QUADRANT BASED ROUTING IN WSN WITH EFFICIENT CHANNEL ALLOCATION IN COGNATIVE RADIO

A Thesis Submitted in Fulfillment of the Requirement for the

Degree of

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in

WIRELESS COMMUNICATION AND SENSOR NETWORK

by

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To the

School of Engineering

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MAY 2019

CERTIFICATE

It is certified that work contained in this thesis entitled **"QUADRANT BASED ROUTING IN WSN WITH EFFICIENT CHANNEL ALLOCATION IN COGNATIVE RADIO"** by **Gopal Shukla** (Roll no 1170454003) for the award of It is certified that work contained in this thesis entitled **"QUADRANT BASED Master of technology** for BABU BANARSI DAS UNIVERSITY has been carried out under the supervision of **Mr Ankit Dalela** and his work has not been submitted elsewhere of degree

Nitin 19/07/19

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Declaration

I, **GOPAL SHUKLA** (Roll no 1170454003) declare that the thesis titled **"QUADRANT BASED ROUTING IN WSN WITH EFFICIENT CHANNEL ALLOCATION IN COGNATIVE RADIO"** has been composed solely by me and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely by my own.

GShukla
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ABSTRACT

The collaboration of nodes in cognitive wi-fi networks is a huge undertaking. This paper studies the collaborative multi-hop routing in cognitive networks. We advise a new set of rules to construct the collaborative routing in multi-hop cognitive networks. Our set of rules takes into account the interference among nodes which include number one and secondary users. The clustering and collaboration are exploited to enhance the overall performance of collaborative routing in multi-hop cognitive wi-fi networks with a couple of number one and secondary users. By reading the most transmission distance, collaborations, transmission angle manipulate and electricity control, and channel allocation, we suggest a brand new clustering-based collaborative multi-hop cognitive routing set of rules to reap better network performance. Simulation effects display that our approach is feasible and effective.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF ABBREVIATIONS

WMNS	Wireless Mesh Network
CRC	Cognitive Radio communication
CC	Cognitive Cycle
CRN	Cognitive Radio Network
DSR	Destination sources routing protocol
DSDV	Destination Sequence distance vector routing protocol
PU	Primary user
PUS	Primary users
SS	Spectrum sensing
AODV	Ad-hoc-on-demand distance
SU	Secondary user
SVS	Secondary user

List Of Symbol

Q_{sv}	SNR Threshold value
P^{b}_{PU}	Primary user
$G^{b}_{pu,pd}$	Receiving power gain
P^{c}_{pk}	Transmitting power gain
Tr	Transmission distance
P^{r}_{sr}	Transmitting metro

CHAPTER 1

INTRODUCTION

This part of thesis describe all over organization and insight of the work. This chapter also provides the over view of cognitive radio commutation system and understanding of exact problem definition, scope of this work and thesis outline.

1.1 BACKGROUND

About 50 years ago, the first research steps on packet switched networks were being carried out, probably without knowing the global impact they would have in the world. Nowadays, the importance acquired by the Internet is unquestionable, and beyond some economic discussions, virtually everyone recognizes the relevance it gained in the various aspects of the lives of people around the planet. Many studies have found a direct relationship between the broadband access and the investment in information and communication technology (ICT) and the job creation, economic growth and human development index of countries [26, 28]. Moreover, in many cases ICT applications are promoted as a way to make significant progress in developing countries [29, 30]. In this sense, education emerges as one of the most important verticals for incorporating ICT, with various initiatives already underway in various countries and regions (e.g. Plan Ceibal [5] in Uruguay, Connecter Igualdad [31] in Argentina, Connected [32] in the US and many more).

In this context, the progress in broadband deployment is key in advancing the reduction of the digital divide [33]. The deployment, maintenance and optimization of the necessary infrastructure is a tough challenge, and an additional complexity is added, as bandwidth requirements evolve every day. For example, the Federal Communications Commission (communications regulator in the US, which implies a great inuence worldwide) includes as part of its 2015 Broadband Progress Report [34] the redefinition of the term broadband, by raising the minimum download speeds needed from 4 Mbps to 25 Mbps, and the minimum upload speed from 1 Mbps to 3 Mbps. This simple redefinition tripled the number of US households without broadband access, now reaching a total of 17% of the population. This situation is much worse in rural areas where the percentage reaches 53% of the people lacking access to 25 Mbps/3 Mbps services. The previous definition of broadband (4 Mbps/1 Mbps) was from 2010, just five years ago, a clear sign of the challenge of keeping up with the necessary infrastructure, with requirements that change so much and so fast. is where it becomes more difficult to afford the necessary infrastructure. The low population density and large swathes of territory to cover, make infeasible the deployment of optical fiber due to the high costs, particularly for developing countries with lower budgets. For those cases, the only affordable alternative to build the necessary infrastructure is to use wireless technologies [35]. This advantage from the economic point of view becomes a major challenge from the technical point of view, since it is necessary to develop wireless solutions, capable to cope with the high bandwidth requirements, but which are based on a finite resource: the shared spectrum available.

1.2 DYNAMIC SPECTRUM ACCESS AND COGNITIVE RADIO

Currently, spectrum assignment policy in term of frequency band. As a result, the spectrum uses is limited to a certain part of frequency spectrum. With the high and increasing demand of mobile services and current studied, dynamically accessing the spectrum can help improve the spectrum utilization. CR is proposed and designed to since and learn from the environment in order to perform the best services to user. By opportunistically accessing the licensed spectrum without interfering the licensed user, CR can improve the efficiency of the spectrum usage.

1.3 MOTIVATION

Routing protocols are at the heart of WMNs which control the formation, configuration and maintenance of topology of the network. Owing to their common features, many routing protocols have been proposed. Some of the commonly used routing protocols in WMNs are Dynamic Source Routing (DSR), Ad-hoc On-demand distance vector (AODV) routing and Destination Sequence Distance Vector Routing Protocol (DSDV) [5, 6, 7]. However, these protocols does not consider about the hidden node, self-flow and multi-flow interference. The design of new routing protocols for WMNs is still an active research topic as new performance metrics need to be discovered and utilized to improve performance of routing protocols. In our first proposal, we focus on the hidden node avoidance technique for the self-flow interference. our objectives is to select a route between the source node and the destination node that is protected from the hidden node of the self-flow. This is accomplished by using a high sensitive sensing function in the route construction. In the proposed routing method, it is considered that every node utilizes high sensitive sensing devices like the secondary terminal in the cognitive radio [21]-[23].

1.4 OBJECTIVE

To analyzes the shortest path in cognitive radio in order to minimize interference between sender and receiver nodes.

1.5 SCOPE OF THESIS

The main motive this work is to utilize spectrum and interference avoidance can be improved then. We have presented a cognitive radio commutation. In this problem relegated to multiple hubs routing is shown. Quadrant based approach is our proposed method, can reduce interference between CR user and PU user.

1.6 THESIS LAYOUT

The thesis is organized follows:

Chapter2 describe history of wireless commutation, Its application and about cognitive radio **communication.**

Chapter3 describe mythology used in cognitive radio communication.

Chapter4 describe simulation result and analysis.

Chapter5 describe conclusion band future work in cognitive network.

CHAPTER 2

LITERATURE SURVEY

2.1 This section gives the details overview of almost all possible types of cognitive radio communication. Here we have shown the function of cognitive radio communication and advantage and disadvantage different type of spectrum sensing. Finally at the end we have discussed the challenge issue related to the CR terminology.

2.2 OVERVIEW OF CR

2.2.1 INTRODUCATION

Current wireless networks are regulated by governmental agencies mainly according to a fixed spectrum assignment policy. Licenses are granted the rights for the use of various, often relatively small, frequency bands on a long term basis over vast geographical regions. Recent studies by the Federal Communications Commission (FCC) highlight that many spectrum bands allocated through static assignment policies are used only in bounded geographical areas or over limited periods of time, and that the average utilization of such bands varies between 15% and 85% [13]. To address this situation cognitive radio technology has been proposed [14]. Cognitive Radio (CR) transceivers have the capability of completely changing their transmitter parameters (operating spectrum, modulation, transmission power, and communication technology) based on interactions with the surrounding spectral environment. They can sense a wide spectrum range, dynamically identify currently unused spectrum blocks for data communications, and intelligently access the unoccupied spectrum called Spectrum Opportunities (SOP) [16]. Since most of the spectrum is already assigned to the licensed user, the most important challenge of the cognitive radio is to share the licensed spectrum without interfering with the transmission of other licensed users. The cognitive radio enables the usage of temporally unused spectrum, which is referred to as spectrum hole or white space [19]. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference as shown in Fig. 1.6 More specifically, the cognitive radio technology will enable the users to (1) determine

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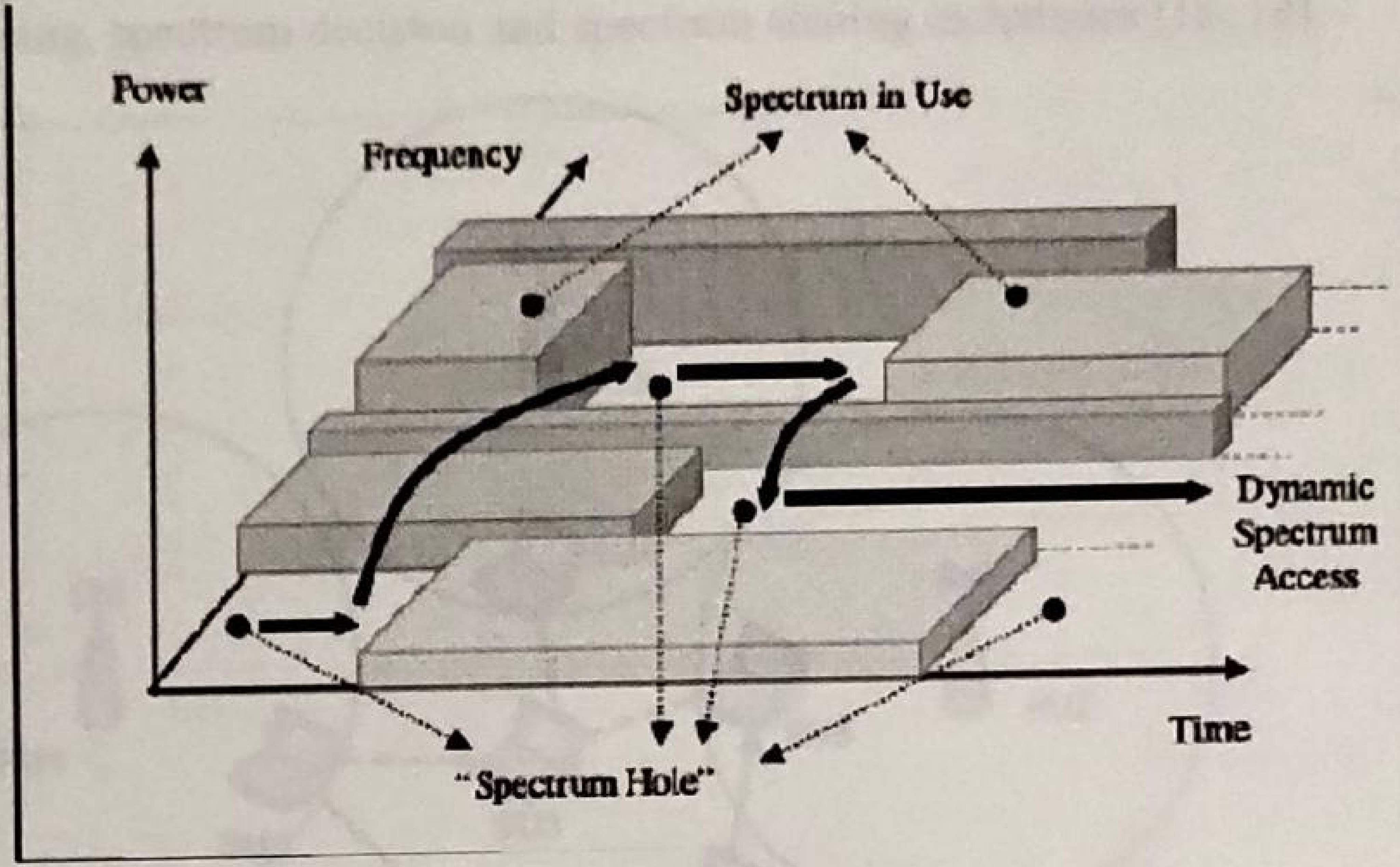

FIGURE 2.1: Spectrum hole concepts

2.2.2 Cognitive radio network

Devices with cognitive capabilities can be networked to create CRNs, which are recently gaining momentum as viable architectural solutions to address the limited spectrum availability and the inefficiency in the spectrum usage [17]. The most general scenario of CRNs distinguishes two types of users sharing a common spectrum portion with different rules: Primary (or licensed) Users (PUs) have priority in spectrum utilization within the band they have licensed, and Secondary Users (SUs) must access the spectrum in a non-intrusive manner. Primary Users use traditional wireless communication systems with static spectrum allocation. Secondary Users are equipped with CRs and exploit Spectrum Opportunities (SOPs) to sustain their communication activities without interfering with PU transmissions. The Fig. 1.7 illustrates simple CRNs where the secondary user share different spectrum band (SOPs) with primary user. Cognitive radio networks changes their configurations on the based on the spectral environment. This capability opens up the possibility of designing flexible and dynamic spectrum access strategies with the purpose of opportunistically reusing portions of the spectrum temporarily vacated by licensed primary users. On the other hand, the flexibility in the spectrum access phase comes with an increased complexity in the design of communication protocols at different layers. Most of the research on CRNs to date has focused on single-hop scenarios, tackling Physical (PHY) layer and/or Medium Access Control (MAC) layer issues, including the definition of effective spectrum sensing, spectrum decision and spectrum sharing techniques [18, 19].

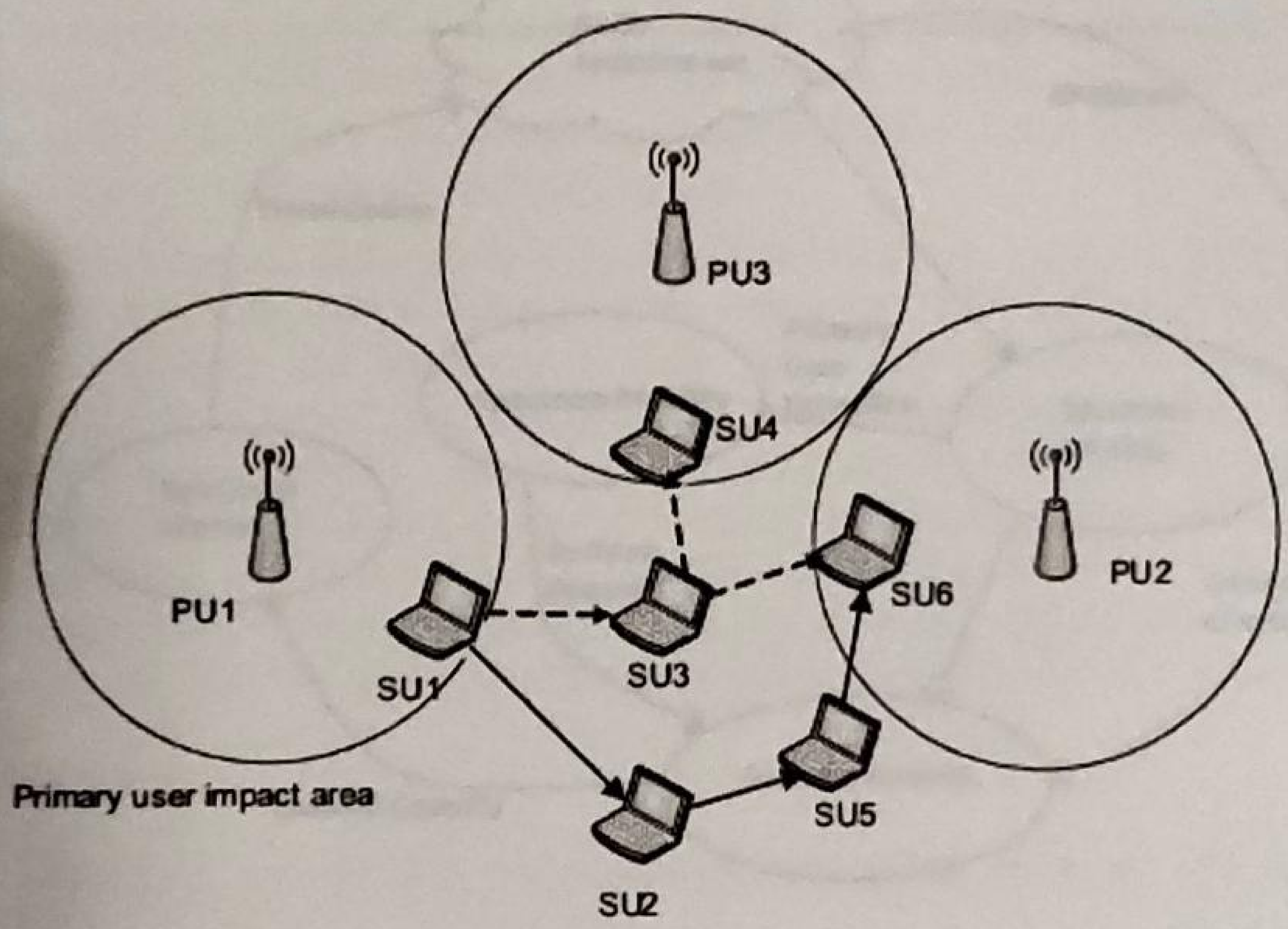

Figure 2.2: An example of a cognitive radio network.

2.2.3 Cognitive cycle

Once the operating spectrum band is determined, the communication can be performed over this spectrum band. However, since the radio environment changes over time and space, the cognitive radio should keep track of the changes of the radio environment. If the current spectrum band in use becomes unavailable, the spectrum mobility function that will be explained in Section 6, is performed to provide a seamless transmission. Any environmental change during the transmission such as primary user appearance, user movement, or traffic variation can trigger this adjustment. B. reconfigurability. Reconfigurability is the capability of adjusting operating parameters for the transmission on the fly without any modifications on the hardware components. This capability enables the cognitive radio to adapt easily to the dynamic radio environment. There are several reconfigurable parameters that can be

Incorporated into the cognitive radio: • Operating frequency: • Modulation: • Transmission power: • Communication technology:

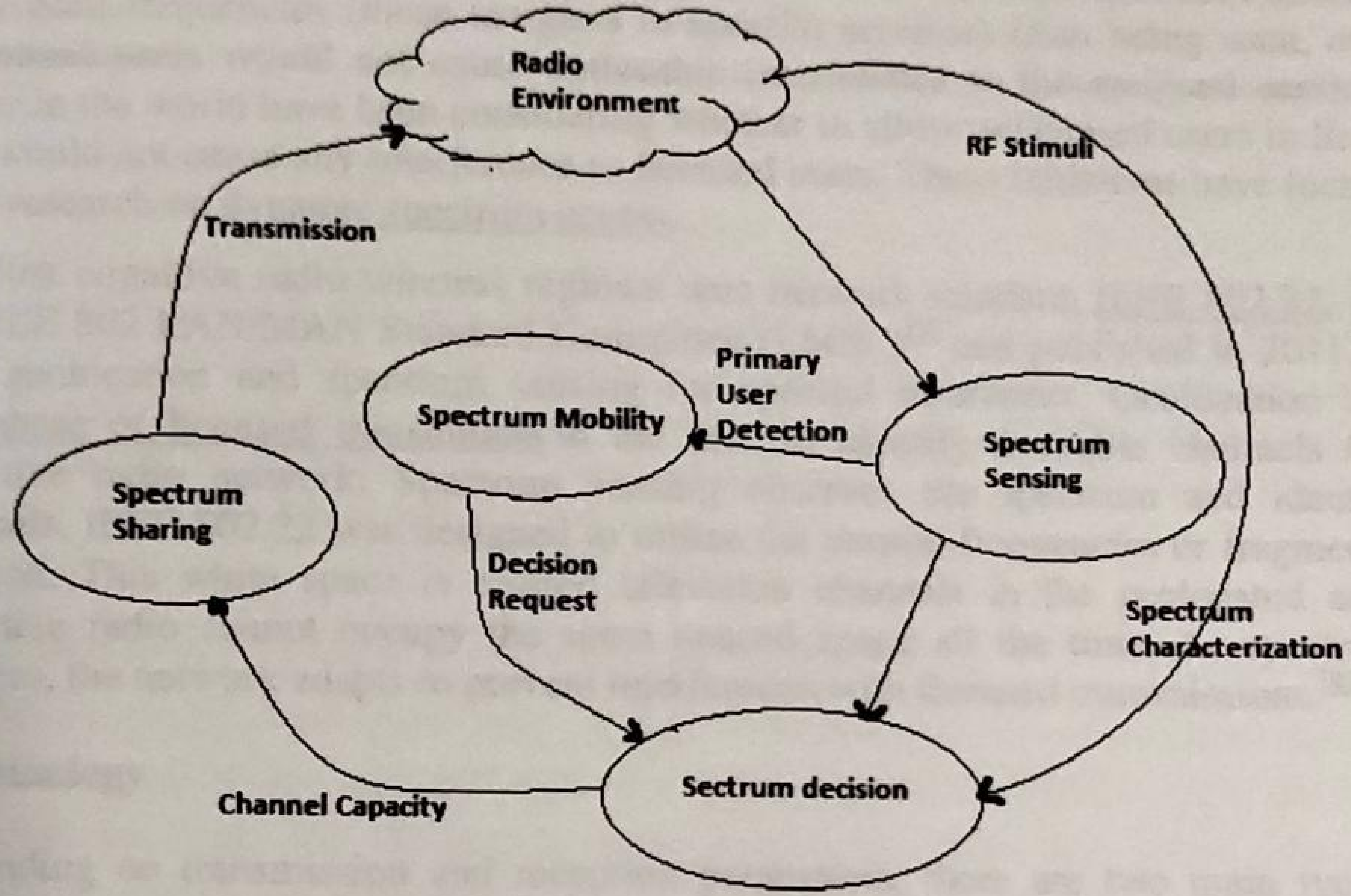

Figure 2.3 Cognitive Cycle

2.2.4: History of cognitive radio

The concept of cognitive radio was first proposed by Joseph Mitola III in a seminar at KTH (the Royal Institute of Technology in Stockholm) in 1998 and published in an article by Mitola and Gerald Q. Maguire, Jr. in 1999. It was a novel approach in wireless communications, which Mitola later described as:

The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs.
[1]

Cognitive radio is considered as a goal towards which a software-defined radio platform should evolve: a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands.

Traditional regulatory structures have been built for an analog model and are not optimized for cognitive radio. Regulatory bodies in the world (including the Federal Communications Commission in the United States and Ofcom in the United Kingdom) as well as different independent measurement campaigns found that most radio frequency spectrum was inefficiently utilized.[2] Cellular network bands are overloaded in most parts of the world, but other frequency bands (such as military, amateur radio and paging frequencies) are insufficiently utilized. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends on time and place. Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used, even when any unlicensed users would not cause noticeable interference to the assigned service. Regulatory bodies in the world have been considering whether to allow unlicensed users in licensed bands if they would not cause any interference to licensed users. These initiatives have focused cognitive-radio research on dynamic spectrum access.

The first cognitive radio wireless regional area network standard, IEEE 802.22, was developed by IEEE 802 LAN/MAN Standard Committee (LMSC)[3] and published in 2011. This standard uses geolocation and spectrum sensing for spectral awareness. Geolocation combines with a database of licensed transmitters in the area to identify available channels for use by the cognitive radio network. Spectrum sensing observes the spectrum and identifies occupied channels. IEEE 802.22 was designed to utilize the unused frequencies or fragments of time in a location. This white space is unused television channels in the geolocated areas. However, cognitive radio cannot occupy the same unused space all the time. As spectrum availability changes, the network adapts to prevent interference with licensed transmissions.[4]

Terminology

Depending on transmission and reception parameters, there are two main types of cognitive radio:

- Full Cognitive Radio (Mitola radio), in which every possible parameter observable by a wireless node (or network) is considered.[5]
- Spectrum-Sensing Cognitive Radio, in which only the radio-frequency spectrum is considered.

Other types are dependent on parts of the spectrum available for cognitive radio:

- Licensed-Band Cognitive Radio, capable of using bands assigned to licensed users (except for unlicensed bands, such as the U-NII band or the ISM band). The IEEE 802.22 working group is developing a standard for wireless regional area network (WRAN), which will operate on unused television channels, also known as TV white spaces.[6][7]
- Unlicensed-Band Cognitive Radio, which can only utilize unlicensed parts of the radio frequency (RF) spectrum.[citation needed] One such system is described in the IEEE 802.15 Task Group 2 specifications,[8] which focus on the coexistence of IEEE 802.11 and Bluetooth.[citation needed]
- Spectrum mobility: Process by which a cognitive-radio user changes its frequency of operation. Cognitive-radio networks aim to use the spectrum in a dynamic manner by allowing radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during transitions to better spectrum.

- Spectrum sharing[9]: Spectrum sharing cognitive radio networks allow cognitive radio users to share the spectrum bands of the licensed-band users. However, the cognitive radio users have to restrict their transmit power so that the interference caused to the licensed-band users is kept below a certain threshold.
- Sensing-based Spectrum sharing:[10] In sensing-based spectrum sharing cognitive radio networks, cognitive radio users first listen to the spectrum allocated to the licensed users to detect the state of the licensed users. Based on the detection results, cognitive radio users decide their transmission strategies. If the licensed users are not using the bands, cognitive radio users will transmit over those bands. If the licensed users are using the bands, cognitive radio users share the spectrum bands with the licensed users by restricting their transmit power.
- Database-enabled Spectrum Sharing,[11][12],:[13] In this modality of spectrum sharing, cognitive radio users are required to access a white space database prior to be allowed, or denied, access to the shared spectrum. The white space database contain algorithms, mathematical models and local regulations to predict the spectrum utilization in a geographical area and to infer on the risk of interference posed to incumbent services by a cognitive radio user accessing the shared spectrum. If the white space database judges that destructive interference to incumbents will happen, the cognitive radio user is denied access to the shared spectrum.

2.2.5 Network architecture of cognitive radio network

Cognitive radio has been considered as a key technology for future wireless communications and mobile computing. We note the cognitive radios can form cognitive radio networks (CRN) by extending the radio link features to network layer functions and above. We categorize CRN rchitecture into several structures and classify the unidirectional links in such structures, to pave Self-organized capability: Spectrum/radio resource management to ably administer and structuring spectrum bands information among secondary users, good spectrum management scheme is needful. Connection and mobility management due to disparate of XG networks, routing and topology information is more complicated but its help to discover the neighborhood, available Internet access can be detected and the vertical handoffs can be supported which aid secondary users to choose route and networks [9]. ...

... Trust/security management: Since CRNs are disparate networks in complexion, various heterogeneities (e.g., system/network operators, wireless access technologies) offers amount of security tasks. Trust is thus a persecution for securing processes in CRNs [9]. ...
... • Transmission power: Power constraints are control the transmission power reconfiguration by enabling dynamic configuration for transmission power within the permissible power limit. If higher power operation is not necessary, the CR reduces the transmitter power to a lower level to decrease the interference and allow more users to share the spectrum [9]. ...

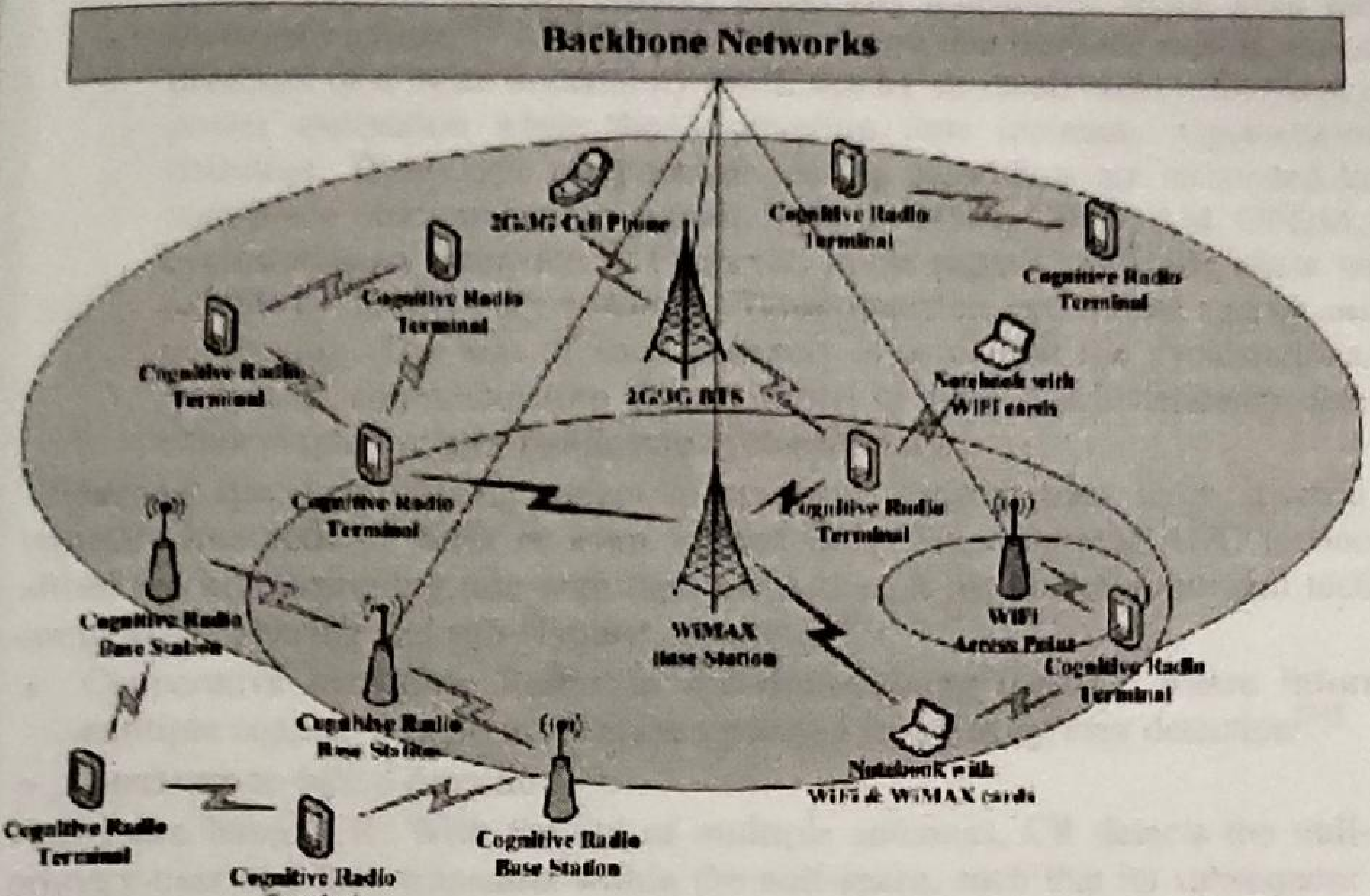

Figure 2.5 Architecture of cognitive radio network

2.2.6 Function perform by CR

The main functions of cognitive radios are:[16][17]

- Power Control: Power control[18] is usually used for spectrum sharing CR systems to maximize the capacity of secondary users with interference power constraints to protect the primary users.
- Spectrum sensing: Detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive-radio network is to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Spectrum-sensing techniques may be grouped into three categories:
  - Transmitter detection: Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. There are several proposed approaches to transmitter detection:
    - Matched filter detection
    - Energy detection: Energy detection is a spectrum sensing method that detects the presence/absence of a signal just by measuring the received signal power.[19] This signal detection approach is quite easy and convenient for practical implementation. To implement energy detector, however, noise variance information is required. It

has been shown that an imperfect knowledge of the noise power (noise uncertainty) may lead to the phenomenon of the SNR wall, which is a SNR level below which the energy detector can not reliably detect any transmitted signal even increasing the observation time.[20] It[21] has also been shown that the SNR wall is not caused by the presence of a noise uncertainty itself, but by an insufficient refinement of the noise power estimation while the observation time increases. Cyclostationary-feature detection: These type of spectrum sensing algorithms are motivated because most man-made communication signals, such as BPSK, QPSK, AM, OFDM, etc. exhibit cyclostationary behavior.[22] However, noise signals (typically white noise) do not exhibit cyclostationary behavior. These detectors are robust against noise variance uncertainty. The aim of such detectors is to exploit the cyclostationary nature of man-made communication signals buried in noise. Cyclostationary detectors can be either single cycle or multicycle cyclostatonary.

- Wideband spectrum sensing: refers to spectrum sensing over large spectral bandwidth, typically hundreds of MHz or even several GHz. Since current ADC technology cannot afford the high sampling rate with high resolution, it requires revolutional techniques, e.g., compressive sensing and sub-Nyquist sampling.[23]
  - Cooperative detection: Refers to spectrum-sensing methods where information from multiple cognitive-radio users is incorporated for primary-user detection[24]
  - Interference-based detection
- Null-space based CR: With the aid of multiple antennas, CR detects the null-space of the primary-user and then transmits within the null-space, such that its subsequent transmission causes less interference to the primary-user
- Spectrum management: Capturing the best available spectrum to meet user communication requirements, while not creating undue interference to other (primary) users. Cognitive radios should decide on the best spectrum band (of all bands available) to meet quality of service requirements; therefore, spectrum-management functions are required for cognitive radios. Spectrum-management functions are classified as:
  - Spectrum analysis
  - Spectrum decision[25][26]

The practical implementation of spectrum-management functions is a complex and multifaceted issue, since it must address a variety of technical and legal requirements. An example of the former is choosing an appropriate sensing threshold to detect other users, while the latter is exemplified by the need to meet the rules and regulations set out for radio spectrum access in international (ITU radio regulations) and national (telecommunications law) legislation.

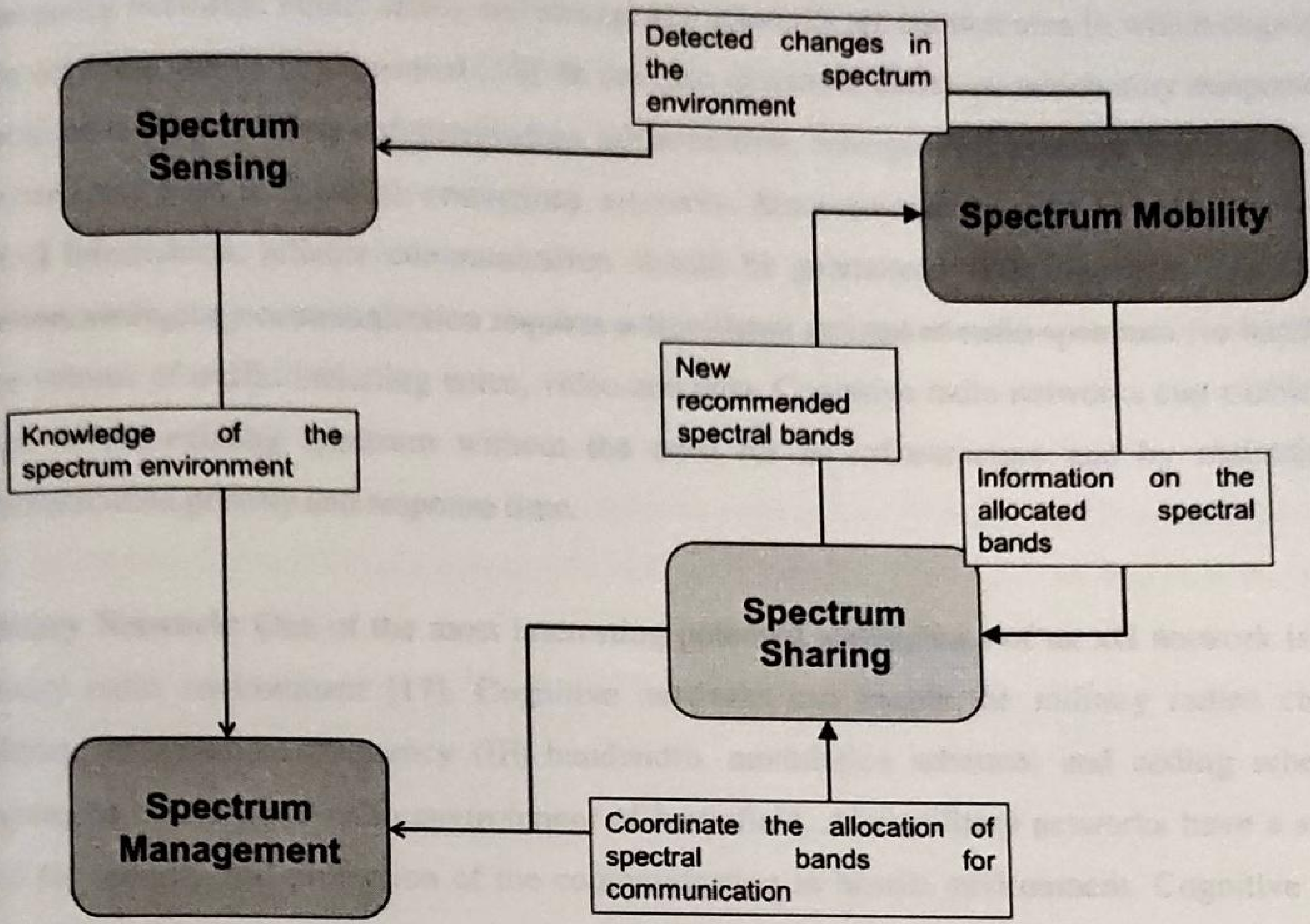

Figure 2.6 Function perform by CR

2.2.7 Applications of Cognitive Radio Networks

Cognitive networks can be applied to the following cases:

Leased network: The primary network can provide a leased network by allowing opportunistic access to its licensed spectrum with the agreement with a third party without sacrificing the service quality of the primary user [14]. For example, the primary network can lease its spectrum access right to a mobile virtual network operator (MVNO). Also the primary network can provide its spectrum access rights to a regional community for the purpose of broadband access.

Cognitive mesh network: Wireless mesh networks are emerging as a cost-effective technology for providing broadband connectivity [16]. However, as the network density increases and the applications require higher throughput, mesh networks require higher capacity to meet the requirements of the applications. Since the cognitive radio technology enables the access to larger amount of spectrum, cognitive radio networks can be used for mesh networks that will be deployed in dense urban areas with the possibility of significant contention [15].

Emergency network: Public safety and emergency networks are another area in which cognitive radio networks can be implemented [16]. In the case of natural disasters, which may temporarily disable or destroy existing communication infrastructure, emergency personnel working in the disaster areas need to establish emergency networks. Since emergency networks deal with the critical information, reliable communication should be guaranteed with minimum latency. In addition, emergency communication requires a significant amount of radio spectrum for handling huge volume of traffic including voice, video and data. Cognitive radio networks can enable the usage of the existing spectrum without the need for an infrastructure and by maintaining communication priority and response time.

Military Network: One of the most interesting potential applications of an xG network is in a military radio environment [17]. Cognitive networks can enable the military radios choose arbitrary, intermediate frequency (IF) bandwidth, modulation schemes, and coding schemes, adapting to the variable radio environment of battlefield. Also military networks have a strong need for security and protection of the communication in hostile environment. Cognitive radio networks could allow military personnel to perform spectrum handoff to find secure spectrum band for themselves and their allies.

2.3 An overview of WMN

2.3.1 Introduction

Wireless mesh network (WMNs) are a new trend in wireless communication promising greater flexibility, reliability and performances over conventional wireless local area networks (WLANs).Wireless mesh networking and mobile ad-hoc networking use the same key concept, communication between nodes over multiple wireless hops on a mesh network topology. However, they are different in many aspects. Mobile ad-hoc networks (MANETs) have an academic background and focus on end user devices, mobility and ad-hoc capabilities. WMNs have a business background and mainly focus on static devices, reliability, network capacity and practical deployment. In WMNs, nodes are comprised of mesh routers and mesh clients. Each node operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations [1]. A WMN is dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves (creating, in effect, an ad hoc network). This feature brings many advantages to WMNs such as low up-front cost, easy network maintenance, robustness, and reliable service coverage. Conventional nodes (e.g., desktops, laptops, PDAs, Pocket PCs, phones, etc.) equipped with wireless network interface cards (NICs) can connect directly to wireless mesh routers. Customers without wireless NICs can access WMNs by connecting to wireless mesh routers through, for example, Ethernet. Thus, WMNs will greatly help the users to be always-on-line anywhere anytime. Moreover, the gateway/bridge functionalities in mesh routers enable the integration of WMNs with various existing wireless networks such as cellular, wireless sensor, wireless-fidelity (Wi-Fi), worldwide inter-operability for microwave access (WiMAX), WiMedia networks. The Fig. 1.4 shows an infrastructure of a WMN.

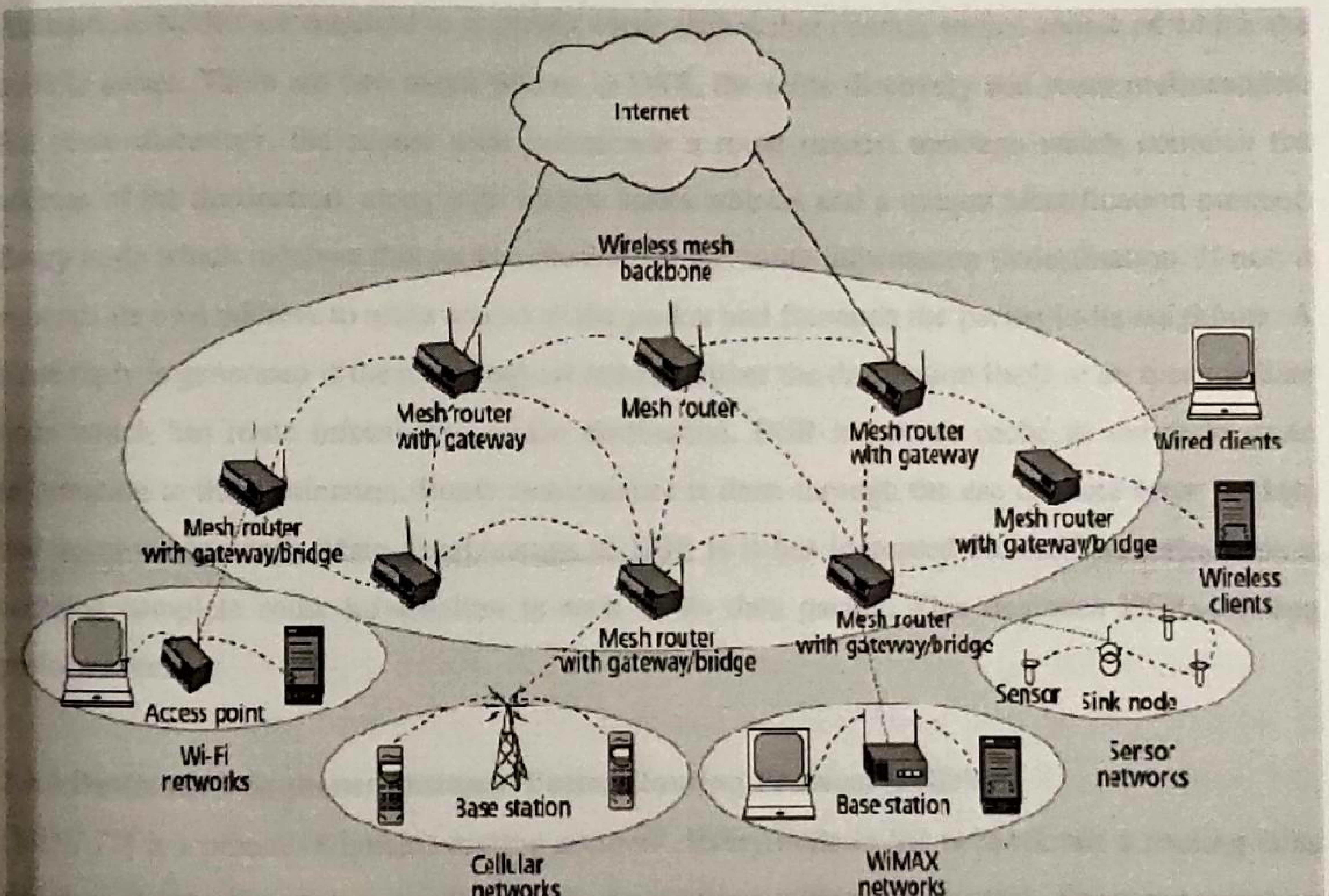

Figure 2.3.1: Infrastructure/backbone of a WMN [1]

2.3.2 Routing Protocols for WMNs

The core functionality of the multi-hop WMNs is the routing capability. Routing protocols provide the necessary paths through a WMN, so that the nodes can communicate on good or optimal path over multiple wireless hops. The routing protocols have to take into account the difficult radio environment with its frequently changing conditions and should support a reliable and efficient communication over the mesh network. Since WMNs share common features with ad hoc networks, the routing protocols developed for ad-hoc networks can be applied to WMNs. For example, mesh routers uses many routing protocols, such as dynamic source routing (DSR) [5], adhoc on-demand distance vector (AODV) routing [6],destination sequence distance vector routing protocol (DSDV) [7].

2.3.3 Destination Source-Routing Protocol (DSR):

DSR[5] is an on-demand routing protocol that is based on concept of source routing. In source routing algorithm, each data packet contains complete routing information to reach its destination. Nodes are required to maintain route caches that contain source routes of which the node is aware. There are two major phases in DSR, the route discovery and route maintenance. For route discovery, the source node broadcasts a route request message which contains the address of the destination, along with source nodes address and a unique identification number. Every node which receives this packet checks if it has route information to destination. If not, it appends its own address to route record of the packet and forwards the packet to its neighbors. A route reply is generated if the route request reaches either the destination itself or an intermediate node which has route information to the destination. DSR has route cache to maintain route information to the destination. Route maintenance is done through the use of route error packets and acknowledgments. Main disadvantage of DSR is it has increased the traffic overhead as it contains complete route information in each of its data packet. This degrades DSRs routing performance.

2.3.4 Destination Sequence Distance Vector Routing Protocol (DSDV):

DSDV [7] is a proactive unicast routing protocol. Every node in the network has a routing table which contains information on all possible destinations within the network. Sequence numbers are used to distinguish stale routes from fresh ones. To maintain consistency, routing table updates are periodically transmitted throughout the network. If two updates have same sequence number, the path with smaller metric is used in order to optimize the path. DSDV protocol only supports bi-directional links.

2.3.5Ad-hoc On-demand Distance Vector Routing Protocol (AODV):

AODV[6] is a reactive on-demand routing protocol which builds on both DSR and DSDV. AODV is an improvement on DSDV as it minimizes the number of required broadcasts by creating routes on demand basis. It is also an improvement on DSR as a node only needs to maintain routing information about the source and destination as well as next hop, thereby largely cuts back the traffic overhead. AODV uses a simple request reply mechanism for the discovery of routes. It uses hello messages for connectivity information and signals link breaks on active routes with error messages. Every routing information has a timeout function associated with it as well as a sequence number. The use of sequence numbers allows to detect outdated data so that only the most current, available routing information is used. AODV is a reactive routing protocol. Route set up on demand and only active routes are maintained. This reduces the routing overhead, but introduces some initial latency due to the on demand route set up. When a source node S wants to send data packets to a destinations node D but does not have a route to D in its routing table, then a route discovery has to be done by the source node S. The data packets are buffered during the route discovery. The source node broadcasts a route request (RREQ) packet throughout the network. In addition to several flags, a RREQ packet contains the hop count, a RREQ identifier, the source address and source sequence number, the destination address and destination sequence number. The hop count field contains the distance to the originator of the RREQ, the source node, S. The RREQ ID is used to uniquely identify the RREQ packets. This is used to ensure that a node rebroadcast a RREQ only once in order to avoid the route loop. When a node receives a RREQ packet, it checks the RREQ ID and the source address, whether this RREQ has been already received. If yes then the RREQ packet is discarded. If no then hop-count is incremented by 1 and the reverse route to the source node, S is updated. When the RREQ packet arrives to the destination node D, it generates a route reply (RREP) packet and sends back to the source node, S. When a link failure along the route happend, the node generates a route error (RERR) message and sent to all neighbors that are precursors of the unreachable destinations on this node. A node receiving a RERR invalidates the corresponding entries in its routing table. When the source node receives the RERR message, then it again initiates the route discovery process. The route discovery and route reply process of the AODV routing protocol are shown in the Fig. 1.5.

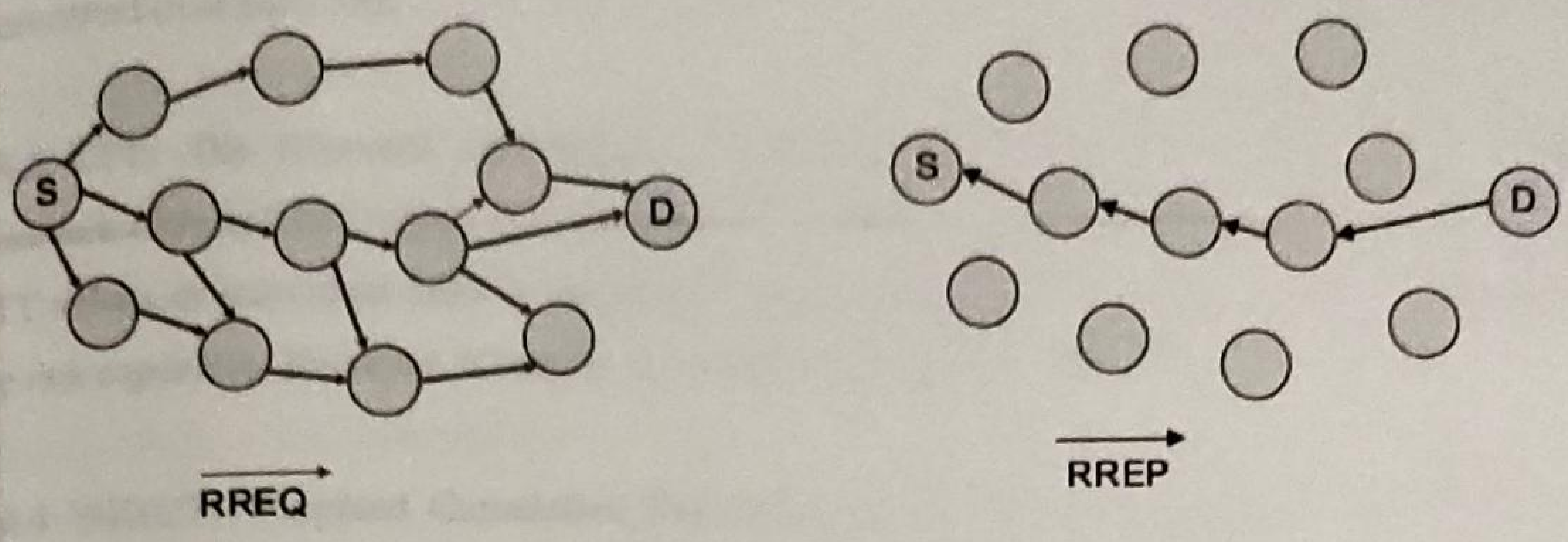

Figure 2.3.5: Route discovery and Route reply in AODV routing protocol

2.4 Routing metric

Routing protocols compute or discover minimum cost or minimum weight paths between the source and the destination node. The weight is defined as the defined through the routing metric. Each route has a route metric that is usually the sum of all link metrics on the route. A good routing metric must accurately capture the quality of network links and aid in computation of good quality paths. Key components that can be utilized to compose a routing metric for mesh networks are: number of hops, link Capacity, link Quality and channel diversity. Different routing metrics are used in WMNs. Such as Hop-count, Expected transmission count (ETX) [24] , Expected transmission time (ETT) [25], Weighted cumulative expected transmission time (WCETT)[26] and Airtime [27].

2.4.1 Hop-count: Hop-count is the traditional routing metric used in most of the common routing protocols like AODV, DSR, DSDV designed for multi-hop wireless networks. It finds paths with shortest number of hops. It is easy to determine. However, it does not give any information about the wireless environment, except that two nodes have a direct link.

2.4.2 ETX: It predicts the number of required transmissions for sending a data packet over the link, which includes retransmissions. ETX is calculated from the forward and reverse delivery ratio of a link. The ETX path metric is the sum of the all ETX link metrics on the path. It only captures link loss ratio ignoring the interference experienced by the linkks, which has a significant impact on the link quality. It also does not consider the data rate at which packets are transmitted over each link.

2.4.3 ETT: The Expected transmission time(ETT) metric is an extension of ETX which considers different link routes or capacities. ETT path metric is obtained by adding up all the ETT values of individual links in the path. It can increase the throughput of path by measuring the link capacities. However, it can not overcome the intra-flow interference.

2.4.4 WEICT: Weighted Cumulative Expected transmission Time(WCETT) is an extension over ETT. It tries to minimize intra-flow interference by penalizing paths that have more transmissions on the same channel. WCETT effectively considers the intra-flow interference but do not consider the effect of the interflow interference.

2.4.5 Airtime: This metric measure the consumed channel resources when transmitting a frame over a certain link.

2.5 Related work

2.5.1 Ian F. Akyildiz, (2006) [1] Today's wireless networks are characterized by a fixed spectrum assignment policy. However, a large portion of the assigned spectrum is used sporadically and geographical variations in the utilization of assigned spectrum ranges from 15% to 85% with a high variance in time. The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. This new networking paradigm is referred to as NeXt Generation (xG) Networks as well as Dynamic Spectrum Access (DSA) and cognitive radio networks. The term xG networks is used throughout the paper. The novel functionalities and current research challenges of the xG networks are explained in detail.

2.5.2 Guo-Mei Zhu,(2008) [4] A unique challenge for routing in cognitive radio networks is the collaboration between the route selection and spectrum decision. To solve this problem, in this paper a Spectrum-Tree base On-Demand routing protocol (STOD-RP) is proposed where a spectrum-tree is built in each spectrum band. The formation of the spectrum-tree addresses the cooperation between spectrum decision and route selection in an efficient way. In addition, a new route metric is proposed as well as a fast and efficient spectrum-adaptive route recovery method. Simulation results show that our proposed STOD-RP reduces the control overhead and shortens the average end-to-end delay significantly. In this paper we introduce the Spectrum-Tree based On- Demand Routing Protocol (STOD-RP) for multi-hop CR networks. The STOD-RP combines tree-based proactive routing and on-demand route discovery. The key concept in this protocol is to establish a spectrum-tree in each spectrum band, by which the collaboration between spectrum decision and route selection is simplified. Moreover, a new cognitive route metric is proposed in this paper as well as a fast and efficient spectrum-adaptive route recovery method. Simulation results show that the average end-to-end delay decreases as the number of gateway nodes increases. Compared with MMAODV, our proposed STOD-RP reduces the control overhead significantly.

2.5.3 Muhammad Zeeshan, (2010) [5] Cognitive radio technology solves the problem of spectrum underutilization by allowing the unlicensed users to opportunistically access available spectrum without affecting the activity of licensed user. Channel assignment and routing in cognitive radio networks is especially challenging in networks where nodes are equipped with only a single transceiver (as is the case in commodity wireless networks that run IEEE 802.11 DCF MAC). We propose a combined framework of routing and channel assignment that exploits channel diversity in cognitive radio networks to optimize routing performance and increase the network capacity. Specifically, we propose a joint cross-layer routing/ channel assignment protocol based on AODV that works without any central control channel and accounts for the state of the links. In this paper, we propose to keep a backup channel to cater for channel heterogeneity thereby avoiding end to end reroute procedures. We also propose cooperative channel switching in which various nodes exchange routing and control information in a coordinated way. Simulation results show that our proposed backup channel approach ensures higher connectivity as compared to the single channel approach as the number of channels interfered with increases. Our backup channel and cooperative channel switching ondemand routing protocol in cognitive ad hoc network provides a cross layer solution for both routing and channel assignment for cognitive radios. To the best of our knowledge, previous routing work done with central control channel in cognitive radio networks have not holistically addressed issues like deafness and channel heterogeneity that arise in networks where each node is equipped with only a single radio transceiver. Our proposed work addresses these issues and uses local route recovery to exploit channel diversity and thereby improve network capacity. Simulation results shows our proposed backup channel approach have ensured almost the same connectivity as with single channel approach. Our initial work is aimed at developing a comprehensive combined routing and spectrum assignment framework for cognitive radio ad hoc networks. We intend to investigate this direction of research to develop a comprehensive framework without using central control channel and exchange local information between nodes in-band along with the data.

2.5.4 Lei Ding (2010)[6] Throughput maximization is a key challenge in cognitive radio ad hoc networks, where the availability of local spectrum resources may change from time to time and hopby- hop. To achieve this objective, cooperative transmission is a promising technique to increase the capacity of relay links by exploiting spatial diversity without multiple antennas at each node. This idea is particularly attractive in wireless environments due to the diverse channel quality and the limited energy and bandwidth resources. In this paper, decentralized and localized algorithms for joint dynamic routing, relay assignment, and spectrum allocation in a distributed and dynamic environment are proposed and studied. A cross-layer protocol to implement the joint routing, relay selection, and dynamic spectrum allocation algorithm is also introduced, and its performance is evaluated through simulation. Performance evaluation results show that the proposed protocol achieves much higher throughput than solutions that do not rely on cooperation. We studied and proposed decentralized and localized algorithms for joint dynamic routing, relay selection, and spectrum allocation in cooperative cognitive radio ad hoc networks. We have shown how the proposed distributed algorithms lead to increased throughput with respect to non-cooperative strategies. The discussion in this paper leaves several open issues for further research. First, we will aim at deriving a theoretical lower bound on the performance of the proposed algorithm. Furthermore, we will evaluate the performance of the algorithm in conjunction with a congestion control module. Finally, we will implement the proposed algorithm on an testbed based on URSP2 [32] and GNU Radio [33].

2.5.4 Jang-Ping Sheu and In-Long Lao,(2012) [7] Cognitive radio (CR) technology enables the opportunistic use of the vacant licensed frequency bands, thereby improving the spectrum utilization. Therefore, considering endto- end throughput in CR ad-hoc networks is an important research issue because the availability of local spectrum resources may change frequently with the time and locations. In this paper, we propose a cooperative routing protocol in CR adhoc networks. An on-demand routing protocol is used to find an end-to-end minimum cost path between a pair of source and destination. The simulation results show that our proposed cooperative routing protocol not only obtains higher end-to-end throughput, but also reduces the end-to-end delay and the amount of control messages compared to previous work. In this paper, we proposed a cooperative routing protocol in CR ad-hoc networks that addresses the concern of end-to-end CR performance over multiple hops. We adopt an on-demand based routing style which is more suitable in CRNs to find the end-to-end minimum cost path. We first define the channel utilization, and then the potential bandwidth for a link at a specific channel. Through combining the potential bandwidth and the channel quality, we can calculate the capacity of direct transmission or cooperative transmission at a specific channel with relay. Finally, we define the relay availability that indicates how often the relay can help for transmission. With these performance metrics, we can calculate the maximum achievable capacity with cooperative benefit between two adjacent nodes and evaluate the cost we used in routing discovery. Therefore, by using this CC technology, we can go one step further to leverage the available recourses in CRNs so as to improve their performance.

CHAPTER 3

PROBLEM FORMULATION AND SIMULATION METHODOLOGY

3.1 OBJECTIVE

We will construct collaborative multi hop routing path between source and path in cognitive network

3.2 PROBLEM STATEMNET

The objective of this project is to study collaborative multi hop routing in cognitive network. As discus above in multi hop routing in cognitive network interference & power lose can occur, So our main aim is reduce interference

3.3 NETWORK MODEL

3.1 Network Model

In this section, we discuss the network models and our algorithm including transmission model with directional antenna and network model with multi-hop cooperation.

3.1.1 Transmission Model with Directional Antenna

In multi-hop wireless cognitive network, the sender of secondary users often know the position of the receiver, so secondary users can make directional transmission to transfer data packets from the source node to the destination node. In this paper, we use the transmission model that sends the message between nodes exploiting directional sending and omni-directional receiving antennas shown in Fig. 1.

In Fig. 1, s_u and s_v denote the sender and receiver of secondary users. s_u uses directional sending mode and main lobe width is θ_u. s_v uses omni-directional receiving mode. When s_u sends data and s_v is in s_u's main lobe, s_v's receiving power gain is:

$$g_{p_{u,v}} = \frac{2\pi}{\theta_{u,v}} \quad (1)$$

The receiving link gain is:

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$$g_{p_{u,v}} = \frac{2\pi}{\theta_{u,v}} \quad (1)$$

The receiving link gain is:

$g_{L_{u,v}}^n = (d_{U,V}^{S,S})^{-\delta^n}$ (2)

If there are r times transmitting power inside the main lobe, i.e. $(1-r)$ times radiate to the environment, then the total receiving gain of the receiving end g_{s_u,s_v}^n is:

$g_{s_u s_v}^n = r \times g_{L_{u,v}} \times g_{p_{u,v}}$ (3)

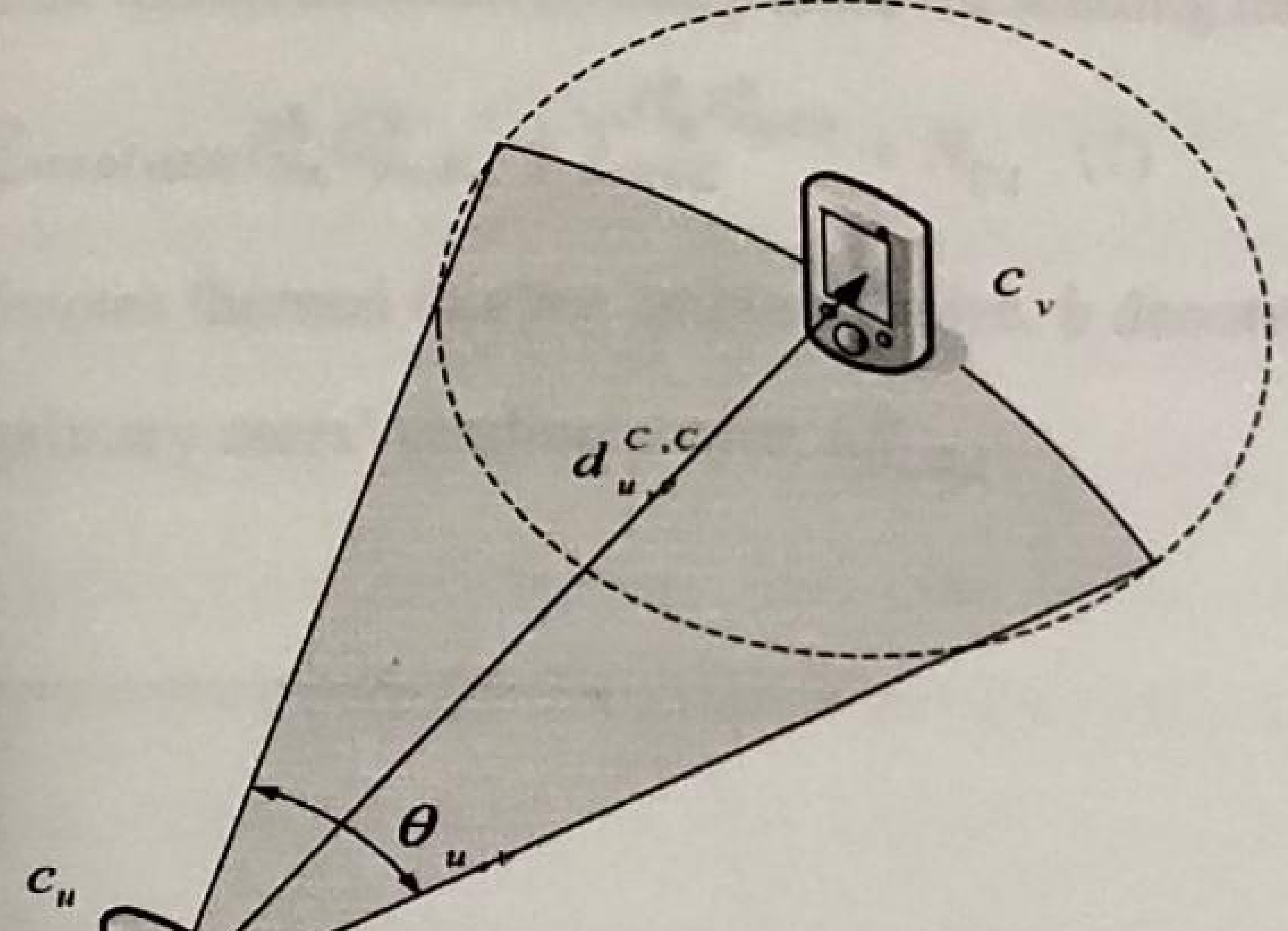
Formula (3) indicates that when secondary users' receiving end lies within the main lobe of the sending end, it can gain good receiving gain. According to formula (3), the receiving power of the secondary user is:

$P_{s_u,s_v}^{n,t} = P_{s_u}^{n,t} \times g_{s_u,s_v}^n$ (4)

Only when the Signal Interference Noise Ratio (SINR) of the receiving end exceeds the threshold value, receiving end can receive signal properly, i.e.:

$\theta_{s_v} \le \frac{P_{s_u,s_v}^{n,t}}{N_{s_v}+W_{s_v}^{n,t}}$ (5)

where θ_{s_v} denotes the threshold value of SINR. N_{s_v} is the noise, and $W_{s_v}^{n,t}$ denotes the interference power. Combining with formula (4), we can get the following minimum transmitting power using the directional transmitting antenna at node s_u[19]:



$$P_{s_u}^{n,t} \ge \frac{\theta_{s_v} \times (N_{s_v}+W_{s_v}^{n,t})}{g_{s_u s_v}^n}$$

Figure 3.3.1 Directional antenna transmission model

3.3.2 Multi-hop Collaborative Communication Model

In this paper, we discuss multi-hop collaborative communication between multiple primary users and multiple secondary users. The network model of multi-hop collaborative communications is shown in Fig. 2. In this network model, multiple primary users send message through a base station while multiple secondary users conduct multi-hop collaborative communications through multiple middle secondary user (cognitive user) nodes. Supposing that in multi-hop wireless network, primary users are $P = \{p_1, p_2\ p_N, p_d\}$ and p_d denotes base station. Secondary users are $s = \{s_1, s_2\ \ldots\ldots s_K\}$ and there are N available channels. Each channel is divided into I time slots. Communication between different secondary users causes interference to the corresponding primary users, and communication between different primary users have the same effect on the secondary users too. In this network model, we should consider how to maximize spectrum efficiency under the situation that secondary users have no impact on primary users' normal communication, and how to provide reliable communication and improve spectrum utilization between secondary users by mutual cooperating between secondary users.

In this network model, the sending end of secondary users uses directional antenna to send signals and the receiving end uses omni-directional receiving antenna to receives signals. Thus the transmission model between primary users for sending message can be expressed as follows:

$$\frac{P_{p_u}^b G_{p_u,p_d}^b}{R_{p_d}} \geq \sum\nolimits_{n \neq b l\, n \in N} P_{p_n}^b G_{p_n,p_d}^b + \sum\nolimits_{k \in K}^{P_{s_k}^b G_{s_k,p_d}^b} + N_{p_d} \quad (7)$$

where N_{p_d} denotes thermal (and/or ambient) noise. b denotes the channel that primary users use, $P_{p_u}^b$ denotes primary users' sending power, G_{p_u,p_d}^b

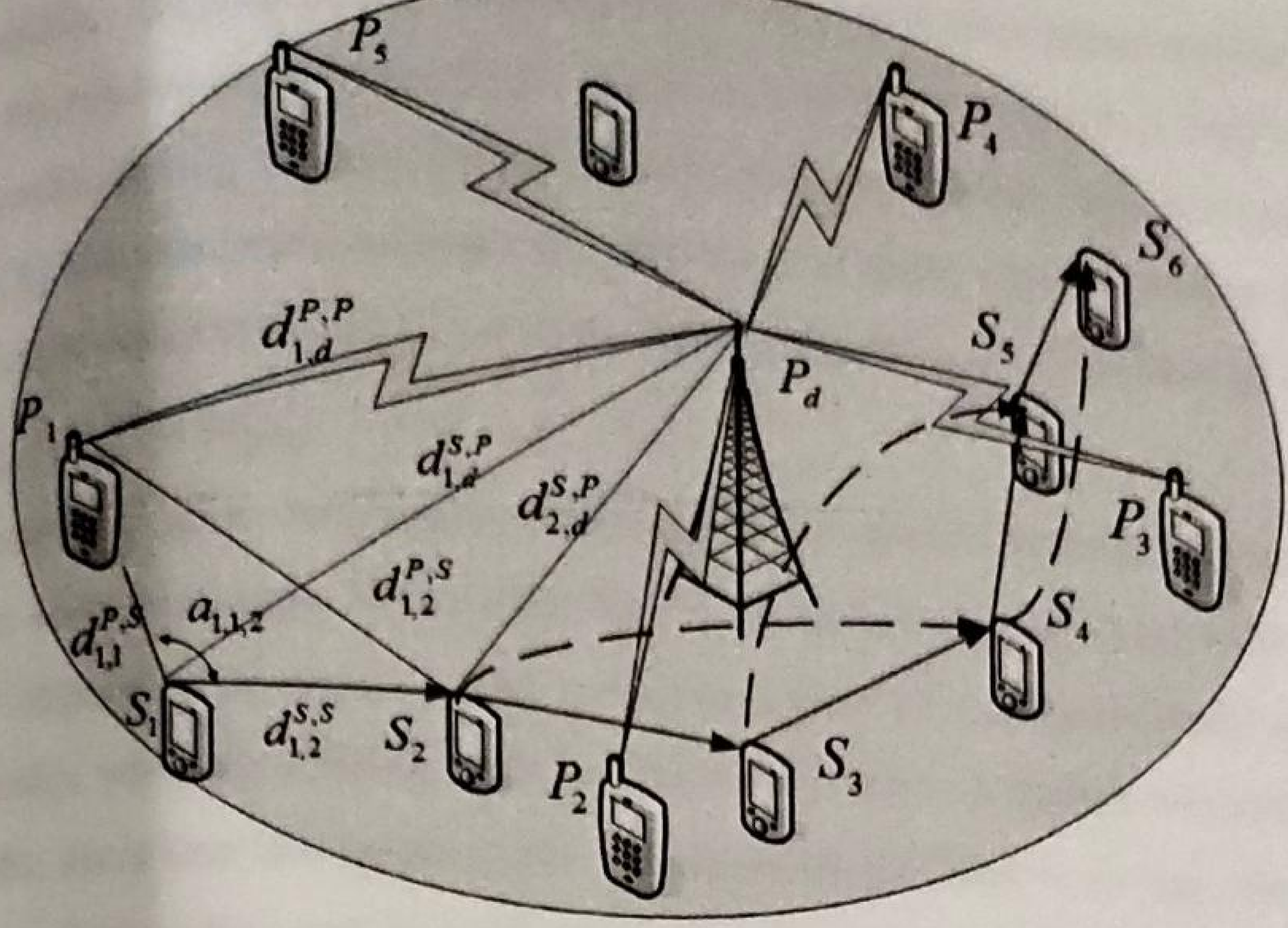


Figure 3.3.2 Multi‐hop Collaborative Communication Model

3.4 Cognitive Multi‐hop Collaboration Algorithm

In the cognitive collaborative multi-hop communication network based on directional antenna, the transmission radius that different secondary users use different channels is often not the same. When we construct multi-hop paths, the paths will change while sending message because the channels which users use are not constant. To decrease the algorithm complexity, we firstly use omni-directional antenna to construct multi-hop collaborative paths, and then change it into directional antenna by adjust antenna main lobe and sending angle. According to the different transmitting radius that different channels users use, each user who participate in communication are assigned to certain channel. In this section, we will discuss the maximum transmission radius, collaborative multi-hop transmission paths, sending angle, transmitting power control, channel allocation strategy and cognitive collaborative multi-hop algorithm of secondary users.

3.4.1 Maximum Transmission Radius

When secondary users use omni-directional antenna, the maximum transmission radius of secondary users concerns with the state of primary users and the inference between sec- ondary users. When primary users don't use channels, the maximum transmission radiuses are all maximum values no matter secondary users use omni-directional antenna or directional antenna. But the sending angle of secondary users is different, the former is 360^o, the latter is θ. According to Fig. 2, in the directional antenna transmission model of our paper, when secondary user s_u use directional antenna, its transmission angle faces receiving end s_v, and if secondary user s_n is out of the range of the main lobe, then the receiving power of secondary user s_n is:

$$p^{n,t}_{s_u,s_n} = P^{n,t}_{s_u} \times (d^{s,'s}_{bln})^{-\delta} \times (1-r) \quad (9)$$

Because r is often very large, secondary user's sending end don't produce any inter- ference to other secondary users. When secondary user s_n is inside the main lobe range, s_n participates in the cooperation of node s_v. The receiving power of s_n is calculated according to formula (4). Thereby, when the sending angle of secondary users is settled, secondary user makes no effect on the users that don'tjoint in the communication. That is to say, the maximum transmission radius of secondary user depends on itself. The formula is shown as follow:

$$d^{s,'s}_{blv} \leq \left(\frac{P^{n,t}_{s_u} 2\pi}{\theta_{s_v}(N_{s_v} + W^{n,t}_{s_v})\theta_{bl,v}} r\right)^{\frac{1}{\delta\pi}} \quad (10)$$

In conclusion, when primary user doesn't use the channel, secondary users calculate maximum transmission radius according to formula (10). When primary user uses the channel, secondary users calculate maximum transmission radius according to the below formula:

$$\begin{cases} d^{s,'s}_{u,v} \leq \left(\frac{P^{n,t}_{s_u.2\pi}}{\theta_{,v}(N_{s_v} + W^{n,t}_{s_v})\theta_{u,v}} r\right)^{\frac{1}{\delta\pi}} \\ stx = \frac{pb_{pu}\ gb_{pu_{pd}}}{2a} \geq \sum_{\substack{n \in N \\ n \neq u}} P^{b_G b}_{p_n p_{n}.p_d +} \\ \qquad P^{b_G b}_{s_u s_u.p_d + N_p d} \end{cases} \quad (11)$$

where θ_{s_v} denotes SNR's threshold value of secondary user s_v at maximum transmission radius, $P^{n,t}_{s_u}$ denotes transmitting power of secondary user s_u, $\theta_{u,v}$ denotes the directional sending angle when s_v sends the message to s_v, and r denotes the power ratio of s_u in main lobe.

3.4.2 Collaborative Multi⍰hop Transmission Paths

In the process of cognitive collaborative multi-hop communication, secondary users can not disturb the normal communication of primary users. What is more, the interference between secondary users should be as small as possible so that primary and secondary users can both communicate reliably. Secondary users will act as none authoritative users and sense the channels that authoritative users don't use. Multiple secondary users perform the cooperation. To realize the above purpose and build collaborative multi-hop trans- mission paths from source node to destination node of secondary users, we propose a maximum receiving power set algorithm based on clustering collaboration. According to the limited maximum transmission radius of secondary users, we take the nodes that can be covered by the radius of sending node as a cluster. The head of the cluster is the sending node. Only the nodes inside the cluster can participate in cooperation and the nodes out of the cluster must take the message inside the cluster as noise and abandon it. Besides, we use achievable rate to guarantee the possibly maximum transmitting power while power is limited. As mentioned in [20], the achievable rate of the receiving signal of node s_r is:

$$V_{s_r}(\mu_{s_r}) = \frac{1}{2}\log(1+\mu_{s_r}) = \frac{1}{2}\log\left(1+\frac{Pr_{s_r}}{N_{s_r}}\right) \quad (12)$$

where μ_{s_r} denotes SNR, N_{s_r} expresses noise, and Pr_{s_r} stands for transmitting power of the secondary user.

If we define paths set $L_j^{s_i} = \{s_1, \phi, c_d\}$, then the achievable rate of the jth path L_j can be denoted as:

$$y_{L_j} = mean\{V_{s_r}\}, \qquad s_r \in L_j \mid s_1 \quad (13)$$

The achievable rate of the path indicates the average achievable rate value of other sec- ondary users' nodes except node s_1 in the path L_j.

The transmission radius of different channels that different users use is different too, that is to say, the clusters are different. So, we define collaboration matrix A_n^t as follows:

$$A_n^t = \begin{pmatrix} a_{is_1}^{n,t} a_{s_2,s_1}^{n^1} S & a_{is_2}^{n,t} a_{s_2,s_2}^{n^1} S & a_{is_{K-1}}^{n,t} a_{s_2,s_{K-1}}^{n^1} S & a_{is_K}^{n,t} a_{s_2,s_K}^{n^1} S \\ \vdots & \vdots & \vdots & \vdots \\ a_{s_{K-1},s_1}^{n,t} a_{s_K,s_1}^{n,t} & a_{s_{K-1},s_2}^{n,t} a_{s_K,s_2}^{n,t} & a_{s_{K-1},s_{K-1}}^{n,t} a_{s_K,s_{K-1}}^{n,t} & a_{s_{K-1},s_K}^{n,t} a_{s_K,s_K}^{n,t} \end{pmatrix} \quad (14)$$

where A_n^t denotes if the data that one secondary user uses channel n to send can be received properly by another secondary user at time t. What's more, the following formula holds:

$$a_{s_i,s_j}^{n,t} = \begin{cases} 1, d_{ij}^{s,s} \le Tr_{s_i}^{n,t} \\ 0, other \end{cases}, \qquad i,j \in \{1,2,\dots,K\} \quad (15)$$

where $Tr_{s_i}^{n,t}$ is the transmission radius of secondary users.

When transmission path L_j is known, the node receiving power in that path can be expressed as follows:

$$\begin{cases} Pr_{s_r}^{n,t} = \sum_{i=1}^{i=r} a_{s_i,s_r}^{n,t} \times P_{s_i,s_r}^{n,t} \; i \in L_j \\ L_j = \{s_1, s_2, \dots, s_r, \dots, s_d\} \end{cases} \tag{16}$$

We can calculate the achievable rate of collaborative multi-hop path L_j according to formulas (12) and (13).

We define achievable node set as $U^t = [U_{s_1}^t, U_{s_2}^t, \dots, U_{s_K}^t]$. From formulas (14) and (15), we know that the message sent from secondary user s_i can not be received by each user in the network. If $a_{s_i,s_j}^{n,t} > 0$, then node s_j is the achievable node of node s_i. $U_{s_j}^t = [u_1, u_2, \dots, u_T]$, $\forall a_{s_i bl_j}^{n,t} > 0, \exists n > 0, t > 0$. Set U^t has nothing to do with the paths.

We define neighbor node set as $B^t = [B_{s_1}^t, B_{s_2}^t, \dots, B_{sK}^t]$. The neighbor node set of sec- ondary user s_i at time t is $B_{s_i}^t = \{b_1^t, b_2^t, \dots, b_{|M|}^t\}$ which means the range of new nodes selected at time t. At first, $B_{c_j}^t = U_{c_j}^t$. After one link is constructed, we update $B_{s_j}^t = B_{s_i}^t \backslash L_k^t$, $s_i \in L_k^t$. When $Pr_{b_j} > Pr_{b_j}*, \forall b_j^* \in \{B_{s_j}^t \backslash b_j\}$, $L_k^t = \{s_1, s_2, \dots, s_i, b_j\}$, sec- ondary user b_j is the next hop node of s_i and the path is updated as $L_k^t = L_k^t \cup b_j$.

The steps of the maximum receiving power set algorithm based on clustering collab- oration can be denoted as follows.

3.5 FORMATION OF MULTI-HOP PATH ALGORITHM

Step 1: Let time $t = 1$ and initialize the maximum T.

Step 2: Initialize the neighbor node set matrix B^t of each secondary user.

Step 3: Choose source node s_1, and initialize $L_1 = \{s_1\}, m = 1$.

Step 4: Construct all possible paths from source node to destination node and calculate the total path number M.

Step 5: Choose path L_i and let $m = m + 1$.

Step 6: Choose the largest receiving power node from $U_{s_j}^t$ as the next hop of node c_j and label as s_t.

Step 7: If s_t does not exist, update $B_{s_j}^t$ Or otherwise let $j = j + 1$ and go back to Step 6. Step 8: If s_j is the last node of path L_i, let $L_i = L_i \cup s_t$. Or otherwise build a new path as follows:

$$L_j = \{s_1, \ldots, s_j\} \cup s_t, \{s_1, \ldots, s_j\} \in L_i.$$

Step 9: Let $i = i + 1$. If $m < M$, go back to Step 5.

Step 10: If $B_{s_j}^t$ is updated, go back to Step 4.

Step 11: Update all the paths sets and delete repeated paths.

Step 12: Save the path information.

Step 13: Let $t = t + 1$. If $t > T$, save the results to the file and exit. Or otherwise go back to Step 2.

According to Algorithm 1, we can get a series of paths from source node to destination node, i.e. $\Pi(L)$. The optimal path is the one whose achievable rate is the largest.

To optimize the path sets obtained in Algorithm, we perform the shortest optimal route set process for the path sets. Then we can get the path with maximum achievable rate and minimum hops through this process.

We define the shortest optimal route candidate set Q_{opt}^{short}, which satisfies three conditions:

· $Q_{opt}^{short} subseteq\ Qopt$;

· $L_{opt}^{short} \in Q_{opt}^{short}$, $|L_{opt}^{short}| = \min[\Pi(|L|)]$, $|L|$ denotes the node number of L; · $V_{L_{opt}^{short}} = \max(y_{\Pi(L)})$ ·

If $L_1 subseteq L_2$ for two random routes L_1, L_2, this means L_1 is the subset of L_2, and the order of nodes in L_2 is the same as that in L_1. If $L_2 = L_{opt}^{short}$ and the achievable rate of its subset L_1 is $y_{L_1} = y_{L_{opt}^{short}}$, then L_1 is the shortest optimal route and we let $L_{opt}^{short} = L_1$.

We can confirm the maximum transmission radius of secondary users from formulas (11) and (12). According to the directional antenna transmission model shown in Fig. 2 and formulas (11) and (12), for sending node s_u whose transmission radius is $d_{uv}^{s,'s}$, when primary user doesn't use the channel, its cover area S_u is:

$$\begin{cases} S_{bl} = \frac{\theta_{U,V}}{2}(d_{blV}^{s,'s})^2 \\ s.t.\, d_{blV}^{s,'s} \le \left(\frac{P_{s_u}^{n,t} 2\pi}{\theta_{s_v}(N_{s_v} + W_{s_v}^{n,t})\theta_{bl,V}} r\right)^{\frac{1}{\delta^n}} \end{cases} \qquad (17)$$

When primary user uses the channel, its cover area S_u can be denoted as:

$$\begin{cases} S_{bl} = \frac{o_{u,v}}{2}(d_{blV}^{s,'s})^2 \\ s.t.\, d_{u,v}^{s,s} \leq (\frac{P_{;u2\pi}^{n,t}}{o_{S_V}\sim(N_{S_V}+W_{S_V}^{n,t})\theta_{u,v}} r)^{\frac{1}{\delta^n}} \\ \frac{P_{pu}^{b} G_{pu,pd}^{b}}{R_{pd}} \geq \sum \\ n \neq u \\ P_{S_u} G_{Su,pd} + N_{Pd} bb \end{cases} \qquad (18)$$

In Eqs. (17) and (18), s_u and s_v are arbitrary sending and receiving secondary users, respectively. Moreover, Eqs. (17) and (18) are correct for any sending secondary user s_u and receiving secondary user s_v. Accordingly, without loss of generality, we can attain the maximum transmission radius of secondary sending user s_u as follows:

$$d_{\max,u,v}^{s,s} = (\frac{P_{S_u}^{n,t} 2\pi}{\theta_{S_v}(N_{S_v}+W_{S_v}^{n,t})\theta_{bl,v}} r)^{\frac{1}{\delta^n}} \qquad (19)$$

Thus the maximum cover area of secondary user s_u is:

$$S_{\max,u} = \frac{\theta_{ll,v}}{2}(d_{\max,u,v}^{s,s})^2$$

$$= \frac{\theta_{ll,v}}{2}(\frac{P_{S_u}^{n,t} 2\pi}{\theta_{S_v}(N_{S_v}+W_{S_v}^{n,t})\theta_{bl,v}} r)^{2\frac{1}{\delta^n}} \qquad (20)$$

$$= \frac{1}{2}(\frac{2\pi P_{S_u}^{n,t}}{\Theta_{S_v}(N_{S_v}+W_{S_v}^{n,t})} r)^{2\frac{1}{\delta^n}} (\theta_{l\ell,v})^{1-2\frac{1}{\delta^n}}$$

According to formulas (19) and (20), we find that the maximum transmission radius and the maximum cover area of the secondary sending node are closely related to the sending angle. When the transmitting power of the secondary user sending node is certain, the maximum transmission radius of the secondary user is inversely proportional to the angle's $\frac{1}{\delta^n}$ power $(\theta_{u,v})^{\frac{1}{\delta^n}}$, and its cover area is in proportional to the angle's $(1-2\frac{1}{\delta^n})$ power $(\theta_{bl,v})^{1-2\frac{1}{\delta^n}}$. Similarly, from formulas (19) and (20), we find that the maximum transmission radius and the maximum cover area of the secondary user sending node are also very closely related to the sending power. When the sending angle of the secondary user sending node is certain, the maximum transmission radius of the secondary user is in proportional to the transmitting power's $\frac{1}{\delta^n}$ power $(P_{S_u}^{n,t})^{\frac{1}{\delta^n}}$, and its cover area is in proportional to the transmitting power's $2\frac{1}{\delta^n}$ power $(P_{S_u}^{n,t})^{2\frac{1}{\delta^n}}$. It can be seen that the secondary user will get different maximum transmission radius and maximum cover area under different sending angles and sending powers. What's more, the different receiving nodes being covered will lead to different collaborative nodes to participate collaborations.

To conduct reliable cognitive multi-hop collaborative communications, we take the following strategies to control the sending angle and transmitting power of the secondary sending node.

Strategy 1 After cognitive multi-hop paths based on the omni-directional antenna is constructed, if there exists the node inside the coverage area of the secondary user and the nodes in the path except the receiving end are in the cluster taking sending end as cluster head, then this node is the collaborative node when the below formulas holds:

$\{s_v, s_t\} \in S_{s_u}, \{s_{bl}, s_v, s_t\} \in L_i$ (21)

where s_u, s_v, and s_t denote sending end, receiving end and collaborative user, L_i and S_{s_u} express the path and the cluster. The secondary user s_t satisfied with formula (21) is the collaborative user. The sending angle is $\theta_u =$ max $[(s_v, s_u, s_t$ The transmission radius of the secondary user changes into $r_{s_u}^{n,t} =$ max $(d_{uv}^{s,'s}, d_{blt}^{s,'s})$.

Strategy 2 When there does not exists the collaborative node inside the coverage area of the secondary user or the nodes in the path do not meet formula (21), i.e. there are no collaborative node, then the sending angle is $\theta_u =$ min (θ) and the transmission radius of the secondary user changes into $Tr_{s_u}^{n,t} = d_{blv}^{s,'s}$, where θ is the minimum sending angle defined in advance. We can calculate the transmitting power of the secondary user sending end according to formula (6).

The collaborations of cognitive nodes (secondary user nodes) is shown in Fig. 3.

3.4 Channel Allocation

In the process of cognitive multi-hop collaborative transmission, to ensure normal communication of all primary and secondary users, we need to allocate proper transmission channels to the corresponding secondary users. As mentioned in [21], we utilize graph coloring model to allocate multi-hop cognitive collaborative transmission channels for multiple secondary users. We define available matrix y, channel interference matrix I and channel utility matrix U to make proper channel allocation.

Because secondary users use directional antenna and the sending angle is not constant, it will only affect the primary or secondary user in a certain direction. Thus, we mainly discuss the interference between primary and secondary users and between secondary and secondary users under directional antennas.

When secondary user s_u uses directional antenna to send data to secondary user s_v, another secondary user s_r is affected by secondary user s_u only if the following formula holds:

- $d_{plr}^{s_i's} \leq Tr_{s_u}^{m,t}$;
- $\theta_u = (s_r, s_u, s_v) + (s_r, s_u, s_t)$ or $\frac{0}{2} \geq (s_r, s_u, s_v)$

The first formula in the condition above is the situation of collaborative node existing in the path while the second formula is the situation of no collaborative nodes. We use the set Ω to denote both conditions above.

There exists interference only if both two conditions above are satisfied. This can be denoted as:

$$I_{s_i,s_j}^{m,t} = \begin{cases} 1, & \Omega \ holds \\ 0, & \Omega \ does \ not \ hold \end{cases}$$

(22)

where $I_{s_i,s_j}^{m,t} = 1$ denotes that there is interference among nodes and $I_{s_i,s_j}^{m,t} = 0$ indicates that there does not exist the interference. In the allocation process, we allocate the channel without interference to secondary users, namely consider the case $I_{s_i,s_j}^{m,t} = 0$.

When calculating the channel available matrix, we suppose that the maximum trans- mission radiuses of secondary users using different channels depends on formula (10) and we ignore the influence of the primary users. Thus, when we allocate channels, we must consider whether the channel m that the secondary user use will influence the primary user. Channel available matrix y can be built as:

$$V_{s_i}^{m,t} = T_t^m \times y_{1s_i}^{m,t} \times I_{s_i,p_m}^{m,t} \quad (23)$$

$$V_{1s_i}^{m,t} = \begin{cases} 1, a_{s_i,s_j}^{m,t} = 1 \\ 0, a_{s_i,s_j}^{m,t} = 0 \end{cases} \quad (24)$$

where $a_{s_i,s_j}^{m,t}$ is defined in formula (15) and denotes whether the message from secondary user s_i to secondary user s_j can be received properly, 1 denotes correct receipt, and 0 denotes incorrect receipt.

As mentioned as above, when secondary users use the channel not used by primary users, they can exploit the maximum transmission distance to send data and can obtain the maximum utility for this channel. Moreover, some channels cannot be used by primary users for a long time and thus secondary users should use this kind of channel first to avoid excessive channel switch and the frequent change of network topology. In addition, when secondary users choose channels, they should choose the channels far from primary users to avoid influence on primary users as possible. The channel utility matrix is related with the transmission distance of the secondary user, usage time of the primary user and the distance between primary and secondary users. This relation can be denoted as:

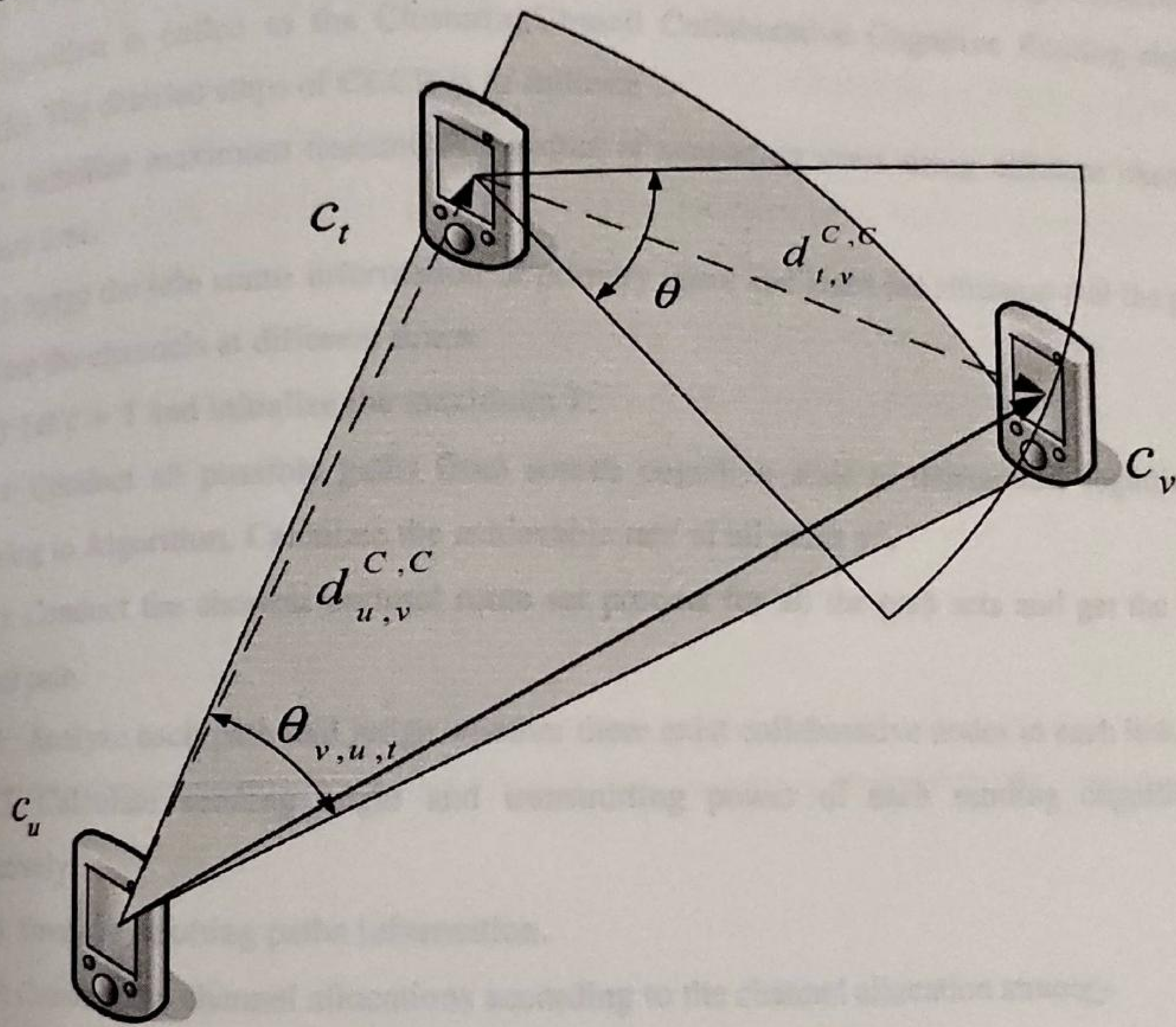


Figure 3.5.2 Collaborations of cognitive nodes

$U_{s_i}^{m.t} = Tr^2 \times num \times D = (Tr_{s_i}^{m.t})^2 \times x_t T_t^m \times d_{i,m}^{S,P}$ (25)

where Tr denotes the transmission distance of the secondary user while using channel m, num denotes the total number of times that the primary user dot not use channel m, D indicates the physical distance between primary and secondary users, T_t^n denotes if the primary user uses channel m at time t, and 0 denotes using it while 1 denotes not using it. Thereby, according to channel available matrix y, channel interference matrix I and channel utility matrix U, we can allocate proper transmission channel for all secondary users.

3.6 Clustering based collaborative algorithm

Our algorithm exploits the clustering idea and node collaborations to perform the multi□ hop collaborative cognitive routing. By such a way, we can effectively reduce the trans□ mission power of sending nodes while can obtain the maximum receiving power through collaborations. Our algorithm is called as the Clustering□based Collaborative Cognitive Routing algorithm (CCCR). The detailed steps of CCCR is as follows:

Step 1: Initialize maximum transmission radius of secondary users using different channels at different time.

Step 2: Judge the idle status information of primary users and learn the situation that the primary users use the channels at different times.

Step 3: Let $t = 1$ and initialize the maximum T.

Step 4: Conduct all possible paths from source cognitive node to destination cognitive node according to Algorithm. Calculate the achievable rate of all paths y^t.

Step 5: Conduct the shortest optimal route set process for all the path sets and get the shortest optimal path.

Step 6 : Analyze each path and judge whether there exist collaborative nodes in each link.

Step 7: Calculate sending angle and transmitting power of each sending cognitive user, respectively.

Step 8: Save the resulting paths information.

Step 9: Conduct the channel allocations according to the channel allocation strategy.

Step 9: Let $t = t + 1$.

Step 10: If $t$is larger than T, then exit. Or otherwise go back to Step 4.

CHAPTER 4

SIMULATION AND RESULT ANALYSIS

4.1 SYSTEM ARCHITECTURE

In this chapter we will discuss the path achievable rate and collaborations of our quadrant based routing algorithm. When the transmission radius of secondary users becomes large, we can obtain the larger path achievable rate shown in figures as bar plot, where N denotes the number of secondary users. This is because the larger the transmission radius is, the more the collaborative nodes are. There by one can obtain the larger path achievable rate. Likewise, when the number of secondary users increases, we also get the higher path achievable rate. It is clear that the more secondary users is, the larger the density of nodes. In a result, there are more nodes

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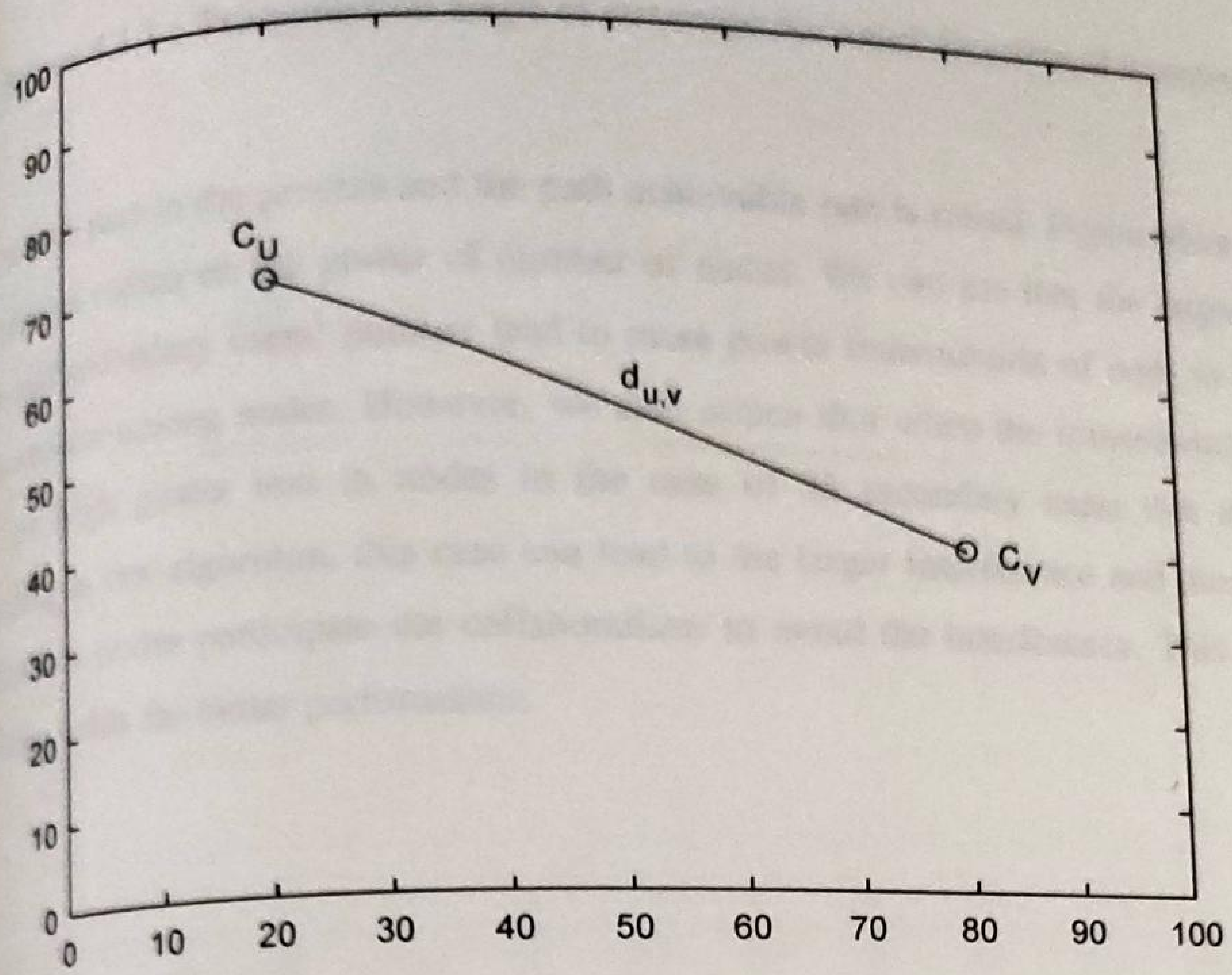

Figure 4.1 : Two primary users u and v with distance $d_{u,v}$.

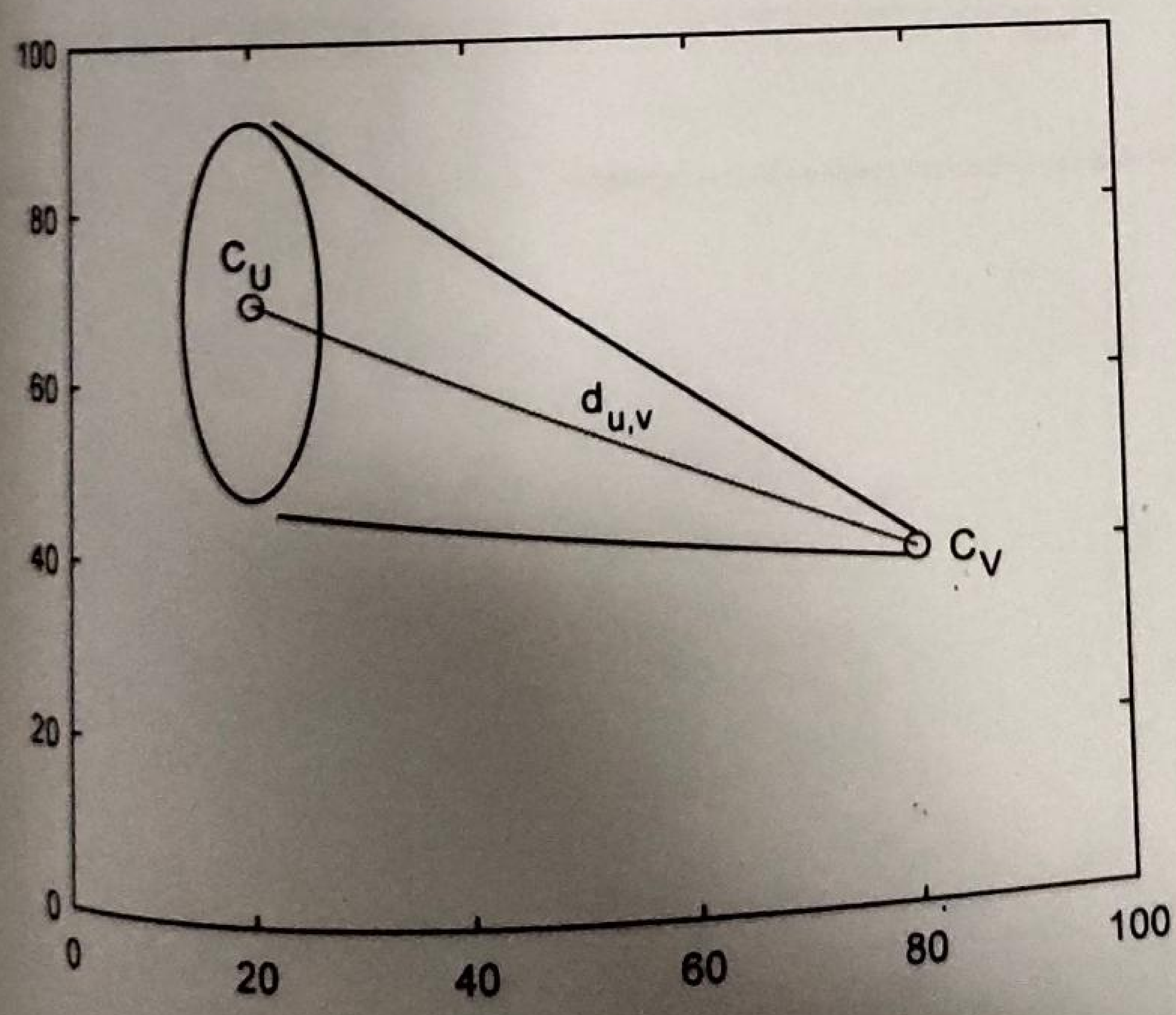

Figure 4.1.1 : Transmission angle of coverage for omni directional antenna.

Able to take part in the process and the path achievable rate is raised. Figure plots the impact of transmission radius on the power of number of nodes. We can see that the larger transmission radius and secondary users' number lead to more power transmission of node to participate the collaborations among nodes. However, we also notice that when the transmission radius is 25, there are high power loss in nodes in the case of 25 secondary users that that of15 ones. According to our algorithm, this case can lead to the larger interference and thus our algorithm only let less nodes participate the collaborations to avoid the interference. This shows that our algorithm holds the better performance.

4.2 SIMULATION

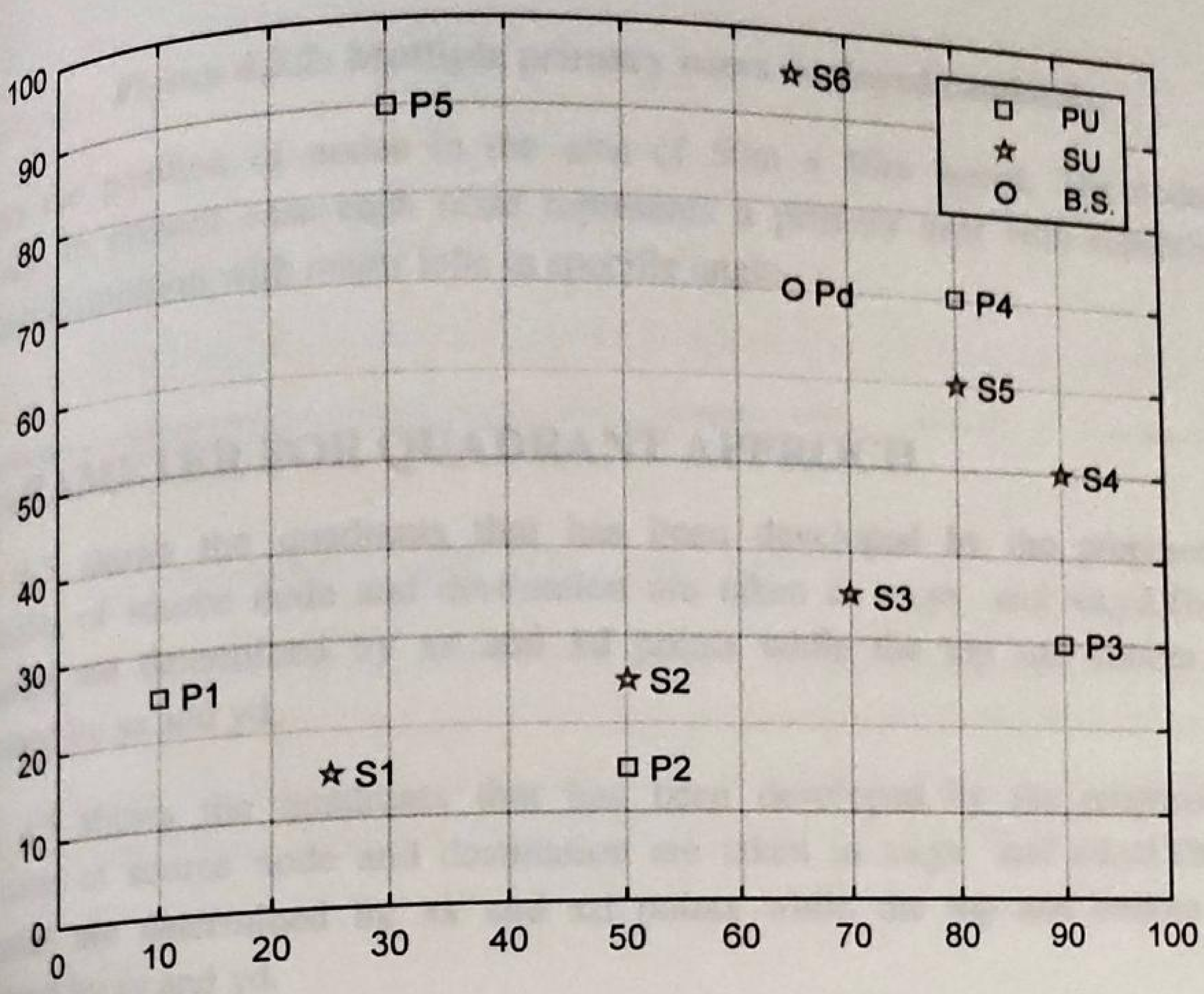

Figure 4.2.1: Multiple primary and secondary user communicating to base station

Shows the network layout of tested simulation scheme. In this figure S1 to S6 are the secondary user and the P1 to P5 are primary user scattered in the area of 100x100m.The BS is the base station and shown as Pd in circle

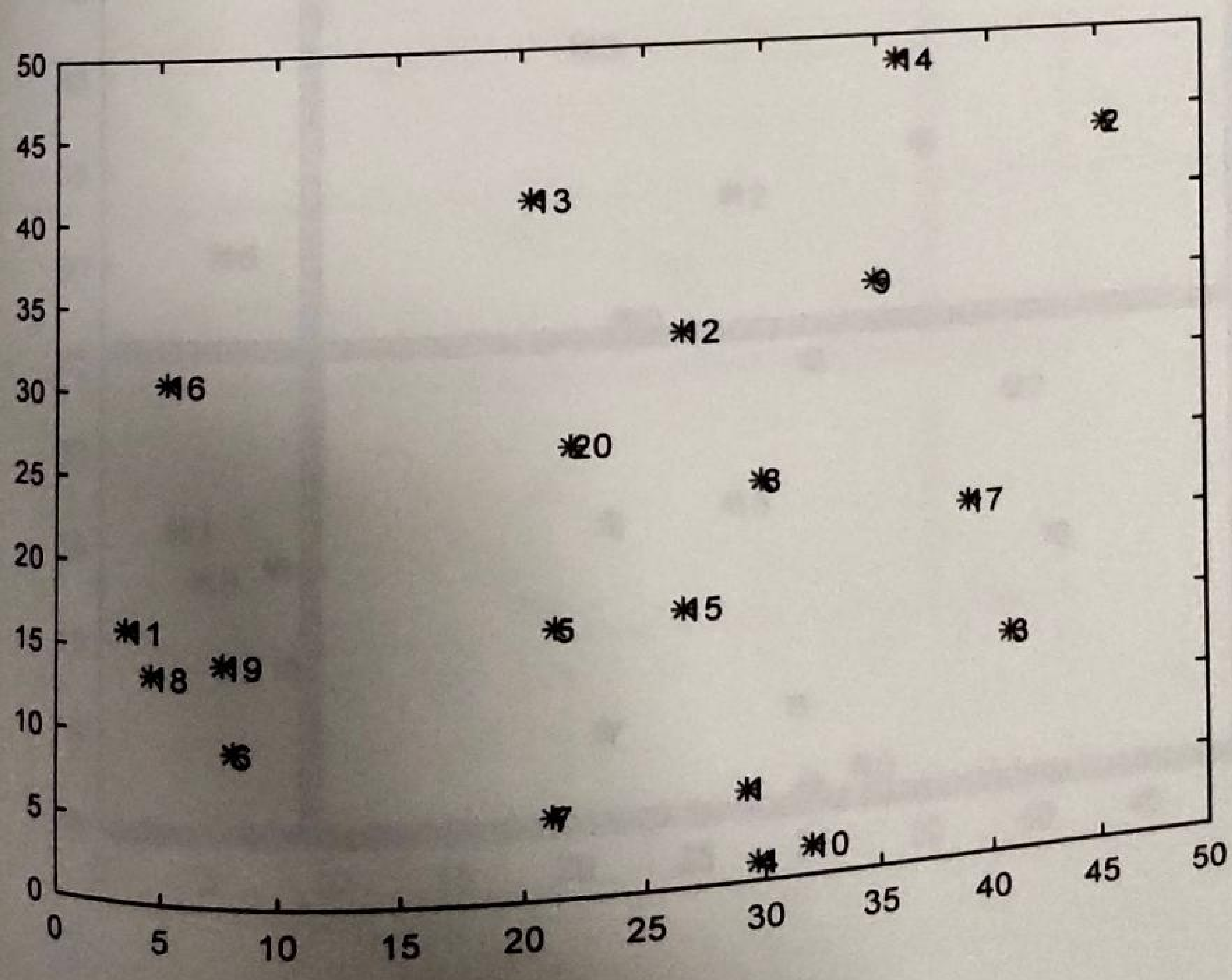

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Figure 4.2.2: Multiple primary users deployed randomly.

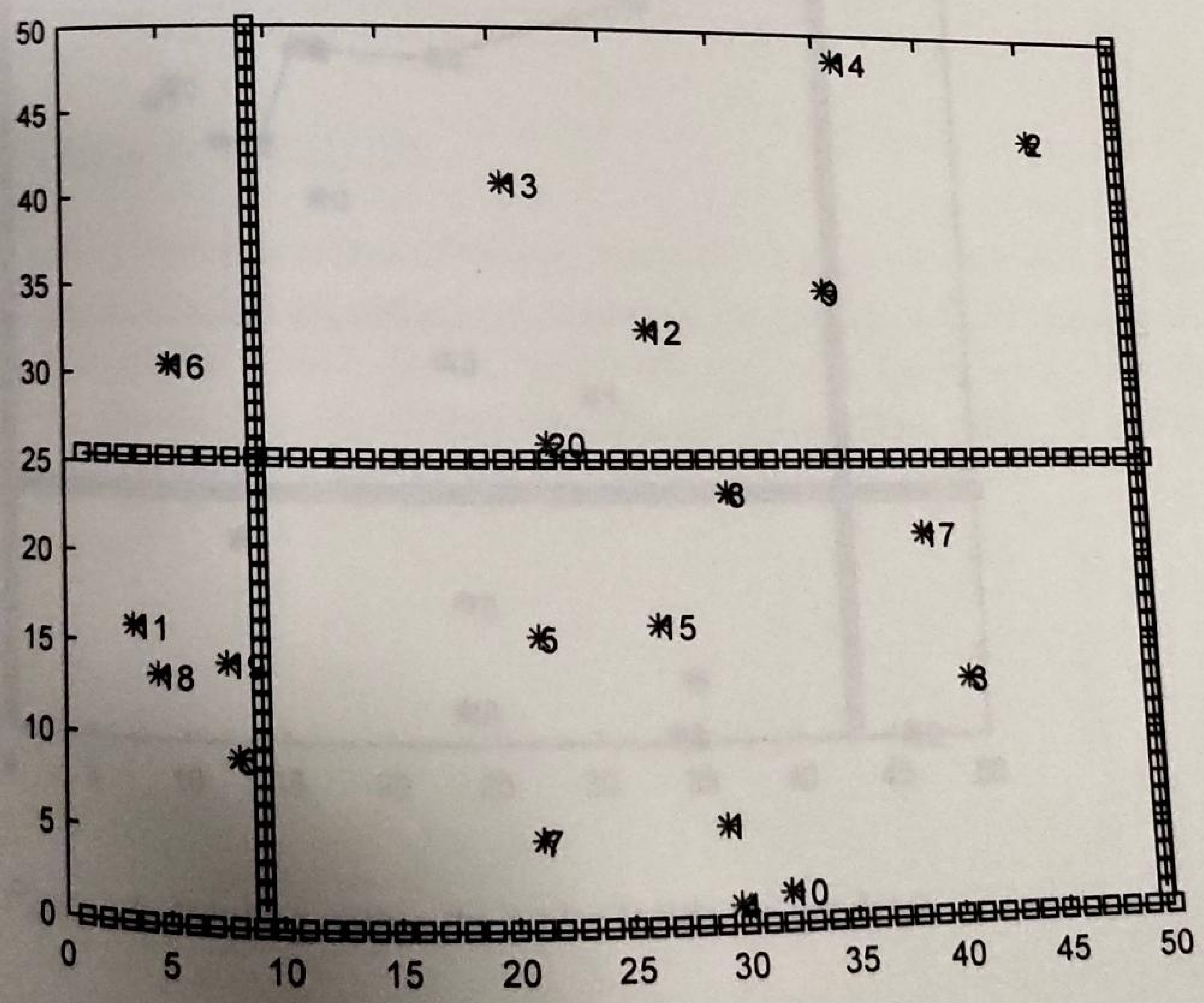
Displays the position of nodes in the area of 50m x 50m layout. The nodes are scattered randomly. In present case each node represents a primary user with capability of direction antenna transmission with major lobe in specific angle.

4.3 PARAMETER FOR QUADRANT APPROCH

Figure 4.5 shows the quadrants that has been developed by the proposed approach.The coordinates of source node and destination are taken as xs,ys and xd,yd.The left and right boundaries are determined by xs and xd points while the top and bottom boundaries are determined by ys and yd.

Figure 4.5 shows the quadrants that has been developed by the proposed approach.The coordinates of source node and destination are taken as xs,ys and xd,yd.The left and right boundaries are determined by xs and xd points while the top and bottom boundaries are determined by ys and yd.

Left boundary: xleft=min(xs,xd)



Right boundary: right=max (xs,xd)

Bottom boundary: ybottom=min (ys,yd)

Top boundary: ystop=max (ys,yd)

After determining the boundaries ae shown in figure the quadrant as drawn at 20% extended lines margins with respect to cleft, right and ybottom , ytop.

4.4 ROUTING WITHIN THE QUADRANT

Figure 4.6 describes the rote developed by quadrant approach using for the roting from source to node. Only those nodes are considered that lies within the quadrants. The source nodes requests the next neighbor at smallest distance that next neighbor is taken as current source that again forwards the data to next nearest node until the destination is not reached.

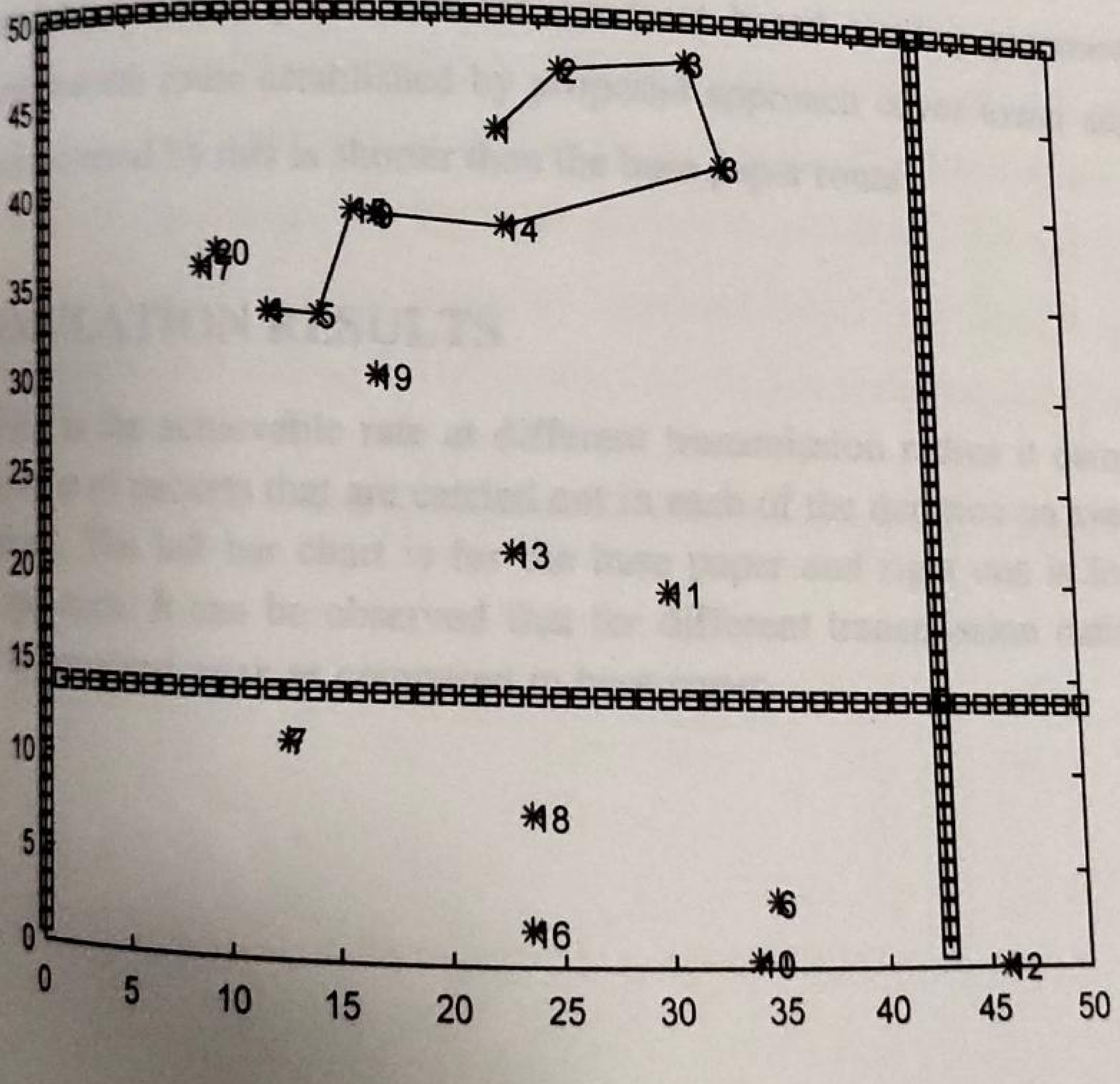
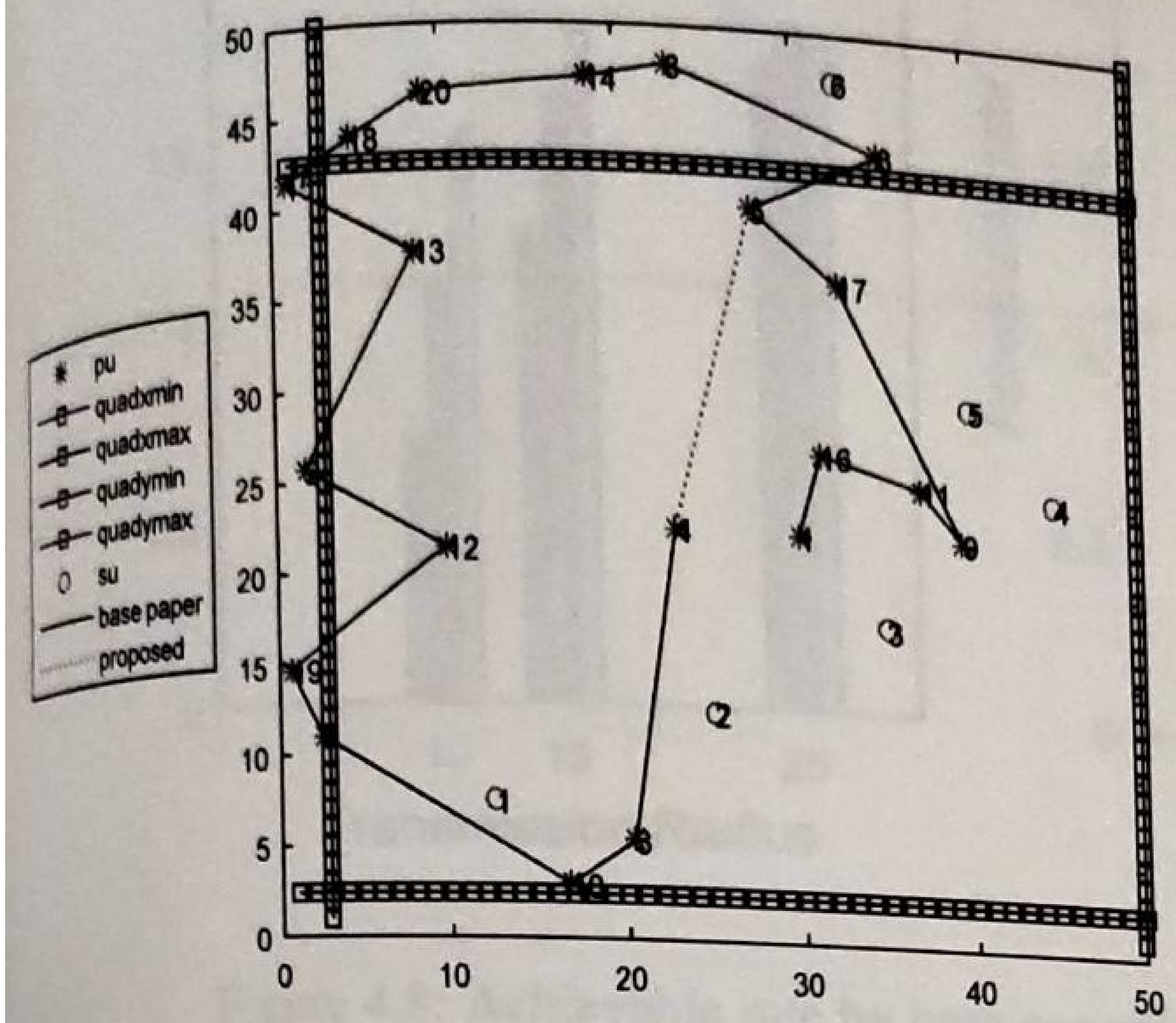


Figure 4.6: Routing within the nodes inside the quadrant.

4.5 FINAL RESULT



The figure 4.7 shows the route developed by the base paper and the quadrant based routing proposed approach. It can be observed that the route established by proposed approach cover lower area inside the quadrants and route covered by this is shorter than the base paper route.

4.6 SIMULATION RESULTS

Figure 4.8 is the achievable rate at different transmission radius it demonstrates the successful transmission of packets that are carried out in each of the iteration on average out of total packets transmitted. The left bar chart is for the base paper and right one is for the proposed quadrant based approach. It can be observed that for different transmission radius the achievable rate is higher in proposed work as compared to base paper.

Chapter 5

Conclusion and Future Scope

5.1 CONCLUSION

The quadrant based routing approach validate better performance of proposed algorithm, we compare base paper with the Shortest-Path-based quadrant Routing algorithm. We analyzed the path achievable rate and power consumption of both algorithms. We can clearly see that proposed work holds the larger path achievable rate than base paper shown in Figures. However, the different sizes of secondary users have lower affection on the path achievable rate while they produce the larger impact on that , this is because proposed work can select the optimal routing according to the proposed strategies and approach. Moreover, from Figure, we can see that when the number of secondary users is 10, 15, 25, the improve ratios of achievable rate one are, respectively higher. This indicates that quadrant routing obtain the better network performance. Figures indicates the number of nodes taking part in the collaboration process for both algorithms. For different scales of secondary users have the larger impact on the number of collaborative nodes . In addition, from, we also see that for algorithms, when we add secondary users, we can generally obtain the more collaborative nodes. This is because both algorithms always takes into account as many nodes as possible to perform the node collaborations. In such a case, we always expect the more network nodes to achieve the higher path rate. In contrast to dynamic selection of the collaborative nodes according to the network In this work, we analyze the total energy consumption of networks for both algorithms. Bar plots the total energy consumption of networks. It is interesting that when the transmission radius is 10, its total transmission power increases with the growth of secondary users, while it decreases when the transmission radius is 25. When the transmission radius is 15, its total transmission power is nearly the same for secondary user with the size by 10 and 15. For 25 secondary users, this exhibits the growth. More importantly, we can clear see that for different transmission and sizes of secondary users, the total transmission power is bigger and the average total transmission power is very low. This is a fairly better for transmission power.

5.2 FUTURE SCOPE

This work proposes a new algorithm to construct the collaborative routing in multi-hop cognitive networks with multiple primary and secondary users. Our approach considers the interference between primary users and secondary users. We take into account the interference between secondary users. After analyzing the maximum transmission distance, collaborations, transmission angle control and power control, and channel allocation, we propose a new clustering-based collaborative multi-hop cognitive routing algorithm. By aeries of simulation tests, we find that if there exist more secondary users and larger transmission radius, we can let more nodes take part in the collaboration process and attain larger achievable rate. Moreover, we also see that our approach holds lower network energy consumption. Simulation results show that our approach is promising.

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Annexure V

BBDU-PG-FORM 01

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CERTIFICATE OF FINALTHESIS SUBMISSION

(To be submitted in duplicate)

1. Name : GOPAL SHUKLA
2. Enrollment No. : 117044003
3. Thesis title: QUADRANT BASED ROUTING IN WSN WITH EFFICIENT CHANNEL ALLOCATION IN COGNATIVE RADIO
4. Degree for which the thesis is submitted: MTECH
5. School (of the University to which the thesis is submitted) BABU BANARASI UNIVESITY
6. Thesis Preparation Guide was referred to for preparing the thesis. ☑ YES ☐ NO
7. Specifications regarding thesis format have been closely followed. ☑ YES ☐ NO
8. The contents of the thesis have been organized based on the guidelines. ☑ YES ☐ NO
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12. All the corrections have been incorporated. ☑ YES ☐ NO
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GShukla

(Signature(s) of the Supervisor(s))

Name(s): Ankit Dalela

(Signature of the Candidate)

Name: GOPAL SHUKLA

Roll No 1170454003

Enrollment No.: 11704540645

Annexure IV
BBDU-PG-FORM 02

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2. Enrollment No. : 11704540649
3. Thesis title: QUADRANT BASED ROUTING IN WSN WI EFFICIENT CHANNEL ALLOCATION IN COGNATIVE RADIO
4. Degree for which the thesis is submitted: MTECH
5. Faculty of the University to which the thesis is submitted ANKIT DALELA
6. Thesis Preparation Guide was referred to for preparing the thesis. ☑ YES ☐ NO
7. Specifications regarding thesis format have been closely followed. ☑ YES ☐ NO
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10. All sources used have been cited appropriately. ☑ YES ☐ NO
11. The thesis has not been submitted elsewhere for a degree. ☑ YES ☐ NO
12. Submitted 2 spiral bound copies plus one CD. ☑ YES ☐ NO

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(Signature of the Candidate)

Name: GOPAL SHUKLA
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Enrollment No.: 11704540649

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