MULTIHOP MOBILE CELLULAR NETWORK

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2005

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Faizal Bin Mohamad Hassan Mukhtar

ABSTRACT

Code Division Multiple Access (CDMA) system capacity is interference limited. Distance of the mobile station (MS) to the base station (BS) affects the capacity and interference of a cellular network system. Relaying is to shorter the distance between BS and MS by adding a relay station (RS) between them. Transmission power is smaller due to shorter distance and thus improves the capacity of the CDMA system due to reduction in interference. Relaying can be done by using fixed relay station or mobile relay station. Both objectives are to improve the capacity and reduce interference but they are different since fixed relay station is constructed on land or building while mobile relay station is additional features added into mobile phones. This project shows the benefits of multihop with mobile relay station which improve the interference by relaying compared to the system without relaying.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In Malaysia today, mobile telecommunication services have grown in demand due to the increase in number of mobile phone subscribers. The mobile phone is now becoming a necessity for the people in this country since the cost of mobile phones and mobile service fee are becoming cheaper and the service coverage are expanding. Technology development and competition among the mobile service providers has reduces the cost of using mobile communication service and these also result the growth of mobile cellular network. The project that is undertaken involves the study of wireless communication field. The objective of this project is to investigate potential capacity gains from implementing relaying in a Code Division Multiple Access (CDMA) system.

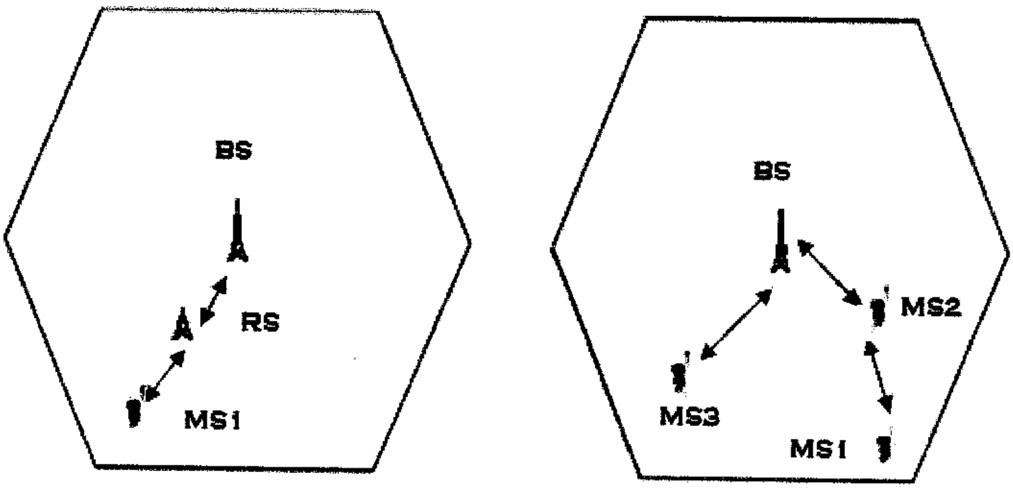
Mobile wireless networks can be classified into two types which are fixed and mobile. In a fixed wireless networks, mobility is not supported and the connection can only be from point to point (e.g. geostationary satellite network). A mobile wireless network also consists of two distinct categories that are infrastructure (Cellular) and infrastructure less (Ad hoc). Infrastructure network usually involved a single-hop wireless link to reach a mobile terminal. Infrastructure-less network normally requires a multihop wireless path from a source to destinations that have no fixed relays which mean that all nodes are capable of movement and can be connected dynamically in an arbitrary manner.

In a cellular land mobile radio system, multiple access techniques are used to permit many users to share a limited resource of radio spectrum. There are three categories of multiple access techniques which are pre-assignment, demand assignment and random access. From all these techniques, the best and commonly used in present cellular system is the demand assignment [1].

Relaying means using other existing terminals located between the originating terminal and the base station (BS) for the purpose of retransmitting the original packet. In this process, the mobile station (MS) at the boundaries of the cells will need less transmission power to reach the relay station (RS) than to reach the BS. This is due to the smaller distance between MS-RS and RS-BS compared to MS- BS. The smaller the transmit power will create less interference in the system therefore improve the capacity. In mobile cellular network, the cost will be much lower when idle mobile phone is used to route the signals from mobile phone to the base station. This is because fixed relay stations do not need to be constructed which means the cost of hardware and land for the system can be reduce. Cost is not the only factor to be considered in the mobile cellular network. In providing a good mobile cellular network, the service providers will also consider the transmit power reduction, coverage extension and capacity gain of the system.

Two cases have been considered for relaying in CDMA system. In the first case, relay stations are not mobile but fixed at certain location in the cell. Fixed RS usually placed in between the MS and BS. RS is able to transmit and receive signal from the MS. However the functionalities and capabilities of RS is less than the BS since RS does not have direct connection to the Public Switching Telephone Network (PSTN). Figure 1(a) shows a MS which is located in the cell requests for service. Since it is nearer to the RS than the BS, the MS uses the fixed RS to relay signals to the BS. The BS will also relay signals to the MS through the fixed RS.

In the second case, mobile relay stations to route the signal between the BS and the MS. The mobile RS can be other mobile phones with additional features to function as fixed RS. The ability such as transmitting pilot signals, resource allocation and code-channels allocation for relayed mobile are the possible criteria to the current MS enhancement. Figure 1(b) shows the MS_1 requests for service. Since MS_1 is nearer to MS_2, MS_1 will relay the signals to MS_2 and MS_2 will transmit the signals to BS. BS will also transmit signals to MS_1 by relaying through MS_2. MS_2 in the system is a non-fixed RS and usually an idle MS located near the BS. MS_3 is connected directly to BS without relaying through any RS.



(a) (b)

Figure 1 : Two types of relaying system: (a) Mobile station relaying with fixed relay station, (b) Mobile station relaying with mobile relay station.

1.2 Problem Statement

Communications become an important area of electrical and electronics engineering mostly for the communication engineers. In this project, the research of multihop mobile cellular network is mostly for the performance analysis and the implementation issues should also be considered.

The use of multihop concepts in a CDMA networks is analyze to see the performance (degradation or improvement) when multihop cellular networks are implemented in the future. Reverse-link is called the uplink which means the mobile users are power controlled by the BS of their own cell. The investigation of this project is only based on the reverse-link capacity with non-fixed RS. The analysis is done through simulations and calculations.

By using non-fixed RS, the distance between BS to MS will be reduced and the transmitted power will be reduced and give a significant improvement to the capacity. Non-fixed RS can be much cheaper compared to using fixed RS.

The investigation takes into consideration of adapting multihop cellular network and making comparison with the existing system. Multihop mobile cellular network will either gives improvement or degradation to the current network system when implemented since there are advantages and also disadvantages. The advantages of multihop are the reduction of interference and higher capacity in the cellular network while the disadvantage is battery power of the mobile which act as the RS will be consumed during the signals transmit This system is still not being implemented and the task is to make a simulation about the concepts the project. If it shows more advantages and better performance, the new technology can be developed in future to implement the system.

1.3 Objectives

The objectives of this project are as follows:

1. To understand the multihop in CDMA network.
2. To investigate the possibility of using idle mobile phones nearby to route signals from a mobile phone to the base stations.
3. To study the advantages or disadvantages of implementing multihop concept in a system using CDMA.
4. To produce a model and simulate a multihop network environment using MATLAB.
5. To identify the potential problems and improvement of using multihop techniques in cellular network.
6. To propose new architecture or solution if relaying is to be implemented as a feature in mobile phones.

1.4 Scope of Study

1. Network system consists of numbers of cells such as 7 or 19 cells in a certain area of coverage. In this project, only 7 cells is used in the modeling the network system.
2. The scenario of the mobile relays is investigated in the reverse-link.
3. The investigation is not considering fading effects.
4. The investigation only considers the distance.
5. No architecture or hardware model is produced in this project. Only simulation using MATLAB is developed.

1.5 Time frame

This project had been completed in two semesters. During the first semester, the project is more focus on the literature review and data collection. A standard model of network simulation was developed for comparison purpose with the proposed system. The focus of this project is on the reverse-link.

In the second semester, the multihop mobile cellular network model simulation was developed so that the system can be analyze and new recommendation can be make either the system can be implemented or not.

1.5.1 Gantt chart

The study started with the understanding of mobile cellular network in general. The first semester was to have the depth of understanding that is required in order to be able to complete the project. In the mean time, an extensive understanding of how the MATLAB works is also relevant due to the fact that the implementation or simulation will be done inside the MATLAB. The general overview of the time frame of the project for the first semester can be referred in Appendix A. The second semester time frame can be referred in Appendix B.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.1 Code Division Multiple Access (CDMA)

Multiple access schemes are used to allow mobile users to share the frequency bands provided. In terms of separating the signals, there are three basic multiple access techniques which are the Frequency division multiple access (FDMA), Time division multiple access (TDMA) and Code division multiple access (CDMA). In FDMA techniques, users share the radio spectrum in the frequency domain. This is by dividing the total bandwidth available to the system into narrow frequency sub-bands. In TDMA techniques, users in the system share the radio spectrum in the time domain. This is achieved by allocating a time slot to one and only one of the contending users for the duration of the communication. In wideband TDMA (WB-TDMA), the user has the access to the full frequency band available to the system. Alternatively, in narrowband TDMA (NB-TDMA), the user is given access only to part of the frequency band available to the system. TDMA techniques are the most suitable for digital system [1].

In CDMA techniques, each user in the system is assigned a unique set of time-frequency waveforms which is governed by a unique pseudorandom user code. Each user can then access the time-frequency domain at any time, in a unique manner according to the user unique code to avoid all users from interfering with each others. Therefore the CDMA system is interference limited. Mobile users which situated far away from BS need more power to transmit their signals. In this case, these users may transmit higher power without satisfying their Quality of Service (QOS) to make the connection. Therefore, this would consume more power from the mobiles and reduce the mobile phones battery life. One-way to counter this problem and therefore to improve the capacity would be to increase the number of BS. However, this solution cannot be efficient as it increases significantly the network infrastructure cost [2]. Another way to improve the capacity is a system applying relaying [3].

Figure 2 shows the bandwidth that is occupied by user #1 and user #2 in different type of basic multiple access techniques.

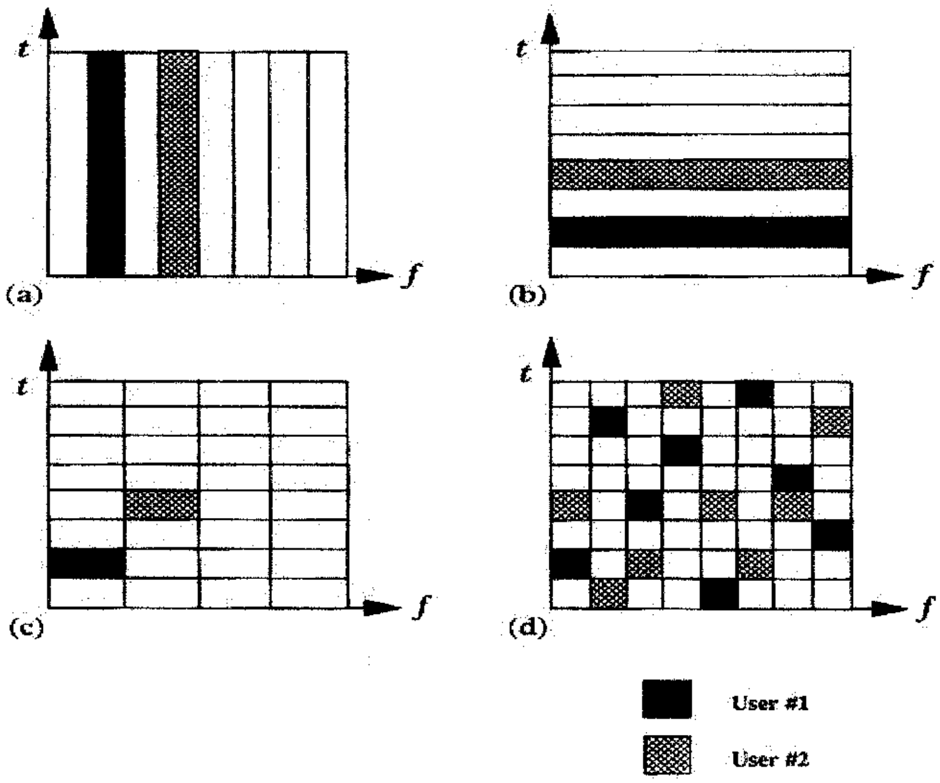


Figure 2 : Basic Multiple Access Techniques. (a)FDMA. (b)WB-TDMA. (c)NB-TDMA. (d)CDMA.

2.2 Relaying

Relaying is achieved by placing a RS in between the MS and the BS. The signal from the MS will not be transmitted directly to the BS but instead is relayed through RS. The transmission power will be reduced since the distance between MS-RS and RS-BS is smaller compared to MS-BS. The overall interference in the system can be minimized due to small transmit power needed.

Relaying also solves the problem of "dead spots" and increase throughput (percentage of calls successfully delivered to the BS to the number of calls generated), and extend the system coverage [6].

According to [4] relaying advantages is to increase the capacity by reducing the transmit power. This is due to the shorter path needed for the MS and BS to communicate when relaying compared to direct path. The main disadvantage discussed in [4] is the complexity of using MS to retransmit data on behalf of another mobile.

Figure 3 illustrate the network structure in two adjacent cells consisting of BS, RS and MS which are distributed uniformly in the cellular network. BS usually is situated in the center of the cells. RS is situated in the middle and MS is at the edge of the cells.

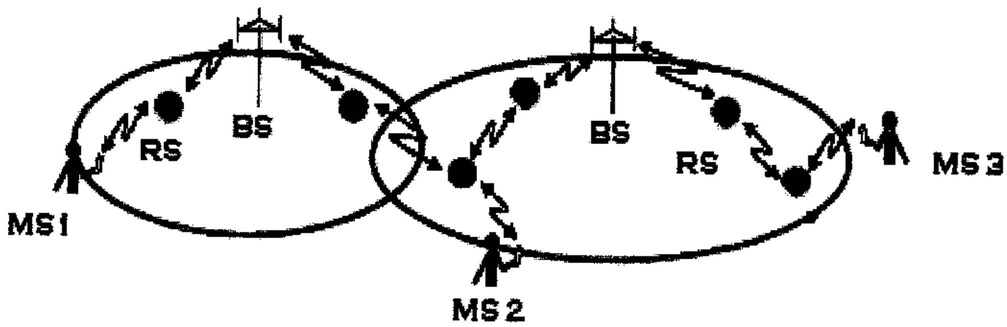


Figure 3 : Network structure: base stations (BS), relay station (RS) and mobile stations (MS) are distributed uniformly in the network.

2.3 Near-Far Problem

The near-far problem is the common problem in CDMA system where the performance of the system suffers when any user transmits extra power [1]. The BS will receive signal from near-by users at a higher power level compared to the further users since all of them are transmitting at the same power level. To eliminate this problem, power control is implemented where the transmit power of each user is controlled by the BS so that overall interference can be limited and this will maximize the capacity.

Rayleigh fading may at times be too rapid to be tracked by the closed-loop power control but variations in relative path losses and shadowing effects [9]. This fading effect is not the same in forward and reverse link.

2.4 Bit Energy-to-Noise Density Ratio, E_b/N_o, Path Loss and Interference

According to [5], the ratio of signal energy to noise power density per hertz, E_b/N_o is a parameter for determining the error rates and digital data rates. This is important to check the system reliability. BS will receive signals from MS at the same power level when the system has a perfect power control [6]. If there are N users in a cell, and the BS will receive signal from each MS with a signal power, S, which the BS will receive a composite waveform containing the desired signal power S, as well as $(N-1)$ interfering signals, each also has a signal power, S. The signal-to-noise (interference) power is:

$$SNR = \frac{S}{S(N-1)} = \frac{1}{N-1} \quad \ldots\ldots (1)$$

To obtain the signal-per-bit-to noise ratio (E_b/N_o), the desired signal power is divided with the information bit rate, R, and the noise, with the total bandwidth, W.

$$\frac{E_b}{N_o} = \frac{S/R}{S(N-1)/W} = \frac{W/R}{N-1} \quad \ldots\ldots (2)$$

Equation (2) can be extend with including background noise, η, due to spurious interference and thermal noise to the denominator.

$$\frac{E_b}{N_o} = \frac{W/R}{(N-1)+(\eta/S)} \quad \ldots\ldots (3)$$

To obtain the average Energy-to-noise density, voice activity factor is multiplied to (3) at the (*N-1*).

$$\frac{\overline{E_b}}{N_o} = \frac{W/R}{(N-1)\alpha + (\eta/S)} \quad \text{.....} (4)$$

The signal-per-bit-to noise ratio is affected by power control effectiveness, amplitude fading, phase coherence and also probability distribution of the interfering signal. By increasing E_b/N_o the capacity of cellular system will be increased.

Putting sectorization and voice activity monitoring in equation (3) gives:

$$\frac{E_b}{N_o} = \frac{W/R}{V_f(N_s - 1) + V_f(I/S) + (\eta/S)} \quad \text{.....} (5)$$

where	W	= total bandwidth
	R	= information bit rate
	V_f	= voice activity factor
	N_s	= number of user per sector
	I	= interference
	η	= background noise
	S	= signal power

According to [4],E_b/N_o is affected by phase coherence, amplitude fading and power control effectiveness as well as the probability distribution of the interfering signal. Increasing E_b/N_o will increase the capacity of the cellular network.

In multiple-cell system, cell membership of a certain MS is not determined by minimum distance alone, but rather, by the maximum pilot power receive by the MS [6]. Attenuation model forms the product of the fourth power of the distanced a log normal random variable whose standard deviation is 8dB is generally used.

$$PL = 10^{(\xi/10)} r^{-4} \ldots\ldots (6)$$

where r = distance from users to cell site

ξ = Gaussian random variable (σ=8dB and zero mean)

There are two major interference categories; the outer-cell interference and the inner-cell interference. The MS-BS attenuation can be used to calculate the interference caused by outer-cell interferers.

Figure 4 illustrates that due to power control, MS_1 is nearer to its own BS_1, i.e. smaller r_m, less power is needed to transmit to BS_1 and therefore less interference is experienced by BS_0. The nearer the MS_1 to BS_0, the more interference is experienced by BS_0.

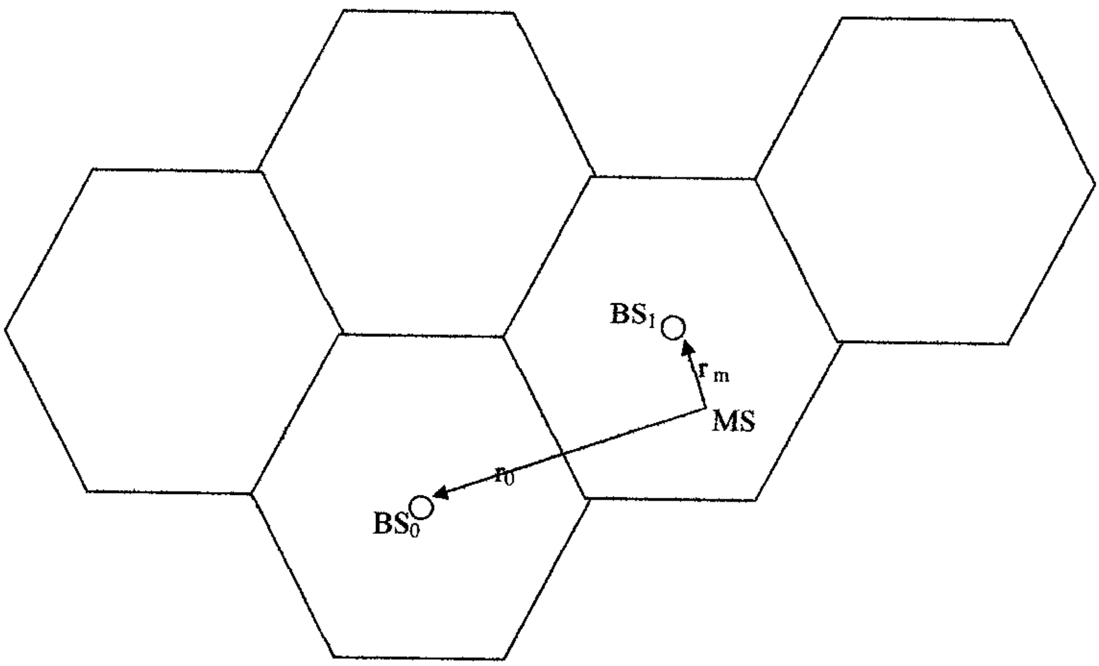


Figure 4 : Distance that contributes to outer-cell interference calculation.

2.5 Project Investigation (Distance Only)

In this project, the assumptions made are:

- The RS can only serve one MS at one time.
- The BS will receive signals from RS and non-relayed MS at same time slot and power level as power control will be implemented.
- The cellular network only consists of 7 cells that contribute the outer-cell interference:

$$\frac{I(r_o, r_m)}{S} = \left(\frac{r_m}{r_o}\right)^4 \quad \text{.....} (7)$$

- Equation (7) is used to calculate the forth power path lost model (distance define in Figure 4) where shadowing factor is assume to be zero.
- The background noise is assumed to be zero, so the energy per noise ratio from equation (5) had become:

$$\frac{E_b}{N_o} = \frac{W/R}{V_f(N_s - 1) + V_f(I/S)}$$

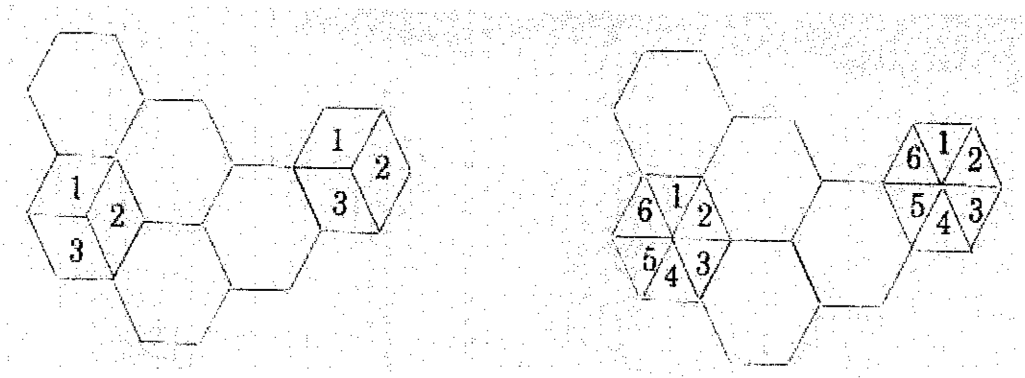
$$= \frac{W/R}{V_f N_s (1 - \frac{1}{N_s} + \frac{(I/S)}{N_s})}$$

$$= \frac{W/R}{V_f N_s (1 + I_f)} \quad \text{.....} (8)$$

where	W	= total bandwidth
	R	= information bit rate
	V_f	= voice activity factor
	N_s	= number of user per sector
	I_f	= interference
	S	= signal power.

2.6 Sectorization and Voice Activity Monitoring

Sectorization is important in a cellular network to increase capacity by reducing other user interference using two methods which are by using the directional antennas at the cell site both for receiving and transmitting (Common sectorization technique) and by monitoring the voice activity. Voce activity monitoring exists virtually in most digital vocoders [9]. Sectorization increases the Signal to Interference Ratio (SIR) so that the cluster size may be reduced therefore sectorization decreases the co-channel interference and thus increases the system performance. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three 120° sectors or 60° sectors as shown in Figure 5 (a) and (b).



(a) (b)

Figure 5 : (a) 120° sectoring; (b) 60° sectoring

For example, if we use 3 directional antennas (120°) at the BS, the number of users that can be occupied per antenna will increase, $N=3Ns$. The average number of user will increase and this means that CDMA is a competitive system compared to TDMA and FDMA.

The second method of increasing the capacity is monitoring voice activity. Extensive studies show that either speaker is active only 35% to 40% of the time. This is proved according to [9] that each transmitter is switched off when no voice activity detected and vise versa.

2.7 Propagation Path Loss

There are two major types of propagation degradation which occurs in cellular communication network:

1) Interference
2) Fading

Fading is caused by propagation path loss and multipath phenomena.

In the cellular environment, as the signal travels, it weakens in a process known as propagation loss. There are also other effects that contribute to propagation loss such as absorption which occurs when the signal travels come into contact with air molecules, rain and water vapor. There are several path loss model which exists such as Egli model, Okumura model, Hata model and etceteras to predict the mean path loss in the cellular communication environment.

2.8 Malaysia Standards

Malaysia is currently using GSM (Global System for Mobile), the 2G (2^{nd} Generation) mobile communication system with features and services limited to voice and low rate data [14]. 3G (3^{rd} Generation) systems however are designed for multimedia communication which enables person-to-person communications with high quality images and video and access to information and services on public and private network with higher data rates and flexible communication capacities compared to 2G.

Table 1 : Parameters in Malaysia

PARAMETERS	VALUE
Bandwidth	5Mhz
Modulation Scheme	Direct-sequence CDMA (DS-CDMA)
Uplink band	1920-1980 MHz
Downlink band	2100-2170 MHz
Power control frequency	1500Hz
Base station height	15-30m
Relay station height	18.288m (60feet)
Mobile station height	1.5 m (assume pedestrian)
Cell size	8 km radius

Universal Mobile Telecommunication System (UMTS), a 3G system is synonymous with a choice of WCDMA radio access technology which is called Universal Terrestrial Radio Access (UTRA), Frequency Division Duplex (FDD) and Time Division Duplex (TDD), the name WCDMA is being used to cover both FDD and TDD operation. CDMA access technology is the approach technology for 3G systems. There are three main standards for 3G; WCDMA which has single carrier CDMA with bandwidth of 5 MHz, cdma2000 which is a multi-carrier CDMA based on the US narrowband CDMA(IS-95) and Enhanced Data rates for GSM Evolution (EDGE) which is TDMA based [15],[16].

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 Methodology

The main procedure and methodology of completing this project can be divided into four main parts.

3.1.1 Literature Review and Information Gathering

- The information regarding mobile cellular network and multihop concepts are gathered by referring to various sources such as books, paper work or even from the Internet.
- All the gathered information is then filtered trough in order to determine which information has the highest relevancy towards the successfulness of the project.
- The information that has been filtered out is studied thoroughly in order to have the highest understanding.
- After gaining sufficient knowledge and information, the project proceeded with designing the cellular network scenario with relaying system.

3.1.2 Programming

- To model the network using MATLAB which are going to be done part by part before combining them into a complete cellular network system.
- The programming consists of simulation on random base station (BS) and mobile station (MS) distribution with or without relaying.
- The results of the simulation are analyzed to find the best solution for the mobile cellular network system.
- The investigation need to be redesigned several times before getting the most reliable system.
- The programming is done based on the equations that were prepared in the MATLAB and also probability and statistics.
- The equations that are involved are studied in order to have a better understanding especially in network distribution.

3.1.3 Testing and Debugging

- A standard simulation model is build for comparison purpose.
- The testing and troubleshooting will be done after the program was build by part to check the results and compared with the standard simulation.
- In between doing the programming there will be also some debugging of the MATLAB source code. This is due to the fact that it will be impossible to encode a flawless code in the first try.

3.1.4 Tool

The tool that will have a great deal in this project is the MATLAB. This is because MATLAB was to model and simulate the environment of the mobile cellular network. The flowchart of creating the CDMA system with non-fixed relay station model started with research and understanding the previous MATLAB source code. The code then been modified part by part to comply with the system needed for this project. Each part was tested and troubleshoots to encounter problems so that simulated model will be completed.

Figure 6 shows the flowchart of creating the model and simulation for the CDMA network using relaying.

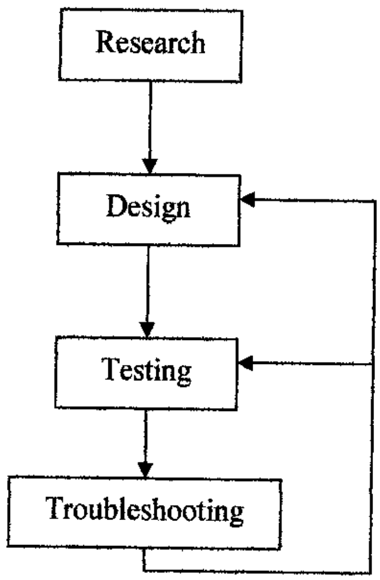


Figure 6 : Flowchart of Project Work

3.2 Project Work

3.2.1 Assumptions

Some assumptions were made throughout the investigation of this project to simplify calculations:

1. Each RS is capable of serving one MS at one time.
2. Network system consists of 7 cells the area of coverage.

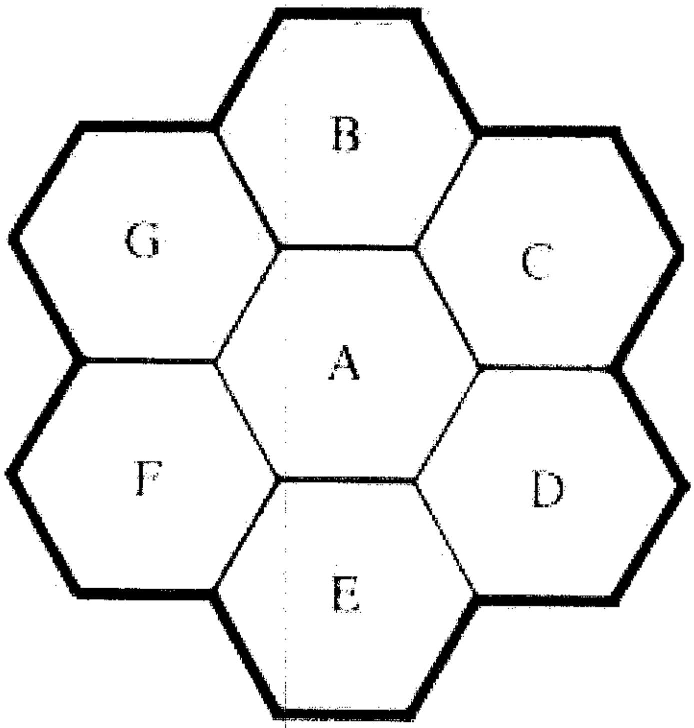


Figure 7 : 7-cell system used in simulation

3. Radius of the cell is normalized to 1.
4. The scenario of the mobile relays is investigated in the reverse-link.
5. The investigation does not consider fading effects.
6. The calculations are only based on the distance of distributed MS and RS.
7. The RS region is situated in middle half of the total radius of the cell. RS can only be selected if it is situated in the region.

8. The MS is situated outside the RS region and inside the cell radius.
9. Figure 8 shows that the shaded area is the region of RS and the white area is the region for the MS.

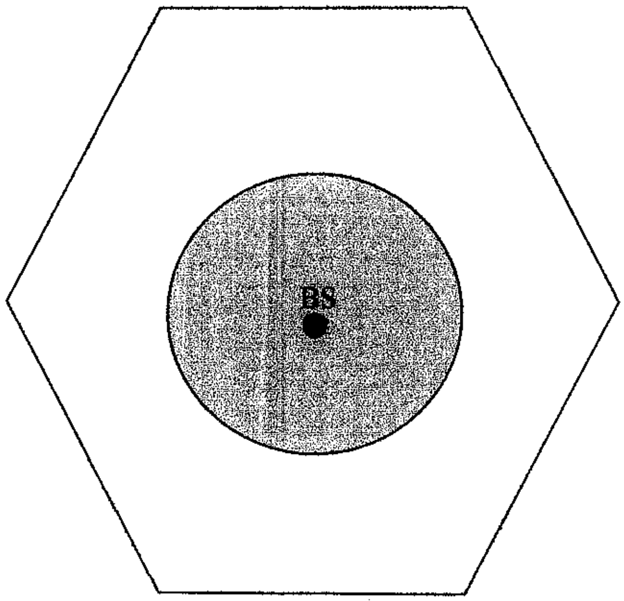


Figure 8 : The region for RS and MS.

10. The radius of the RS region is half of the cell radius.
11. RS and MS are uniformly distributed in the 7-cells network.

3.2.2 Model Simulation

The model investigated consists of 7 cells, with each cell containing one BS which is in the center of the cell, RS region which is the shaded area and the MS region which is outside the RS region. Figure 9 illustrate the complete model of the 7-cells network with RS and MS region.

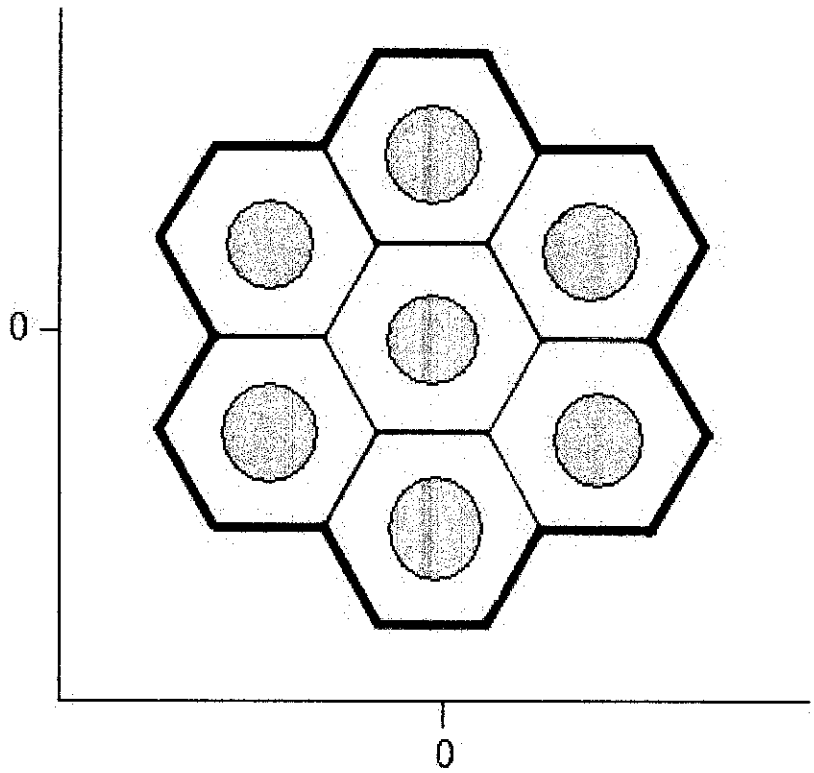


Figure 9 : The complete model of 7 cells CDMA network with RS and MS region.

3.3 Decision Schemes

Figure 10 indicates the flow chart for this project model. The decision schemes are to determine whether the mobile users shall communicate directly to base station or routed through the relay station. The distance between MS to both BS and RS is used to calculate the interference of the system. MS will choose the RS which is closer to it and en the distance of the MS to RS

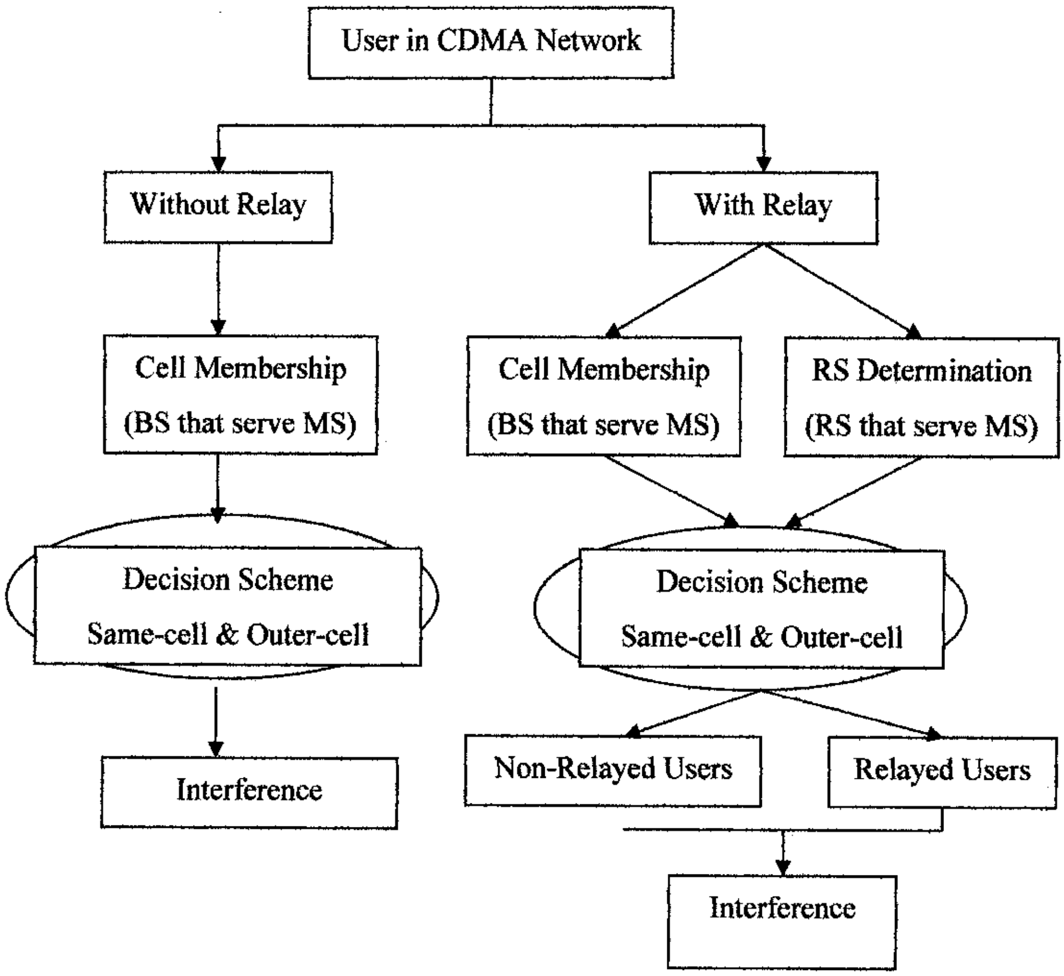


Figure 10 : Flow Chart of Model Simulation.

3.4 Interference

This project investigation is based on the interference experienced by the center base station for relayed CDMA system. The basic calculation of interference is as stated below:

Total Interference = Same-Cell Interference + Outer-Cell interference

3.4.1 Same-Cell Interference

Same-cell interference is caused by MS and RS other than the investigated MS within the center cell. Figure 11 shows the interferences from same-cell which affects the BS. There are two time slot given to reduce the interference. Both time slots will not interfere with each other.

1. RS-BS and MS-BS (1^{st} time slot)
2. MS-RS (2^{nd} time slot)

From MS to BS

MS is a non-relayed MS transmitting directly to the BS and does not interference to RS due to the different timeslots. The BS received signals from all MS with equal power level due to power control. For N users, there will be (N-1) interfering signals.

From MS to RS

The interference from each relayed MS is given by equation:

$$\frac{I(r_{m\_b}, r_{m\_r})}{S} = \left(\frac{r_{m\_r}}{r_{m\_b}}\right)^4 \quad \text{.....} (9)$$

Where r_{m_r} is the distance from MS to RS and r_{m_b} is the distance from MS to BS.

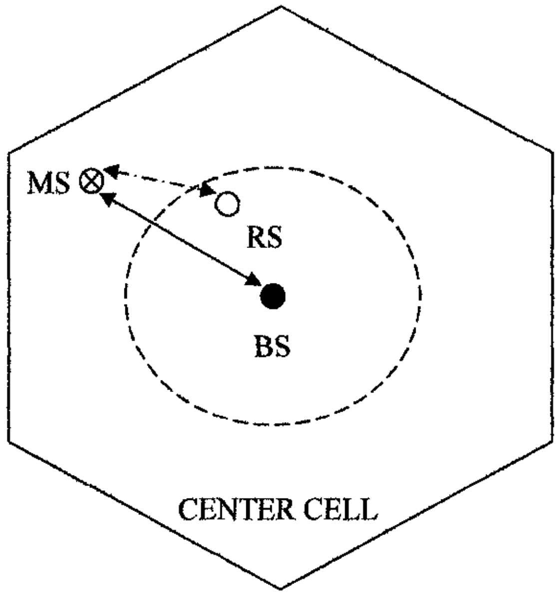


Figure 11 : Same Cell Interference from non-relayed MS to center BS.

From RS to BS

BS receives all signals at same power level due to power control. RS will transmit signals received from the relayed MS it served. Each of these signals will receive by BS at normalized power. Therefore the interfering signal will be the N user being relayed to selected RS.

3.4.2 Outer-Cell Interference

Outer-cell interference is caused by MS and RS in the others cell surrounding the center cell. Figure 12 show the interferences from outer-cell which affects the center BS.

From MS to BS

The interference caused by MS_1 for non-relayed outer-cell to center BS_0 is given by:

$$\frac{I(r_{m1\_b0}, r_{m1\_b1})}{S} = \left(\frac{r_{m1\_b1}}{r_{m1\_b0}}\right)^4 \text{ ..... (10)}$$

Where r_{m1_b0} is the distance from MS_1 to BS_0 and r_{m1_b1} is the distance from MS_1 to BS_1.

From MS to RS

The interference caused by MS_2 for relayed outer-cell to center BS_0 is given by:

$$\frac{I(r_{m2\_b0}, r_{m2\_r})}{S} = \left(\frac{r_{m2\_r}}{r_{m2\_b0}}\right)^4 \text{ ..... (11)}$$

Where r_{m2_b0} is the distance from MS_2 to BS_0 and r_{m2_r} is the distance from MS_2 to RS.

From RS to BS

The interference caused by RS to BS_0 which is the center BS is given by:

$$\frac{I(r_{r\_b0}, r_{r\_b1})}{S} = \left(\frac{r_{r\_b1}}{r_{r\_b0}}\right)^4 \text{ ..... (12)}$$

Where r_{r_b0} is the distance from RS to BS_0 and r_{r_b1} is the distance from RS to BS_1.

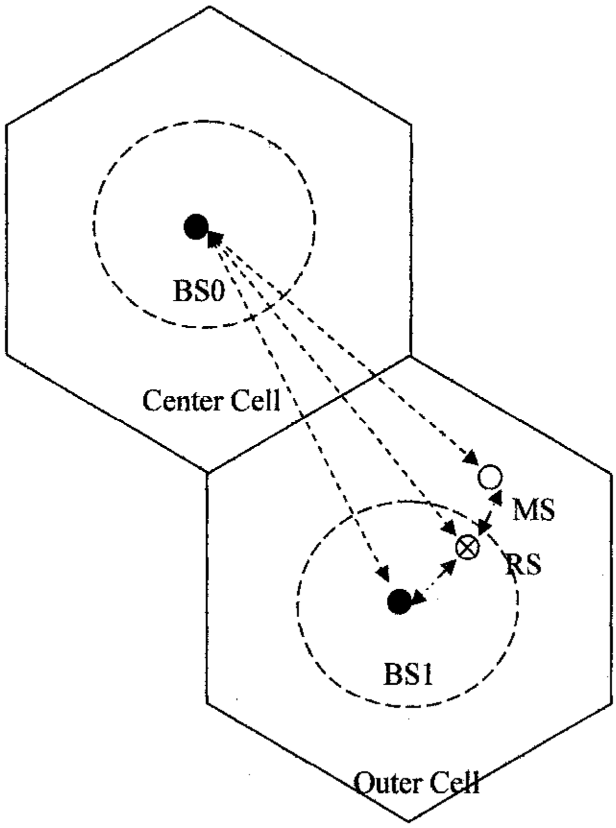


Figure 12 : Outer-Cell Interference Experienced by Center BS.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results and Findings

In this project, simulations were carried out to investigate the performance of multihop cellular network based on the distance calculation. The interference investigations were conducted for the MS which served through RS and MS which served directly to BS in the same cell. Time slots were introduced to the system to eliminate the possibility of having high interference in the system. All the following results of the simulation and calculations are presented in the following sections.

4.1.1 MATLAB Simulation

The Figure 13 shows the output of the simulated MATLAB code for the system.
In the simulation, there were 7-cells cellular network with five RS and ten MS in each cell. There were five MS which connected to five RS in the system while the other five MS were connected directly to the BS which was in all the cells.

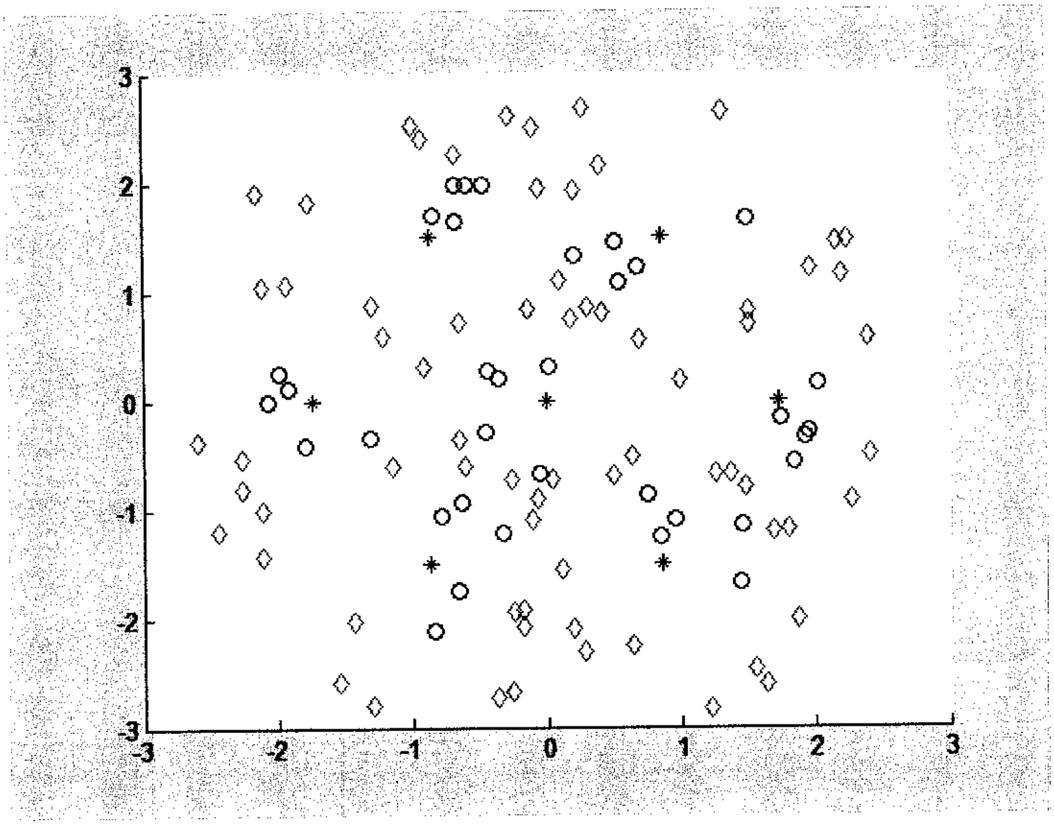


Figure 13 : MATLAB model simulation of the multihop cellular network.

Legend:

1. Black stars indicate all BS.
2. Blue diamonds indicate all MS.
3. Red circle indicate all RS.

4.2 Interference Based on Distance in Same Cell and Outer Cell

Using calculations from the formulas, the interference of the system is determined.

Table 2 : Interference for Non-Relayed System for Same-Cell and Outer-Cell using Decision Scheme based on Distance.

	Non-Relayed	
	Same Cell Interference	Outer Cell Interference
MS-BS	9	6.39
RS-BS	-	-
MS-RS	-	-
Total Interference	9	6.39
	15.39	

Table 3 : Interference for Relayed System for Same-Cell and Outer-Cell using Decision Scheme based on Distance (First time slot).

	Relayed	
	Same Cell Interference	Outer Cell Interference
MS-BS	4	0.090
RS-BS	5	0.001
MS-RS	-	-
Total Interference	9	0.091
	9.091	

Table 4 : Total Interference and Improvement percentage for Non-Relayed and Relayed System for Same-Cell and Outer-Cell (First time slot).

	Non-Relayed	Relayed
Total Interference	15.390	9.091
Improvement (%)	40.93	

The interference of MS-RS to the BS is zero. This is because center BS does not received any interference from MS-RS due to the different time slots.

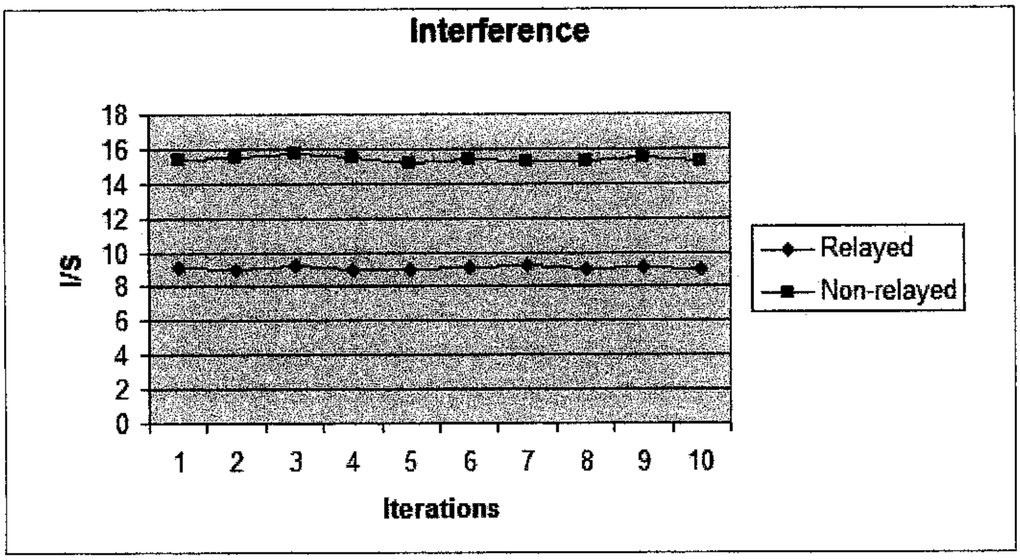


Figure 14 : Interference Comparison for Relayed and Non-relayed System (First time slot).

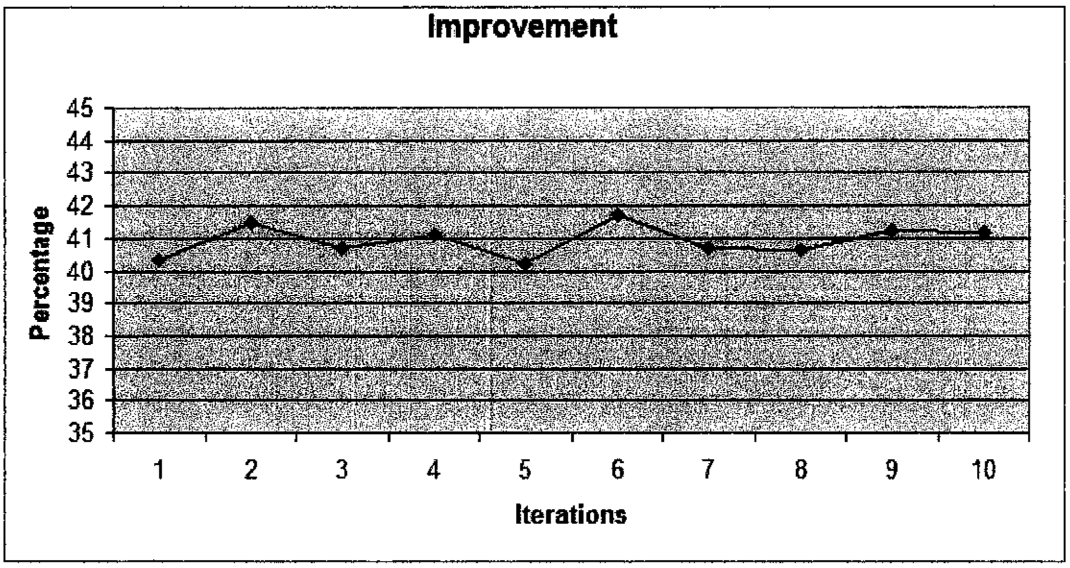


Figure 15 : Percentage of Improvement based on Distance (First Time Slot).

Table 5 : Interference for Relayed System for Same-Cell and Outer-Cell using Decision Scheme based on Distance (No time slots).

	Relayed	
	Same Cell Interference	Outer Cell Interference
MS-BS	4	0.090
RS-BS	5	0.010
MS-RS	0.020	0.004
Total Interference	9.020	0.104
	9.124	

Table 6 : Total Interference and Improvement percentage for Non-Relayed and Relayed System for Same-Cell and Outer-Cell (No time slots).

	Non-Relayed	Relayed
Total Interference	15.390	9.124
Improvement (%)	40.7	

From the results shown, it shows that by introducing two time slots, the interference is reduced. The percentage of improvement given for the first time slot is about 40.93%. If time slots are not introduced to the system, the improvement percentage is slightly reduced since the total interference in the outer-cell for relayed system is increased.

4.3 Practical Issues

Multihop in cellular network shown that the improvement is sufficient for the system to be implemented but there are several factors that need to be considered before implementing this technique. There is possibility of having handover issues in multihop. This issue occurs when a mobile which is relaying a user is changing from idle mode to a non-idle mode. This happen when the user of the relaying mobile is switching off or using the mobile at that time. A MS which is making the connection to the BS from its RS must now find a new RS or connecting directly to the BS. At this moment, the MS might loss its connectivity or having high interference and also delays during the data transmission.

The cost of implementing new technology is a challenge to make this project possible. The new mobile phones technology must be able to allow the mobile phones to become a transmitter and also receiver. This can be done by installing new circuit design or new hardware in the mobile phones. The new circuit design can be cheaper compared to constructing new BS or new fixed RS. The mobile phones can detect the region where it is situated, either the RS or MS region. The mobile phones must also able to switch modes. When the phone is in idle mode, it will become RS and in non-idle mode, it will only become the MS. This can be done by developing new software which can be installed in the mobile phones.

Some ethical issues should also be considered in implementing this technology such as the privacy issues. Some users might not allow other users to relay through their mobile phones. This is due to power consumption which can decrease the battery life time. Mobile phones which become a RS can suffer battery power loss since there are transmitting and receiving data activities during the idle mode. Mobile phones service providers should balance this issue by giving incentives to the users who allow their mobile phone to become a RS. The incentives are such as lower fees rate or free airtime credits. This will encourage the mobile users to allow their mobile phones to be part of this new system.

CONCLUSION

The objective of this project was to investigate the benefits of implementing relaying in a CDMA system. The most important thing is to have the understanding of the mobile cellular network and the multihop concept. There are many multiple access techniques in the wireless network such as the frequency division multiple access (FDMA), time division multiple access (TDMA) and also code division multiple access (CDMA) but the main concern about this project is only by CDMA techniques. All the advantages and also disadvantages of the difference techniques are going to be studied as a reference for comparison between the techniques performance. Most of the progresses done are about the findings of the topics relevant to this project such as the power control, sectorization, system performance, and the uplink-downlink capability of the CDMA network system. As expected, the overall interference experienced by the BS was reduced due the shorter distance and less transmit power needed to transmit signal from MS-RS and RS-BS. This leads to an increase of the E_b/N_0 which means the increase of capacity at the BS. Setting two timeslots during transmitting the signals; first timeslot for MS-BS and RS-BS and the second timeslot for MS-RS can remove the interference. Each RS can only transmit signal for a single MS. This is also to reduce the interference and battery power consumption of the RS. The total interference will be the sum of interference of same-cell and outer-cell of the system. The project has shown that relaying using mobile RS is possible and does increase the capacity of a CDMA system but certain operation need to be implemented. Relaying with time slots improves the multihop cellular network system by 40.93%.

RECOMMENDATION

In this project, only relaying for reverse or uplink transmission, from MS to BS has been investigated. The project would be more complete if relaying for forward or downlink transmission, BS to MS is investigated. This is to ensure the capacity in both direction of transmission.

The simulation of the environment of mobile cellular network had been created to make the research easier. The first step is to implement a system with fixed relay station then followed a system with non-fixed relay station. The non-fixed relay station can be the mobile station which also called as the user's cell phone. The result of this project might be possible to be implemented in future since multihop mobile cellular network can produce better performance compared to the existing system.

This project considered same-cell and outer-cell interference to obtain the total interference of the system. The result is more accurate if more iteration is done on the signal per signal values. This project had concentrated on using mobile RS that will be less costly compared to fixed RS. It might be possible to implement the system in hardware and software in the future.

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APPENDICES

APPENDIX A

FIRST SEMESTER TIME FRAME

Gantt Chart														
Task	***Week***													
	3	4	5	6	7		8	9	10	11	12	13	14	15
Data Collection/ Literature Study/ Research														
1) Mobile Cellular Network Concepts														
2) CDMA														
-Power Control														
-System Performance														
-Sectorization														
- Uplink/Downlink														
3) Multihop														
Design/Modeling														
1) Cellular without relay														
2) Cellular with relay														
Testing and Debugging														

APPENDIX B

SECOND SEMESTER TIME FRAME

Gantt Chart														
Task	***Week***													
	3	4	5	6	7		8	9	10	11	12	13	14	15
Data Collection/ Literature Study/ Research														
1) Mobile Cellular Network Concepts														
2) Alternatives for peer-to-peer														
2) Radio Network Planning														
-Capacity														
-Path loss														
3) Radio Source Management														
- Power Control														
- Uplink/Downlink														
- System Performance														
3) Multihop														
Design/Modeling														
1) Cellular with non-fixed RS														
Testing and Debugging														

APPENDIX C

MATLAB CODING

```
%list of parameters
clear all
user=500;          %numbers of user
r=1;               %radius of cell
cells=7;
n_relay=5;        %n relay per cell
m_user=10;        %m user per cell
s_nu=10^-0.1;     %SNR=-1dB
Eb_No=10^0.7;  %Eb/No=7dB
dist = sqrt((r).^2 + (r).^2);
no=0; no1=1;  %no-relay, relay
iter=100;      %no of iteration repeated
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%BS coordinate assignment
x_a=r*0;y_a=r*0;       %Base Station A (BS_A)
x_b=-0.866*r;y_b=1.5*r; %Base Station B (BS_B)
x_c=0.866*r;y_c=1.5*r;  %Base Station C (BS_C)
x_d=1.732*r;y_d=0*r;   %Base Station D (BS_D)
x_e=0.866*r;y_e=-1.5*r; %Base Station E (BS_E)
x_f=-0.866*r;y_f=-1.5*r; %Base Station F (BS_F)
x_g=-1.732*r;y_g=0*r;  %Base Station G (BS_G)

X_BS=[x_a x_b x_c x_d x_e x_f x_g];
Y_BS=[y_a y_b y_c y_d y_e y_f y_g];

x_min=-2.5988*r;x_max=2.5498*r;          %limitation of distribution in x-axis
y_min=-3.0*r;y_max=3.0*r;                %limitation of distribution in y-axis

%Random distribution of users
x_rand=unifrnd(x_min,x_max,1,user);
y_rand=unifrnd(y_min,y_max,1,user);

% X_rand and Y_rand is reform to matrix 2* # of user, however calculation remains done in natural
%form 1st row indicate the x coordinate while 2nd row indicate y coordinate for each point

XY_rand =[x_rand;y_rand]          %scatter(x_rand,y_rand,'k*-');

%Dist_BS_A  is reformated into matrix 7 *# of user(# of row * # of Coluoms), Thus
%Distance of all BS to all users.
Dist_BS_A = sqrt((x_rand-x_a).^2 + (y_rand-y_a).^2);
Dist_BS_B = sqrt((x_rand-x_b).^2 + (y_rand-y_b).^2);
Dist_BS_C = sqrt((x_rand-x_c).^2 + (y_rand-y_c).^2);
Dist_BS_D = sqrt((x_rand-x_d).^2 + (y_rand-y_d).^2);
Dist_BS_E = sqrt((x_rand-x_e).^2 + (y_rand-y_e).^2);
Dist_BS_F = sqrt((x_rand-x_f).^2 + (y_rand-y_f).^2);
Dist_BS_G = sqrt((x_rand-x_g).^2 + (y_rand-y_g).^2);

%Dist_BS_A  is reformated into matrix 7 *# of user(# of row * # of Coluoms), Thus
Distance_BS=[Dist_BS_A; Dist_BS_B; Dist_BS_C; Dist_BS_D; Dist_BS_E; Dist_BS_F;
Dist_BS_G]
```

```
%Coordinate of cells
x_coor=zeros(1,cells);
y_coor=zeros(1,cells);
x_coor(1)=0;y_coor=0;                    %BS_A coordinate.
x_coor(2:7)=[x_b x_c x_d x_e x_f x_g];   %BS_B-G ccoordinate.
y_coor(2:7)=[y_b y_c y_d y_e y_f y_g];

%Determine the cell of each user.
x_mat=repmat(x_rand,cells,1);
xc_mat=repmat((x_coor)',1,user);
y_mat=repmat(y_rand,cells,1);
yc_mat=repmat((y_coor)',1,user);

dist1 = sqrt((x_mat-xc_mat).^2 + (y_mat-yc_mat).^2);
[Distance_BS,cel]=min(dist1);

%Eliminates user outside cells,choose valid user only.
%Show the coordinate where users are located.
v_user=find(Distance_BS<dist);
Distvu_bs=Distance_BS(v_user);    %Distance of valid mobile user.
x_vucoor=x_rand(v_user);
y_vucoor=y_rand(v_user);
v_usercoor=[x_vucoor;y_vucoor]
cell=cel(v_user);                 %Cell where the valid user located.

%Setting the area of relay region(RR)
Dist_BS_RS=0.5;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Setting the Mobile to become RS
RS = find(Distvu_bs<=Dist_BS_RS);       %Index for Relay
cellRS = cell(RS);
RSD = Distvu_bs(RS);                    %Distance for Relay

%Get coordinates for RS from valid user
x_RScoor=x_vucoor(RS);
y_RScoor=y_vucoor(RS);

%Setting the Mobile to become MS
MS = find(Distvu_bs>Dist_BS_RS);        %Index for Mobile
cellMS = cell(MS);
MSD = Distvu_bs(MS);                    %Distance for Mobile

%Get coordinates for MS from valid user
x_MScoor=x_vucoor(MS);
y_MScoor=y_vucoor(MS);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i=1:cells
  idx_RS = find(cellRS == i);
  idx_MS = find(cellMS == i);

%Choose n relays only at each cell
%Choose n relay(5) per cell that curently using their mobile for relaying.
temp = idx_RS(1:n_relay);        %Choose first n_relay from RS index
xrs_coor=x_RScoor(temp);
yrs_coor=y_RScoor(temp);

x_RSelected=repmat(xrs_coor,m_user,1);
y_RSelected=repmat(yrs_coor,m_user,1);
```

```
scatter(X_BS(i),Y_BS(i),'k*');
hold on
scatter(xrs_coor,yrs_coor,'r');

%Choose m user only at each cell
%Choose n user(10) per cell that currently using their mobile.
temp1 = idx_MS(1:m_user);          %Choose first m_user from RS index
xms_coor=x_MScoor(temp1);
yms_coor=y_MScoor(temp1);

x_MSelected=repmat((xms_coor)',1,n_relay);
y_MSelected=repmat((yms_coor)',1,n_relay);

scatter(xms_coor,yms_coor,'bd');

%Distance selected RS and MS
  dist3 = sqrt((x_MSelected-x_RSelected).^2 + (y_MSelected-y_RSelected).^2);
  [Distance_RS_MS,idx_rs]=min(dist3);
  idx_RS
  end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%INTERFERENCE EFFECTS
%Different types of interference seen by BS
%Same cell:
MS_same_BS=zeros(1,iter);
%Outer cell:
MSRS_out_BS=zeros(1,iter);
MSBS_out_BS=zeros(1,iter);
RSBS_out_BS=zeros(1,iter);

%Different types of interference seen by RS
%Same cell:
MSRS_same_RS=zeros(1,iter);
MSRS_same_BS=zeros(1,iter);
RSBS_same_RS=zeros(1,iter);
%Outer cell:
MSRS_out_RS=zeros(1,iter);
MSBS_out_RS=zeros(1,iter);
RSBS_out_RS=zeros(1,iter);
tot_int_norelay=zeros(1,iter);
int_rel=0;

ratio=zeros(1,iter);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Determine whether user is relayed or communicate directly to BS
%FLAG:
%Direct connection to BS =0
%Relayed connection to BS=1

flag=zeros(1,length(temp));

temp2=find(min(dist3));
flag(temp2)=1;  %User will be relayed.

%Select user from relayed and non-relayed region
%k=1:n_relays
for i=1:cells
```

```
idx_percell=find(idx_RS);
idx_non= find(flag(idx_percell)==0);
idx_nonMB = idx_MS(1:m_user);
idx_non= idx__nonMB(idx_non);
idx_rel= find(flag(idx_percell)==1);
idx_rel= idx_percell(idx_rel);

if error ==1
   display('Error');
   break;
else

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Calculate the interference
%Calculate interference by BS without relaying (1st time slot)

 RM_B=[RM_B(idx_non) RM_B(idx_rel)];
 RM_B0=[RM_B0(idx_non) RM_B0(idx_rel)];
 interf_norel=((RM_B)/(RM_B0)).^4;
 idx=find (interf_norel<=1);
 idx_relo=idx(1:m_user);
 tot_interf_norel(no)=(m_user-1)+sum(interf_norel(idx_relo));

if i==1

 %Calculate interference by BS with relaying (1st time slot)

 RM_RS=RM_R(idx_rel);
 RM_BS=RM_B(idx_rel);
 interf_MR_same= ((RM_RS)/(RM_BS)).^4;
 idx= find(interf_MR_same<=1);
 idx_relo=idx(1:m_user);
 MS_RS_same(no)= 0;
 MS_BS_same(no)=m_user-1;
 RS_BS_same(no)=n_relay;
 tot_interf_rel=MS_BS+RS_BS

 %Calculate interference by BS with relaying (No time slot)
 RM_RS=RM_R(idx_rel);
 RM_BS=RM_B(idx_rel);
 interf_MR_same= ((RM_RS)/(RM_BS)).^4;
 idx= find(interf_MR_same<=1);
 idx_relo=idx(1:m_user);
 MS_RS_same(no)= sum(interf_MR_same(idx_relo));
 MS_BS_same(no)=m_user-1;
 RS_BS_same(no)=n_relay;
 tot_interf_rel=MS_BS+RS_BS+MS_RS_same

 %Interference seen by RS in center cell
 idx_relo=idx_rel(idx_relo);
 idx_rel1=find(rel(idx_relo)==1);
 idx_rel1=idx_relo(idx_rel1);
 perRS=length(idx_rel1);
 MS_RS_(no)=perRS;

 rM_BmbSR=Rm_b(idx_nonMB);
 temp=Rm_cr(1,:);
 rM_R0mbSR=temp(idx_nonMB);
```

```
interf_MB_sameRS=((rMBmbSR)/(rM_R0MB)).^4;
idx=find(interf_MS_sameRS<=1);
idx_norel=idx(1:m_user);
MS_BS_sameRS1(no)=sum(interf_MB_sameRS(idx_norel));

interf_RB_sameRS=((rR_B)/(rR_R1)).^4;
idx=find(interf_RB_sameRS>1);
interf_RB_sameRS(idx)=1;
RS_BS_sameRS1(no)=(length(idx_relo)-perRS)*sum(interf_RB_sameRS);

temp=Rm_cr(1,:);
idx_relo=m_user-perRS;
rM_R=Rm_r(idx_relo);rM_R0=temp(idx_relo);

interf_MR_sameRS=((rM_R)/(rM_R0)).^4;
idx=find(interf_MR_sameRS>1);
interf_MR_sameRS(idx)=1;
MS_RS_sameRS1(no)=sum(interf_MR_sameRS);

else

%Interference seen by center BS from puter cell
rM_Bmro=Rm_r(idx_rel);
rM_b0mro=Rm_b0(idx_rel);
interf_MR_outer=((rM_Rmro)/(rM_B0mro)).^4;
idx=find(interf_MR_outer<=1);
idx_relo=idx(1:m_user);
MS_RS_outer_BS(no)=MS_RS_outer_BS(no)+sum(interf_MR_outer(idx_relo));

rM_Bmbo=Rm_b(idx_nonMB);
rM_B0mbo=Rm_b0(idx_nonMB);
interf_RB_outerRS=((rR_B)/(rR_R0)).^4;
idx= find(interf_RB_outerRS>1);
interf_RB_outerRS(idx)=1;
RS_BS_outer_RS(no)=RS_BS_outer(no)+sum(interf_RB_outerRS)*(length(idx_relo)-perRS);

rM_B=Rm_b(idx_non);
temp=Rm_cr(1,:);
rM_R0=temp(idx_non);
interf_MB_outerRS=((rM_B)/(rM_r0)).^4;
idx=find(interf_MB_outerRS>1);
interf_MB_outerRS(idx)=1;
MS_BS_outerRS(no)=MS_BS_outer_RS(no)+sum(interf_MB_outerRS);

end
end
end

%total interference no relay
tot_interf_norel=((m_user)-1)+tot_interf_outnorel;
tot_sameBS=MS_RS_same_BS+MS_BS_same_BS+RS_BS_same_BS;
tot_outerBS=MS_RS_outer_BS+MS_BS_outer_BS+RS_BS_outer_BS;

%total interference with relay
tot_interf_rel=tot_sameBS+tot_puterBS;
tot_sameRS=MS_RS_RS+MS_BS_same_RS1+RS_BS_sameRS1+MS_RS_sameRS1;
tot_outerRS=MS_RS_outer_RS+RS_BS_outer_RS+MS_BS_outer_RS;
tot_RS=tot_sameRS+tot_outerRS;
```

```
%improvement
improv=((tot_interf_norel-tot_interf_rel)./tot_inter_notrel)*100;

interf_MB_outer=(((rM_Bmbo/rM_B0mbo)).^4);
idx=find(interf_MB_outer<=1);
idx_relo=idx(1:m_user);
MS_BS_outer_BS(no)=MS_BS_outer_BS(no)+sum(interf_MB_outer(idx_relo));

rR_B0rbo=Rr_b0(:,i);
rR_Brbo=repmat(Rr_b,n_relay,1);
interf_RB_outer=sum(((rR_Brbo/rRb0rbo)).^4);
idx=find(interf_RB_outer>0.5);
interf_RB_outer(idx)=0.5;
RS_BS_outer_BS(no)=RS_BS_outer_BS(no)+(lentgh(idx_relo)/relays)*interf_RB_outer;

end
```