference a secondary transmitter causes to a primary receiver is one of the greatest difficulties in underlay frameworks. The secondary user can decide this interference at a given primary receiver by catching a transmission from that primary user if the connection between them is corresponding. For MIMO frameworks, a secondary user just meddles with a primary user in their covering spatial measurements. In the event that the secondary user involves just the invalid space of the MIMO primary receiver, no obstruction is brought about, and thus this falls inside the interweave paradigm examined below, whereby the primary and secondary users possess orthogonal spatial measurements. The underlay paradigms is most normal in the authorized range, where the primary users are the licensees; however it can likewise be utilized as a part of unlicensed bands to give different classes of administration to various users.

b) Overlay Paradigm

The preface for overlay system is that the secondary transmitter knows about the primary user's transmitted information succession and how this grouping is encoded. Comparable thoughts apply when there are numerous secondary and primary users. Code-book information can be obtained by different methods, for instance, if the primary users take after a uniform standard for communication in light of an exposed code-book. On the other hand, the primary user could communicate their code-books intermittently. A primary user's information grouping may be acquired by interpreting it at the secondary user's recipient or in different ways. Information of a primary user's information succession can be exploited in an assortment of approaches to either wipe out or relieve the obstruction seen at the primary and secondary receiver. From one viewpoint, this information can be utilized to drop the interference because of the primary signal at the secondary receiver. The secondary users can relegate some portion of their energy for their own communication and the rest of the ability to help (transfer) the essential transmissions.

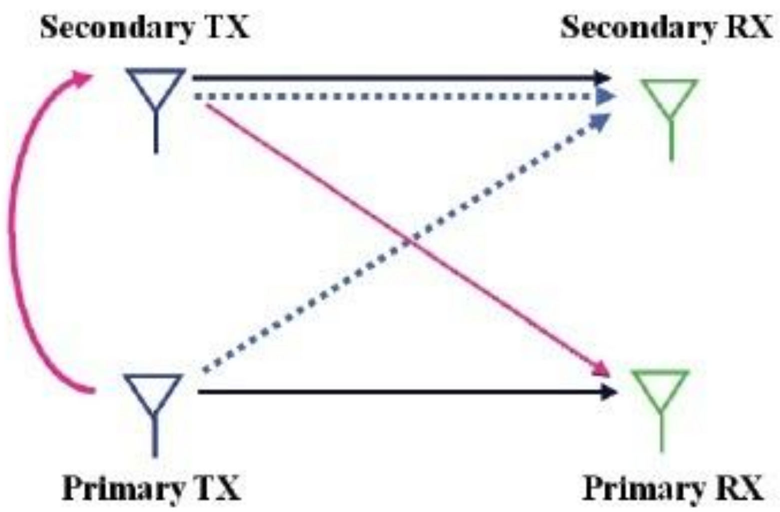

Figure 1.6: The overlay paradigm [14]

Via cautious decision of the power split, the expansion in the primary user's signal to interference plus noise power ratio (SINR) because of the collaboration with secondary users (SU) can be precisely counterbalanced by the decline in the primary user's SINR because of the obstruction brought on by the part of the primary user's energy doled out to its own correspondence. In the event that the primary receiver can be adjusted to decode both its information arrangement and all or some portion of the secondary user's information succession, then the interference brought on by the primary transmitter to the secondary receiver can be halfway or totally expelled. This ensures the primary user's rate either stays unaltered or can be expanded, while the secondary users acquires limit in light of the power it designates for its own particular transmissions. At the point when there are numerous primary and secondary users then a MAC convention for every user's class and more refined encoding and unravelling methods will be required. There are numerous commonsense obstacles that must be overcome for overlay frameworks to be successful. These incorporate the specialized difficulties of catching primary user transmissions and decoding them, and in addition the encoding and decoding related with secondary users in these frameworks. Moreover, sharing of primary user private information successions with secondary users, even when scrambled, will raise significant security and protection worries for the essential framework. However, a portion of these difficulties can be overcome in specific settings, particularly when the primary users information is not private, e.g. in a cellular overlay inside the TV communicate range. Overlay paradigm can be connected to either authorized or unauthorized band interchanges. In authorized bands, secondary users would be permitted to impart the band to the authorized users since they would not meddle with, and may even enhance, their communication. In unlicensed bands secondary users would give more productive spectral users by exploiting information of the primary user's information arrangements and encoding procedures to decrease interference.

c) Interweave paradigm

The interweave paradigm depends on the possibility of opportunistic correspondence, and was the original inspiration for cognitive radio. The thought came to fruition after reviews led by the FCC, colleges, and industry demonstrated that a major some portion of the range is not completely used more often than not. As it were, there exist temporary space-time-frequency voids, referred to as range gaps or blank areas that are not in steady use in both the authorized and unauthorized band. The spatial range gaps might be in a solitary spatial measurement or, for MIMO gadgets, in the subset of spatial measurements not possessed by the PU. Spectral openings can be misused by SU to work in orthogonal measurements of space, time or frequency in respect to the primary user signals. Along these lines, the usage of range is enhanced by opportunistic reuse over the spectral openings. The interweave system requires location of primary users in one or more of the space-time measurements. This recognition is very testing since primary user movement changes after some time and likewise relies on upon topographical area. Interlace frameworks can likewise be connected to networks where all users in a given band have measure up to priority, yet existing users are use as primary user, and new users end up plainly secondary users that can't meddle with correspondences officially occurring between secondary users. For interweave networks with numerous secondary users, a MAC convention is expected to share the accessible range holes among them. To compress, an interweave cognitive radio is a intelligent remote correspondence framework that intermittently monitors the radio range, recognizes primary user occupancy after some time, space, and frequency, and opportunistically imparts over range openings with negligible interference to the primary users.

1.8 Application of Cognitive Radio

Cognitive radio techniques can be applied to many of communication systems. In the following, we discuss some examples of CRN applications:

a) **Cellular Networks**

The presentation of cell phones, informal communities, and developing media sites has expanded the movement heap of current wireless networks. This presents both an opportunity (expanded income per user because of included administrations) and a test (in certain topographical zones, networks are over-burden in view of restricted range resources) for cell benefit operators. By permitting cell networks like WCDMA and LTE to powerfully get to the TV bands, can encourage cell networks to take care of activity demand. This can be actualized, for example, by utilizing cognitive femto-cells and authorized shared access (LSA).

b) **Mesh Networks**

Wireless mesh networks are developing as a financially good solution for giving broadband availability, i.e., for last-mile Internet get to. The test for conventional wireless mesh networks is the higher bandwidth required to meet the applications as the network thickness increments. Since the CR innovation reduces the bandwidth shortage, cognitive mesh networks can be utilized to give broadband access in thick urban regions. For instance, the scope region of remote mesh networks can be enhanced by setting up backbone networks in light of psychological get to focuses and fixed subjective relaying hubs.

c) **Public Safety and Emergency Networks**

A natural disaster (e.g., hurricanes, earthquakes, and so forth.) may temporally cripple or crush existing correspondence framework. For example, some BSs of cellular networks can fall, existing WLANs can be harmed, and the availability between sensor hubs and the sink hub in remote sensor networks can be lost, and so forth. In this way, a crisis network should be set up. Moreover, crisis correspondence requires a lot of radio range for conveying a volume of activity including voice, video and information. Since a CR can perceive range accessibility and reconfigure itself, CRNs can be utilized for such crisis networks. Further, CRNs can encourage interoperability between various correspondence frameworks through adjusting the necessities and states of another network.

d) Wireless Medical Networks

A wireless medical body region network gives an extensive variety of medicinal services administrations. Executing pervasive monitoring of patients in hospitals facilities for essential signs, for example, temperature, weight, blood oxygen, and electro-cardiogram is of interest. The arrangements of remote platforms in restorative conditions convey new difficulties identified with obstruction with neighbouring therapeutic gadgets and in addition QoS necessities. The use of CR in remote medicinal networks can be an answer for these difficulties due to its capacity to watch, take in and make a move from the working condition.

e) Military Networks

Accomplishing reliable and secure communications in military networks is a testing assignment. Likewise, the limit of military networks is restricted in view of necessities of significant measure of bandwidth for correspondences between fighters, armed vehicles, and different units in the war zone among themselves and with the central station. The CRN is a key empowering innovation for acknowledging such thickly conveyed networks to accomplish the bandwidth and unwavering quality needs. In this regard, the defence advanced research project agency (DARPA) started the wireless network after Next (WNaN) program with the fundamental objective to make an adaptable design for next generation military correspondences. The idea driving the WNaN program is to build up a minimal effort CR gadget that is fit for choosing its own particular recurrence and to support a wide assortment of military communication needs. Specifically, the WNaN framework has shown CR usefulness in genuine word military trials for up to 100 hubs.

1.9 Combining Techniques used in Wireless Network

Diversity is the method used to make up for fading channel impairments. It is actualized by utilizing two or more receiving antennas. While Equalization is utilized to counter the impacts of ISI, Diversity is normally utilized to minimize the profundity and term of the fades experienced by a receiver in a flat fading channel. These systems can be utilized at both base station and mobile receiver. The fading is available when the diversity methods can be used to fabricate the farthest point of the wireless correspondences channels. Different types of diversity technique that can be utilized in wireless communication are Selection combining (SC), Equal gain combining (EGC), Maximal Ratio Combining (MRC) and Optimum Combining (OC). Specifically, MRC gives the greatest output of the signal to noise ratio (SNR) and limits the bit error rate (BER) contrasted with other diversity techniques [19]. In cognitive radios diversity is utilized to improve the limit of the SU connects. With diversity limit is upgraded regardless of the possibility that the connection between essential transmitter and secondary beneficiary is in less extreme fading. It has been watched that the ergodic capacity limit increments when the diversity at SU is furnished with the extra antennas, and decrease for greater number of radio wires at PU unit, for both the normal and peak power interference constraint.

1.9.1 Selection Combining (SC)

In selection combining (SC), the receiver signal receives the highest signal to noise ratio on the branch for further processing. Since just a single branch is utilized at once, SC regularly requires only single beneficiary i.e. exchanged into the dynamic receiving antenna branch. In any case, a committed receiver on every reception apparatus branch might be required for systems, and transmit interminably in order at the same time and persistently monitor SNR on each branch as shown in figure 1.7.

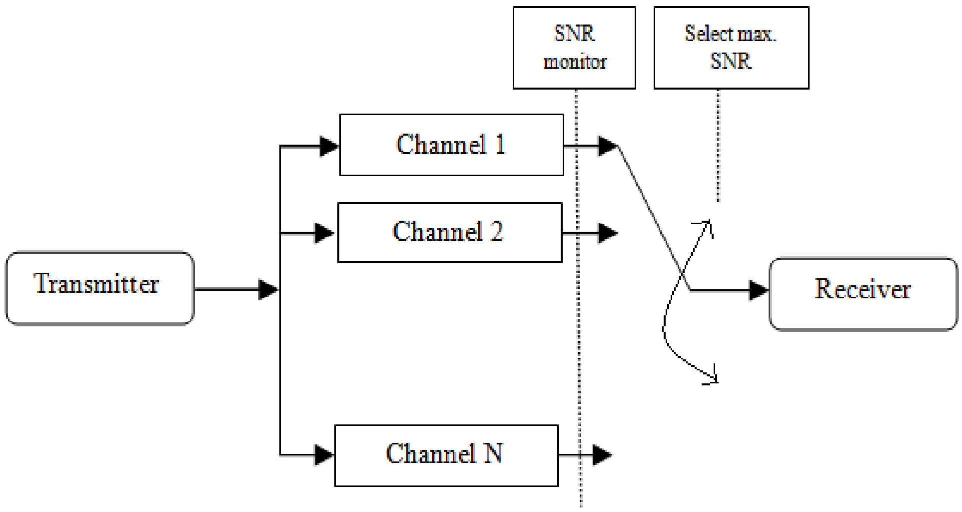

Figure 1.7: Block diagram of selection combining

The output from the receiver of the SC has an equivalent SNR to the most extreme SNR of all the branches. Moreover, only a single branch of SC output is utilized, co-phasing of various branches is not required. Therefore, this method can be used with further coherent or differential modulation technique.

For M branch differing qualities, the CDF of γ_{sum} is given by

$$p_{\gamma_{sum}} = \prod_{i=1}^{M} p(\gamma_i < \gamma) \tag{1.1}$$

1.9.2 Equal Gain Combining (EGC)

In equal gain combining, firstly the signals on each branch are co-phased and then join them with equivalent weighting factor. The required SNR of the combined output, expecting the equal noise PSD N_0 in each branch, is then given by (for M branch diversity).

$$p_{\gamma_{sum}} = \frac{1}{MN_0} \sum_{i=1}^{M} (\gamma_i)^2 \tag{1.2}$$

Performance of EGC is very near that of MRC, ordinarily showing less than 1 dB of energy penalty. This is the cost paid for the diminished complexity of utilizing equivalent gain.

1.9.3 Maximal ratio combining (MRC)

In maximal ratio combining (MRC) the output of the system is a weighted aggregate of all the branches. In this the signals are co-phased and so $\alpha_i = a_i e^{-j\theta i}$ where θ_i is the period of the approaching signal on the i^{th} branch.

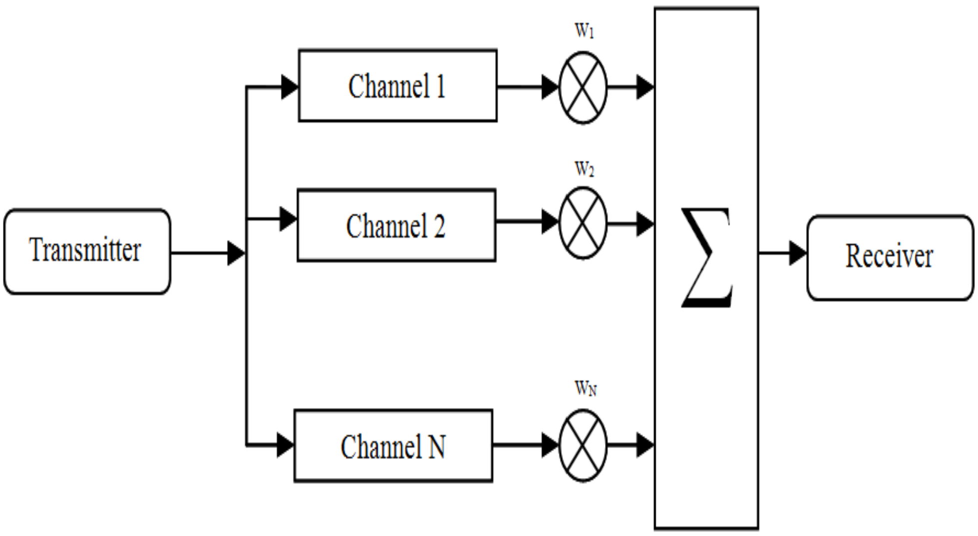

Figure 1.8: Block diagram of maximal ratio combining

In MRC, the weight vector is made proportional to the branch of the SNR. The MRC weight are given as

$$w = h \tag{1.3}$$

Where *h* is the channel gain and the envelope of the combined output will be as given in [24]

$$p_{\gamma_{sum}} = \sum_{i=1}^{M} (\gamma_i) \tag{1.4}$$

1.9.4 Optimum Combining (OC)

At the point when the required signal is a mixture of a few waves (i.e. multipath), the total signal amplitude may encounter profound fades (i.e. Rayleigh fading), after some time or space. The real issue is to battle these profound fades, which result in a framework outage. Most mainstream and proficient procedure for doing as such is to utilize some type of diversity combining. Diversity: various duplicates of the required signal are accessible, which encounter autonomous fading. Essential guideline, makes numerous autonomous ways for the signal, and consolidates them in an optimum or close optimum way. The best system to utilize is the one which maximizes the SINR at the receiver output. In this situation, the diversity named as OC gives a better SINR in comparison with the other diversity technique even when the numbers of antenna nodes are less than the interfering signals. The OC is different from other is only because of the weights are chosen to maximize the signal to interference in addition to noise ratio at the combiner output. Let us assume that a single interferer is present and the signal received at the output is given by

$$x(t) = \sqrt{E_s} g d(t) + \sqrt{E_I} g_I d_I(t) + n(t) \tag{1.5}$$

Where E_s and E_I are the average power, $d(t)$ and $d_I(t)$ are their corresponding desired and interfering signal respectively and the channel gains are g and g_I respectively. Now, the received signal is given by

$$r(t) = u^H x(t) \tag{1.6}$$

The OC weight vector are given by [11]

$$u = \frac{h}{R_{ni}} \tag{1.7}$$

where R_{ni} is the matrix defined by

$$R_{ni} = E_I g_I g_I^H + \sigma^2 I \tag{1.8}$$

where σ^2 is noise power and the maximum SINR output obtained at the combiner is given as

$$\gamma = E_d g^H {R_{ni}}^{-1} g \tag{1.9}$$

When no interference occurs then the performance of OC become similar to MRC technique.

$$\gamma = \sum_{k=1}^{K} \gamma_k \tag{1.10}$$

1.10 Thesis Organization

The different chapters of my thesis are organized as following:

Chapter 1: Introduction discusses about need of cooperative and cognitive radio network. Different types of cooperative transmission protocols and cognitive radio paradigms are discussed. Also discusses the diversity techniques uses in wireless communication in an underlay spectrum and explains all diversity schemes.

Chapter 2: Literature Survey which briefs about the developments made in cooperative, cognitive radios network and the performance of different diversity techniques in the wireless communication system and also the effects of different parameters on the system are described.

Chapter 3: Cooperative Cognitive Radio Network with Optimum Combining System describes system model of the cooperative cognitive radio network. The best relay is selected among all relays, average bit error rate and ergodic capacity of the system are described in this chapter.

Chapter 4: Results and Discussion presents the analytical results of average bit error rate and ergodic capacity of the proposed system.

Chapter 5: Conclusion and Future Scope summarizes the results obtained from the proposed technique and discuss the possibility of future work.

At last section important references that have been referred throughout my thesis and without which my thesis work could not have been proficient.

CHAPTER 2
LITERATURE SURVEY

A. Nosratinia, et al. [18]: In this paper concept of cooperative communication is introduced. As transmit diversity needs more number of receiving antenna at the transmitter. In any case, numerous remote gadgets are restricted by size or equipment many-sided quality to one receiving antenna. Cooperative communication empowers single reception apparatus mobiles in the multi-client condition to share their radio wires and create a virtual numerous receiving antenna transmitters that enable them to accomplish transmit diversity.

J. N. Laneman, et al. [19]: This paper creates and investigates low unpredictability cooperative diversity protocols that battle blurring actuated by the multipath spread in remote systems. Paper layout a few methodologies utilized by the collaborating radios, including settled relaying schemes, for example, amplify and forward and decode and forward, choice relaying schemes that adjust in view of channel estimations between the coordinating terminals, and incremental relaying schemes that adjust in light of restricted criticism from the destination terminal. The outcome demonstrates that aside from fixed decode and forward, all other cooperative diversity protocols are effective as in they accomplish full diversity (i.e. second order diversity on account of two terminals).

A. F. S. Shah and Md. S. Islam, et al. [20]: Cooperative communication in remote systems has turned out to be increasingly alluring as of late since it could alleviate the especially extreme channel debilitations emerging from multipath proliferation. Here the more prominent advantages picked up by abusing spatial assorted qualities in the channel. In this paper, a diagram on cooperative communication in remote systems is displayed. We write the advantages of cooperative transmission than customary non-cooperative communication. Commonsense issues and difficulties in cooperative communication are recognized. Specifically, we show an investigation on the preferences, applications and distinctive steering strategies for cooperative work systems, Ad hoc systems and remote sensor systems.

A. Meier, et al. [21]: An ad-hoc connect with a base station, a cell and a third station going about as hand-off are broke down. The channels are demonstrated the utilization obviously misfortune, Rayleigh fading, and warm clamor. Distinctive combining techniques and differing qualities protocols are looked at. In the reproduction open up and forward protocol shows preferred general execution over decode and forward protocol. To consolidate the approaching markers the channel extraordinary should be expected and additionally practical. Whatever mix of differences protocol and blending system is utilized, the second level assorted qualities are found. The relative separation among the transfer and the stations highly affects the execution.

L. Fei and L. U. O. Tao, et al. [22]: In this paper, we analyze the symbol error rate (SER) execution for a two client amplify-and-forward cooperative system. By making utilization of M-PSK modulation, the closed form SER formulation and relating upper bound are inferred first. As indicated by the SER execution examination, the effect of hand-off area is talked about by making utilization of a straightforward line topology. In the event that the power allotment to the source and hand-off is equivalent, we can reach an intriguing determination that the SER execution in such topology demonstrates a symmetry property and the ideal transfer area is simply in the centre concerning the source and destination.

S. Weifeng, et al. [23]: In this paper, symbol error rate (SER) execution investigation and optimum power allocation are obliged encoded cooperative in remote networks with either unravel and-forward (DF) or amplify-and-forward (AF) cooperation protocol, in which source and focus relays send data to objective through orthogonal channels. In both the DF and AF cooperation structures, for no good reason a comparable power strategy is extraordinary, however when all is said in done not optimum in accommodating trades. The optimum power allocation depends on upon the channel interface quality. An entrancing result is that if all channel associations are available, the optimum power allocation does not rely upon the immediate association among source and objective, and it depends just on the channel joins related to the hand-off.

M. Abrar, S. Khan, M. Iqbal and X. Gui, et al. [24]: Cooperative communication, another method for communication has discovered its applications in practically every remote network, from cell to ad-hoc and sensor networks. The essential thought of cooperative correspondence is to copy virtual receiving wire cluster to mirror a multi-radio framework and hence get enhanced performance. This paper, we provide performance analysis of cooperative correspondence utilizing two fundamental cooperative protocols (Amplify and Forward and Decode and Forward) and error rate performance correlation of cooperative framework with non-cooperative single input single output (SISO) and multi input single output (MISO) systems under similar power limitations.

R. Cao, et al. [25]: Cooperative networks give updated structure execution by abusing spatial differing qualities in a spread manner. Optimum resource allocation can upgrade the execution of cooperative networks and augmentation the capability of resource use. This paper investigates the relative effects of improvement metric (error rate versus outage probability), adjustment sort and relaying protocol (amplify and forward (AAF) versus decode and forward (DAF)). A resource change issue that restrains the total transmit vitality is planned. The examination and recreations prescribe that the blunder rate and blackout likelihood estimations yield near streamlining occurs for AAF exchanging structures, relaying protocol chooses the change comes to fruition while the adjustment sort has no effect and the complexity between different relaying protocols decreases when the amount of relays increases.

P. Mangayarkarasi and S. Jayashri, et al. [26]: Relay Selection (RS) is a framework that has for the most part been thought about for a few protocols. In this paper, relay selection is considered for amplifying and forward protocol. Relay station is used to enhance the execution of helpful relay frameworks. The otherworldly profitability of relay selection behaves better when appeared differently in relation to vitality productivity. Furthermore, relay station shows better results when the amount of jumps between the source and the objective is less. There are various systems used at the beneficiary end, for instance, Maximal Ratio Combining (MRC), selection combining and so forward. In this paper, selection combining is used at the collector. In the wake of performing relay selection, those customers having a signal to noise ratio (SNR) more conspicuous than the limit esteem are picked.

J. H. Winters, et al. [27]: This paper concentrates optimum signal combining for space diversity qualities gathering in cell portable radio system. With optimum combining, the signals received by the antennas are weighted and joined to boost the output signal-to-interference-plus-noise ratio. In this way, with co-channe1 interference, space diversity is utilized not exclusively to battle Rayleigh fading of the desired signal (as with maximal ratio combining) additionally to diminish the power of interfering signals at the recipient. Comes about conclusion that optimum combining is fundamentally superior to anything maximal ratio combining even when the quantity of interferers is more than the quantity of reception antennas. Results for common cellular mobile radio system demonstrate that optimum combining builds the output signal to-interference ratio at the receiver by a few decibels.

A. Shah and A. M. Haimovich, et al. [28]: In this paper, space diversity reception is studied for optimum combining and examined in the digital cellular mobile radio correspondence with different co-channel interferers and Rayleigh fading. This paper considers binary phase shift keying (BPSK) modulation in a flat Rayleigh fading condition when the quantity of impedances L is not as much as the number of antenna elements N (L ≥N). Probability Distribution Function of most extreme signal to interference ratio is determined and it is demonstrated that it has Hostelling T^2 distribution.

E. Villier, et al. [29]: This paper is an execution of optimum combining inside seeing different proportional power interferers and noise when the amount of interferers is not as much as the amount of reception apparatus components. Fancied signal and interferers are at risk to level Rayleigh blurring, and the spread channels are autonomous. An inexact articulation of the likelihood thickness capacity of the yield signal to obstruction in addition to noise ratio (SINR) is resolved methodically. It is then associated with procure the aggregate circulation capacity of the SINR, and the bit-error-rate (BER) of some twofold balances, including intelligent parallel stage move keying. Because of a solitary interferer, a correct examination is performed to demonstrate the legitimacy of the guess. By virtue of different interferers, the precision of the guess is studied through recreations. Albeit constrained to square with control interferers, this examination is an advantageous technique for assessing the execution of optimum combining in some common conditions and looking at it and that of maximal ratio combines. The last results are surprisingly straightforward and give a supportive supplement to past examinations, especially in the range of sensibly high BER's which are of handy intrigue.

N. Suraweera and N. C. Beaulieu, et al. [30]: Cooperative relaying accomplishes an extensive variety of points of interest including coverage extension, diversity gain and mitigation of shadowing. By and by, the execution points of interest of cooperative relaying reduce considerably if co-channel interference is available. Optimum combining (OC) can be utilized to mitigate the unfriendly impacts of co-channel interference in remote communications. The execution of optimum combining in a decode and forward transfer coordinates with N equal power interferers is investigated. The probability density function of the yield signal to interference plus noise ratio is acquired and then for $N \geq M + 1$, the right outage probability closed form expression is determined where M represents the quality of transferring nodes. An approximation for the symbol error rate (SER) is displayed. The execution comes about to and for outage probability, SER that propose for the asymptotic\diversity gain of optimum is equivalent to M, which is a critical change over the maximal ratio combining whose asymptotic diversity shows the gain equal to zero when the co channel interference is working in the system.

N. Suraweera and N. C. Beaulieu, et al. [31]: The differing qualities additions of cooperative relay frameworks are debased inside seeing co-channel interference (CCI), which is the primary limiting factor in a legitimately organized cell network. Optimum Combining (OC) is used for relieve the ominous effects of interference, which engages fulfilling differing qualities pick up when the interference is available. The execution of OC in channel state information (CSI) intensified and-forward (AAF) relay framework is poor down when the goal hub is impacted by interference, with the guide of a tight gauge for the signal to interference in addition to noise ratio (SINR) at the goal hub. Shut shape articulations are resolved for the blackout likelihood and the minute producing capacity for the approximated SINR. It is demonstrated that the optimum combining realizes a various differing qualities pick up of M, where M is the amount of relay hubs. OC shows huge execution improvements over maximal ratio combining (MRC), which accomplishes error rate at low to medium power levels.

M. Ju and Il-Min Kim, et al. [32]: The differing qualities additions of cooperative relay frameworks are debased inside seeing cochannel interference (CCI), that has the primary limiting factor in a legitimately organized cell network. Optimum Combining (OC) is utilized for the relieve of the ominous effects of interference which is present in co channel, and engages fulfilling differing qualities pick up when interference is available. The execution of optimum in channel state information (CSI) amplify and forward (AAF) relay framework is poor down when the goal hub is impacted by the interference, with the guide of a tight gauge for the signal to interference in additio to noise ratio (SINR) at the goal hub. Shut shape articulations are resolved for the blackout likelihood and the minute producing capacity for the approximation of the SINR. It is demonstrated that OC realizes various differing qualities pick up of M, where M represents the number of relays node. Optimum presents huge execution improvements over maximal ratio combining (MRC), which accomplishes error rate at low to medium power levels.

Z. Yong Liu, et al. [33]: In this paper, a flexible multiple relay selection (MRS) scheme for cooperative communication with amplify and forward (AAF) relay under frequency selective channels is proposed. In the proposed scheme, the relays are ordered initially by the end-to-end SNR, then the relays are consecutively chosen out from N relays and the quantity of participating relays is balanced powerfully as indicated by the present channel state data. The point of this work is to progressively estimate the optimum number of cooperative relays. "Optimum" means the minimum number of cooperative relays accomplishing the greatest level of joined SNR. Numerical outcomes check the analysis and demonstrate that the plan can adaptively modify the quantity of cooperative relays, and beat regular relay selection plans. Thus, the proposed scheme gives better trade-off between BER execution and spectral efficiency and to save more energy in cooperative remote systems.

Y. Zou, B. Zheng and W. P. Zhu, et al. [34]: The cooperative communication technology proposed as of late empowers arrange hubs to share their reception apparatuses to accomplish assorted qualities. In this paper, an effective variety conspire on collaboration is proposed by utilizing an outage paradigm, in which the collaboration mode will be received just when the channel from source to relay does not occur outage event. In this paper, bit error rate (BER) expression for the proposed conspires over Rayleigh channels, demonstrating that the full diversity is accomplished by the new scheme. Additionally, the BER execution of the known coded cooperation is displayed with the end goal of correlation with our scheme. Numerical outcomes represent the prevalence of the proposed system over the coded cooperation in wording of BER execution. Advantage of BER in the proposed scheme comes to the detriment of expanding framework overhead since the new scheme needs a few feedbacks from relay to both source and destination.

M. Sharif, A. Sharif and M. J. M. Niya, et al. [35]: This paper enhances the execution of range detecting use for Cognitive Radio (CR) users which uses the weighted Energy Detection (ED) strategies are proposed. Cooperative Spectrum Sensing (CSS) in unified for the cognitive radio systems is considered. The primary reason for existing is to outline another weight vectors which is presents by received detecting energy from all cognitive users and its probability distribution function. In this manner, a technique for getting an ideal limit to limit the sensing error probability is given. Result comes out in detection accuracy compared with another Equal Gain Combining (EGC) method, when Signal-to-Noise ratio region is low and system achieved significant gain in proposed strategies.

Z. Liu, R. Ali, I. Khan, I.A. Khan and A. A. Shah, et al. [36]: Spectrum sensing is the mainly studied now-a-days in cooperative cognitive networks. Energy and Cyclostationary spectrum absence and presence of the primary user and to maintain a strategic distance from impedance. In this paper, the execution of Energy and Cyclostationary range identification over Rayleigh, Nakagami and Additive White Gaussian Commotion (AWGN) channel condition is examined by considering cooperative intellectual radio systems utilizing Amplify-and-Forward (AF) relaying plan. Optimum cognitive relays areas have been considered between Primary Base Station (PBS) and Fusion Center (FC) wherein results come for probabilities of detection and false alarm. The performance is made by utilizing Monte Carlo Simulation, for two relays based cooperative with Maximal Ratio Combining on collector side.

A. M. Elmahdy, A. E. Keyi, T. EIBatt and K. G. Seddik,et al. [37]: The problem of optimizing cooperative cognitive radio network subject to constraint on the quality of service (QoS) of the cognitive radio primary user is considered. Specifically, outline for the probabilistic confirmation control parameter of the PU bundles in the secondary user (SU) relaying line and the randomized parameter at the SU under non-work-conserving (non-WC) and WC strategies. In the non-WC approach, two constrained enhancement issues are defined; the main issue is maximizing the SU throughput while the second issue is minimizing the SU normal delay. In both issues, an imperative is forced on the most extreme reasonable normal delay of the PU. By demonstrating the equality of the two issues and builds up a low-complexity-sided quality line algorithm to locate the ideal parameters. Along these lines, the thought of upgrading the SU normal delay is produced for the more complex WC approach, for its predominant resource usage and execution. Because of the sheer complexity of this issue, we define another issue whose arrangement yields a imperfect upper bound on the ideal SU delay. A short time later, a down to earth WC arrangement based algorithm is planned with a specific end goal to nearly approach the ideal estimation of the SU delay. A numerical result shows that the proposed participation arrangements speak to the best compromise between improving the SU QoS, fulfilling the PU QoS necessities. Moreover, the execution of the suboptimal WC approach over the non-WC strategy is outlined. At last, the benefits of the WC-policy based calculation are exhibited through simulations.

X. Kang, Y. C. Liang, A. Nallanatham, H. K. Garg and R. Zhang, et al. [38]: A cognitive radio network (CR) is formed by either allowing the auxiliary client in a correspondence network to insightfully work in the recurrence bands at first circulated to an essential network or by empowering SCN to exist together with the essential clients in PCN the length of the interference caused by SCN to each PU is suitably overseen. For fulfilling the ergodic limit and blackout limit of auxiliary clients channel under different sorts of imperatives and blurring channel are examined under the ideal power allocation strategies. In particular, other than the interference requirement at an essential client, the transmit control limitation of auxiliary client is likewise considered. Since the power transmitted and the interference power can be limited either by a normal limitation or a pinnacle requirement, diverse blends of energy imperatives are inspected. It is demonstrated that there is a pick up for SU under the ordinary over the pinnacle interference limitation. It is also demonstrated that blurring for the channel between optional client transmitter and essential client recipient is generally leeway for enhancing the secondary user channel limits.

Y. C. Liang, K. C. Chen, G. Yu and P. Mahonen, et al. [39]: Cognitive radio (CR) is the empowering innovation for supporting dynamic range, the approach that addresses the range shortage issue that is experienced in numerous nations. Along these lines, CR is generally viewed as a standout amongst the most encouraging advancements for future remote communications. To make radios and remote systems really cognitive, a basic undertaking, and it requires collective exertion from different research groups, including correspondences hypothesis, networking designing, signal preparing, game hypothesis, software equipment joint plan, and reconfigurable receiving antenna and radio-frequency plan. This paper represented, an efficient outline on cognitive systems and communications by taking a gander at the some capacities of the physical (PHY), medium access control (MAC), and network layers required in a CR outline and these layers are how crossly related to each other. Specifically, for the physical layer, we were addressing the signal to preparing systems for range detecting, cooperative range detecting, and handset transceiver for cognitive raido spectrum. For the MAC layer, survey on detecting scheduling plans, detecting access trade-off plan, range aware access MAC, and CR MAC conventions. In the system layer, cognitive radio system (CR) tomography, range aware routing, and quality-of-service (QoS) control will be addressed. CRNs that are effectively created by different institutionalization boards and range sharing economics matters will be explored.

M. N. Koli, M. Z. Sarkar, S. Tazrin and M. F. Pervej, et al. [40]: We consider a framework in which private information is sends by source terminal to the goal within the sight of different relays and meddler. Cooperative assorted qualities are given by the various relays at the goal terminal. The end terminal and spy is outfitted with various receiving wires while each relay and source is outfitted with single gathering radio wire. We are intrigued to shield the transmitted information from listening in and to find the effect of assorted qualities contrasts on the limit of the proposed framework. We consider the maximal ratio combining (MRC) framework at the goal and deduce the declaration of combiner yield signal-to-noise (SNR) ratio using optimum weighting vector with the goal that the busybody is not ready to disentangle a single piece from the first information. At long last, we gather the statement of perfect limit as far as the amount of relays and the amount of radio wires at the goal. Our outcomes demonstrate that the change of weighting vector at the beneficiary redesigns limit of a wiretap channel.

Z. Mo, W. Su, S. Batalama and J. D. Matyjas, et al. [41]: Cooperative communication has developed with parameters such as time allocation and power budget plays main role in the wireless cooperative protocol designs. While most existing topic on cooperative relaying protocol outlines considered equivalent time allocation situation, i.e. each source and each relay is assigned to equal time duration, in this work we expect to design and improve cooperative communication protocols by investigating every possible variety in time and power domains. The power and time allotments for the cooperative relaying are combined optimize such that the outage probability is minimized of the protocol. In particular, for any given time designation, we can decide the comparing optimum power allocation diagnostically with a closed form expression. We likewise demonstrate that keeping in mind the end goal to limit the blackout likelihood of the protocol; one should to dependably distribute more energy and time to the source than the relay. Numerical and simulation results illustrate our theoretical improvements.

N. Suraweera, N. C. Beaulieu, et al. [42]: In wireless networks, spatial point processes are regularly used to place the model and the quantity of interferers in present wireless networks in which the ad-hoc organization of transmitters is kept common in the system. Most popular spatial point process i.e. homogeneous Poisson point process (PPP) is used to show co-channel interference. Optimum combining (OC) is another method that boosts the signal-to-interference-in addition to noise ratio at the receiver. The execution of cooperative relaying with the optimum combining is interferer field demonstrated by a homogeneous PPP is examined. Both decode-and-forward (DF) and amplify-and-forward (AF) relay protocols are analysed. Multi-relay selects transmission and relay selected in all the relays methods are considered. Precise approximations for the outage probability are inferred for DF and AF relaying when the destination is evaluated the commotion in addition to interference relationship grid perfectly. An estimate for the outage probability of DF relaying is gotten when the destination as it were gauges the channel state data of the nearest interferer. Relay selection beats multi-relay transmission in both DF and AF relaying protocol. The interference relationship at the relays fundamentally corrupts the outage performance. Constrained estimation of the NICM results in preferred execution over regular maximal-ratio combining, despite the fact that it neglects to accomplish the diversity gain.

V. A. Aalo, and J. Zhang et al. [43]: The impact of co-channel interference on the execution of computerized versatile radio systems in a Rayleigh fading condition is considered. The average bit error rate of a reception antenna model with an optimum combining plan that amplifies the output signal-to-interference-in addition to noise ratio is dissected. BER expressions which are simple but difficult to assess numerically are determined for binary-phase-shift-keying in coherent schemes with co-channel interference and noise.

R. Duan, M. Elmusrati, R. Jantti and R. Virrankoski, et al. [44]: In this paper we consider the limit of range sharing Cognitive radios (CR) with Maximal Ratio Combining (MRC) at the auxiliary collector under lopsided confronting, where the channel from the optional transmitter to the beneficiary of essential endure Nakagami blurring while the one from transmitter of optional to its recipient takes after Rayleigh Multipath blurring. In the wake of examining scientific and numerical outcomes demonstrate that with MRC joining grouped qualities at the optional beneficiary, more noteworthy limit is refined. Besides, when the SUtx PUrx channel has less blurring which unequivocally impacts the limit of CR channel, utilizing MRC system for CR structure could decrease the effects.

H. A. Suraweera, P. J. Smith and M. Shafi, et al. [45]: Cognitive radio (CR) design expects to build range usage by permitting the auxiliary clients (SUs) to exist together with the essential clients (PUs), the length of the interference caused by the SUs to every PU is legitimately managed. At the SU, channel-state data (CSI) between its transmitter and the PU collector is utilized to compute the most extreme reasonable SU transmit control to restrain the interference. We assume that this CSI is blemished, which is a vital situation for CR frameworks. In addition to got interference control imperative, a furthest utmost to the SU transmit control requirement is additionally considered. We infer a closed form expression for the mean SU limit under this situation. Because of flawed CSI, the SU can't generally fulfil the received interference control limitation at the PU and has to back off it’s transmit control. The resulting limit misfortune for the SU is measured utilizing the combined dissemination work of the interference at the PU. Also, we research the effect of CSI quantization. To examine the SU mistake execution, a closed form of average bit error rate (BER) expression was additionally determined.

D. Li, et al. [46]: In this paper, we analyse the impact of maximum ratio combining diversity on the execution of cognitive radio frameworks, in which the cognitive user (CU) shares a similar range with an primary user (PU) and the transmit energy of the CU fulfils both the transmit, interference power constraints. Using the determined cumulative distribution function (CDF) of the signal to noise ratio, we examine the ergodic capacity and the average symbol error rate of the considered framework and infer new expressions for their asymptotic execution. Both diagnostic and simulations results demonstrate that the MRC diversity qualities can give full diversity qualities arrange and a capacity scaling law as a logarithmic of the quantity of cognitive receiving antennas when the transmit energy of the CU is commanded by the transmit control constraint.

L. Zhi-yong, et al. [47]: In this paper, various relay is selected for cooperative communication with amplify-and-forward (AF) relay under frequency selective channels is proposed. In the proposed method, the relays are requested for the end-to-end SNR, at that point the relays are successively chosen out from N relays and the quantity of participating relays is balanced progressively as indicated by the present channel state data. This work is to progressively apprise the ideal number of cooperative relays. "Optimum" means the least number of cooperative relays accomplishing the most extreme level of joined SNR. Numerical results confirm the model can adaptively modify the quantity of cooperating relays, and perform traditional relay schemes. Thus, the proposed model gives better trade-off between bit error rate execution and efficiency in spectral and to save more energy in cooperative remote systems.

J.H Winters *et al.* [48]: This paper presented the upper bounds for the BER of OC with multiple co-channel interferers in a Rayleigh fading environment. Closed form expressions for the upper bound on the BER of the OC are derived for BPSK, QAM and DPSK schemes. Bounds on the performance gain of OC are also given over MRC. These bounds are tight for the decreasing value of the BER. The results show that the asymptotic gain is within 2dB of the gain as given by simulations. These expressions allow the calculation of the performance of OC under different conditions including the analysis of outage probability under the combined effect of adaptive arrays and dynamic channel assignment and shadow fading in mobile radio systems.

E. Villier *et al.* [49]: OC under the impact of multiple equal power interferers for the case when number of receive antennas are more than the number of co-channel interferers is studied. The desired signal and interfering signals undergo Rayleigh fading and independently distributed. An expression is derived for the probability density function of the SINR at the output of receiver which is then applied to obtain the CDF of the SINR and average bit error rate for some binary modulations. An exact analysis is done for the single interferer to validate the approximations.

CHAPTER 3
COOPERATIVE COGNITIVE RADIO NETWORK WITH OPTIMUM COMBINING SYSTEM

3.1 CCRN-OC System

We have considered an underlay system of cooperative cognitive radio (CCRNs) which co-exist with primary and DF cooperative communication based secondary network. In primary network, data is been transferred to the primary destination (PD) by the primary transmitter (PT), simultaneously in secondary network, data is been transferred to the secondary destination (SD) by the secondary transmitter (ST) in co-ordination with the primary transmission over the channel as depicted in figure 3.1. Along with the secondary transmitter and secondary destination, secondary relays are also present and they are denoted by L ($R_i,\ i \in \Omega\ = \{1,2, \dots, L\}$). Let M_i and N denotes the total number of co-channel interference (CCI) that affect secondary relays (SR_s) and secondary destination (SD) respectively. It is supposed that $M_i = M,\ i = 1,2, \dots, L$. For the protection of primary destination (PD) from the interferences which are harmful to the primary network, thus restricting the transmitted peak power, $P_P << Q$ [9]. In DF technique, relay nodes strongly decodes the entire message received from the secondary transmitter (ST), re-encodes and then forwarding it to the secondary destination (SD).

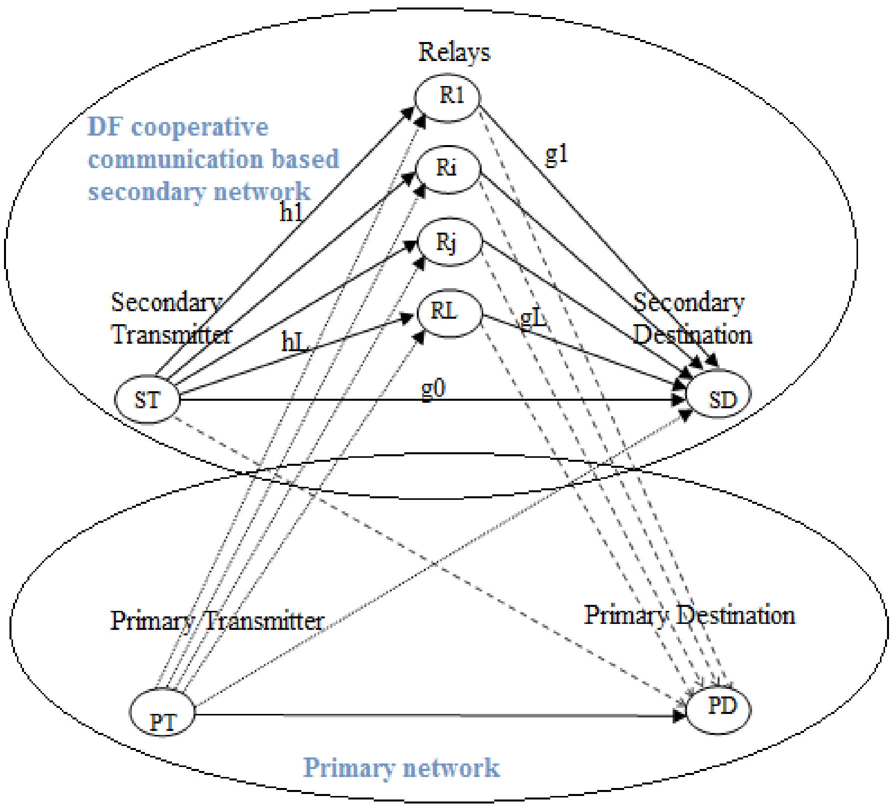

Figure 3.1: The system model of cooperative cognitive radio network [11], [14].

Cooperative communication categorized into two processes: Amplify and Forward or Decode and Forward [15]. In AF the approach behind this convention is very straight forward. As the signal gotten at the relay station was debilitated and it is required to be enhanced before it is transmitted to the destination. At the same time the commotion display in the signal is additionally getting increased, that is the fundamental confinement of this convention. AF protocol can be further split up into two phases. In the first phase, information is transmitted to the relays and the destination. In the second phase, relay received the transmitted signal from the source node and further re-transmits it to the destination node after amplification [16]. The incoming signal is amplified block wise as shown in the previous section1.3.1. Then, the entire received signal combines at the destination by using OC technique. In OC technique the weights are chosen to maximize the signal to interference in addition to noise ratio at the combiner output. OC is the best system which utilize the maximum SINR at the receiver output and gives the better SINR results in comparison to the MRC diversity even when the number of interference signal are more than the number of antenna nodes.

In the first phase, source broadcast its signal to destination and relay simultanelsy. Now the signal we received from source to destination, $y_{S,D}$ and source to relay, y_{S,R_i} is given by

$$y_{S,D} = \sqrt{E}_S g_0 d_0 + \sum_{j=1}^{N} \sqrt{E}_{Ij} \alpha_{j,0} d_{j,0} \tag{3.1}$$

$$y_{S,R_i} = \sqrt{E_S} h_i d_0 + \sum_{j=1}^{N} \sqrt{E_{I_j}} \beta_{j,i} d_{R_{j,i}} \tag{3.2}$$

where E_S and E_{Ij} are energies of received signal S and j^{th} interferer, respectively. d_0 and $d_{j,0}$ are the corrosponding symbols transmitted by S and the j^{th} interferer, which are assumed to be independent. $d_{R_{j,i}}$ represents the j^{th} interfering symbol at the i^{th} relay. Channel gain g_0, h_i and $\alpha_{j,0}$, $\beta_{j,i}$ resemble to the flat Rayleigh fading channels for S and j^{th} interferer.

In the second phase, relay amplifies noisy version of the signal received from the first phase and forward it to the destination. Received signal at D with respect to the i^{th} relay, $y_{R_i,D}$ is given as

$$y_{R_i,D} = \sqrt{E_R} g_i d_0 + \sum_{j=1}^{N} \sqrt{E_{I_j}} \alpha_{j,i} d_{j,i} \tag{3.3}$$

where $d_{j,i}$ is the j^{th} interferer at the destination. $\alpha_{j,i}$ and g_i are the channel gains. E_{I_j} represents the average received energy from the j^{th} interferer. It is assumed that $E_R = E_S$ and $E_{I_j} = E_I$, $j=1,.........,N$.

3.2 Performance Analysis of CCRN-OC System

In this section, we describe the following steps for finding the best relay selection scheme, average bit error rate and ergodic capacity for the system under study.

Step-1: For obtaining the expression for best relay, first we obtain best transmitting antenna pdf and cdf by using the theory of order statistics.

Step-2: From the pdf and cdf of best transmitting antenna, we can derive the expression for best relay selected among all the relays in cooperative cognitive radio network by using order statistics selection scheme.

Step-3: Now, average bit error rate can be evaluated by using the best relay pdf as described in section 3.2.2.

Step-4: Further ergodic capacity of the system is calculated by finding the first and second moment of the cooperative cognitive radio network as stated in section 3.2.3.

The above steps are implemented as given below:

3.2.1 Best Relay Selection

The best transmit antenna selection [17] b_{R_i} is expressed as

$$b_{R_i} = \arg\max \{\gamma_{S,Ri}(t)\} \tag{3.4}$$

where $R_{i,}$, $i=\{1,.....L\}$ and $\gamma_{S,Ri}\,(t)$ is the instantaneous SNR in time slot t. Now, the CDF and PDF of the SNR for the best transmit antenna is expressed by using the theory of order statistics [17] such as

$$F_{\gamma_{bm,m}}(\gamma) = [F_{\gamma_{S,Ri}}(\gamma)]^S \tag{3.5}$$

$$f_{\gamma_{bm,m}}(\gamma) = S\, f_{\gamma_{S,Ri}}(\gamma)\, [F_{\gamma_{S,Ri}}(\gamma)]^{S-1} \tag{3.6}$$

The PDF and CDF of $\gamma_{S,Ri}$ is given by (3.7) and (3.8) [11] where M denotes the co-channel interferer and by substituting these values in above equation (3.5) and (3.6), we get

$$f_{\gamma_{S,Ri}}(\gamma) = M\left(\frac{\Omega_h e_s}{\Omega_\beta e_r}\right)^M \left(\frac{\Omega_h e_s}{\Omega_\beta e_r} + \gamma\right)^{-(M+1)} \tag{3.7}$$

$$F_{\gamma_{S,Ri}}(\gamma) = 1 - \left(1 + \frac{\Omega_\beta e_r}{\Omega_h e_s}\gamma\right)^{-M} \tag{3.8}$$

The best relay selection [17] b_m is expressed as

$$b_m = \arg\ \max\{\gamma_{bm,m}(t)\} \tag{3.9}$$

where R_i, $i = \{1,.....L\}$ and $\gamma_{bm,m}\ (t)$ is the instantaneous SNR of the cooperative network. Hence, the best relay is selected among R_i relays. Thus, the CDF and PDF of the best relay chosen among all R_i relays is given as

$$F_{\gamma_{br,r}}(\gamma) = [F_{\gamma_{bm,m}}(\gamma)]^L \tag{3.10}$$

The PDF can be achieved by differentiating CDF, we get

$$f_{\gamma_{br,r}}(\gamma) = L\, f_{\gamma_{bm,m}}(\gamma)\ [F_{\gamma_{bm,m}}(\gamma)]^{L-1} \tag{3.11}$$

where $F_{\gamma_{bm,m}}(\gamma)$ and $f_{\gamma_{bm,m}}(\gamma)$ are defined in (3.5) and (3.6). Substituting (3.5) and (3.6) into (3.10) and (3.11), we get

$$F_{\gamma_{br,r}}(\gamma) = [F_{\gamma_{S,Ri}}(\gamma)]^{SL} \tag{3.12}$$

$$f_{\gamma_{br,r}}(\gamma) = SL\, f_{\gamma_{S,Ri}}(\gamma)\ [F_{\gamma_{S,Ri}}(\gamma)]^{SL-1} \tag{3.13}$$

By substituting (3.7) and (3.8) into (3.13) the closed form expression of CDF and PDF for best relay in cooperative relaying network is obtained through order statistics selection scheme and given as

$$F_{\gamma_{br,r}}(\gamma) = \left(\left(1 - \left(1 + \frac{\gamma e_r \Omega_\beta}{e_s \Omega_h}\right)^{-M}\right)^S\right)^L \tag{3.14}$$

$$f_{\gamma_{br,r}}(\gamma) = \frac{L\times M\times S\left(\gamma + \frac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{-1-M}\left(\frac{e_s\Omega_h}{e_r\Omega_\beta}\right)^M\left(\left(1-\left(1+\frac{\gamma e_r\Omega_\beta}{e_s\Omega_h}\right)^{-M}\right)^S\right)^L}{1-\left(1+\frac{\gamma e_r\Omega_\beta}{e_s\Omega_h}\right)^{-M}} \tag{3.15}$$

Knowing $f_{\gamma_{br,r}}(\gamma)$ given by (3.15), we can derive the closed form expression for the average bit error rate and ergodic capacity as shown in 3.2.2 and 3.2.3.

3.2.2 Average Bit Error Rate

The conditional BER i.e. the BER computed for a value of γ, is simply given as

$$P_{e/\gamma} = Q(\sqrt{2\gamma}) \tag{3.16}$$

Where Q(.) is the area under the Gaussian probability density function and is defined as

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-t^2/2}\, dt \tag{3.17}$$

To obtain result, the erfc(.) (complementary error function) is usually found and the relation between two function is given by $Q(\sqrt{2x}) = \frac{1}{2}\, erfc(\sqrt{x})$. The average bit error rate [48] performance P_e is calculated by integrating the PDF of variable node given by (3.13) from 0 to ∞

$$P_e = \frac{1}{2} \int_0^{\infty} erfc\ (\sqrt{\gamma})\ f_{\gamma_{br,r}}(\gamma)\, d\gamma \tag{3.18}$$

$$P_e = \frac{1}{2}\,(\,L\times M\times S) \int_0^{\infty} erfc\left(\sqrt{\gamma}\right) \left(\frac{\left(\gamma + \frac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{-1-M} \left(\frac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{M} \left(\left(1-\left(1+\frac{\gamma e_r\Omega_\beta}{e_s\Omega_h}\right)^{-M}\right)^{S}\right)^{L}}{1-\left(1+\frac{\gamma e_r\Omega_\beta}{e_s\Omega_h}\right)^{-M}} \right) d\gamma \tag{3.19}$$

which can be evaluated using software such as Wolfram Mathematica, as given in (3.20), where $\eta = \frac{e_s\Omega_h}{e_r\Omega_\beta}$ and ${}_1F_1$(.,.,.) is the generalized hyper-geometric function series. Alternatively, (3.19) can be evaluated numerically.

$$P_e = \frac{1}{2}\ L\times M\times S\ \left(1-(1+\gamma\eta)^{-M}\right)^{-1+L} \eta^{M} \left[-\frac{\eta^{\frac{1}{2}-M}\,\Gamma\left[-\frac{1}{2}+M\right] 1F1\left[\frac{1}{2},\frac{3}{2}-M,\eta\right]}{\Gamma[1+M]} + \frac{\eta^{-M}-\frac{\Gamma\left[\frac{1}{2}-M\right] 1F1\left[M,\frac{1}{2}+M,\eta\right]}{\sqrt{\pi}}}{M} \right] \tag{3.20}$$

3.2.3 Ergodic Capacity

In this, first we derive the expression for the first moment of $f_{\gamma_{br,r}}$ which is given as

$$\mathbb{E}\{\gamma_{br,r}\} = \int_0^{\infty} \gamma\, f_{\gamma_{br,r}}(\gamma) d\gamma \tag{3.21}$$

where $\mathbb{E}\{.\}$ is an expectation operator and the value of $f_{\gamma_{br,r}}$ is given in (3.13). Equation (3.21) is evaluated by using software Wolfram Mathematica and is given as

$$\mathbb{E}\{\gamma_{br,r}\} = \int_0^{\infty} \gamma \left(\frac{L\times M\times S \left(\gamma + \frac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{-1-M} \left(\frac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{M} \left(\left(1-\left(1+\frac{\gamma e_r\Omega_\beta}{e_s\Omega_h}\right)^{-M}\right)^{S}\right)^{L}}{1-\left(1+\frac{\gamma e_r\Omega_\beta}{e_s\Omega_h}\right)^{-M}} \right) d\gamma \tag{3.22}$$

$$\mathbb{E}\{\gamma_{br,r}\} = \frac{L \times M \times S\,(1+\gamma\eta)^{M}((1-(1+\gamma\eta)^{-M})^{S})^{L}\sqrt{\eta}\Gamma\left[-\frac{1}{2}+M\right] 1\text{F}1\left[\frac{1}{2},\frac{3}{2}-M,\eta\right]}{8(-1+(1+\gamma\eta)^{M})\Gamma[1+M]} + \frac{LS(1+\gamma\eta)^{M}((1-(1+\gamma\eta)^{-M})^{S})^{L}\eta^{M}\Gamma\left[\frac{1}{2}-M\right] 1\text{F}1\left[M,\frac{1}{2}+M,\eta\right]}{8\sqrt{\pi}(-1+(1+\gamma\eta)^{M})} \tag{3.23}$$

Where the L, M, S are number of relays, number of interference and transmitted source respectively. Gamma and hyper geometric function is used to solve this equation. The ergodic capacity $C_{\gamma_{br,r}}$ is defined as the maximum long term achievable rate and determined by averaging of instantaneous capacity over all possible channel states and is given as

$$C_{\gamma_{br,r}} \approx log_2\left(1+\gamma\ \mathbb{E}\{\gamma_{br,r}\}\right) - \frac{\gamma^2\ \sigma^2_{\gamma_{br,r}}}{2(1+\gamma\ \mathbb{E}\{\gamma_{br,r}\})^2} \tag{3.24}$$

where the variance $\sigma^2_{\gamma_{br,r}}$ of $\gamma_{br,r}$ is also computed in Wolfram Mathematica software.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 CCRN-OC System

This chapter presents the results for the cooperative cognitive radio network system with optimum combining method. For the system model, number of relays L are taken as 2,4,8,16 and interferers as M=2,4,8,16. We assume that $\Omega_h = \Omega_g = \Omega_\alpha = \Omega_\beta = 1$ and binary phase shift keying modulation scheme is considered here. The results of average bit error rate and ergodic capacity for different number of relays *(L)* and co-channel interferers *(M)* are depicted in the cases below.

4.1.1 Average Bit Error Rate

a) Relays L=2 and varying interferences, M

Figure 4.1 shows the average bit error rate results for different number of CCI at relay L=2. The average bit error increases from 0.061 for (L=2, M=2) to 0.143 for (L=2, M=4). At (L=2, M=8) error slightly increases to 0.233 and at (L=2, M=16) error rises from 0.233 to 0.307. From the figure.4.1 it is clear that significant gain is achieved for the cooperative cognitive ratio network system when the number of interferers increases, which can be inferred from the table 4.1.

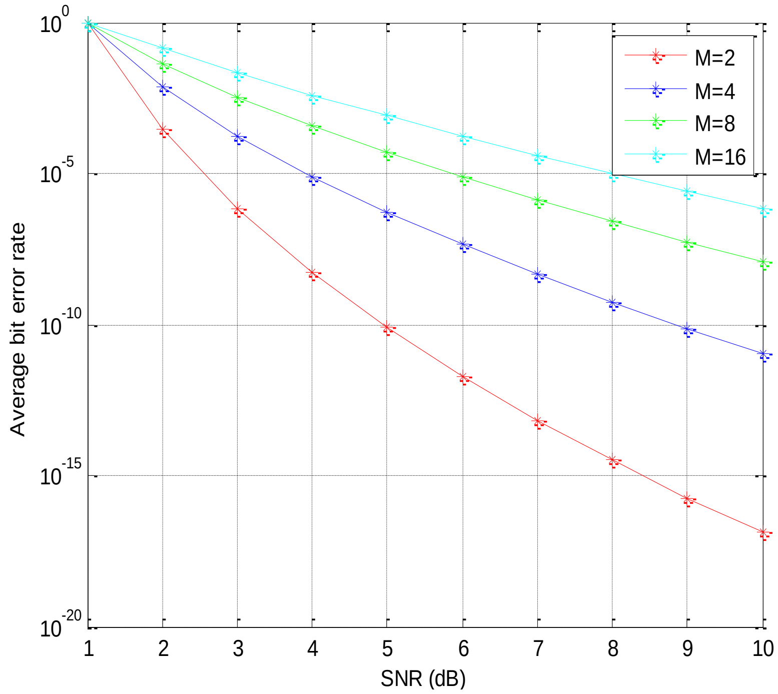

Figure 4.1: Average BER performance curves for different interferences at relay, L=2

Table 4.1: When the relays are fixed at L=2 and the interferences are varied accordingly from M=2 to 16.

Parameters	Number of interference, M				Notes
	M=2	M=4	M=8	M=16	
Average BER	0.061	0.143	0.233	0.307	L=4
Power Gain (dB)	2.5	3	3.5		

b) Relays L=2 and varying interferences, M

The average bit error rate performance for different number of relays at interferer M=2 is analysed as shown in Fig 4.2. From the Table 4.2, it is clear that there is a rapid decrease in the bit error rate as the numbers of relays are increased from 2 to 16.

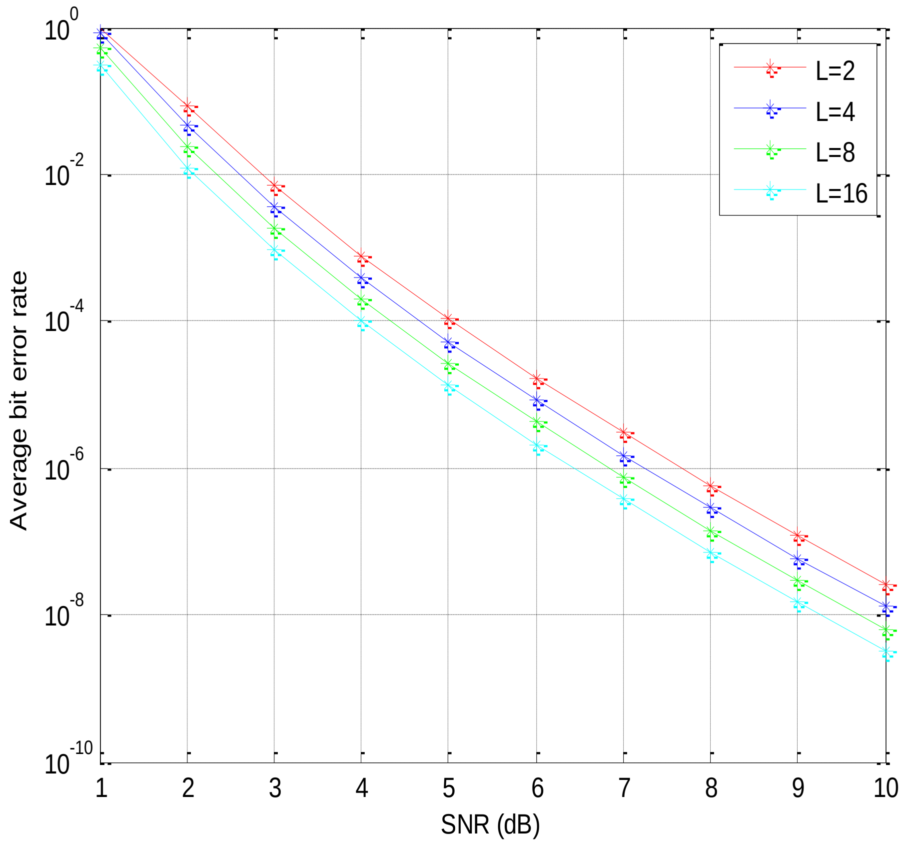

Figure 4.2: Average BER performance curves for different relays at interferences, M=2

Table 4.2: When the interference are fixed at M=2 and the relays are varied from L=2 to 16.

Parameters	Number of relays, L				Notes
	L=2	L=4	L=8	L=16	
Average BER	0.198	0.143	0.099	0.065	M=4
Power Gain (dB)	1.5		1	2	

4.1.2 Ergodic Capacity

(a). Relays L=2 and varying interferences, M

Figure 4.3 shows the ergodic capacity for different number of interferers in cooperative cognitive radio network at relay, L=2. From the Table 4.3, it can be seen that when (L=2, M=16) the ergodic capacity achieved is 5.184. At (L=2, M=8), capacity increases to 9.182. By taking L=M i.e. (L=2, M=2) the capacity rises from 16.168 to 30.426. With a decrease in the number of interferers there is a significant increase in the ergodic capacity of the system.

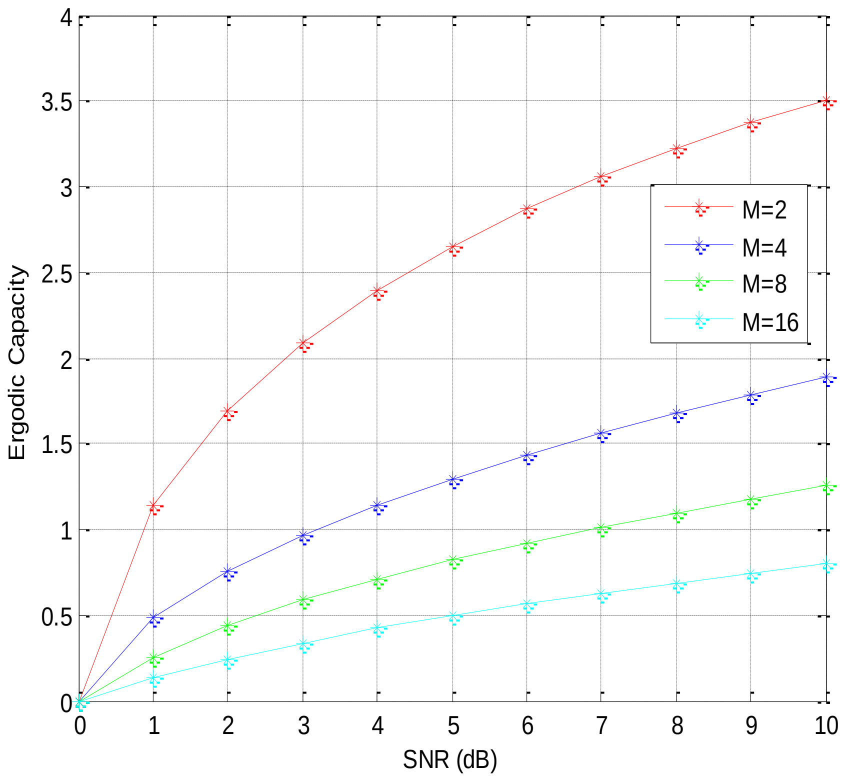

Figure 4.3: Ergodic capacity of cooperative cognitive radio network for different interference, M at relay, L=2

Table 4.3: When the relays are fixed at L=2 and the interferences are varied accordingly from M=2 to 16.

Parameters	Number of interference, M				Notes
	M=2	M=4	M=8	M=16	
Ergodic Capacity	5.184	9.182	16.168	30.426	L=2
Capacity Gain (%)	42%	45%	46%		

(b). Relays L=2 and varying interferences, M

Figure 4.4 shows the ergodic capacity for different number of relays in cooperative cognitive radio network at interferer, M=2. From the Table 4.4, 30.426 capacity is achieved at (L=2, M=2) as the M increase to 4 and L=2 our capacity also increases to 36.841. Now at (L=16, M=2) then the capacity rises to 48.517 from 42.830 when (L=8, M=2). We analyze that there is a significant increase in capacity as the number of relays increases.

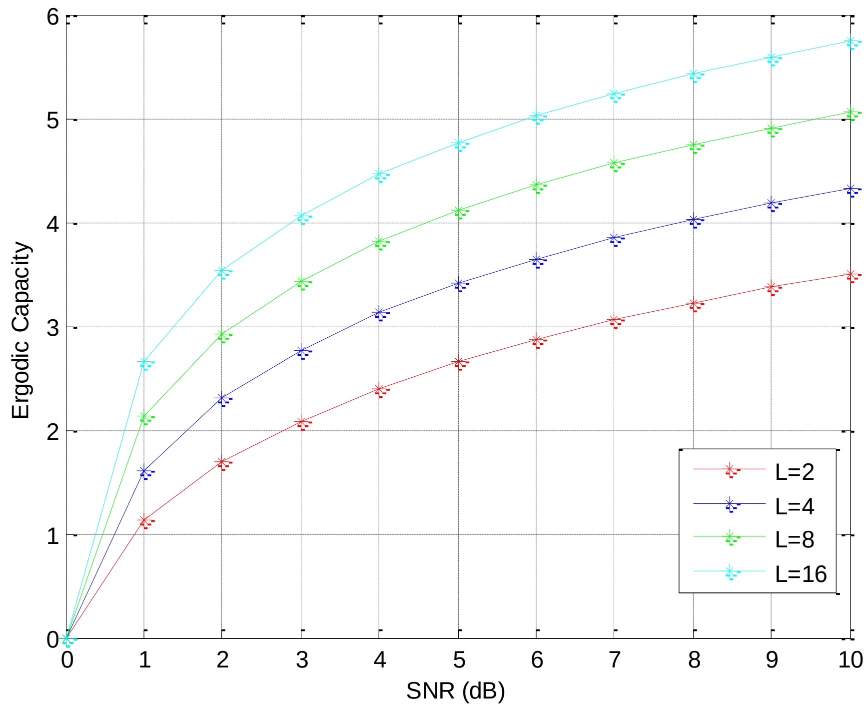

Figure 4.4: Ergodic capacity of cooperative cognitive radio network for different relays, L at interferer, M=2

Table 4.4: When the interference are fixed at M=2 and the relays are varied from L=2 to 16.

<table>
<tr><th rowspan="2">Parameters</th><th colspan="4">Number of relays, L</th><th rowspan="2">Notes</th></tr>
<tr><th>L=2</th><th>L=4</th><th>L=8</th><th>L=16</th></tr>
<tr><td>Ergodic Capacity</td><td>30.426</td><td>36.841</td><td>42.830</td><td>48.517</td><td rowspan="2">M=2</td></tr>
<tr><td>Capacity Gain (%)</td><td colspan="4">17% | 13% | 11%</td></tr>
</table>

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

In this, optimized relay selection scheme for cooperative cognitive radio network with optimum combining has been discussed. An underlay system was taken which co-exist with primary and DF cooperative communication based secondary network. From the proposed system, a closed form of PDF and CDF has been derived by using ordered statistics selection scheme method and further utilized for evaluating the closed form expression for the average bit error rate in terms of confluent hyper-geometric function and ergodic capacity performance of CCRNs system. Based on this approach, performance of bit error rate with different interference and relays can be evaluated. With a significant decrease in the average bit error rate of the system and the capacity of the system increases; this is when the interferers in the system increases. Similarly, when the relays increase for the system the bit error rate decreases which lead to an increase in the capacity of the system. This is helpful in the present scenario where the number of users and the demand for the radio spectrum is increasing simultaneously.

5.2 Future Scope

As my work is done with two networks i.e. cooperative and cognitive radio network in optimum combining, so this work is extended with delay tolerant and energy harvesting. And the simulation can be done on this with different diversity techniques.

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Adel M. Elmahdy, Amr El-Keyi, Tamer ElBatt, Karim G. Seddik. "Optimizing Cooperative Cognitive Radio Networks Performance With Primary QoS Provisioning", IEEE Transactions on Communications, 2017 Publication	%1
2	Himal A. Suraweera. "Channel Capacity Limits of Cognitive Radio with Imperfect Channel Knowledge", GLOBECOM 2009 - 2009 IEEE Global Telecommunications Conference, 11/2009 Publication	%1
3	Li, Dong. "Performance Analysis of MRC Diversity for Cognitive Radio Systems", IEEE Transactions on Vehicular Technology, 2012. Publication	%1
4	Suraweera, Navod, and Norman C. Beaulieu. "Performance analysis of decode-and-forward relaying with optimum combining in the presence of co-channel interference", 2013 IEEE International Conference on	%1