IMPLEMENTATION OF RELAY-BASED SYSTEMS IN WIRELESS CELLULAR NETWORKS

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ABSTRACT

IMPLEMENTATION OF RELAY-BASED SYSTEMS IN WIRELESS CELLULAR NETWORKS

The wireless cellular networks are limited by interference and coverage issues where the users at the edge of the cell usually do not receive enough signal energy. To combat these problems and provide higher signal to interference noise ratio and capacity without increasing the transmit power, the idea of using relays in cellular networks was explored and evaluated in the literature. On the other hand, multiple input multiple output (MIMO) antenna systems have great potential to increase capacity and reliability of a wireless cellular network compared to single input single output systems. Hence, the integration of MIMO systems in the relay-based cellular networks has great potential to meet the growing demands of future communication. In this thesis, we explore the performances in conventional and relay-based wireless systems with single and multiple antennas by adjusting the frequency reuse factor as one and four. We consider wireless cellular based networks where six fixed relays are placed evenly in each cell in a hexagonal layout. A user chooses to receive the transmitted signal either directly from the base station or via one of the relays by employing selection algorithms. Throughout this thesis, we first determine the optimum relay locations considering different relay powers. Then, we investigate the system capacity for the cell with and without relays. Next, we examine the capacity performances by changing the cell diameter and the relay power. Finally, we explore the performances of relay based networks with multiple antennas.

ÖZET

KABLOSUZ HÜCRESEL AĞLARDA RÖLE TABANLI SİSTEMLERİN GERÇEKLEŞTİRİLMESİ

Hücresel kablosuz ağlar, hücre köşelerindeki kullanıcıların yeterli sinyal seviyesini alamamalarına bağlı olarak, girişim ve kapsama alanı sorunlarından dolayı sınırlandırılmıştır. Bu sorunların çözümü ve sinyal gücünü arttırmadan daha yüksek işaret/parazit gürültü oranının ve kapasitenin sağlanması için, hücresel ağlarda röleli sistemlerin kullanılması literatürde incelenmiş ve değerlendirilmiştir. Diğer taraftan, tek giriş tek çıkışlı anten sistemleri yerine çok giriş çok çıkışlı (ÇGÇÇ) anten sistemlerinin kullanımı kapasiteyi ve güvenilirliği önemli ölçüde arttırmaktadır. Dolayısıyla, ÇGÇÇ anten sistemlerinin röleli sistemler ile birlikte kullanılması ile gelecek nesil haberleşme sistemlerinin artan ihtiyaçları karşılanabilecektir. Bu tezde biz günümüz hücresel ağlar ve sabit röleli hücresel ağlarının performanslarını, frekans kullanım derecesini bir ve dört alarak, tekli ve çoklu antenler kullanarak araştırdık. Tez içerisinde, altıgen hücresel yapıyı baz aldık ve altı adet sabit röleyi hücre içerisine yerleştirdik. Seçim algoritması kullanılarak kullanıcının sinyali direk olarak baz istasyonundan veya röle üzerinden aldığını kabul ettik. Tez boyunca, ilk olarak biz uygun röle pozisyonlarını farklı röle güçleri için analiz ettik. Daha sonra röleli ve rölesiz durumlar için hücre içi kullanıcı kapasitelerini araştırdık. Sonraki aşamada, hücre çapını ve röle gücünü değiştirerek kullanıcıların kapasitelerini inceledik. Tezin son kısmında ise çoklu antenler için röle bazlı hücresel ağların performanslarını araştırdık.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3G	Third generation
4G	Fourth generation
AF	Amplify and forward relaying
AWGN	Additive white Gaussian noise
bps	Bits per second
BS	Base station
CDMA	Code division multiple access
CN	Channel number
DF	Decode and forward relaying
IMT	International mobile telecommunications
ITU	International telecommunication union
LAN	Local area network
LOS	Line of sight
LTE	Long term evolution
MIMO	Multiple input multiple output
MMSE	Minimum mean squared error
MRC	Maximal ratio combining
MS	Mobile station
ODMA	Opportunity driven multiple access
OFDM	Orthogonal frequency division multiplexing
PL	Pathloss
RS	Relay station
QoS	Quality of service
SINR	Signal to interference and noise ratio
SISO	Single input single output
TDMA	Time division multiple access
VoIP	Voice over IP
WCDMA	Wireless code division multiple access
WINNER	Wireless world initiative new radio

CHAPTER 1

INTRODUCTION

1.1. Overview

Modern cellular networks not only need to provide high quality voice for customers, but also a large amount of data transfer services as well, such as wireless internet, multimedia, file transfer and downloading. These concerns lead to the new demand to enhance the capacity and high data rate coverage for future cellular networks. However, conventional cellular networks cannot offer the signal to interference and noise ratio (SINR) that is high enough to meet the new requests. Under limited frequency resources, the conventional approach to increase network capacity is to install more base stations (BSs). This solution is not very efficient because the cost of the BS is quite high. An alternative approach is to employ relay stations (RSs) as intermediate nodes to establish multihop communication paths between mobile users and their corresponding BSs.

Relay communication systems have recently attracted much attention due to their potential to substantially improve the signal reception quality when the direct communication link between the source and the destination is not reliable. The relaying concept may be considered as an alternate solution to the conventional cellular systems. Relays are much simpler devices than base stations and they are not connected to the wired network; therefore, they are very cost effective. Cellular relay networks is generalized form of the relaying concept. The whole cell area is covered by a number of relays. Each relay serves a small area with a small amount of power. Adding relays in the cells reduces the signal transmission distances, resulting in lower propagation loss and higher average SINR to the mobile users. In relay based systems, mobile users receive signal directly from BS or receive signal from relay station using one or more relays or receive both the relay station and relays. This guarantees stronger and more stable receiving signals, especially for the mobile users near the edge of the cell and improving the overall system capacity. Many researchers have explored the relay based wireless networks. Digital fixed relay performance was investigated in (Hu 2004), relaying channel selection scheme and coverage enhancement were explored in (Sreng et al. 2002), a novel frequency reuse scheme of OFDMA based networks was given in (Liang et al. 2009) and modified frequency reuse scheme was proposed in (Guan et al. 2007).

On the other hand, the multiple input multiple output (MIMO) relay channel has attracted a lot of interest where the source, relay, and destination have multiple antennas. Use of MIMO technique in a wireless relay network has gained special attentions in recent years due to its ability to provide significant improvements in data rate and reliability compared with single-antenna systems. Antenna selection strategies for amplify and forward relaying were proposed in (Peters and Heath 2008), capacity performance analysis for MIMO relay channels with single antenna relay was investigated in (Chen et al. 2009), fixed relays with multiple antennas in a two hop wireless network was analyzed in (Adinoyi and Yanikomeroglu 2007) and the outage performance of several transmit antenna selection strategies in the amplify and forward MIMO relay channel has been analyzed by (Cao et al. 2009).

In this thesis, we explore the performances of the conventional and relay-based wireless systems for single and multiple antennas. We first investigate optimum relay locations. Then, we examine the user capacity performances at the edge of the cell. Next, we analyze the capacity for different relay powers and diameters. Finally, we investigate the performance of the relay systems by employing multiple antennas for all nodes and compare the performances with the single-input single-output (SISO) antenna systems.

1.2. Motivation

This thesis is related to the fixed relays on wireless cellular networks. The advantages of using fixed relays in a cellular network instead of mobile relays are:

1. If all of the users act as mobile relays, additional hardware and software will be needed for the users, and thus its cost will be higher than the conventional cellular networks.

2. The user acting as relay might be reluctant to offer relaying assistance with weak received signals, because by doing so, their batteries would be overused.

3. There could be billing and security issues by using mobile relays.

Fixed relaying is an alternative solution for the conventional systems instead of the mobile relaying. This system provides the following advantages:

1. Shorter transmission distances and more efficient utilization of the transmitted signal energy result in lower power levels throughout the system. This implies increased channel capacity, decreased interference levels, reduced terminal radiation, and longer battery life.

2. There is no battery consumption compared to the mobile systems.

3. There is no billing and security problems.

In addition, the motivation of using multi antennas to the fixed relay based network can be explained as follows:

1. The capacity and the reliability of the relay channel can be further improved by using multiple antennas at the nodes. The benefits of fixed relaying combined with the advantages of multiple antennas make the MIMO relaying technique as a powerful candidate for the implementation in the next generation of wireless networks.

2. MIMO systems introduce a spatial diversity to combat fading. By taking advantage of the rich scattering environment, multiple antenna systems can provide higher rates of the data transmission than a single-antenna system in a scattered environment.

Main objectives of this thesis are:

1. To investigate whether a fixed relaying can provide better performance over a mobile relaying.

2. To analyze the optimum locations of the RSs in the cell.

3. To analyze the capacity for both the cluster size N=1 (a single hexagonal cell constitutes one cluster) and N=4 (four hexagonal cells constitute one cluster) and compare them.

4. To determine the optimum cell diameter and the relay power.

5. To investigate the MIMO relaying system performance.

1.3. Thesis Organization

In chapter 2, an overview of the relay based wireless cellular network including relay standards and relays types are examined. In addition, the network architecture and the cellular layout are presented. Cell layout introduces the geometric locations of the BSs and relays in the cluster sizes $N = 4$ and $N = 1$ cases. A relay partition scheme is introduced at the last part of this chapter.

In chapter 3, three relay selection algorithms are introduced; distance based, pathloss based, and pathloss-SINR based algorithms. The simplified interference analysis is also explained. In addition, the simulation models and algorithms for both the cluster size $N = 4$ and $N = 1$ are described and the overall simulation flowcharts are provided in detail. Finally, the simulation results including performance comparisons for no relaying and relaying of the cluster sizes $N = 4$ and $N = 1$ are demonstrated.

In chapter 4, the background information on MIMO are presented in details. In addition, MIMO antenna systems are adopted to the relay-based networks and SINR and the capacity results are investigated.

In chapter 5, the conclusion of this thesis is presented and some possible future studies are suggested to extend this research.

CHAPTER 2

RELAY BASED WIRELESS NETWORK

2.1. Relay Deployment Benefits

The deployment of RSs offers performance and cost benefits over the use of BSs in a traditional cellular network. Performance benefits include improvements in coverage and/or increase in the capacity. Cost benefits include the reduction in the cost of providing service, equipment and site development.

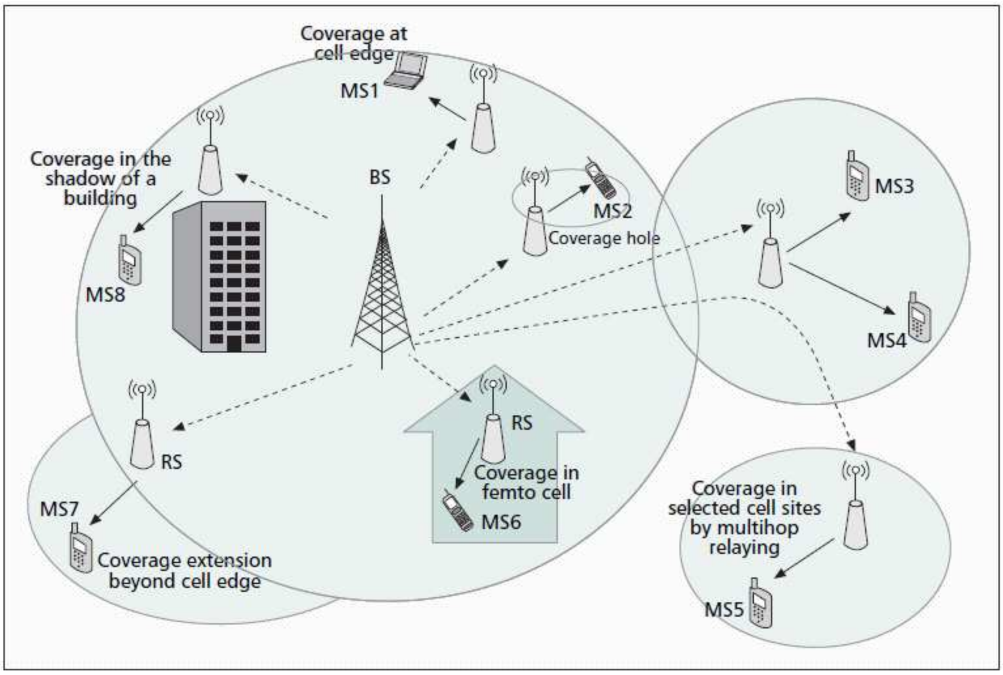

Figure 2.1. The deployment scenarios for relay stations
(Source: Sydir and Taori 2009)

RS deployment enhances the coverage and the capacity in areas where the capacity of the direct link between the BS and MSs is low. Such areas can exist at the cell edge (e.g., MS1 in Fig. 2.1) or in the shadows of large objects such as tall buildings (e.g., MS8), within the buildings themselves, or underground. RS deployment enhances coverage in areas where the capacity of the direct link between the BS and MS is zero (e.g., MS2 in a coverage hole or MS7 beyond the edge of the cell) (Sydir and Taori 2009).

Compared to a traditional BS, the equipment cost associated with an RS is likely to be lower due to the lower complexity, and lower cost of the chassis and power amplifier. It is likely that RS antennas are deployed on top of the buildings or on lamp posts; therefore, RS cell sites are likely to be less expensive to develop and maintain than traditional cell sites with tall towers. These differences in cost are expected to decrease over time, however, as the coverage area of BSs becomes smaller (Sydir and Taori 2009).

2.2. Relay Enabled Standards

In recent years, there has been significant advances in signal processing techniques (such as interference cancelation algorithms) and antenna architectures which are generally referred to as smart antennas (such as MIMO and adaptive antennas). Although incorporation of these techniques in future wireless system is crucial for practical reasons, these techniques alone do not seem to be sufficient in enabling almost-ubiquitous very high data rate coverage. For instance, it may be infeasible to deploy complex antenna systems at wireless terminals, besides in the presence of heavy shadowing, even the smartest antennas will not be of much help (Yanikomeroglu 2002).

Therefore more fundamental enhancements are necessary for the very ambitious capacity and coverage requirement of future. Towards that end, in addition to advanced signal processing techniques, some major modifications in wireless network architecture itself, which will enable the distribution and collection of signal and wireless users are sought. The integration of multihop capability in conventional wireless networks is one such promising architectural upgrade (Yanikomeroglu 2002).

The potential benefits of the relay-based network architectures have been realized by industry as early as late-1990's. The first notable initiative that we are aware of was a proposal discussed in UMTS 3GPP which was aiming at including fixed relays (called "seeds") in the WCDMA networks; this concept was being referred to as "opportunity-driven multiple access (ODMA)". It seems however that modifying the WCDMA standard to enable relaying is more than a trivial task; as a result, the ODMA concept was dropped subsequently (Yanikomeroglu 2004). In order to meet ever increasing requirements on higher wireless access data rate and better quality of service (QoS), the Third

Generation Partnership Project (3GPP) initiated its Long Term Evolution (LTE) standardization work at the end of 2004 and successfully completed this task at the end of 2007. Immediately after that, 3GPP started its LTE-Advanced standardization process to address the requirements and challenges of IMT-Advanced systems by considering a series of new transmission technologies such as carrier aggregation, coordinated multiple point transmission and reception, and relays. It is anticipated that 3GPP will submit this newly developed LTE-Advanced standard as a candidate technical proposal for IMT-Advanced mobile systems (Yang et al. 2009).

As of January 1st, 2004, an integrated project called WINNER (Wireless World Initiative New Radio) within the 6th Framework Programme of the European Union started. The aim of WINNER is ”to develop a ubiquitous radio system concept covering the full range of scenarios from short range to wide area networks providing significant improvements compared to current systems in terms of performance, efficiency, and coverage flexibility”. Development of relay-based deployment concepts constitutes an integral part of the WINNER project (Yanikomeroglu 2004).

Through a different approach, the IEEE 802.16 Working Group has developed, since July 1999, several global standards of WiMAX for providing the first-mile/last-mile broadband wireless access in metropolitan areas, as well as backhaul services for voice/data communication hotspots. In October 2007, WiMAX was approved to become a 3G standard in the ITU IMT-2000 standards family. Recently, IEEE launched the 802.16j working group to develop relay-based multihop techniques for WiMAX standards. For future evolution of WiMAX, IEEE 802.16m has been planned to meet the requirements and time schedule of IMT-Advanced standards (Yang et al. 2009).

International Mobile Telecommunications-Advanced (IMT-Advanced) is the name, defined by International Telecommunication Union (ITU), for the next-generation (4G) mobile wireless broadband communication systems. The standardization process of IMT-Advanced systems will enter the technical proposal evaluation stage by the end of this year, and the first IMT-Advanced air interface standard is expected to be released in early 2011. The commercial deployment of IMT-Advanced systems and services is anticipated to be after 2015. According to the ITUs requirements, future IMT-Advanced systems can support peak data rates of 100 Mbps and 1 Gbps, respectively, in high speed mobility environments (up to 350 km/h) and stationary and pedestrian environments (up to 10 km/h). The transmission bandwidth of IMT-Advanced systems should be scalable and can change from 20 to 100 MHz, with downlink and uplink spectrum efficiencies in the ranges of [1.1, 15 bps/Hz] and [0.7, 6.75 bps/Hz], respectively. The minimum requirements on voice over IP (VoIP) capacities in high- and low-mobility environments are 30 and 50 active users/sector/MHz (Yang et al. 2009).

2.3. Relay Types

2.3.1. Digital and Analog Relaying

Depending on their nature and complexity, relays systems can be classified as either decode-and-forward (DF) or amplify-and-forward (AF) systems. Digital relaying referred to as "regenerative relaying" or "decode-and-forward relaying". It fully decodes the received signal from the first hop, and re-encodes and retransmits the decoded signal through the second hop. Digital relaying is a technique that uses certain mobile terminals that have good communication links with the base station to act as relay nodes for those that do not have. With this technique, the signal quality at the destination is expected to improve since the signal only goes through favorable links and at each intermediate node, the signal is decoded and re-encoded before forwarding. No noise is propagated but the encoding and re-encoding process add non negligible delay.

Analog relaying is referred to as non-regenerative relaying or amplify-and-forward relaying (AF). In the AF mode, the relay terminal simply amplifies and retransmits the signal received from the source terminal. AF relays have the advantage of introducing a minimum delay but have the drawback of amplifying the noise. (the signal received at the relay terminal is corrupted by fading and additive noise). No demodulation or decoding of the received signal is performed in this case.

A relay cooperative communication system is shown in Figure 2.2. It consists of the source (s), the relay (r) and the destination (d). The relay receives and transmits the signal to enhance the communication between the source and destination. There are three different protocols introduced in the literature (Nabar et al. 2004).

Protocol I : The source terminal communicates with the relay and destination ter-

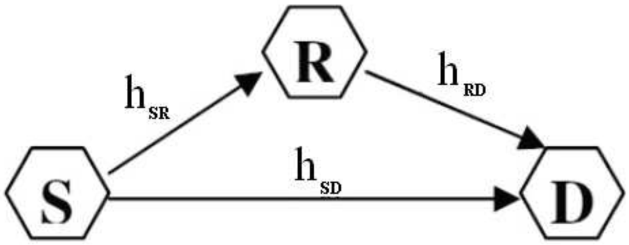

Figure 2.2. Single and relay cooperative communication system

minals during the first time slot. In the second time slot both the relay and source terminals communicate with the destination terminal.

Protocol II: In this protocol the source terminal communicates with the relay and destination terminals over the first time slot. In the second time slot, only the relay terminal communicates with the destination terminal.

Protocol III: The third protocol is identical to Protocol I apart from the fact that the destination terminal chooses not to receive the signal from source terminal during the first time slot.

The input-Output relation for decode-and-forward and amplify-and-forward, are described as follows.

In the amplify and forward mode, the signals transmitted by the source terminal during the first and second time slots are denoted as $x_1[n]$ and $x_2[n]$. The signal received at the destination terminal in the first time slot is $y_{D,1}[n]$, the average signal energy received are E_{SD}, E_{SR}, E_{RD} and the noise is additive white Gaussian noise $E\ \{n_{D,1}^2\} = N_0$. h_{SD} is a complex valued random variable with unit power channel gain between source and destination terminals. The signal received at the destination terminal in the first time slot is given by:

$$y_{D,1} = \sqrt{E_{SD}} h_{SD} x_1 + n_{D,1} \tag{2.1}$$

The signal received at the relay terminal during the first time slot is given by:

$$y_{R,1} = \sqrt{E_{SR}} h_{SR} x_1 + n_{R,1} \tag{2.2}$$

where h_{SR} is a complex valued random variable with unit power channel gain between the source and relay terminals. The relay terminal normalizes the received signal by a factor of $E\{|y_{R,1}|^2\}$(so that the average energy is unity) and retransmits the signal during the second time slot. The destination terminal receives a superposition of the relay transmission and the source transmission during the second time slot according to

$$y_{D,2} = \sqrt{E_{SD}} h_{SD} x_2 + \sqrt{E_{RD}} h_{RD} \frac{y_{R,1}}{\sqrt{E\{|y_{R,1}|^2\}}} + n_{D,2} \tag{2.3}$$

where h_{RD} is a complex valued random variable with unit power channel gain between the relay and destination terminals and $n_{D,2}$ is additive white Gaussian noise $E\ \{n_{D,2}^2\} = N_0$. Using $E\{|y_{R,1}|^2\} = E_{SR} + N_0$ so it is written by

$$y_{D,2} = \sqrt{E_{SD}} h_{SD} x_2 + \sqrt{\frac{E_{SR} E_{RD}}{E_{SR} + N_0}} h_{SR} h_{RD} x_1 + \tilde{n} \tag{2.4}$$

the effective noise term $E\ \{\tilde{n}^2\} = N_0'$ with $N_0' = N_0(1 + (E_{RD}|h_{RD}|^2)/(E_{SR} + N_0))$. The receiver normalizes $y_{D,2}$ by a factor $\omega = (1 + (E_{RD}|h_{RD}|^2)/(E_{SR} + N_0))^{1/2}$. The effective input-output relation in the AF mode can now be summarized as;

$$y_D = Hx + n \tag{2.5}$$

where $y_D = [y_{D,1}\ \ y_{D,2}/w]^T$ is the received signal vector, n is additive white Gaussian noise with $E\{n\} = 0$ and $E\{nn^H\} = N_0 I_2$, H is the effective $2x2$ channel matrix given by in (Nabar et al. 2004):

$$\mathbf{H} = \begin{bmatrix} \sqrt{E_{SD}} h_{SD} & 0 \\ \frac{1}{w}\sqrt{\frac{E_{SR} E_{RD}}{E_{SR} + N_0}} h_{SR} h_{RD} & \frac{\sqrt{E_{SD}}}{w} h_{SD} \end{bmatrix} \tag{2.6}$$

The received signal is written:

$$y_D = \mathbf{H} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n \tag{2.7}$$

In the Decode-forward relaying mode, the signal received at the destination terminal during the first time slot is identical to that for the AF mode. Unlike the AF mode, the relay terminal now demodulates and decodes the signal received during the first time slot. If the relay decodes the received symbol correctly, then it forwards the decoded symbol to the destination in the second slot, otherwise it remains idle. Assuming that the signal is decoded correctly and retransmitted, it is obtained;

$$y_{D,2} = \sqrt{E_{SD}} h_{SD} x_2 + E_{RD} h_{RD} x_1 + n_{D,2} \tag{2.8}$$

The effective input-output relation in the DF mode can be summarized as $y_D = Hx + n$, where $y_D = [y_{D,1} \;\; y_{D,2}]^T$ is the received signal vector, **H** is the effective $2x2$ channel matrix given by (Nabar et al. 2004):

$$\mathbf{H} = \begin{bmatrix} \sqrt{E_{SD}} h_{SD} & 0 \\ \sqrt{E_{RD}} h_{RD} & \sqrt{E_{SD}} h_{SD} \end{bmatrix} \tag{2.9}$$

$x = [x_1 \;\; x_2]^T$ the transmitted signal vector, and n is additive white Gaussian noise with $E\{n\} = 0$ and $E\{nn^H\} = N_0 I_2$.

2.3.2. Single or Multiple Relaying

In cellular networks, the users receive the signal directly from the base station or receive signal from relay stations or both of them. If the users receive the signal directly from the base station, it is called a single hop relaying or a direct transmission. If the users receive the signal via one or more of the relays, it is called a multihop relaying. If the users receive the same signal from the base station and relays at the same time, it is called diversity.

2.3.3. Fixed and Mobile Relaying

In relay based wireless networks, two types of relays could be used; fixed or mobile relaying. A fixed relaying means that a number of relays are set up at the fixed positions. A mobile relaying means that all of the users acts as a relays in a cell. Fixed relays can be much cheaper than the normal BSs because their function is just to decode received packets, then re-encode and forward them to the next station along the routing path. Fixed relays can be installed in each edge between each pair of cells in multiple rings in each cell centered by the corresponding BS. For mobile relays, a significant performance gain can be achieved free of charge in low traffic load and high node density because many idle mobile relays are available to relay data from active mobile relays. The average power consumption of each mobile relays increases due to this extra relaying functionality. However, it is expected that the increase in the power consumption is not significant because the transmission range of each hop is now decreased. In high traffic load, the performance gain may reduce because idle mobile relays are less likely to be available (Le and Hossain 2007).

2.4. Network Architecture

The wireless multihop cellular system which consists of 7 hexagonal cells for the cluster size of $N = 1$ and 28 hexagonal cells for the cluster size of $N = 4$ are investigated throughout this thesis. The cluster size of $N = 1$ means that a single hexagonal cell constitutes one cluster. 7 hexagonal cells include 7 cluster, one main cluster and six neighboring cluster. The cluster size of $N = 4$ means that four hexagonal cells constitute one cluster. 28 hexagonal cells include 7 cluster (one main and six neighboring cells) and each cluster consists of 4 cells. In each cell, as shown in Figure 2.3, BS and six RSs are respectively located at the cell center and edge, and each RS is on the line that connects the base station and the cell vertices. The cell radius is R, and the distance from BS to relays is R_1. The different relay positions (R_1/R) are investigated to find the optimum one in the thesis. Users can be served directly by the BS through a one-hop link, or establish a two-hop link from a RS, which can be decided by different selection algorithms.

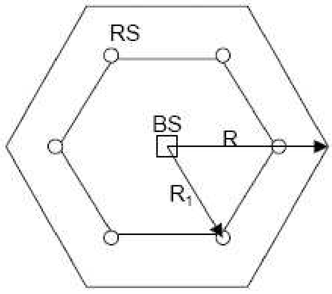

Figure 2.3. Structure of the fixed two-hop cellular relaying network

2.5. Wireless Channel Model

In real environments, the signal power from a transmitter to a receiver is attenuated by different factors such as fading, shadowing and path loss. These factors along with the interference at the receivers are a critical component of any model for a wireless system. The received signal is inversely proportional to the distance between the transmitter and the receiver. The received power is determined by the following formula:

$$P_r = P_t \frac{G_t G_r}{PL} Y, \tag{2.10}$$

$$P_{r_{dB}} = P_{t_{dB}} - PL_{dB} + Y_{multipath_{dB}} \tag{2.11}$$

where P_t is the transmitted power and P_r is the received power, G_r and G_t are the antenna gains of the transmitter and the receiver respectively, and are set to 1 throughout this thesis. Y is an exponential random variable with unity mean which captures the effects of multipath fading. Y can be generated as follows:

$$Y = X_1^2 + X_2^2 \tag{2.12}$$

where X_1 and X_2 are two independent Gaussian random variables with zero mean and a standard deviation of $\frac{1}{\sqrt{2}}$. $E\,[Y] = 1$. The average pathloss, denoted by PL, can be calculated as:

$$PL = \left(\frac{4\pi d_0 f}{c}\right)\left(\frac{d}{d_0}\right)^n \tag{2.13}$$

where d_0 is the reference distance and is set to 10 m, f is the carrier frequency, c is the speed of light, d is the distance between the transmitter and the receiver, n is the propagation exponent.

2.6. Capacity Analysis

The signal to interference noise ratio (SINR) at the receiver node j is calculated as:

$$\gamma_{ij} = \frac{|h_{ij}|P_i}{I_j + P_N} \tag{2.14}$$

where $|h_{ij}|$ is the signal attenuation from source node i to destination node j, P_i is the transmission power of node i, I_j is the external interference and P_N is the noise power (Liang et al. 2009).

The potentially achievable link rates in networks is calculated by using the Shannon capacity formula:

$$C = Blog_2(1 + \gamma_{ij}) \text{ [in bits per second].} \tag{2.15}$$

2.7. Frequency Reuse Scheme

There are two groups of users: one hop users and two hop users. One hop users means that the users receive a signal directly from a base station and two hop users means that the users receive a signal from the selected relay. In general, relay stations are used to improve the quality of service (QoS) of the cell edge users and BS focus on the central users. Each cell can be supposed to be composed of two parts; the inner zone and the outer zone which contains one hop users and two hop users respectively as shown in Figure 2.4. The total frequency band is divided into six equal parts. In the outer zone, total frequency bands are assigned to the six RS, respectively. Each zone utilizes the whole frequency

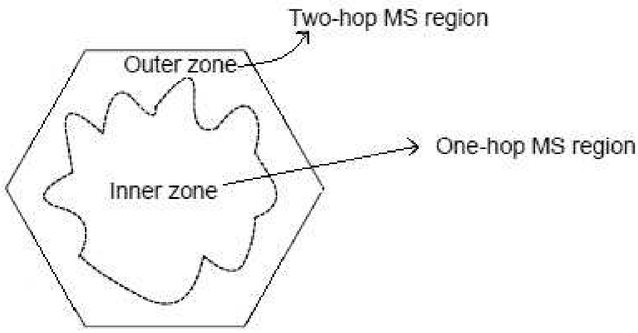

Figure 2.4. Two partitioning region in relaying cell

band. The frequency reuse factor of one can be achieved in both zones. Each sector contains one RS and the frequency bands used by the inner zone and outer zone users are orthogonal in each sector (Le and Hossain 2007).

2.8. Cellular Layout

Two different values for the cluster size N are considered: $N = 4$ and $N = 1$. The cell radius is chosen $500m$. In addition, cells with different sizes are also investigated.

In this thesis, hexagonal cells are studied. The BS is located in the center of the hexagonal cell. Six fixed relays are located on the line connecting to BS and six cell vertices. Each relay is located on the line that connects the center of the cell to one of the six cell vertices, and it is R_1 away from the BS. Figure 2.5 and 2.6 shows BS and relay positions in a cell for the cluster sizes $N = 1$ and $N = 4$, respectively. The square in the center of the cell represents BS and the circles close to the cell boundary represent relays. With this relay position design, the BSs and relays are spread out evenly across the hexagonal layout. Figure 2.7 shows the cellular layout for the cluster size of $N = 1$ (seven clusters with one cell) and Figure 2.8 shows the cellular layout for the cluster size of $N = 4$ (seven clusters with four cells).

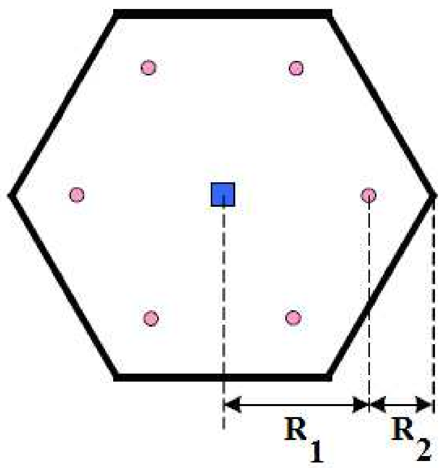

Figure 2.5. BS and relays position $(N = 1)$

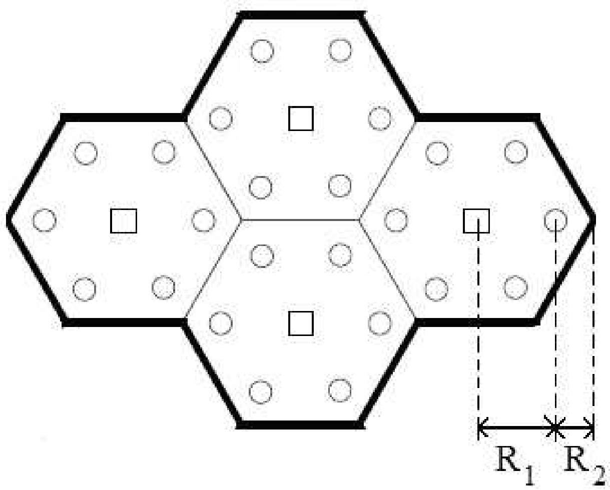

Figure 2.6. BS and relays position $(N = 4)$

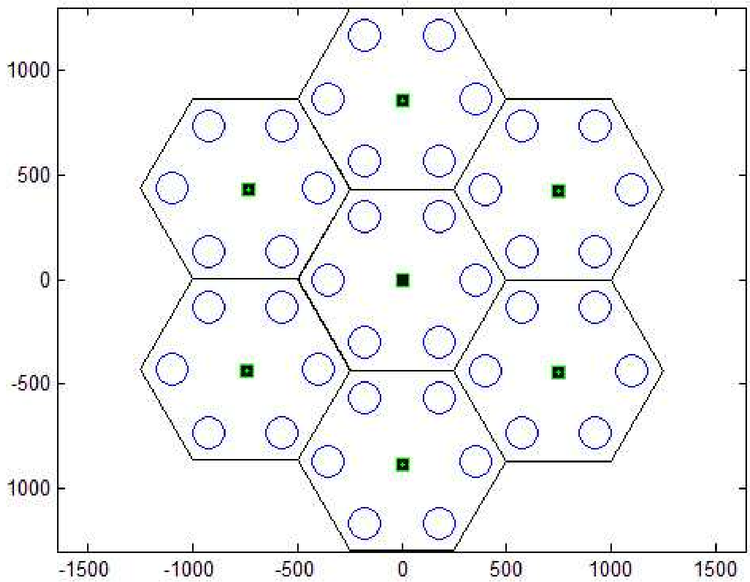

Figure 2.7. Cellular layout $(N = 1)$

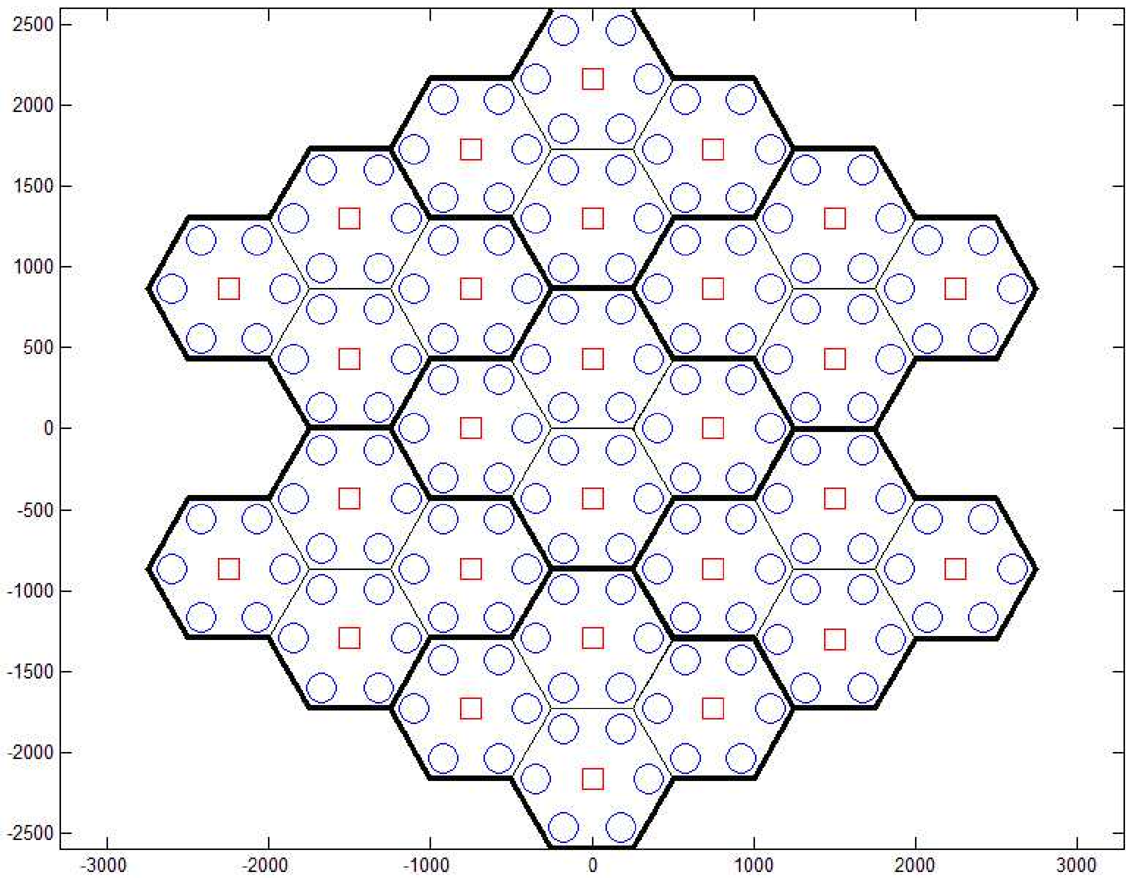

Figure 2.8. Cellular layout $(N = 4)$

2.9. Relaying Channel Partition Scheme

For the cluster size of $N = 1$, a single hexagonal cell constitutes one cluster. All the available channels are divided into six disjoint groups with an equal number of channels. Each relay will reuse one group of them. Once the relay is selected, it knows which channel it should be used. Figure 2.9 shows the cellular layout for $N = 1$.

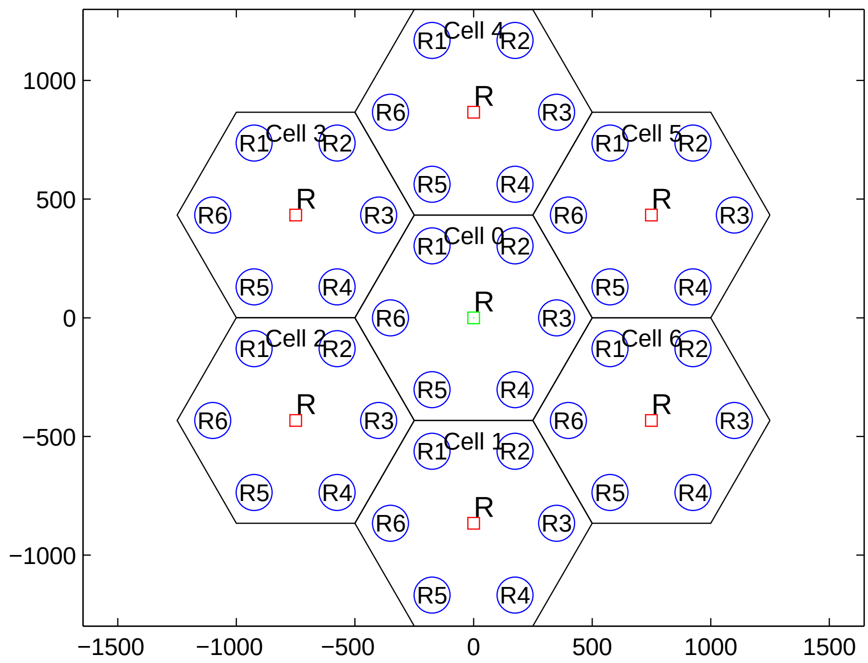

Figure 2.9. Cellular layout for the cluster size of $N = 1$

For the cluster size of $N = 4$, four hexagonal cells constitutes one cluster. To avoid a self interference, a relay is not allowed to reuse any channel in the same cell. For example, in a type A cell, all the relaying channels must be from type B, C, or D cells. Because a cell farthest from a relay most probably has the least co-channel interference to this relay, it is decided to let a relay reuse the channel from the cell farthest from it. For example, a relay marked as "A" indicates that relay is reusing channels from the type A cells, because a type A cell is the farthest away cell from the relay in comparison to type B, C, and D cells. The overall channel partition scheme is seen in the Figure 2.10. In this relaying channel partition scheme, any two relays in a cluster will choose the same relaying channel. For example, it can be seen in each cluster, there will be twenty-four relays and every six relays will reuse a group of channels from the type A, B, C, and D cells, respectively. In order to avoid these six relays reusing the same channel, all channels belonging to a certain cell are divided into six disjoint groups with an equal number of channels, and each relay reuses channels only from one group. Relays written as A1 or C5 represent relays reusing a certain group of channels. A1 reuses the first group of the channels from type A cells, C5 reuses the fifth group of channel from type C cells.

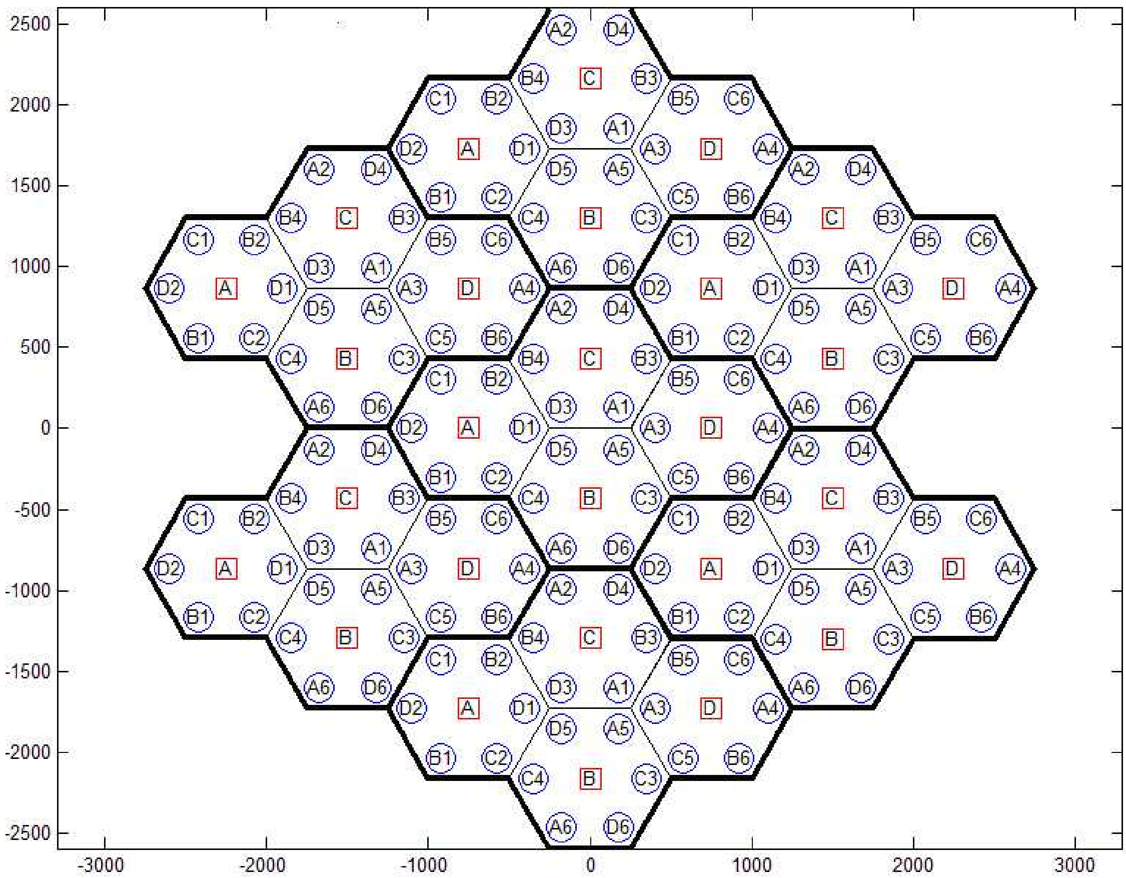

Figure 2.10. Cell layout and relaying channel partition scheme $(N = 4)$

The geometric locations of all the co-channel relays reusing channels from the same cell have a common characteristic. They are all located on circles whose centers are exactly the co-channel BSs where these relays are reusing channels from. Figure 2.11 (Hu 2004) shows this geometric characteristic. All these co-channel BSs and relays are shaded. All these different colors represent the channels belonging to different cell. For example, yellow colors show the channels belonging to a cell C, blue colors show the channels belonging to B.

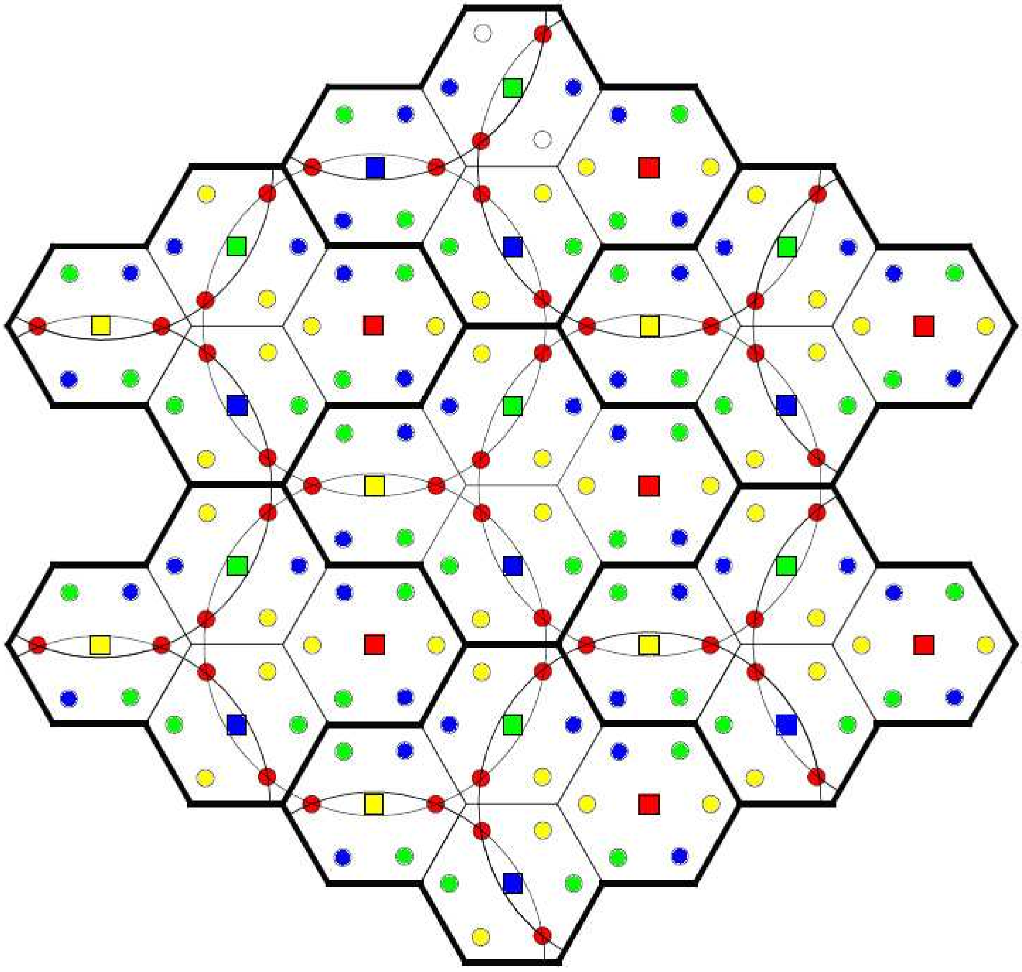

Figure 2.11. Geometric characteristic of co-channel BSs and relays $(N = 4)$
(Source: Hu 2004)

CHAPTER 3

EVALUATION OF RELAY BASED WIRELESS NETWORK

In this chapter, three relay selection algorithm are firstly discussed. Then, the interference analysis for the cluster sizes of $N = 1$ and $N = 4$ are given. Afterwards, the simulation performances of the selection algorithms are obtained at the last section of this chapter.

3.1. Selection Algorithm

This section describes the three algorithms used to determine from which node (BS or relays) a user will receive its signal. The algorithms are based on the following three criteria: distance, pathloss and SINR. The distance-based algorithm is the simplest. The SINR-based algorithm produces the best performance improvement.

3.1.1. Distance-based Algorithm

This algorithm is related to the distances from the user to BS and relays. To find the boundary taking the receiving signal from the BS and the corresponding relay P_{B_1} and P_{R_1} are identical when shadowing and multipath fading are averaged out.

$$P_{B_1} = \frac{kP_B}{d_1^4}, P_{R_1} = \frac{kP_R}{d_2^4} \tag{3.1}$$

where k is a constant. For $P_{B_1} = P_{R_1}$

$$\frac{P_B}{d_1^4} = \frac{P_R}{d_2^4} \tag{3.2}$$

P_B is the BS transmit power, P_R is the relay transmit power, d_1 and d_2 are the distance from the BS to the user and from the relay to the user, respectively. Since P_B and P_R are constants:

$$\frac{d_1^4}{d_2^4} = \frac{P_B}{P_R} = constant; \tag{3.3}$$

since d_1 and d_2 are constant as well.

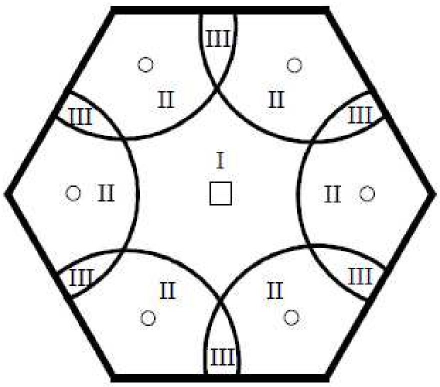

Figure 3.1. BS-relay selection boundary in distance-based algorithm

The solution of this equation is a circle and its boundary is dependent on the ratio of P_B/P_R. Figure 3.1 shows the selection boundary of the BS and six relays in a hexagonal cell.

The six arcs show the boundaries where the user receive its signal from the BS and relays are identical. Three regions are marked in Figure 3.1. In the region I, the receiving signal from the BS is greater than the receiving signal from the relay therefore the user selects to receive its signal from the BS. In the region II and III, the receiving signal from the relay is greater than the receiving signal from the BS therefore user selects to receive its signal from the closest relay (Hu 2004).

3.1.2. Pathloss-based Algorithm

The pathloss-based algorithm is supposed to have better results than a distance-based algorithm. The pathloss-based algorithm has two steps:

1. Calculate all the distance from the user to the relays and the BS and select the BS then three relays which are closest to the user in the main cell.

2. Compute the pathloss between three closest relays and the user and between the BS and the user. The node with the least pathloss is responsible for transmitting the signal for that user (Hu 2004).

$$n_s = argmin(PL_{R_1}, PL_{R_2}, PL_{R_3}, PL_{BS} - \beta) \tag{3.4}$$

where n_s is the selected node and $\beta = 10log_{10}(\frac{P_{BS}}{P_R})$

3.1.3. Pathloss-SINR Based Algorithm

In this thesis, the pathloss-SINR based algorithm is chosen when an user receives its signal from the BS or relays. The pathloss-SINR based algorithm has four steps:

1. Calculate all the distance from the user to the relays and select three relays which are closest to the user in the main cell. Then, calculate all the distance from the corresponding co-channel relays of the neighboring cells to the user.

2. Calculate all the pathloss values from selected three closest relays to the user and the corresponding co-channel relays of neighboring cells to the user using the given formula in (2.13). (Assuming that the user receives its signal from the corresponding relay)

3. Calculate all the pathloss values from the base station to the user and the base station of the neighboring cells to the user using the formula given in (2.13). (Assuming that the user receives its signal from the base station)

4. Compute the SINR between the three closest relays and the user, and between the BS and the user. The maximum SINR will be responsible for transmitting signals for the user.

Figure 3.2 shows that a user listens to the three closest relays and the BS in pathloss-SINR based algorithms. The relay selection is made among these four candidates. In the Figure, the yellow point sign represents a user.

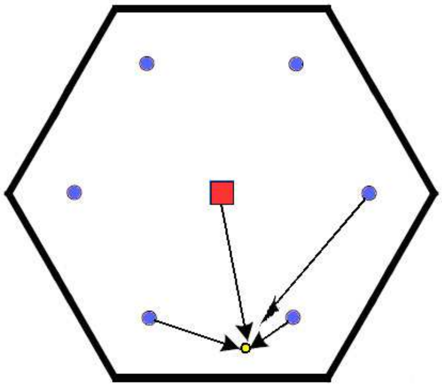

Figure 3.2. Pathloss-SINR based algorithm

$$n_s = \arg\max(SINR_{R_1}, SINR_{R_2}, SINR_{R_3}, SINR_{BS}) \tag{3.5}$$

3.2. Simplified Interferences Analysis

For no relaying case of the cluster size of $N = 4$, user receives its signal directly from its served BS of the cell that the user is allocated inside. The total interference is calculated as:

$$P_{INT} = \sum_{i=1}^{6} \sum_{c} \frac{P_B}{PL(d_{ic})} \tag{3.6}$$

where P_B is the transmission power of the BS of the corresponding cell, d_{ic} is the distance between the user and the co-channel BSs of the neighboring cells and $PL(d_{ic})$ is the pathloss for the distance d_{ic}. In these equation c represents the corresponding cell. Figure 3.3 shows the interferences received from the co-channel BSs. The SINR is calculated as:

$$SINR = \frac{\frac{P_B}{PL(L_{Bc})}}{\sum_{i=1}^{6} \sum_{c} \frac{P_B}{PL(d_{ic}) + P_N}} \tag{3.7}$$

where L_{Bc} is the distance between the user and its served BS, $PL(L_{Bc})$ is the pathloss for the distance L_{Bc} and P_N is the noise power.

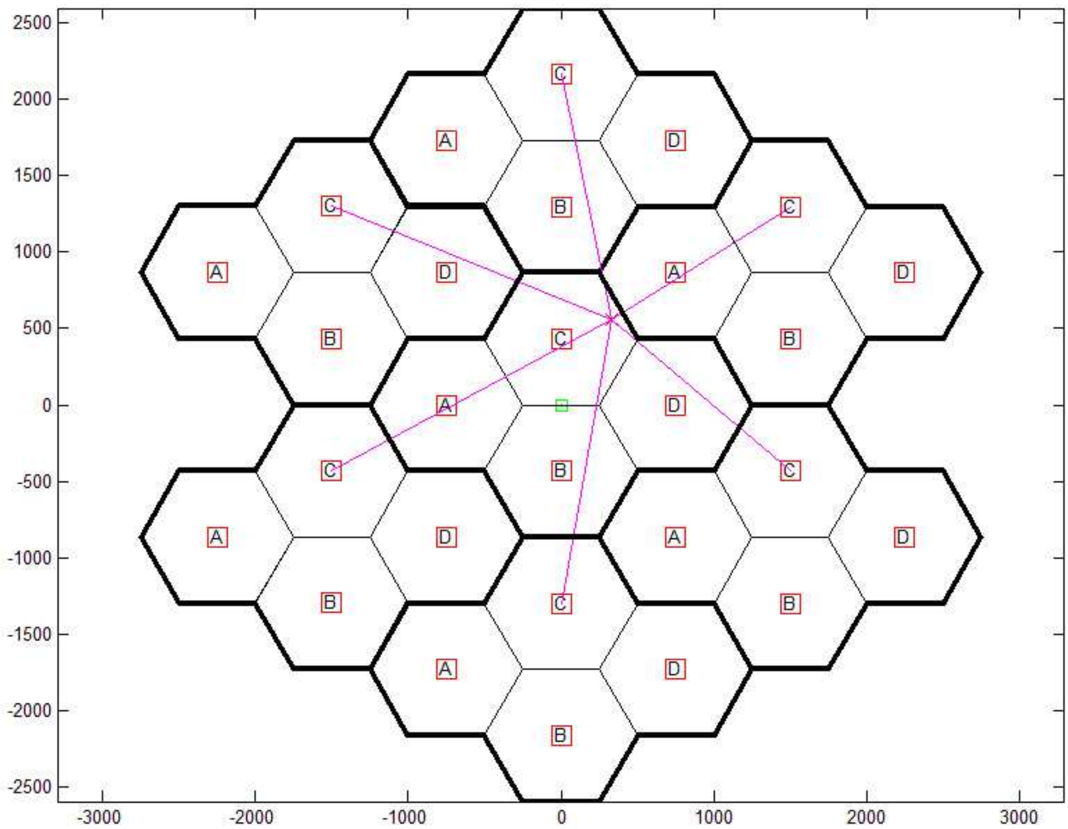

Figure 3.3. Interferences received by the user from the co-channel BS without relaying $(N = 4)$

For $N = 4$ relaying cases, the received signal can be either from the BS or from the relay. The interference power is different from no relaying case, because it is needed to consider the co-channel interference from other relays of neighboring cells and the interference generated by the co-channel BSs. Here, the worst case scenario in calculating the interference is considered. It is assumed that all relays can be used all channels to transmit signals. the total interference is calculated as:

$$P_{INT} = \sum_{i=1}^{6} \sum_{b} \frac{P_R}{PL(d_{ib})} + \sum_{i=1}^{6} \sum_{c} \frac{P_B}{PL(d_{ic})} \tag{3.8}$$

where P_R is the transmission power of relay, d_{ic} is the distance between the user and co-channel BSs, d_{ib} is the distance between the user and the dominant interference source relays, $PL(d_{ib})$ represents the pathloss at distances d_{ib}, $PL(d_{ic})$ is the pathloss at distances d_{ic}, i represents the neighboring cell number, b represents the interference source relays numbers in the neighboring cells, c represents its served BS and $1-6$ represent the six relays in each cell.

If the received signal is coming from the BS, the SINR in the inner zone is calculated as:

$$SINR_{INNER} = \frac{\frac{P_B}{PL(L_{Bc})}}{P_{INT} + P_N} \tag{3.9}$$

If the received signal is coming from the relay that the user communicates, the SINR in the outer zone is calculated as:

$$SINR_{OUTER} = \frac{\frac{P_R}{PL(L_{Rb})}}{P_{INT} + P_N} \tag{3.10}$$

where P_R is the transmission power of the relay which transmits the signal , L_{Rb} is the distance between the user and its served relay and $PL(L_{Rb})$ is the pathloss for distance L_{Rb}. The capacity is calculated as:

$$T = \frac{W}{CN} log_2(1 + SINR) \tag{3.11}$$

where W is the bandwidth and CN is the total channel number. We set C as 6.

Figure 3.4 and 3.5 show the interference sources from the co-channel BSs and corresponding relays. In these figures, the solid lines indicate the interference received by the user from co-channel BSs using the same channel and the dotted lines indicate the interferences received by the user from the co-channel relays of neighboring cells.

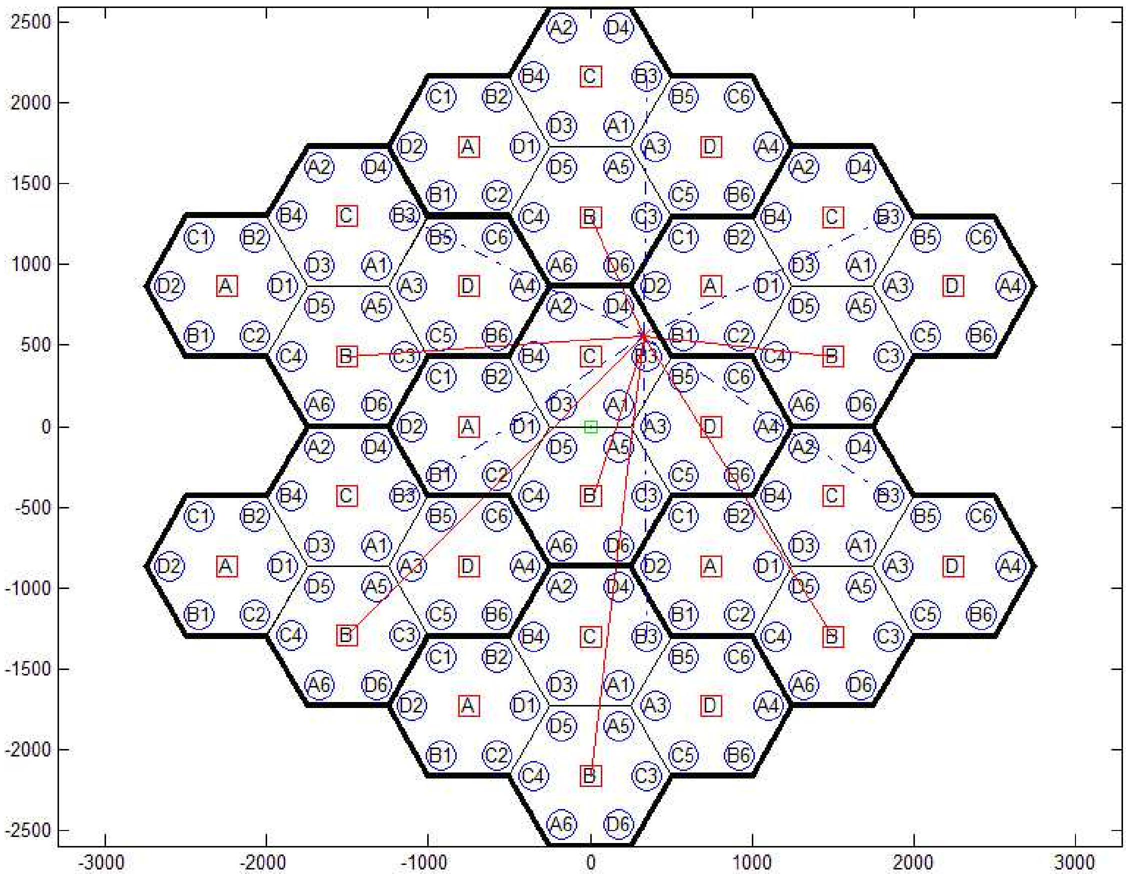

Figure 3.4. Interferences received by the user from the co-channel BSs and relays for $N = 4$ (the user is in the outer zone)

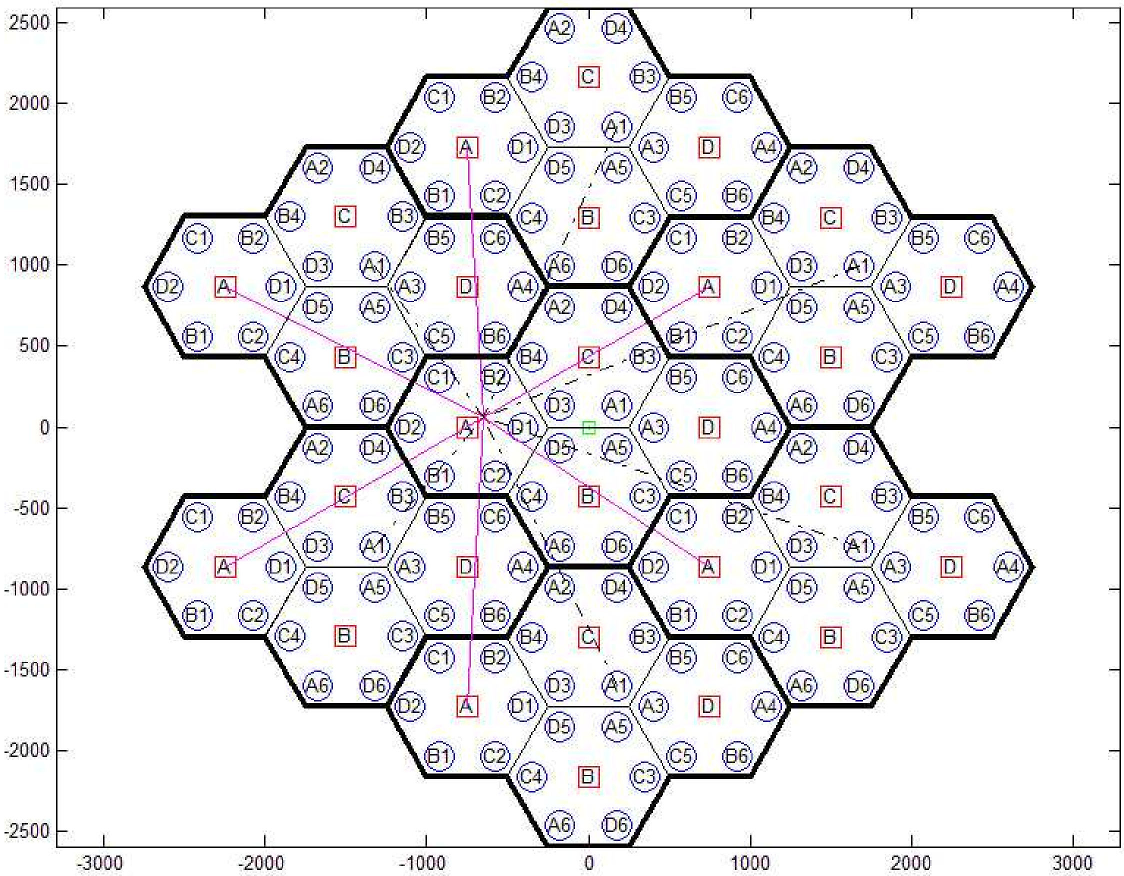

Figure 3.5. Interferences received by the user from the co-channel BSs and relays for $N = 4$ (the user is in the inner zone)

For no relaying cases of $N = 1$, user receives its signal directly from the BS. The total interference is calculated as:

$$P_{INT} = \sum_{i=1}^{6} \frac{P_B}{PL(d_{i0})} \tag{3.12}$$

where d_{i0} is the distances from user to the co-channel BSs and $PL(d_{i0})$ is the pathloss for distances d_{i0}. Figure 3.6 shows the interference received from the co-channel BSs of the neighboring cells. Now, SINR can be calculated as:

$$SINR = \frac{\frac{P_B}{PL(L_{B0})}}{\sum_{i=1}^{6} \frac{P_B}{PL(d_{i0})} + P_N} \tag{3.13}$$

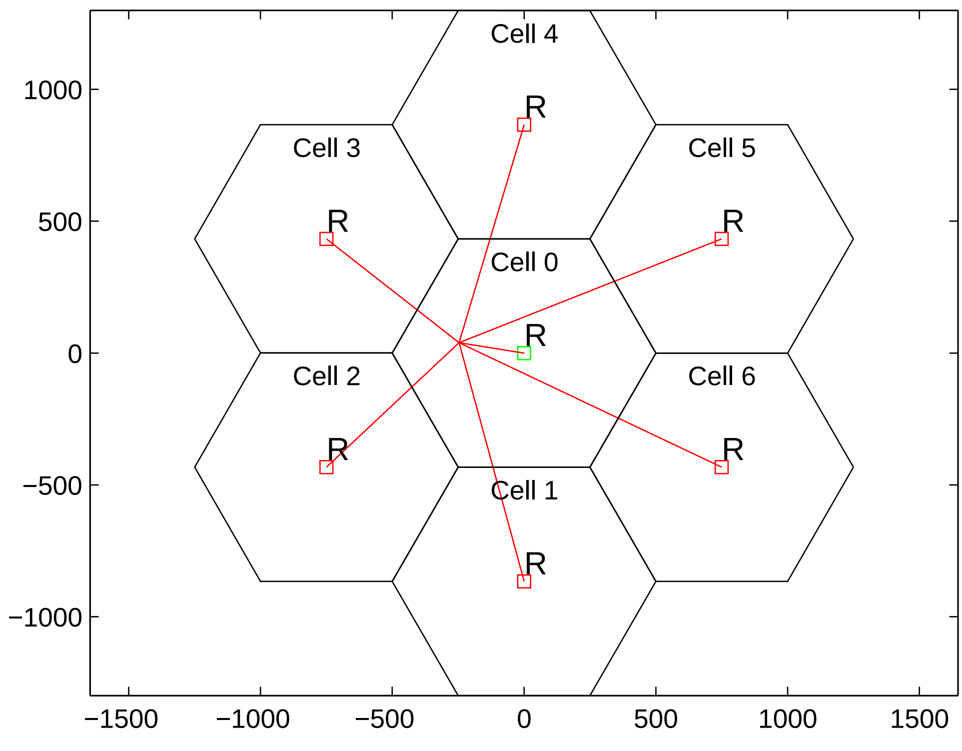

Figure 3.6. Interferences received from the co-channel BSs without relaying $(N = 1)$

For relaying cases of the cluster size of $N = 1$, the received signal can be either from the BS or from the relay which the user communicates. The interference power is different from the no relaying case, because it is needed to consider the interference from other relays of the neighboring cells using the same channel in addition to the interference generated by the co-channel BSs. The worst case scenario in calculating the interference is considered, it is assumed that all the relays are using all channels to transmit the signals. The total interference is calculated as:

$$P_{INT} = \sum_{i=1}^{6} \sum_{b} \frac{P_R}{PL(d_{ib})} + \sum_{i=1}^{6} \frac{P_B}{PL(d_{i0})} \tag{3.14}$$

If the received signal is from the BS, the SINR in the inner zone is calculated as:

$$SINR_{INNER} = \frac{P_B/PL(L_{B0})}{P_{INT} + P_N} \tag{3.15}$$

where L_{B0} is the distance between the user and its served BS, $PL(L_{B0})$ is the pathloss for the distance L_{B0}.

If the received signal is from the corresponding relay on which node the user is communicating, SINR in the outer zone is calculated as:

$$SINR_{OUTER} = \frac{P_R/PL(L_{R0})}{P_{INT} + P_N} \tag{3.16}$$

where L_{R0} is the distance between the user and its served relay and $PL(L_{R0})$ is the pathloss for the distance L_{R0}. The capacity is calculated as:

$$T = \frac{W}{CN} log_2(1 + SINR) \tag{3.17}$$

where W is the bandwidth and CN is the total channel number. For the cluster size of $N = 1$, CN is set to 6 .

Figure 3.7 and 3.8 show the interference sources from co channel BSs and the corresponding relays. In these figures, the solid red lines indicate the interference received by the user from the co-channel BSs, the dotted blue lines indicate the interferences received

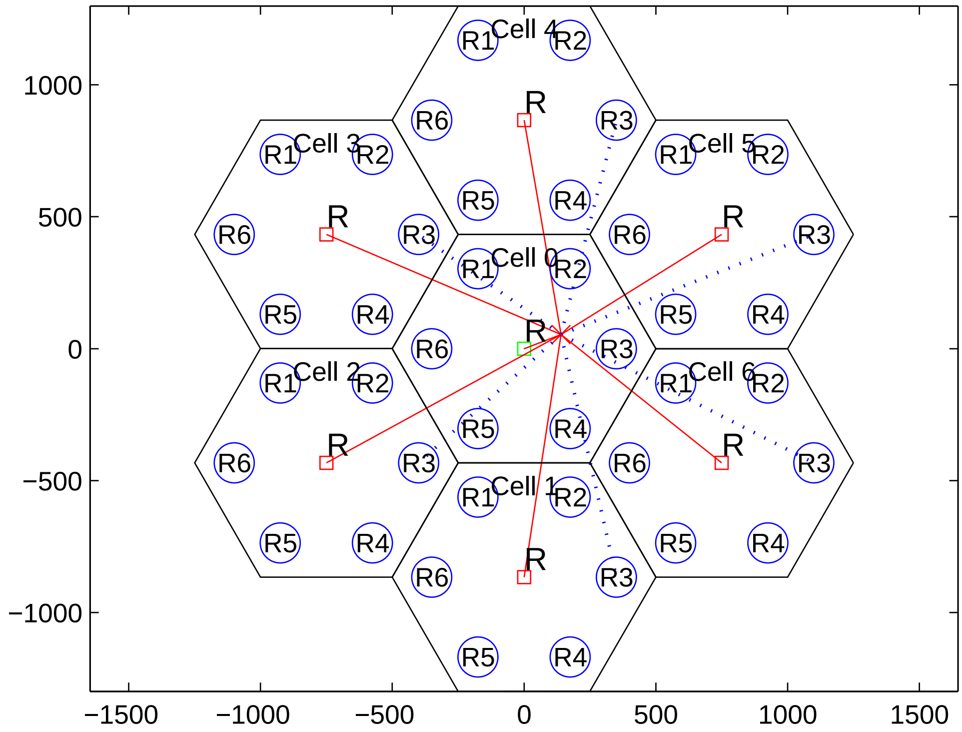

Figure 3.7. Interference received by the user from other BSs and relays for $N = 1$ (the user is in the inner zone)

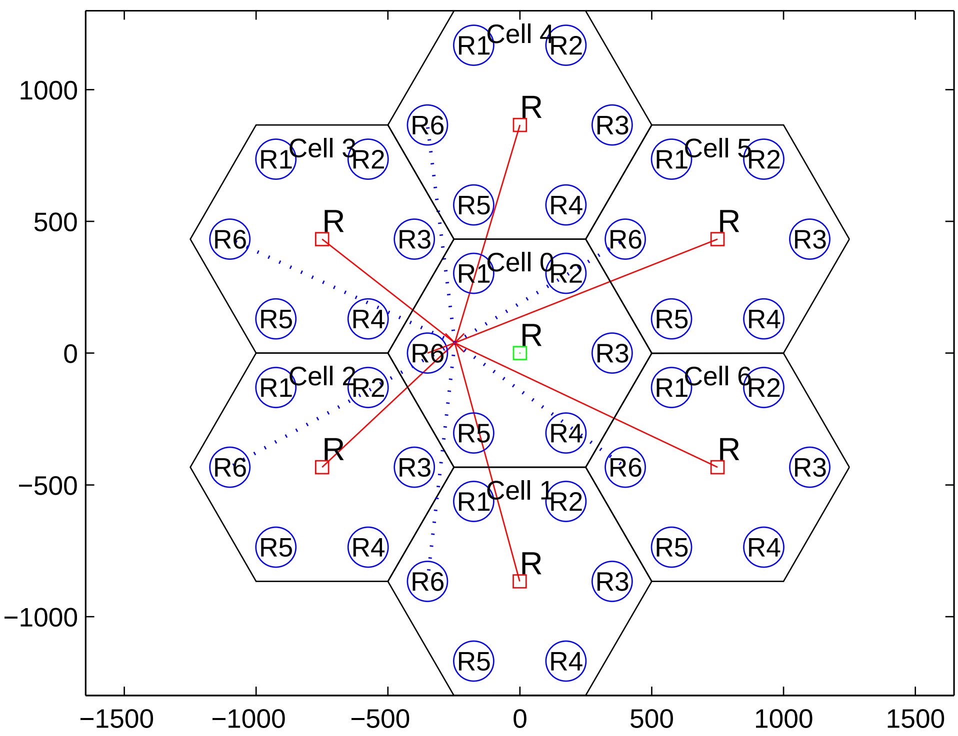

Figure 3.8. Interference received by user from other BSs and relays for $N = 1$ (the user is in the outer zone)

by the user from the relays in other clusters using the same channel. The intersection point represents the user.

3.3. Simulation Results

Table 3.1 gives a list of main simulation parameters used through simulation performances. These parameters are widely used to simulate the wireless cellular networks.

Table 3.1. Parameter List

Parameter	Values
Carrier Frequency	2 GHz
Transmission Bandwidth	10 MHz
Pathloss Propagation Exponent n	3.7
Simulation Area	Hexagonal Cell with Cell Radius $R = 500m$ $R = 1000m$ and $R = 1500m$
Cluster size	$N = 1$ and $N = 4$
Noise Figure	-174 dBm/Hz
Base Station Power P_B	10W
Relay Transmit Power P_R	0.1 W, 0.3 W, 1 W, 2 W
Antennas	Isotropic Antennas with Unit Gain
Relay Position	$0.1R$ to $1R$
Number of Relay	$i = 6$ for each cell
Fading	1-step Rayleigh fading channel

3.3.1. Relay Based Algorithm Structure

Figure 3.9 and Figure 3.10 show the flowcharts used to evaluate in the simulation performances. Firstly, one user is generated by the computer. After generated one user,it

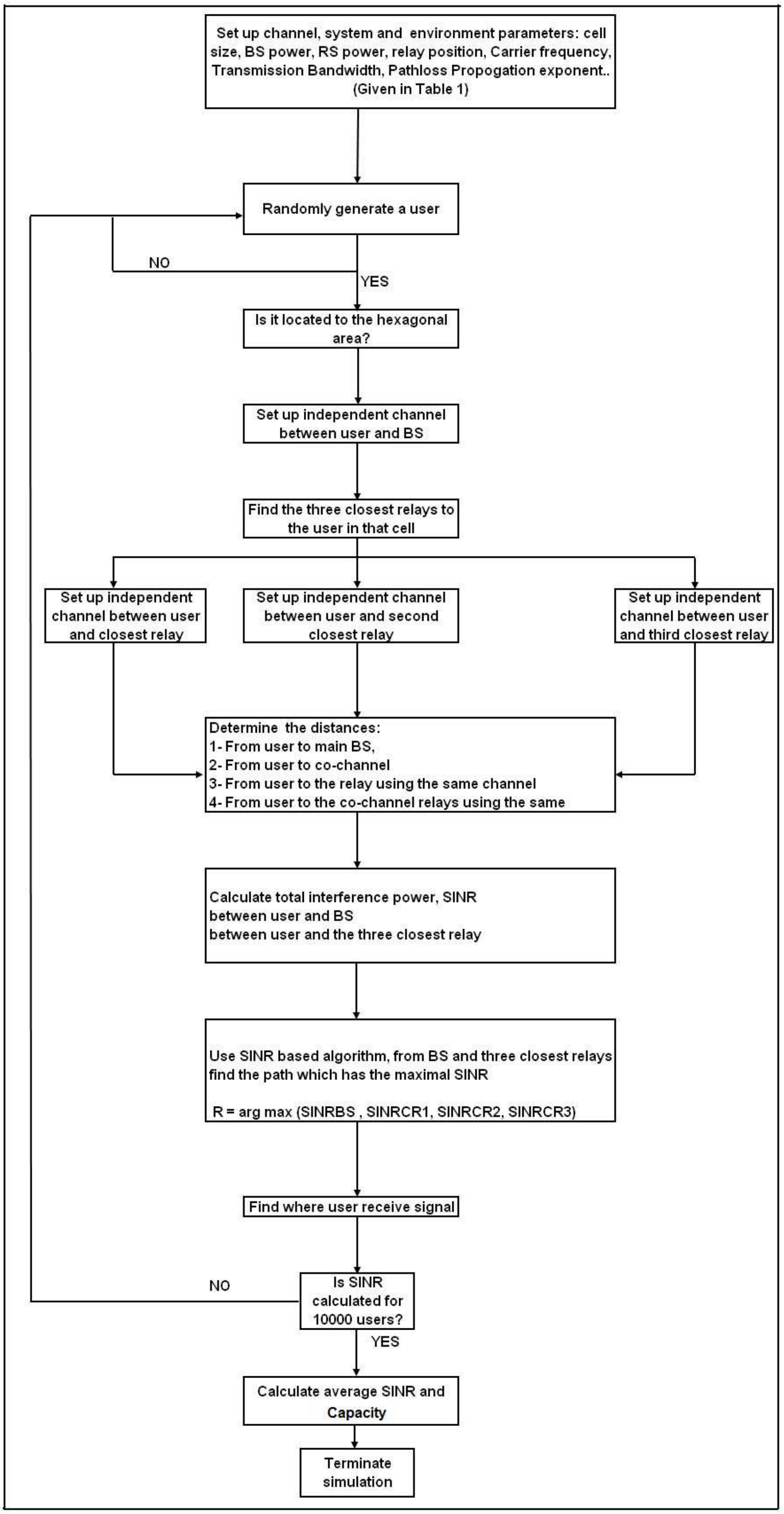

Figure 3.9. General flowchart for average capacity performances

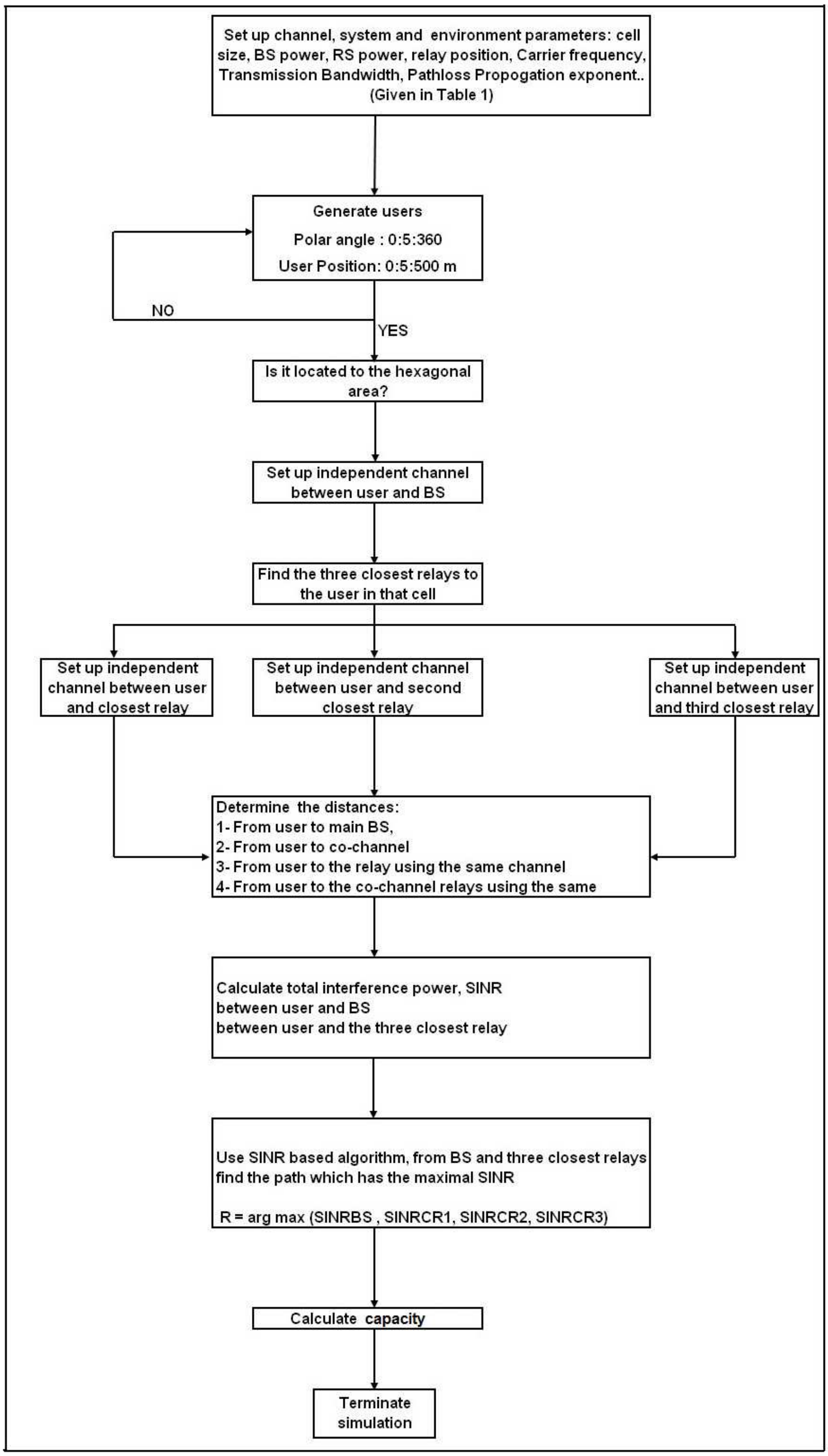

Figure 3.10. Flowchart for relay effects in wireless networks

is checked if it is inside of the hexagonal cell or not, determined all the interferences sources and calculated the SINR and the capacity according to the pathloss-SINR based algorithm as described in the section 3.1.3. These steps are applied for each users in the cell. Totally, it is generated 10000 users. At the second flowcharts, all channel parameters are determined and six relays are placed in each cell. After, the location of users is generated non-uniformly in the cell by setting the polar angle. Then, it is calculated the SINR and the capacity for all of user positions inside of the cell for no-relay and with relay cases.

3.3.2. Average Capacity With Respect to The Relay Position

Optimum relay positions are calculated considering different relay power values. As discussed in section 2.4, each relay is located on the line that connects the center of the cell. Here, relay position is indicated by a parameter r showing how far away the relay from the BS. Please refer to Figure 2.3.

$$r = \frac{R_1}{R} \tag{3.18}$$

where R_1 is the distance from the BS to the relay, R is the distance from the BS to one corner of the cell. r values are examined for the range of 0.1 to 1 and at the relay power values of 2 W, 1 W, 0.3 W, 0.1 W. The base station power is set to a fixed value of 10 W. The cluster diameter is set to a fixed value of $1000m$. The flowchart for this simulation is drawn in Figure 3.9.

Figure 3.11, Figure 3.12, Figure 3.13 and Figure 3.14 show the average capacity with respect to the relay position for different relay powers for the cluster size of $N = 4$. Simulation results show that $r = 0.73$ gives the maximum capacity value for the relay power range of 0.1W to 2W. For the relay power smaller than 0.1W, $r = 0.76$ gives the maximum capacity. It is observed that the range of 0.7 to 0.8 is the optimum relay location range for the cluster size of $N = 4$.

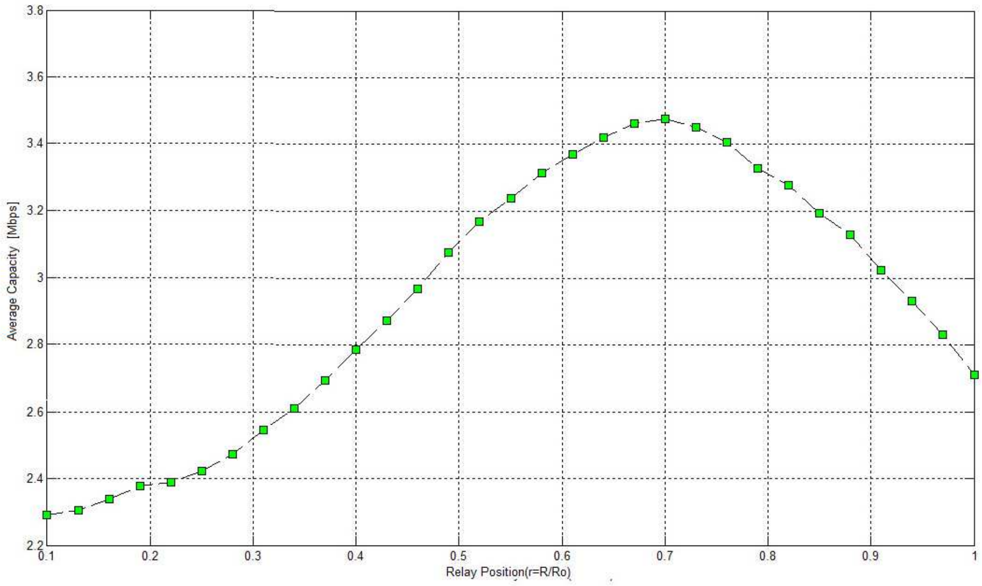

Figure 3.11. Average capacity with respect to the relay positions for the cluster size of $N = 4\,(P_R = 2W)$

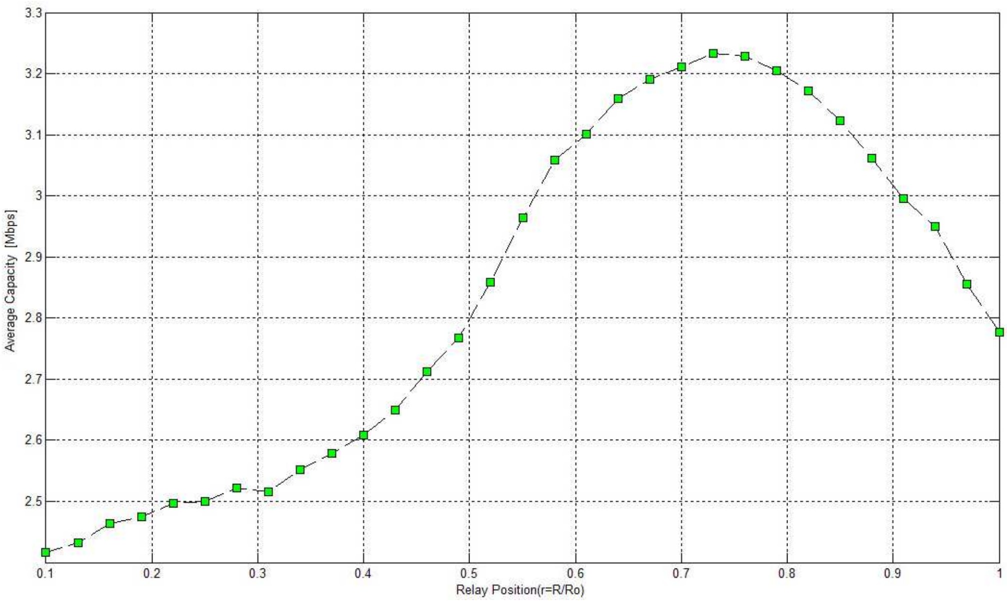

Figure 3.12. Average capacity with respect to the relay positions for the cluster size of $N = 4\,(P_R = 1W)$

Figure 3.15, Figure 3.16, Figure 3.17 and Figure 3.18 show the average capacity with respect to the relay position at different relay powers for the cluster size of $N = 1$. It is observed that the relay location is dependent on the relay power. Relays must be located to the r value range of 0.6 to 0.8 for the cluster size of $N = 1$.

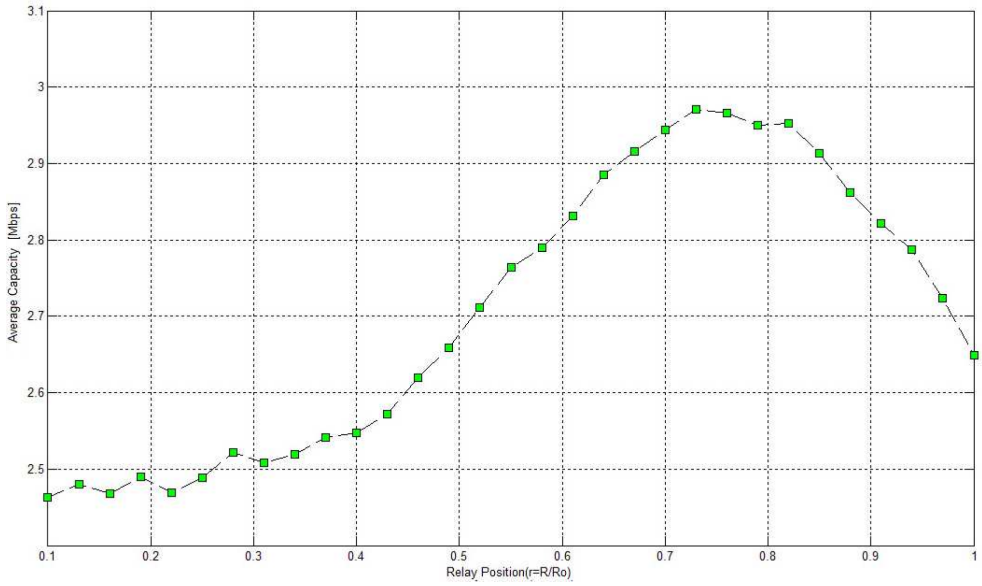

Figure 3.13. Average capacity with respect to the relay positions for the cluster size of $N = 4\ (P_R = 0.3W)$

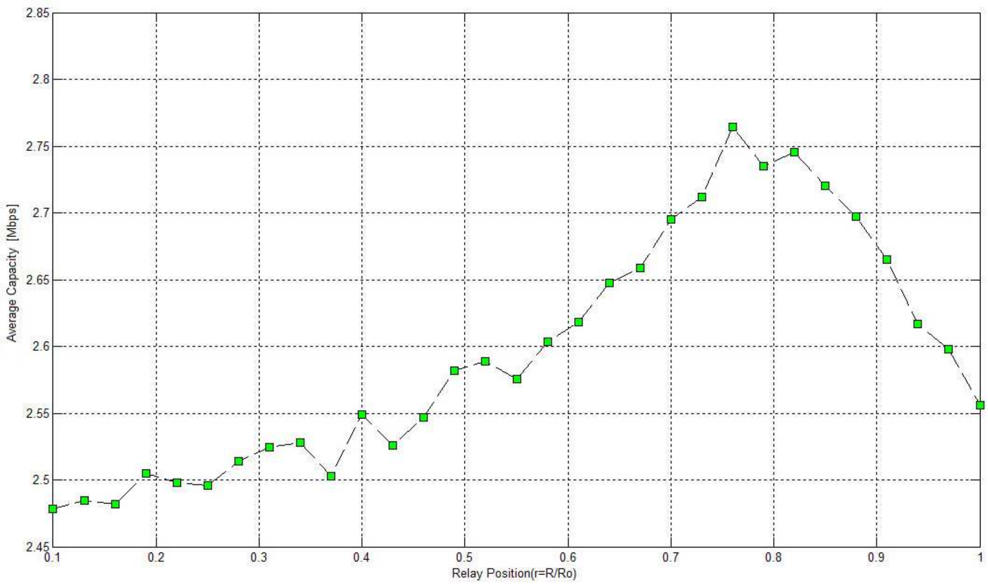

Figure 3.14. Average capacity with respect to the relay positions for the cluster size of $N = 4\ (P_R = 0.1W)$

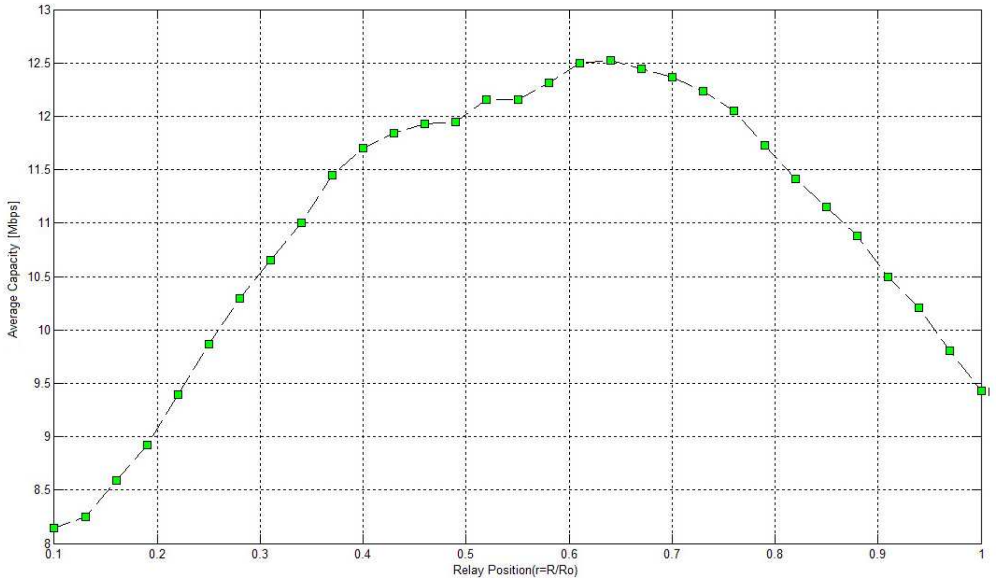

Figure 3.15. Average capacity with respect to the relay positions for the cluster size of $N = 1$ $(P_R = 2W)$

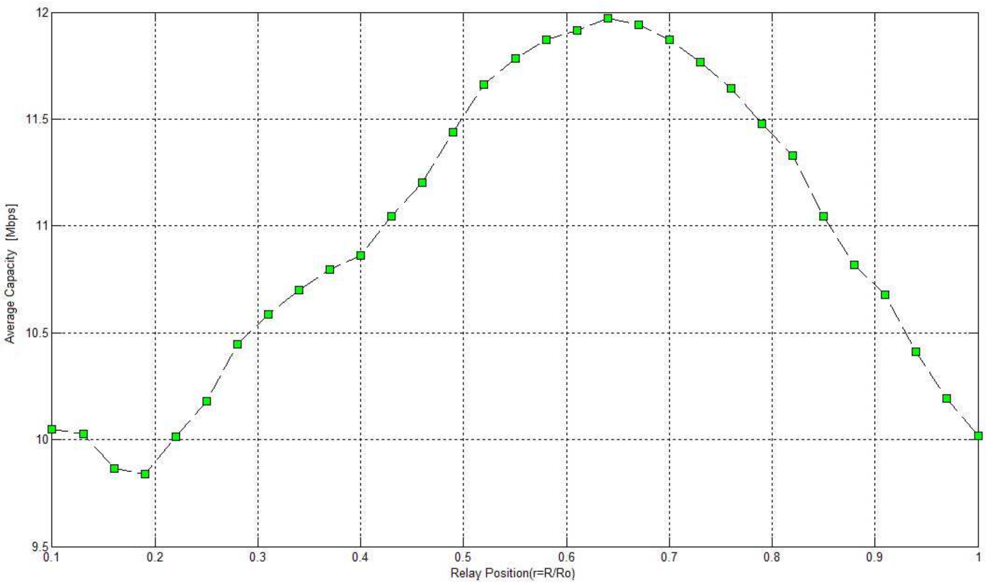

Figure 3.16. Average capacity with respect to the relay positions for the cluster size of $N = 1$ $(P_R = 1W)$

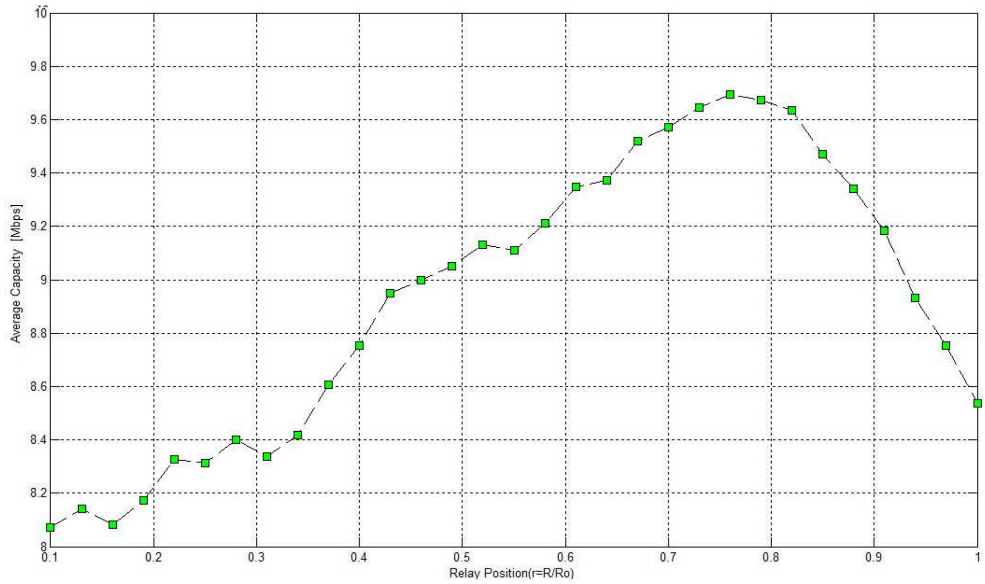

Figure 3.17. Average capacity with respect to the relay positions for the cluster size of $N = 1$ ($P_R = 0.3W$)

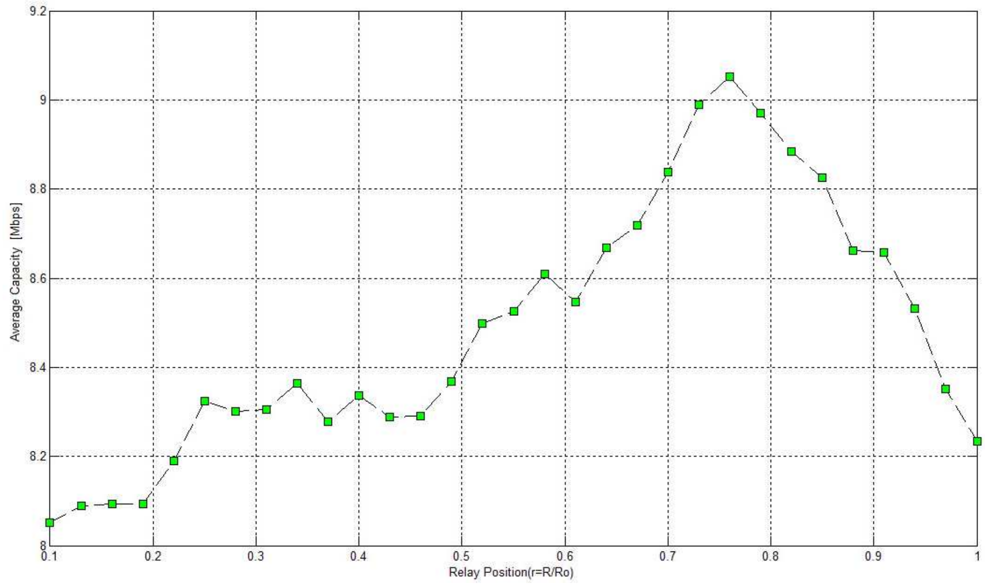

Figure 3.18. Average capacity with respect to the relay positions for cluster size of $N = 1$ ($P_R = 0.1W$)

3.3.3. The Effect of Relays in Wireless Networks

At this part, the effect of relays is investigated for the cluster sizes of $N = 1$ and $N = 4$. Please refer to the Figure 3.10 for the flowchart algorithm.

Figure 3.19 and Figure 3.20 show the SINR performance of users inside of the cell for no relaying and with relaying cases, respectively. Important SINR performance improvement is observed at the cell edge.

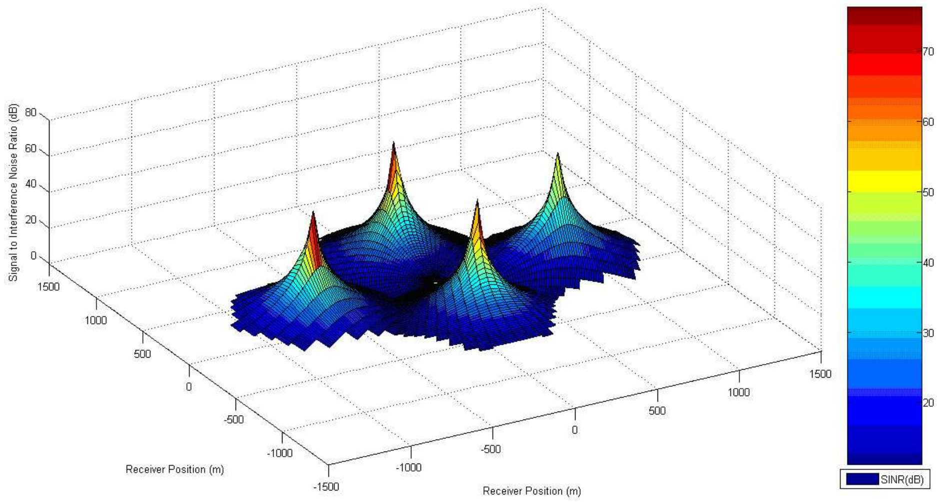

Figure 3.19. SINR in the cell without relay

Figure 3.21 shows the capacity of no relaying and relaying cases along the distance from the cluster center point to the cell edge at the fixed angle of 0 radian. The center point refers to the center of gravity of the structure consisting of four hexagonal cells. It is observed that the capacity is increased drastically near the edge (The performance gain from 1.58 Mbps to 3.05 Mbps for the user distance of 1240 m). In addition, approximately 90% percentage capacity gain is seen at the cell edge.

The capacity along different angles for no-relay and relaying cases are shown in Figure 3.22 and 3.23. The angles are chosen from 0 radian to $11\pi/36$ radian with $\pi/36$ radian increment on the counterwise direction. The capacity values for users outside of the cell are not showing in figures. Figure 3.24 shows the average capacity for no relaying and relaying cases. In this figure, vertical axes shows the angles from 0 radian to $11\pi/36$ radian with $\pi/36$ radian increment. Nearly 30% percentage average capacity

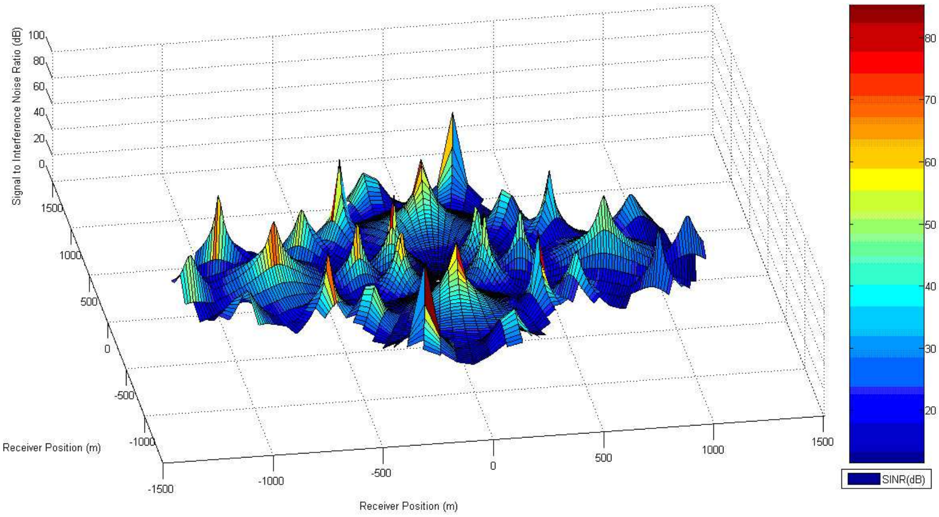

Figure 3.20. SINR in the cell with relay

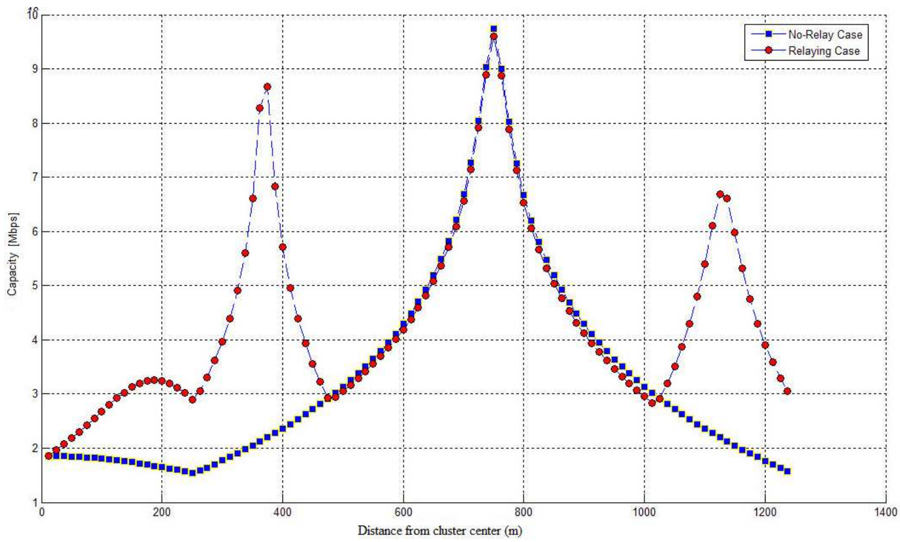

Figure 3.21. Capacity of users from the cluster center for no relaying and relaying cases of the cluster size of $N = 4$ (Cell diameter=$1000m$, maximum cluster distance=$1250m$, $P_B = 10W$,$P_R = 1W$, Fixed Angle)

improvement is provided by using relays as seen in Figure 3.24.

Figure 3.25 and Figure 3.26 show SINR values in a cell area of users inside of the cell for no-relay and relaying cases for the cluster size of $N = 1$, respectively.

Figure 3.27 shows the capacity performance of no-relay and relaying cases along the distance from the BS to the cell edge at the fixed angle of 0 radian. It is observed that the user receives its signal from the relay for the distances greater than 220m. The capacity increases drastically near the edge. (The capacity from 0.94 Mbps to 3.3 Mbps

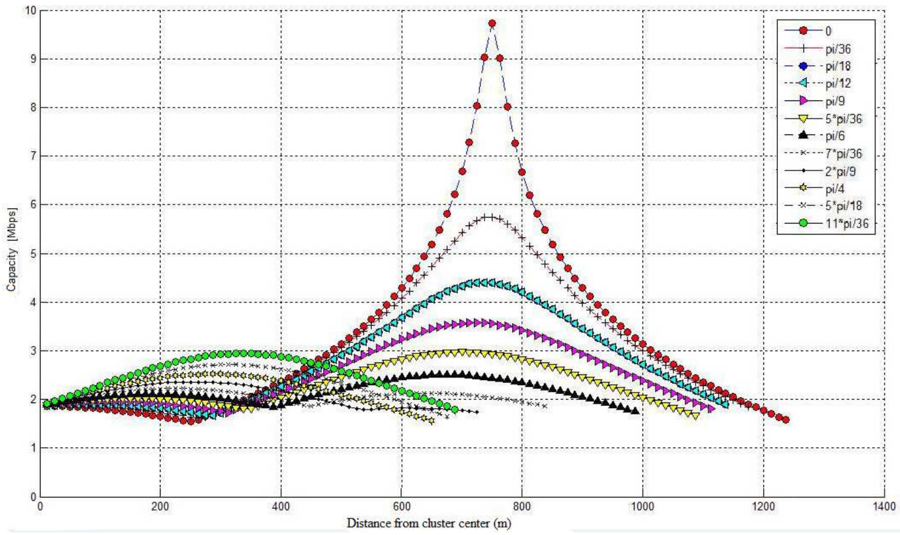

Figure 3.22. Capacity of users from the cluster center for no relaying case along different angles for the cluster size of $N = 4$ (Cell distance=$1000m$, maximum cluster distance=$1250m$, $P_B = 10W$, $P_R = 1W$)

for the user distance of 495 m).

Figure 3.28 and 3.29 show the capacity along different angles for no-relay and relaying cases. Figure 3.30 shows the average capacity for no relaying and relaying cases along different angles. In this figure, the vertical axes indicate the angles from 0 radian to $11\pi/36$ radian with $\pi/36$ radian increment on the counterwise direction. It is observed that 50$\%$ percentage average capacity improvement is provided by using relays.

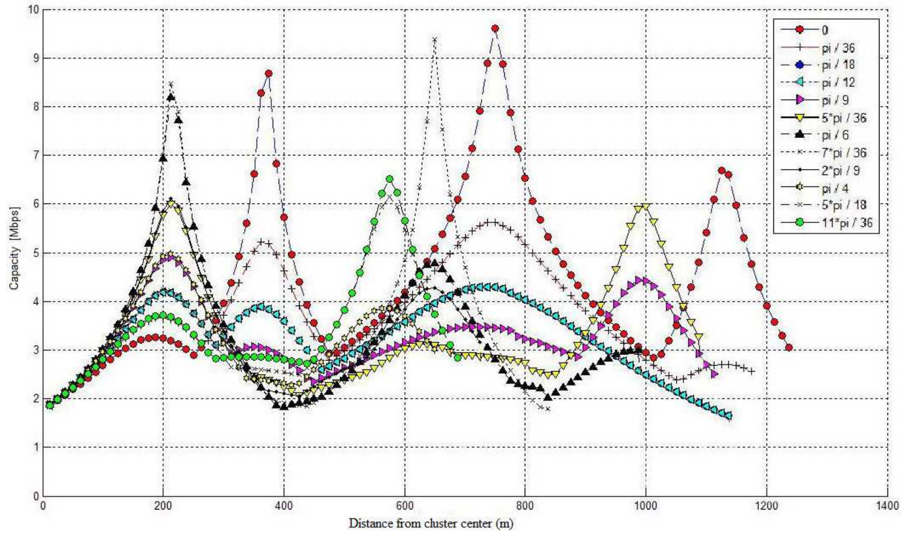

Figure 3.23. Capacity of users for the relaying case along different angles for the cluster size of $N = 4$ (Cell diameter=$1000m$, maximum cluster distance=$1250m$, $P_B = 10W$, $P_R = 1W$)

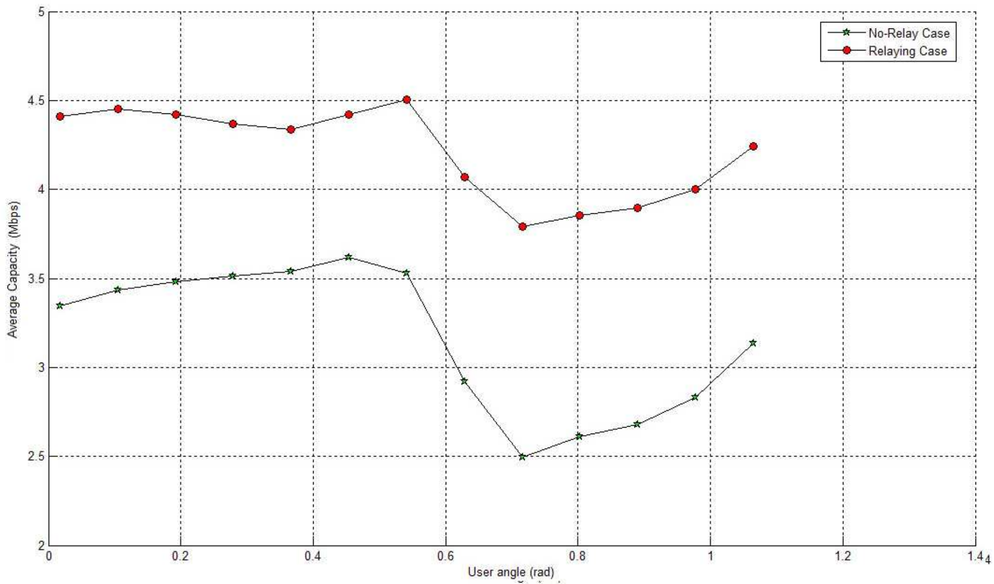

Figure 3.24. Average capacity for no relaying and relaying cases along different angles (rad) for the cluster size of $N = 4$ (Cell diameter=$1000m$, $P_B = 10W$, $P_R = 1W$)

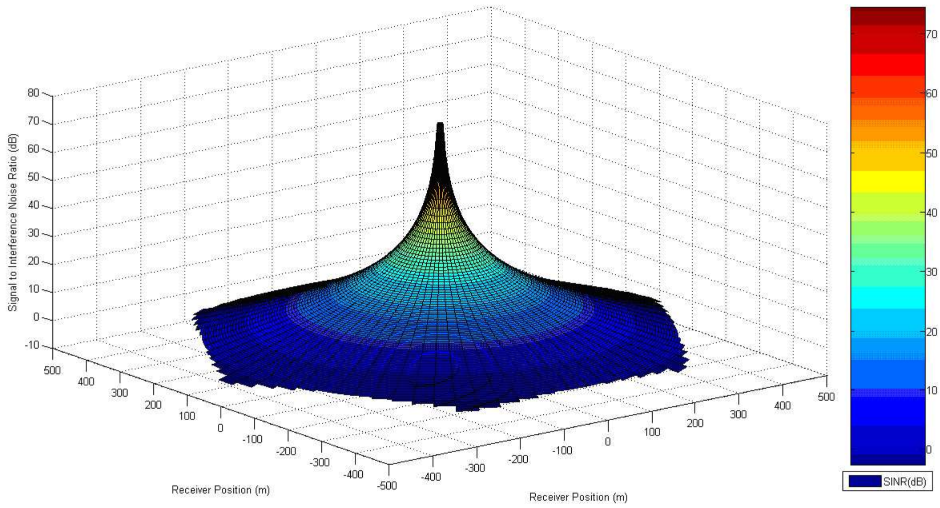

Figure 3.25. SINR in cell for $N = 1$ (No Relaying Case)

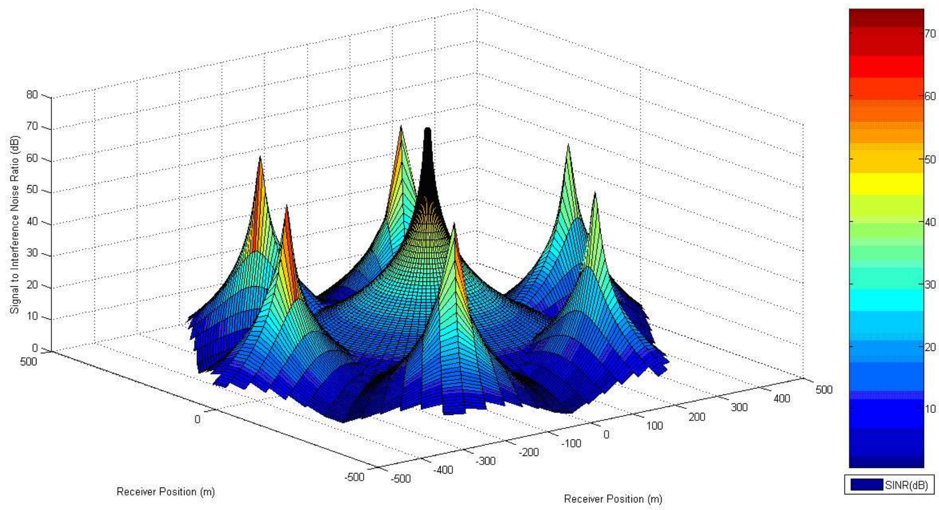

Figure 3.26. SINR in cell for $N = 1$ (Relaying Case)

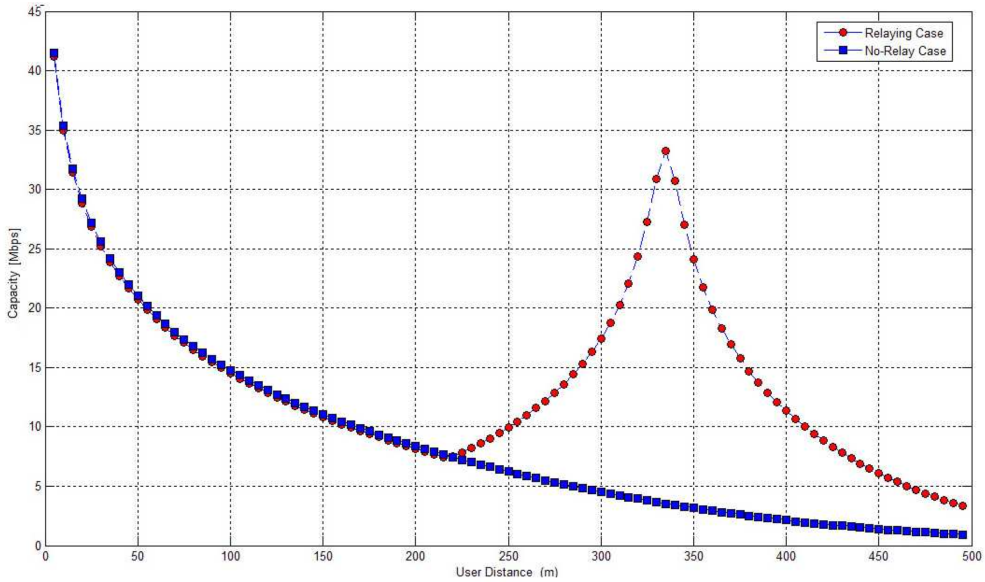

Figure 3.27. Capacity of users for no relaying and relaying cases of the cluster size of $N = 1$ (Cell diameter=$1000m$, $P_B = 10W$, $P_R = 1W$, fixed angle)

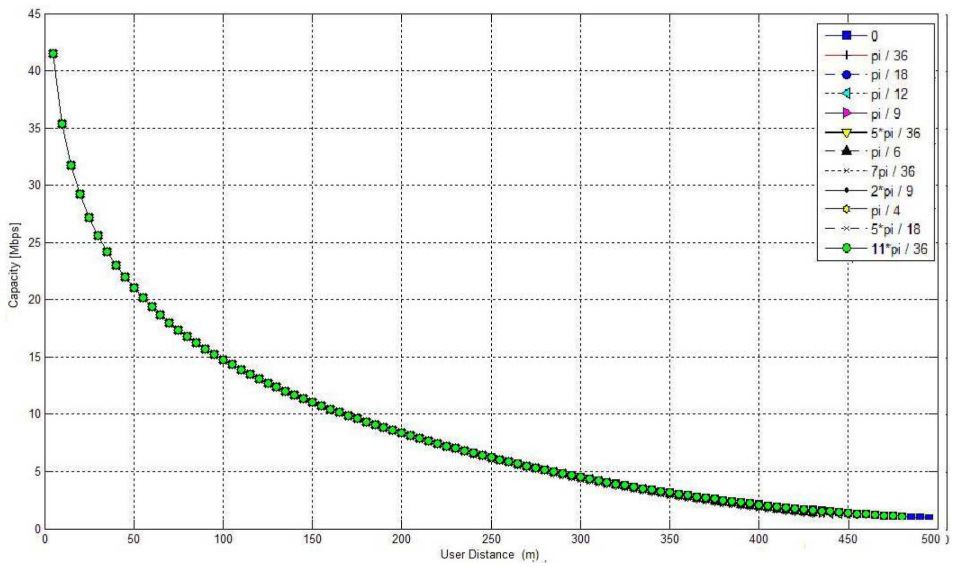

Figure 3.28. Capacity of users for no relaying case along different angles for the cluster size of $N = 1$ (Cell diameter=$1000m$, $P_B = 10W$, $P_R = 1W$)

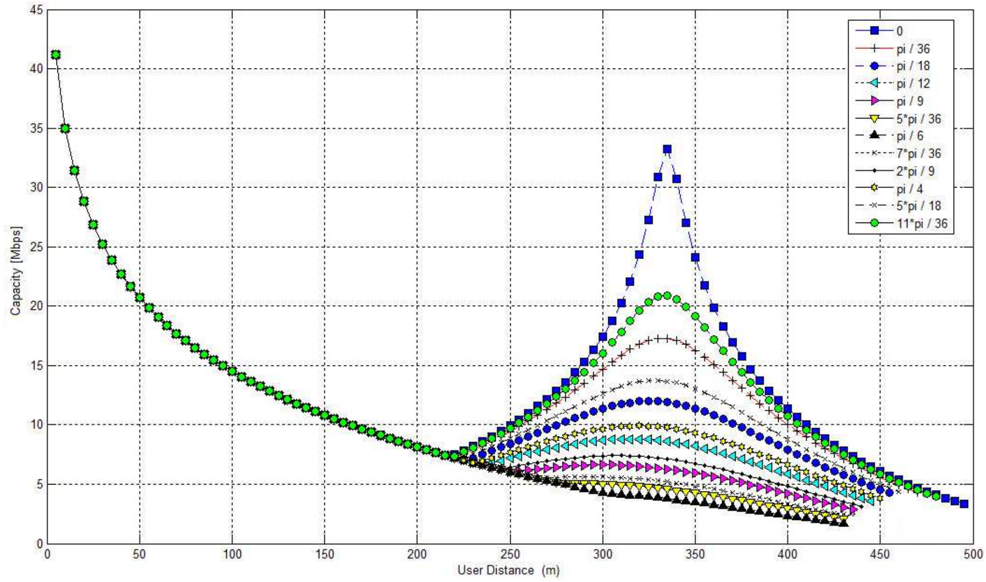

Figure 3.29. Capacity of users for relaying case along different angles for the cluster size of $N = 1$ (Cell diameter=$1000m$, $P_B = 10W$, $P_R = 1W$)

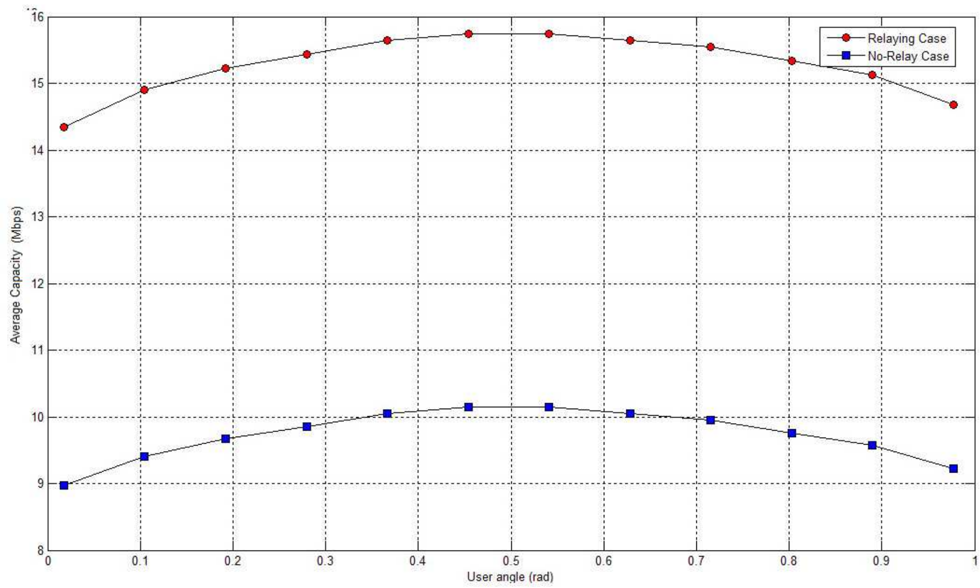

Figure 3.30. Average capacity for no relaying and relaying cases along different angles (rad) for the cluster size of $N = 1$ (Cell diameter=$1000m$, $P_B = 10W$, $P_R = 1W$)

3.3.4. Capacity Performance with Respect to The Relay Powers

In this performance evaluation, relay powers are set to the values from 0.1W to 10W and the average capacity is observed for different relay power levels for a cell diameter of 1000 m, 2000 m and 3000 m, for the cluster sizes of $N = 1$ and $N = 4$. The relay position is fixed to $0.7R$. The relay power is indicated by a parameter r_p showing the ratio of P_R over P_B when the base station power is set to the fixed value of 10W.

$$r_p = \frac{P_R}{P_B} \tag{3.19}$$

where P_R is the relay station transmission powers, P_B is the base station transmission. r_p values are examined for the range of 0 to 1 . Please refer to Figure 3.9 for the algorithm flowchart.

Figure 3.31 shows the average capacity performance with respect to relay powers. It is observed that although the power of relays increases the interference power, small amount of average capacity improvement is observed. An increment of relay power from 0.1W to 1W increase average capacity from 3.32 Mbps to 3.6 Mbps for a cell diameter of 1000m.

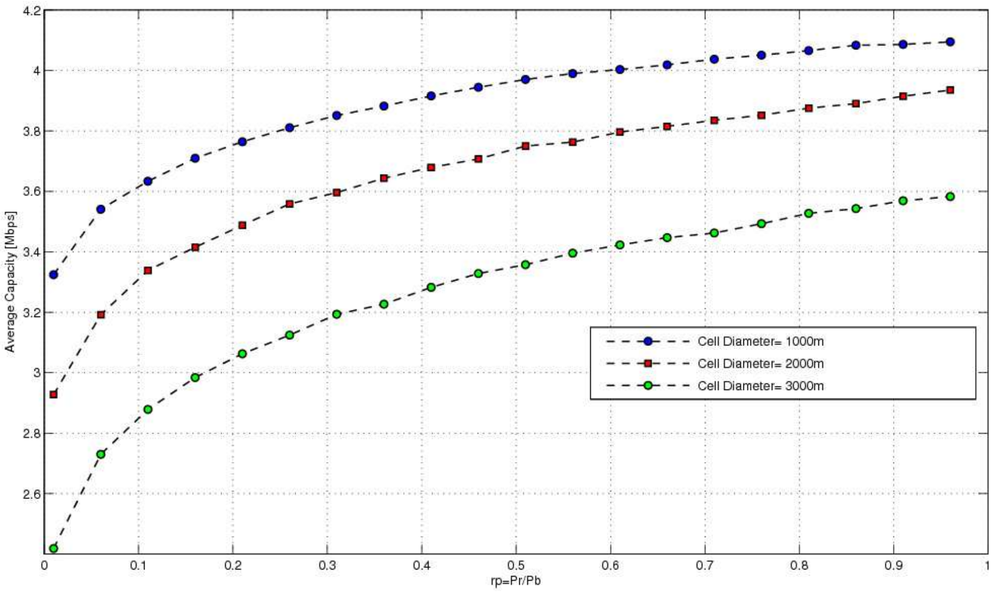

Figure 3.31. Average capacity with respect to the relay powers for the cluster size of $N = 4$ ($P_B = 10W$, cell diameter=$1000m$, $2000m$, $3000m$)

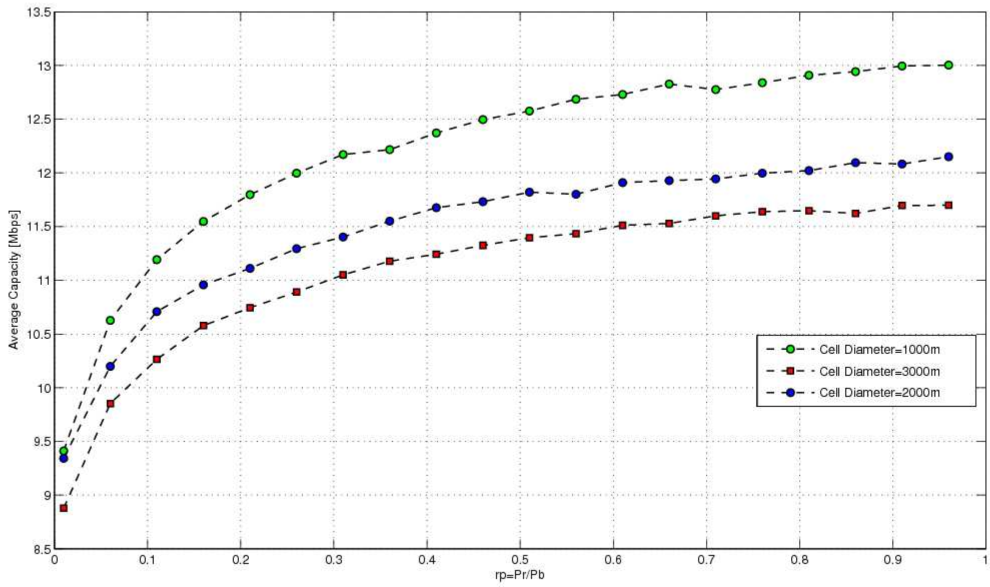

Figure 3.32. Average capacity with respect to the relay powers for the cluster size of $N = 1$ ($P_B = 10W$, cell diameter=$1000m$, $2000m$, $3000m$)

The average capacity performance with respect to the relay power for the cluster size of $N = 1$ is seen in Figure 3.32. The relay power increment from 0.1 W to 10 W increases the average capacity from 9.4 Mbps to 13 Mbps.

Figure 3.33 and Figure 3.34 show the average capacity with respect to huge relay power increases for the cluster sizes of $N = 1$ and $N = 4$. The larger relay power causes larger interference and this decreases the system capacity. The system capacity increases up to the relay power equal 1.5 times greater than base station power for the cluster size of $N = 1$ and 2 times greater than the cluster size of $N = 4$ as shown in Figure 3.33 and Figure 3.34.

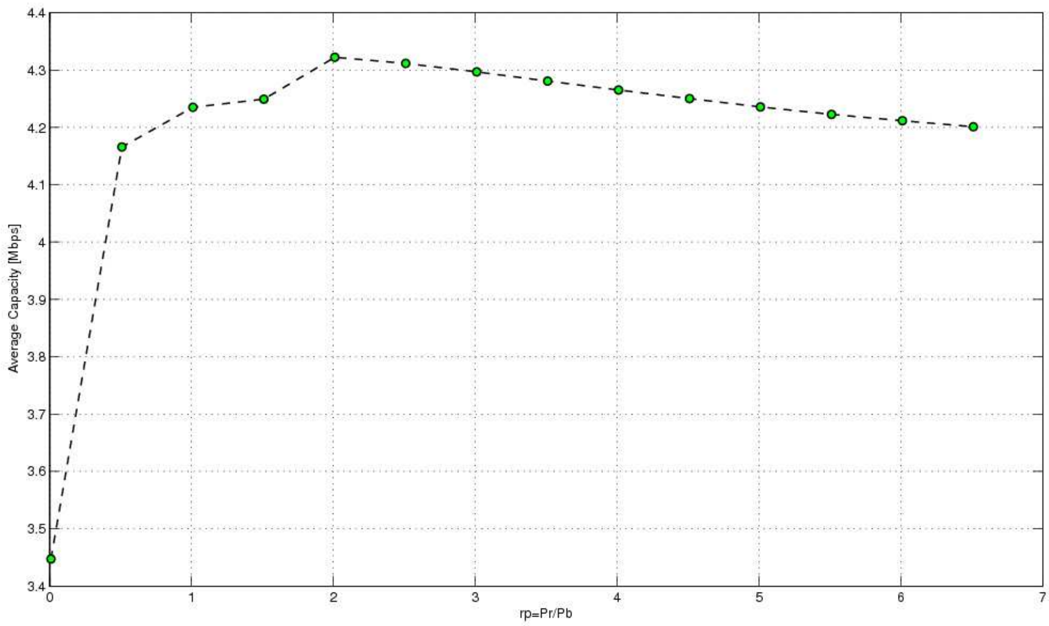

Figure 3.33. Average capacity with respect to the relay powers for the cluster size of $N = 4$ ($P_B = 10W$, cell diameter=$1000m$)

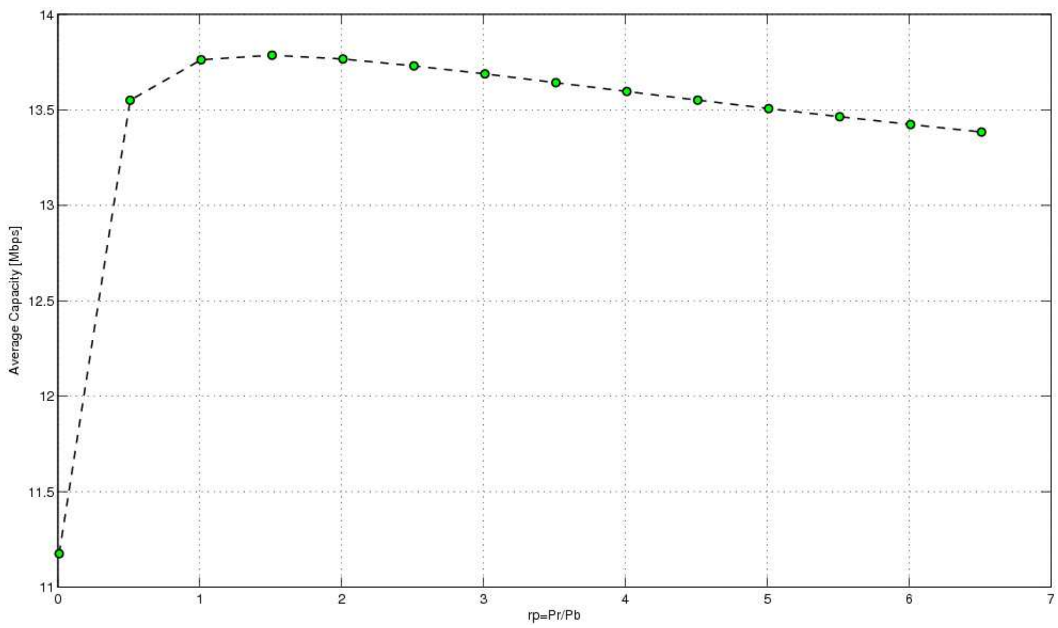

Figure 3.34. Average capacity with respect to the relay powers for the cluster size of $N = 1$ ($P_B = 10W$, cell diameter=$1500m$)

3.3.5. Average Capacity Performance With Respect to The Cell Diameter

In this performance evaluation, the average capacity is observed for different cell diameters. The relay and base station powers are set to fixed values of 1W and 10W, respectively. Please refer to Figure 3.9 for the algorithm flowchart.

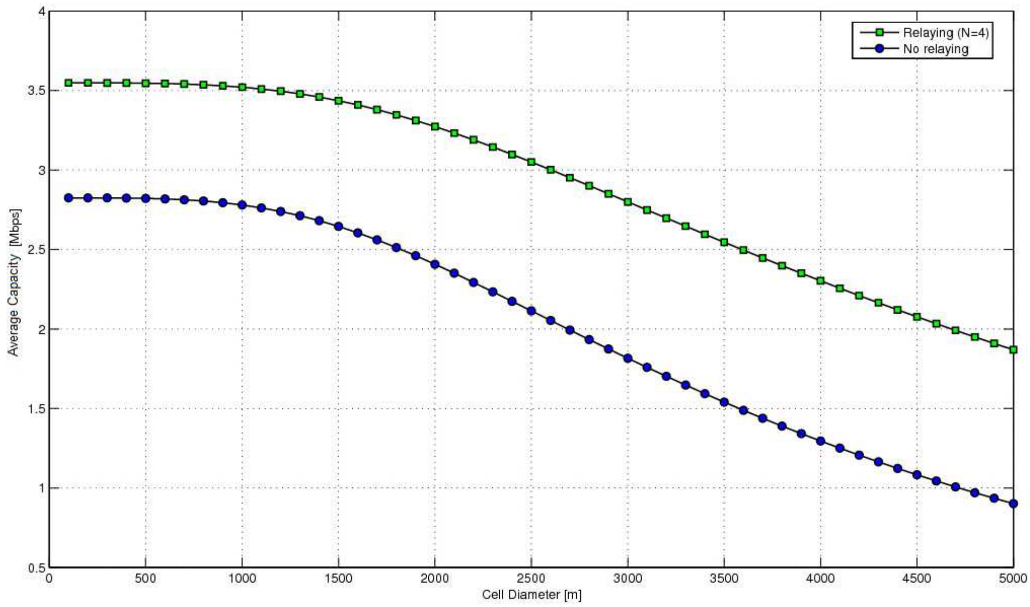

Figure 3.35. Average capacity with respect to the cell diameter ($N = 4$, $P_B = 10W$, $P_R = 1W$)

The average capacity performance of the cell diameter from 100m to 5000m for relaying and no relaying cases of the cluster size $N = 4$ is shown in Figure 3.35 . It is observed that the average capacity is nearly same up to the cell diameter of 1000 m. This value should be the optimum cell diameter for $N = 4$. Figure 3.36 shows the average capacity performance for no relaying and relaying cases of the cluster size of $N = 1$. The average capacity is nearly same for a cell diameter smaller than 1500m and this value should be the optimum cell diameter for $N = 1$.

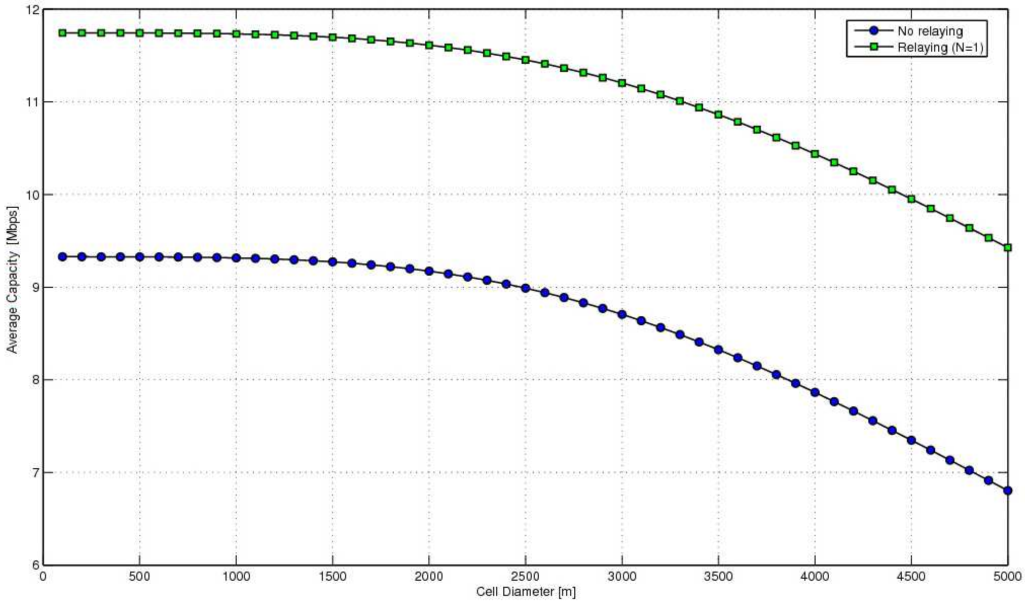

Figure 3.36. Average capacity with respect to the cell diameter ($N = 1$, $P_B = 10W$, $P_R = 1W$)

3.3.6. Pathloss SINR-based Algorithm Effects in Wireless Cellular Networks

In this performance evaluation, the capacity performance of pathloss SINR-based algorithm is compared to the distance based algorithm performance. Figure 3.37 and Figure 3.38 show the average capacity performance comparison of the pathloss SINR-based and distance based algorithms. Nearly, $5\ \%$ average capacity performance is observed for the cluster size of $N = 1$ and $N = 4$.

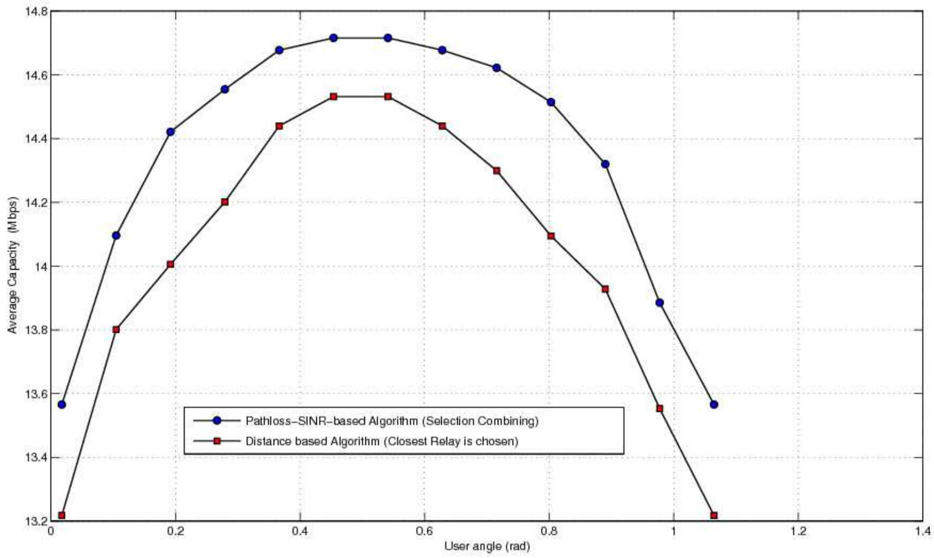

Figure 3.37. Average capacity performance for the pathloss SINR based algorithm and the distance based algorithm along different angles (rad) ($N = 1$, Cell Diameter =$1000m$, $P_B = 10W$, $P_R = 1W$)

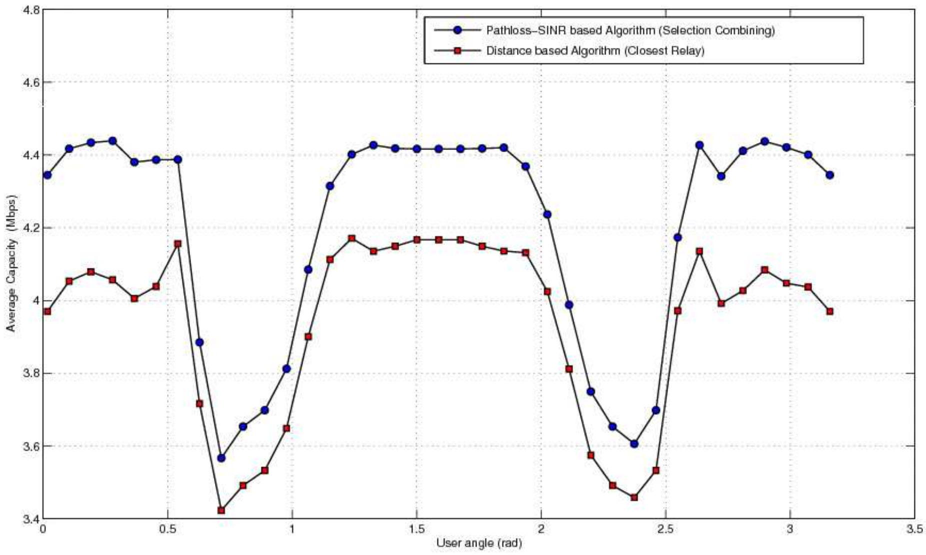

Figure 3.38. Average capacity performance for the pathloss SINR based algorithm and the distance based algorithm along different angles (rad) ($N = 4$, Cell Diameter =$1000m$, $P_B = 10W$, $P_R = 1W$)

CHAPTER 4

IMPLEMENTATION OF MIMO IN WIRELESS FIXED RELAYS

Next-generation wireless communication systems demand high transmission rates and a QoS guarantee. In recent wireless communication systems, using the fixed relays in cellular systems has been considered as one of the powerful techniques to improve the reliability and extend the coverage in shadowing propagation conditions and under limited transmit power conditions. In the relay-based communication system, a source communicates with a destination with the help of other relay or relays. They provide the benefit of the distributed diversity gain and also extending the coverage without requiring large transmit powers. Fixed relays are low cost and low transmit power elements that receive and forward data from the base station to the users via wireless channels. Using fixed relays increase coverage and link capacity in cellular networks in regions where significant shadowing. Because of the implementation is easy, fixed relays are a low cost and low complexity solution to meet the requirement of high data rate communication far from the base station at the cell edge.

As a result of the scatterers in the environment and mobile stations, signal components received over different propagation paths may add destructively or constructively and cause random fluctuations in the received signal strength. This phenomena is called fading and degrades the system performance. MIMO systems introduce spatial diversity to combat fading and MIMO increases spatial multiplexing at the rich scattering environment. MIMO technology promises significant improvements in terms of spectral efficiency and link reliability.

The capacity and reliability of the relay channel can be further improved by using multiple antennas at the nodes. The benefits of relaying combined with the advantages of multiple antennas make the multiple-input multiple-output relaying technique a powerful candidate for implementation in the next generation of wireless networks. Combining the MIMO systems with the fixed relay systems can be considered as an enabling technique for future wireless system to achieve high sum capacity with the reliability.

Recently, MIMO relaying have received a great interest. The performance analysis of the MIMO relay channel has been studied in (Peters and Heath 2008), (Munoz et al. 2005) and practical signalling and routing schemes for MIMO relay channels in terms of the network capacity in (Fan and Thompson 2007). The capacity of MIMO relay channel is investigated at (Wang et al. 2005), (Chen et al. 2009) and (Molish and Win 2005) and the impact of multi antennas on fixed relays is analyzed in (Adinoyi and Yanikomeroglu 2006). This section concerns about the capacity analysis of the system in section 3 by the integration of the multi antennas at the all nodes.

4.1. MIMO for Relay-based Networks

Consider a MIMO relay system where the source, destination and relay are equipped with N_S, N_D, N_R antennas, respectively in Figure 4.1. A single source transmits its signal to the destination with a single relay. All nodes operate in half-duplex mode in MIMO relaying.

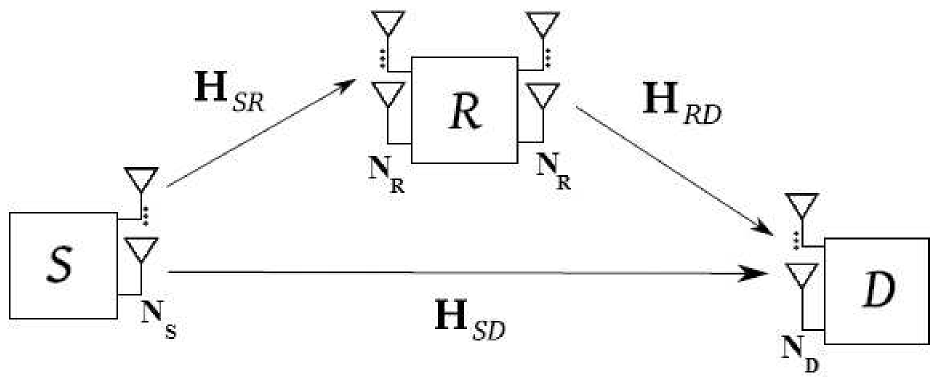

Figure 4.1. MIMO relay system

It is considered narrowband transmissions suffering from the effect of the slow fading. The channel node X to Y, $X \in \{S, R\}, Y \in \{R, D\}, X \neq Y$, is denoted as $\mathbf{H}_{XY}$ and $\mathbf{h}^i_{XY}$ represents the vector channel from ith transmit antenna at $X \rightarrow Y$. It is also defined as

$$\gamma^i_{XY} = \|\mathbf{h}^i_{XY}\|^2 SNR \tag{4.1}$$

to the equivalent receive signal-to-noise ratio (SNR) from the node $X \rightarrow Y$. Capital boldface letters denote matrices and lowercase boldface letters denote for column vectors. The notation $||h||$ refers to L2 norm of the vector **h** , and $\mathbf{H}^*$ is complex conjugate transpose of the matrix **H**. $\mathbf{h}^i$ represents the ith column of the matrix **H**. Only, one transmit antenna is selected and activated at both source and relay for transmission. The whole transmission is accomplished in two phases: in the first phase, the source transmits to the relay and the destination with one of its antennas and in the second phase, the relay transmit to the destination.

At the first phase transmission;

$$y_{R,1} = \mathbf{h}^i_{SR} x_1 + \mathbf{n}_{R,1} \tag{4.2}$$

$$y_{D,1} = \mathbf{h}^i_{SD} x_1 + \mathbf{n}_{D,1} \tag{4.3}$$

where x_1 is the signal transmitted by the source, $y_{R,1}$ and $y_{D,1}$ are the relay and destination received signals, respectively. $\mathbf{n}_{R,1}$ is the zero-mean spatially white complex Gaussian noise vector with covariance $\sigma^2 \mathbf{I}_{N_{R,1}}$. The relay is also transmitting on only one of its antennas, it must combine its received vector to form a single symbol. The relay performs maximal ratio combination (MRC) on $y_{R,1}$,

$$x_R = \alpha (\mathbf{h}^i_{SR})^* y_{R,1} \tag{4.4}$$

where α is the scaling factor to ensure relay transmits at its expected power constraints;i.e.,

$$\alpha^2 = \frac{1}{||\mathbf{h}^i_{SR}||^4 + \frac{||\mathbf{h}^i_{SR}||^2}{SNR}} \tag{4.5}$$

At the second phase transmission;

$$y_{D,2} = \mathbf{h}^k_{RD} x_R + \mathbf{n}_{D,2} \tag{4.6}$$

where x_R is the relay transmitted signal and $y_{D,2}$ is the destination received signal.

The destination now has two observations containing the signal x_1. To put the channel in standard MIMO notation, it is defined as;

$$\mathbf{h} = \begin{bmatrix} \mathbf{h}^i_{SD} \\ \frac{\|\mathbf{h}^i_{SR}\|\mathbf{h}^k_{RD}}{\sqrt{\|\mathbf{h}^i_{SR}\|^2 + \frac{1}{SNR}}} \end{bmatrix} \tag{4.7}$$

$$\mathbf{n} = \begin{bmatrix} \mathbf{n}_{D,1} \\ \frac{\mathbf{h}^k_{RD}(\mathbf{h}^i_{SR})^* n_{R,1}}{\|\mathbf{h}^i_{SR}\|\sqrt{\|\mathbf{h}^i_{SR}\|^2 + \frac{1}{SNR}}} + \mathbf{n}_{D,2} \end{bmatrix} \tag{4.8}$$

$$\mathbf{y}_D = \begin{bmatrix} \mathbf{y}_{D,1} \\ \mathbf{y}_{D,2} \end{bmatrix} \tag{4.9}$$

so that

$$y_D = \mathbf{h}x_1 + \mathbf{n} \tag{4.10}$$

Due to the different noise variance, MRC is not the optimal receiver for the combination of signals at destination(Peters and Heath 2008). In this case, the optimal receiver filter in the minimum mean-squared error (MMSE) sense is

$$\mathbf{w} = \mathbf{R}^{-1}_{y_D}\mathbf{R}_{\mathbf{y}^{x_1}_D} \tag{4.11}$$

where $\mathbf{R}_{y_D} = E\{\mathbf{y}_D\mathbf{y}^*_D\}$ and $\mathbf{R}_{y^{x_1}_D} = E\{\mathbf{y}_D x^*_1\}$. The post-processing SNR is

$$\gamma^i = \gamma^i_{SD} + \frac{\gamma^i_{SR}\gamma^k_{RD}}{\gamma^i_{SR} + \gamma^k_{RD} + 1} \tag{4.12}$$

4.2. Transmit Antenna Selection Strategies

It is seen that γ^i in equation 4.12 is monotonous increasing function. Since γ^i_{SD}, γ^i_{SR} and γ^k_{RD} are independent varied, maximizing γ^i_{SD}, γ^i_{SR} or γ^k_{RD} should maximize the overall system SNR. In (Peters and Heath 2008), γ^i is maximized as γ^I simultaneously by both transmit antenna selections at source and relay,

$$I = \arg\max_{1 \leqslant i \leqslant N_S}\{\gamma^i\}, \quad K = \arg\max_{1 \leqslant i \leqslant N_R}\{\gamma^k_{RD}\}$$

This strategy is able the full diversity order but the optimal transmit antenna selection strategy has high complexity of searching for the optimal transmit antenna at the source and relay. The destination should compute γ^i_{SD}, γ^i_{SR} and γ^k_{RD} for each transmit antenna at the source and relay to get the maximum γ^I. In (Cao et al. 2009), the antenna selection at the relay is independent of the selection at the source. The transmit antenna selection strategy is fixed at the source only $S \to D$ channel or $S \to R$ channel with maximizing γ^I_{SD}, $I = \arg\max\{\gamma^i_{SD}\}$ or γ^I_{SR}, $I = \arg\max\{\gamma^i_{SR}\}$. There are three transmit selection strategies in the amplify and forward MIMO relaying.

1. Optimal transmit antenna selection at the source and relay.

   $$I = \arg\max_{1 \leqslant i \leqslant N_S}\{\gamma^i\}, \quad K = \arg\max_{1 \leqslant i \leqslant N_R}\{\gamma^k_{RD}\}$$

2. Optimal transmit antenna from $S \to D$ and from $R \to D$.

   $$I = \arg\max_{1 \leqslant i \leqslant N_S}\{\gamma^i_{SD}\}, \quad K = \arg\max_{1 \leqslant i \leqslant N_R}\{\gamma^k_{RD}\}$$

3. Optimal transmit antenna from $S \to R$ and from $R \to D$.

   $$I = \arg\max_{1 \leqslant i \leqslant N_R}\{\gamma^i_{SR}\}, \quad K = \arg\max_{1 \leqslant i \leqslant N_R}\{\gamma^k_{RD}\}$$

The maximum capacity for the amplify and forward MIMO relaying with the transmit antenna selection is calculated by

$$C = \frac{1}{2}log(1 + \gamma^I_{SD} + \frac{\gamma^I_{SR}\gamma^K_{RD}}{\gamma^I_{SR} + \gamma^K_{RD} + 1}) \tag{4.13}$$

In this thesis, the users receive signals from the base station or via relays. It is assumed that relays are located at the positions that they always receive its signals from the base station without any problems. Because of this reason, the channel from the source to relay is neglected. In literature, post-processing SNR methods are applied in transmit antenna selection strategies. It is discussed in the beginning of this section. In this antenna selection strategy, the maximal ratio combination is performed for the combination of signals at destination and the selection combining method is applied. Antenna sets given maximum SINR is responsible for transmitting the signals.

Assume that the number of transmitting antennas of the base station is M and the number of receiving antennas of the destination is N, If the received signal is from the base station, for the inner zone SINR is calculated as:

$$SINR_{INNER} = \frac{P_B/PL(L_B)}{P_{INT} + P_N}\mathbf{H}_{SD}\mathbf{H}^*_{SD} \tag{4.14}$$

where $\mathbf{H}_{SD}$ is the MxN channel matrix of the source to the destination, $\mathbf{H}^*_{SD}$ is the complex conjugate transpose, L_B is the distance between the considered user and its served base station, $PL(L_B)$ is the pathloss and P_N is the noise power.

Assume that the number of transmitting antennas of relay is R and the number of receiving antennas of destination is N, If the received signal is from the corresponding relay, for the outer zone, the SINR is calculated as:

$$SINR_{OUTER} = \frac{P_R/PL(L_R)}{P_{INT} + P_N}\mathbf{H}_{RD}\mathbf{H}^*_{RD} \tag{4.15}$$

where $\mathbf{H}_{RD}$ is the RxN channel matrix of relay to destination, L_R is the distance between the considered user and its served relay and $PL(L_R)$ is the pathloss for the distance L_R.

The antenna selection strategies to maximize the SINR also maximize the system SINR which means the best way to choose the transmit antenna i and k (the index of the base station and relay antennas) are:

$$\begin{aligned} SINR^i_{INNER} &= \arg\max_{1\leqslant i\leqslant M}\{SINR^i_{INNER}\} \\ SINR^k_{OUTER} &= \arg\max_{1\leqslant k\leqslant R}\{SINR^k_{OUTER}\} \end{aligned}$$

The best way to choose the system SINR is:

$$SINR = \arg\max\{SINR^i_{INNER},\ \ SINR^k_{OUTER}\}$$

4.3. Simulation Results

At this section, the MIMO is adopted to the cellular system. Different number of antennas are placed to the source, relay and destination nodes. The capacity performances are shown and the results are compared to relay based system with the single antenna.

4.3.1. MIMO Effects in Wireless Networks

The MIMO effects in cellular wireless networks is investigated for the cluster sizes of $N = 1$ and $N = 4$ through simulation results. Please refer to Figure 3.10 for the algorithm flowchart. Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5 show the average capacity performance of the users along different angles for different number of antennas. The relay position are set to 0.64R and 0.55R in the cluster size of $N = 1$ and 0.73R and 0.66R in the cluster size of $N = 4$ for the relay powers of 1W and 10W, respectively. It is observed that the average capacity increases 25% percentage by using 2 antennas, 32% percentage by using 3 antennas and 36% percentage by using 4 antennas for the cluster size of $N = 1$ and 15% percentage by using 2 antennas and 22% percentage by using 3 antennas and 26% percentage by using 4 antennas for the cluster size of $N = 4$ at each nodes compared to the single antenna system.

Figure 4.6 and Figure 4.7 show the capacity performance of 2 antennas systems using the maximum ratio combining and Alamouti methods for cluster size of $N = 1$ and $N = 4$. 5% average capacity improvement is observed by using the MRC selection criterion compared to the Alamouti method.

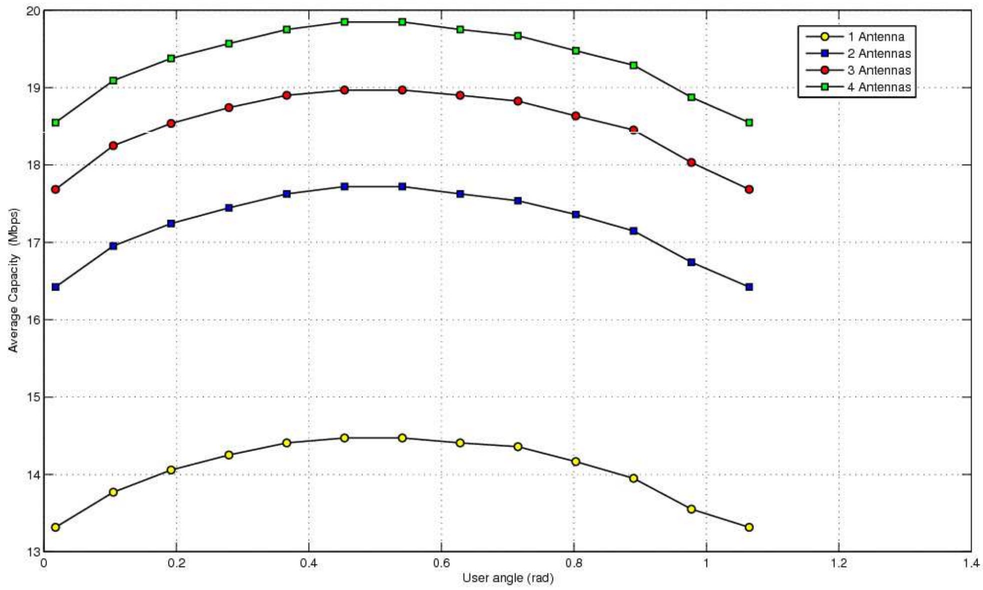

Figure 4.2. Average capacity performance for 1-4 antenna sets along different angles (rad) ($N = 1$, Cell Diameter = $1000m$, $P_B = 10W$, $P_R = 1W$)

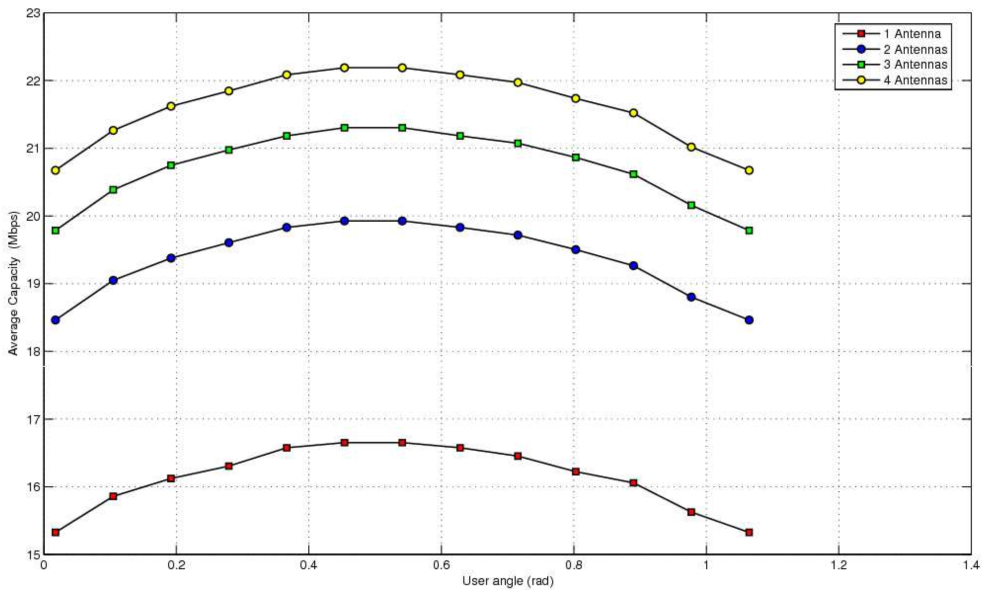

Figure 4.3. Average capacity performance for 1-4 antenna sets along different angles (rad) ($N = 1$, Cell Diameter = $1000m$, $P_B = 10W$, $P_R = 10W$)

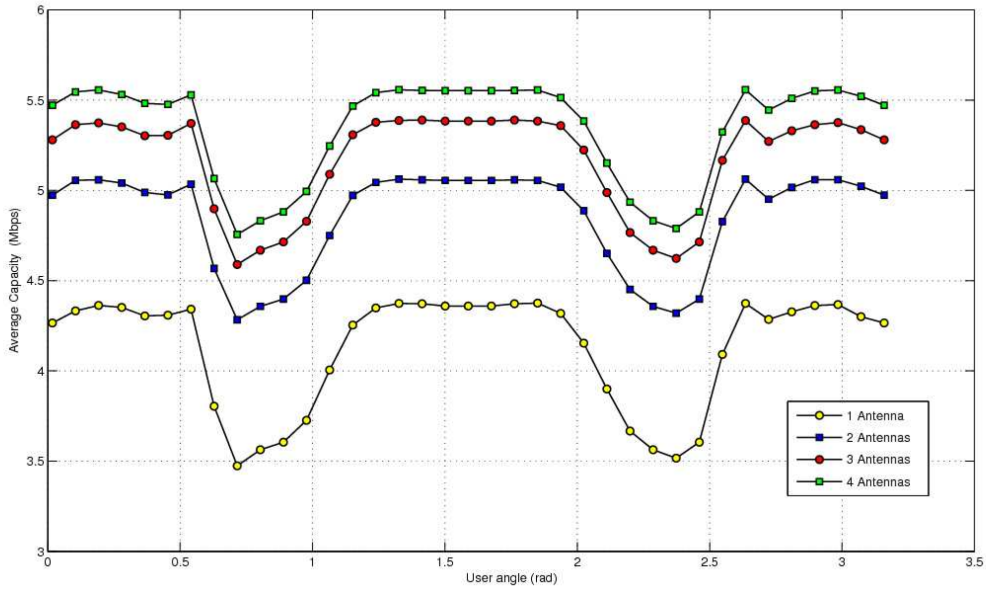

Figure 4.4. Average capacity performance for 1-4 antenna sets along different angles (rad) ($N = 4$, Cell Diameter = $1000m$, $P_B = 10W$, $P_R = 1W$)

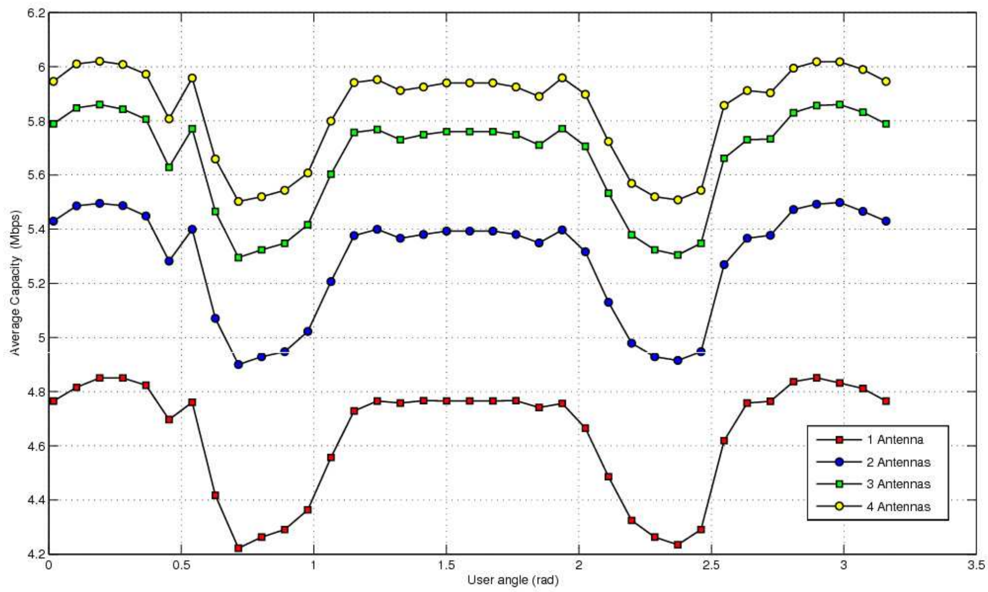

Figure 4.5. Average capacity performance for 1-4 antenna sets along different angles (rad) ($N = 4$, Cell Diameter = $1000m$, $P_B = 10W$, $P_R = 10W$)

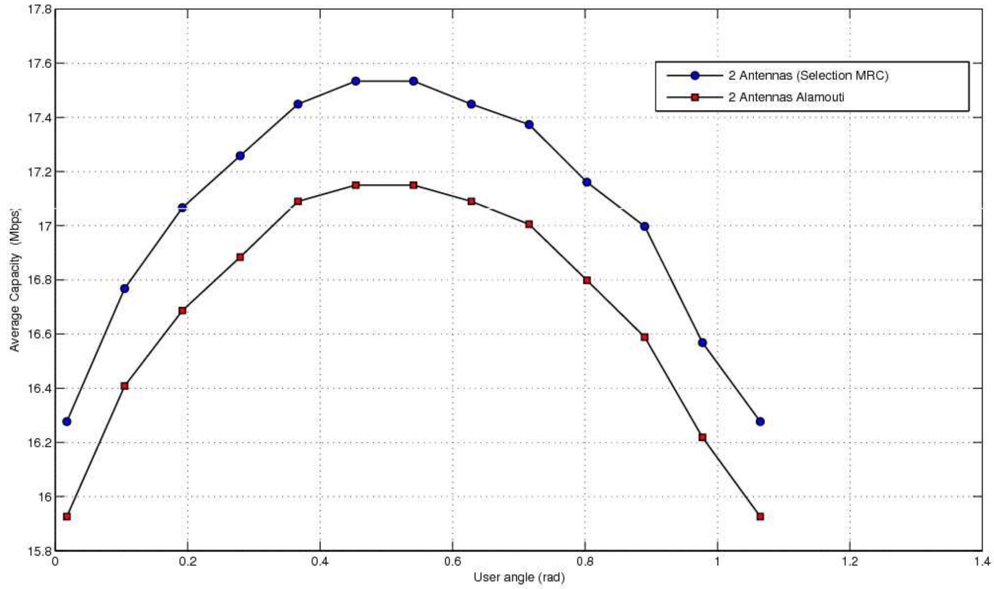

Figure 4.6. Average capacity performance for 2 antennas sets along different angles (rad) ($N = 1$, Cell Diameter = $1000m$, $P_B = 10W$, $P_R = 1W$)

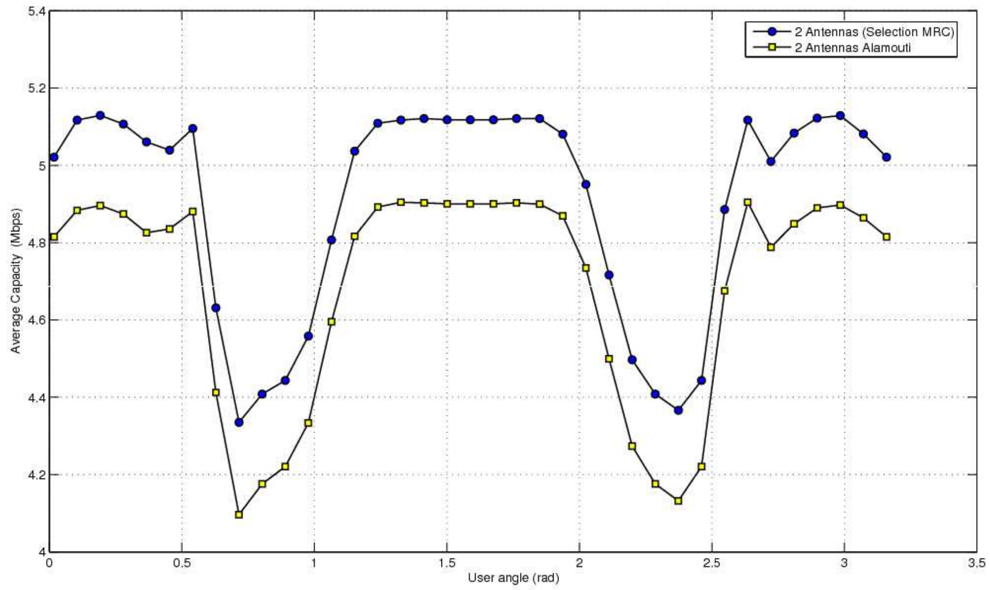

Figure 4.7. Average capacity performance for 2 antennas sets along different angles (rad) ($N = 4$, Cell Diameter = $1000m$, $P_B = 10W$, $P_R = 1W$)

4.3.2. MIMO Capacity Performance with Respect to The Relay Powers

The relay powers are set to the values from 1W to 10W and the average capacity performance is observed at all of the power levels for the cluster sizes of $N = 1$ and $N = 4$. The multi antenna systems including from one, two and four antennas at all nodes are adopted to the system. The relay positions are set to 0.64R for the cluster size of $N = 1$ and 0.73R for the cluster size of $N = 4$. Please refer to the Figure 3.9 for the flowchart. Figure 4.8 and Figure 4.9 show the average capacity performance with respect to the relay powers for the cluster sizes of $N = 1$ and $N = 4$. It is observed that the average capacity performance of the multiple antennas is not dependent to the relay power. It is seen that the average capacity improvement for the relay power of 1W is nearly same for the average capacity improvement of the relay power of 10W.

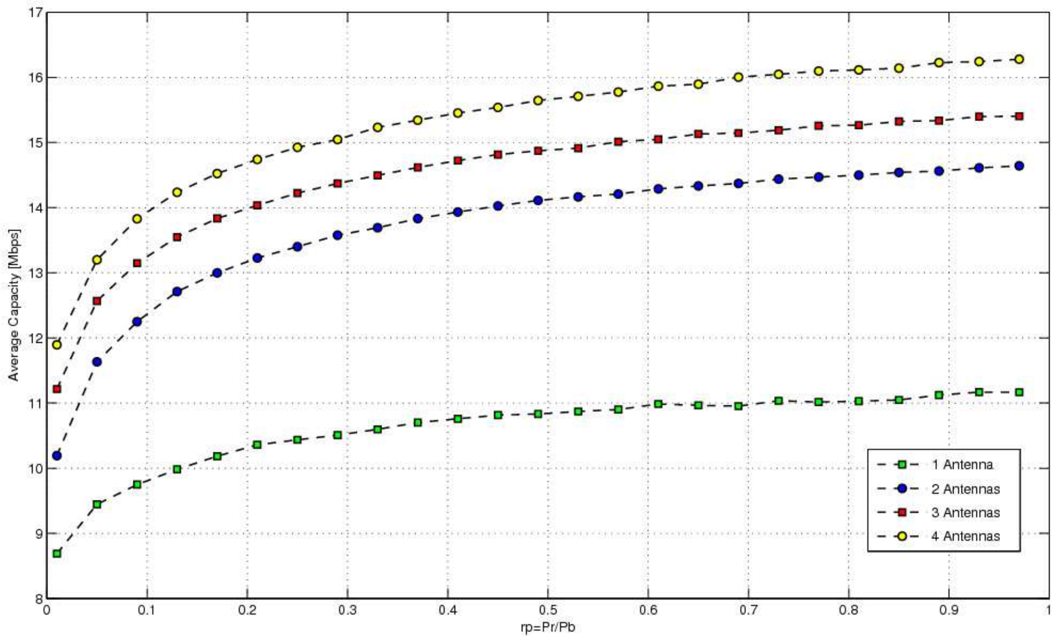

Figure 4.8. Average capacity with respect to the relay powers for $1-4$ antenna sets ($P_B = 10W$, $N = 1$, Cell Diameter = $1000m$)

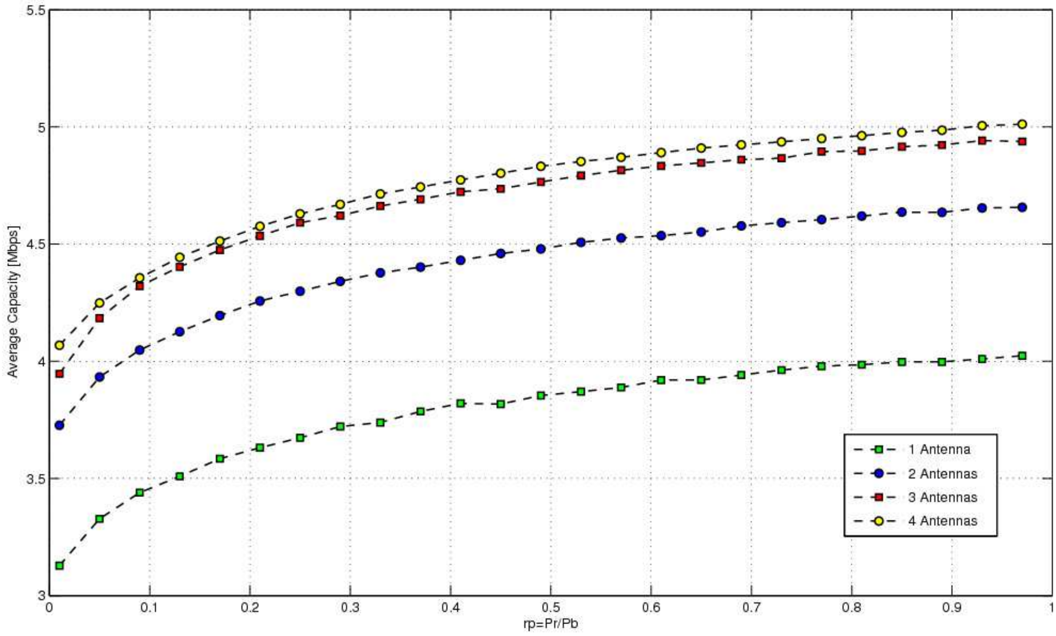

Figure 4.9. Average capacity with respect to the relay powers for $1-4$ antenna sets ($P_B = 10W$, $N = 4$, Cell Diameter = $1000m$)

4.3.3. MIMO Capacity Performance with Respect to The Cell Diameter

The average capacity is investigated for the different cell diameters. Relay and base station powers are set to 1W and 10W, respectively. Please refer to the Figure 3.9 for the flowchart. Figure 4.10 and Figure 4.11 show the average capacity performance for a cell diameter from 200m to 5000m. The average capacity of 3.5 Mbps is obtained by setting the cell diameters of 1000m, 2700m, 3200m, 3700m by using 1,2,3 and 4 antennas at each nodes as shown in Figure 4.11 for the cluster size of $N = 4$, respectively. It is observed that the coverage is significantly improved by using multiple antennas.

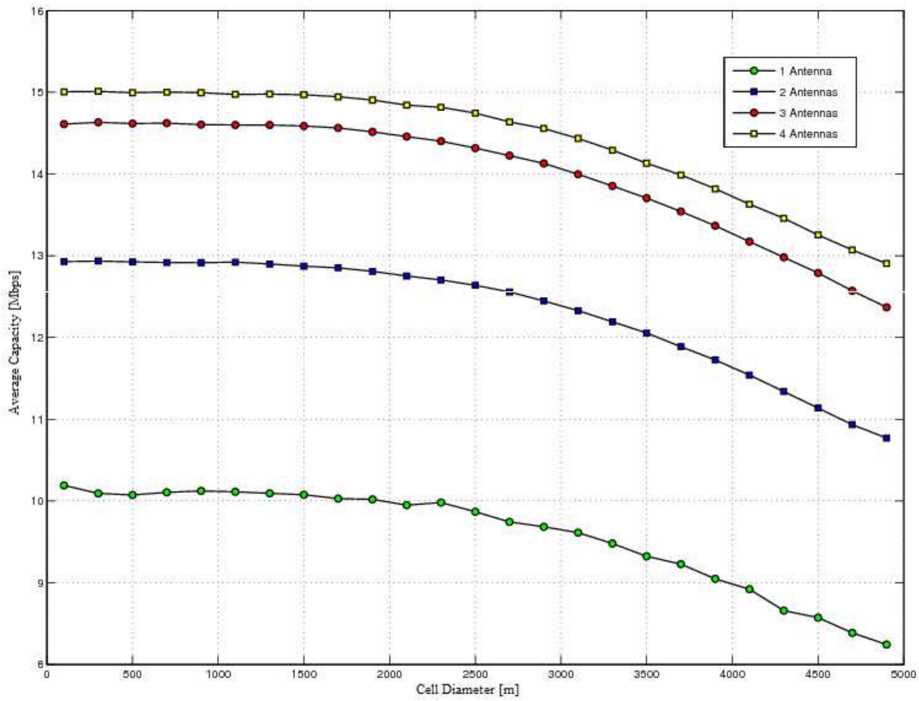

Figure 4.10. Average capacity with respect to the cell diameter for $1-4$ antenna sets ($P_B = 10W$, $P_R = 1W$, $N = 1$)

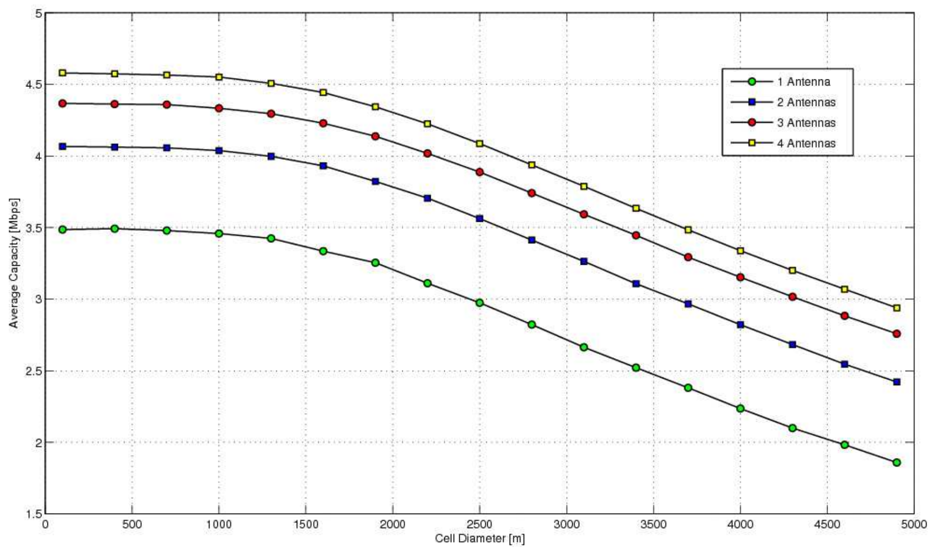

Figure 4.11. Average capacity with respect to the cell diameter for $1-4$ antenna sets ($P_B = 10W$, $P_R = 1W$, $N = 4$)

CHAPTER 5

CONCLUSION

In this thesis, we have focused fixed relay technologies on wireless cellular network. The main goal of this research is to design fixed relay systems to improve the capacity of wireless cellular networks.

First of all, we have investigated the hexagonal cellular architecture. The base station and six relays are located to the cell center and edge respectively and each relay is on the line that connects the base station and cell vertices. We have examined the effective relay position for the different values of the relay power. We have shown that the best performance can be attained with the placement of relays at 0.6R to 0.8R away from the BS where R is a radius of the cell, when the ratio of the relay power to the base station power is set from 0.01 to 0.2.

Secondly, we have observed the effect of relays for two different cluster sizes of $N = 1$ and $N = 4$. We have seen that the capacity is increased by nearly 30% in average and up to 90% at the cell edge compared to the cellular network without relays. According to the simulation results, the capacity is significantly improved by using a fixed relaying system.

Thirdly, we have analyzed the relay power effect when the base station power is set to a fixed value of $10W$. Even the larger relay power causes the interference, it is observed that the average capacity increases when the relay power is set from $0.1W$ to $10W$. For the relay power greater than $10W$, it is shown that the interference power is getting much more powerful than the relay power which causes degradation on the capacity performace. When the relay power is 1.5 and 2 times of the base station power for the cluster size of $N = 1$ and $N = 4$ respectively, the capacity is started to decreases in relay-based wireless cellular networks.

Next, we have observed the capacity performance by increasing the cell diameter from 100 m to 5000 m to compare the system without relaying. We have concluded that the system capacity is increased by a percentage of 25-30% with the usage of relays. According to the simulation performances, the optimum cell diameters are demonstrated as 1500-2000m and 1000-1500m for the cluster size of $N = 1$ and $N = 4$ respectively. Then, we have compared the distance based algorithm to the pathloss SINR based algorithm and it is shown that the 5% of capacity improvement is achieved by using pathloss SINR based algorithm.

Finally, we have adopted multiple antennas to the relay-based wireless cellular networks by comparing the results for different strategies and the system having single antenna. In the selection strategies, we have used maximal ratio combining for the combination of the signal at destination and selection combining method for choosing the transmit signal. The antenna sets giving maximum SINR is responsible for transmitting the signal. We have achieved 25%, 32%, 36% of capacity improvement by using 2, 3 and 4 antennas at all nodes compared to single antenna system.

In addition to that, the interference powers are calculated by the sum of the interferences coming from the base stations and relays of neighboring cells using the same channels. The interferences coming from co-channels are neglected by assuming perfect synchronization and channel state information is available at the relays and base stations without any error. Because of these reasons, the capacity of practical systems can be lower than the capacity obtained by the simulation results which give us a theoretical view to show the gain of relay-based wireless cellular networks with and without multiple antennas.

As a future work, a fixed relaying with more than two hops can be implemented and the channel uncertainties and synchronization problems can be investigated for the wireless cellular systems with multiple antennas.

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