GSM CELLTRAFFIC CHANNELS' LOAD REDISTRIBUTION

By

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Declaration

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of another degree at any institution, except where due acknowledgement has been made in the text.

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Abstract

User behaviours such as mobility, mean holding time, mean inter-arrival time of calls and cell parameters such as the number of traffic channels are factors that affect the blocking probability and grade of service (GoS) of GSM cells. Depending on the value of these parameters, individual cells (and the GSM system as a whole) may become congested leading to performance degradation, customer frustration and revenue loss on the operators' part. A careful study of these factors and the necessary adjustments improve the blocking probability and GoS of the system.

A simple model is developed to investigate the effect of these factors on the blocking probability and GoS of the GSM cell and the GSM system as a whole. Aspects of user behaviour investigated are the user mobility, mean holding time and mean intearrival time of calls to the cell. The cell parameter investigated is the number of traffic channels at the air interface of the cell. The model is also used to study the effects of cell load redistribution. The effect of redistributing the load of a spontaneously congested cell to freer neighbouring cells was found to improve upon the overall GoS of the system.

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Abbreviations

ARFCN ….......Absolute Radio-Frequency Channel Number

AUC................Authentication Centre

BCCH.............Broadcast Control Channel

BSC.................Base Station Controller

BSS.................Base Station Subsystem

BS…………… Base Station (same as BTS)

BTS.................Base Transceiver Stations

CC5 ………….Channel Combinations 5

CCCH.............Common Control Channel

DCCH............Dedicated Control Channel

EIR..................Equipment Identity Register

FACCH...........Fast Associated Control Channel

FCCH..............Frequency Control Channel

FDD................Frequency Division Duplex

FFT…………..Fast Fourier Transform

GMSC.............Gateway Mobile Services Switching Centre

GoS………… Grade of Service

GSM................Global System for Mobile Communications

HLR................Home Location Register

IMEI................International Mobile Equipment Identity

ISDN...............Integrated Services Digital Network

LA...................Location Area

LU…………....Location Update

MAS…………Multi-Agent Simulation

MS..................Mobile Station

MSC................Mobile Services Switching Centre

NSS.................Network Switching Subsystem

OMC...............Operation and Monitoring Centre

PCH.................Paging Channel

PLMN.............Public Land Mobile Network

PSTN...............Public Switched Telephone Network

QoS…………..Quality of Service

RACH.............Random Access Channel

SACCH...........Slow Associated Control Channel

SDCCH...........Standalone Dedicated Control Channel

SCH.................Synchronization Channel

SIM.................Subscriber Identity Module

SMS................Short Message Service

TCH................Traffic Channel

TCH/F.............Full Rate Traffic Channel

TCH/H............Half Rate Traffic Channel

TDMA............Time Division Multiple Access

VLR................Visitor Location Register

Dedications

To Tina and John, thanks for all the support.

Acknowledgement

First I would like to thank my course mates for all the support and Inspiration. I would also like to thank my colleague Switch Operation and Maintenance Engineers at MTN especially Charles Kwadwo Adjei for all the assistance. To Nana (Dr.) Kwesi Diawuo, I say a big thank you for supervising my thesis. Finally, and most of all, I will like to thank God, the giver and keeper of life, for blessing me with all these people.

CHAPTER ONE

1.0 INTRODUCTION

All subscribers should be interconnected, and should be able to communicate with each other simultaneously as shown in *Figure 1-*. If one connecting device is allocated to a pair of subscribers, the number required will be unreasonably high [1]. It is also impractical for all subscribers to be busy simultaneously, so assigning each pair of subscribers a dedicated channel is a waste of resources, if not impossible. For this reason, only a relatively small number of resources are used practically, putting a limit on the number of simultaneous calls that can be made in the network. This limit introduces the incidence of some blocked calls or congestion.

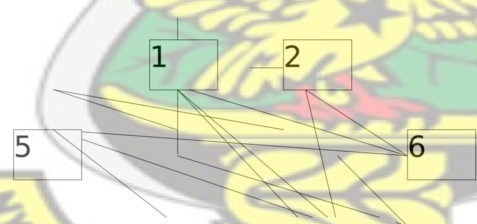

Figure 1- An Ideal Network Topology

Congestion is the unavailability of network to the subscriber at the time of attempting to use it. It is the situation when blocking occurs and no free path is available for an offered call [1]. Cellular systems have a "pool" of resources, which are not strictly assigned to any one subscriber. Whenever a caller needs to access the network, the caller seizes a resource from the "pool". Congestion occurs when all the resources from the pool have been seized and another caller wants to place a call. Congestion can also occur when as a result of a fault, the resources in the pool become unavailable and subscribers still need to access the network.

One of the most important parameters that define the Quality of Service (QoS) of a GSM system is the Grade of Service (GoS). The Grade of Service in a loss system is described as that proportion of calls that are lost due to congestion in the busy hour [2].

To cater for subscriber demand, RF optimization teams ensure minimum blocking/congestion over the air interface in order to provide better QoS to guarantee significant network performance [3]. To minimize the number of unsuccessful calls due to congestion, the planning phase of network implementation employs some projections; salient amongst them is the projected peak traffic. This projection has sometimes failed. Examples of when this projection has failed include a trade fare, a football tournament or any such events that cause an unusually high number of people to gather in an area. The number of network users at these events far exceeds the projected value of the planners. If nothing is done about these high numbers, there will be a serious degradation in service, causing loss of revenue to the operator and customer frustration. Instead of trying to manually reallocate resources whenever there is a change in subscriber distribution, RF optimization Engineer study the cells' resource utilization pattern over a period of time and decide whether a permanent or temporary cell resource upgrade is required to take care of the traffic increase on the cell.

Cellular systems such as GSM have cells that can be arranged in clusters and have the ability to redistribute subscribers depending on the availability of resources. Cells experiencing congestion/service degradation will have to handover some of their traffic to neighbouring cells with acceptable congestion/service degradation levels [4].

Practical cell congestion management comes in two fold. The first has to do with studying cell performance over a period of time and upgrading cell resources to take care of any increase in the number of callers in that cell. The second method of congestion management is real time subscriber redistribution to take care of the sudden changes in number of subscribers per cell.

This second method of cell redistribution has been investigated by Klockar *et al* [5], Novak [6] and Qui *et al* [7]. Their feedback indicates that quality of service is improved considerably if cell load redistribution is employed.

1.1 Motivation

One of the major Key Performance Indicators (KPIs) used to judge network performance and evaluate the QoS is radio traffic channel (TCH) congestion rate.

Optimum allocation of this cell resource and subscriber movement within the network, come together to impact on the networks grade of service (GoS). These in turn affects subscribers' perception about the network quality. To be successful in optimizing their network, network optimization engineers need to understand fully the factors that affect GoS, and control them. Subscriber distribution at any point in time cannot always be predicted and controlled but cell resource allocation can, and this is what the engineers can use to optimize radio resource utilization of the network.

Radio resources are finite and the gateway to any mobile network, so if their usage is not optimized it could prove very detrimental to any network operator. It is therefore necessary for network operators to continuously monitor and ensure optimum usage of radio resources. As much as possible, callers should be evenly distributed in the cluster.

1.2 Objectives

This work aims at achieving the objectives listed below;

1. model a cluster of cells with static parameters and use it to study:
    a. The interactions between mobiles and these created cells.
    b. How these cells handle congestion (blocking probability).
2. Introduce cell redistribution to this same model and study how it also handles congestion.

1.3 Outline

This thesis has five chapters. Chapter one introduces the work; it presents the motivation and objectives of this work. This sets the stage for the chapters that follow.

Chapter two gives a review of relevant literature. Chapter three describes the model used in the simulation and the simulation itself. The chapter also contains rationalizations of some of the design decisions made. Chapter four present an analysis of results of the simulations. Chapter five contains conclusion and general recommendation as to how the results obtained can be used and areas of refinement and further study.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 GSM System overview

GSM is the most popular standard for mobile communications standards in the world today.

Salient among the reasons why GSM is so popular are it's;

- Good subjective speech quality
- Low terminal and service cost
- Support for international roaming
- Ability to support handheld terminals
- Support for a wide range of new services and facilities
- Spectral efficiency
- ISDN compatibility

2.1.1 GSM Structure

GSM system is divided into the following main sub systems;

- Base station subsystem (BSS)
- Mobile services switching subsystem (MSS)/Network subsystem (NSS)
- Operations and Maintenance subsystem (OMS)

Figure 2-1 shows a typical GSM System structure.

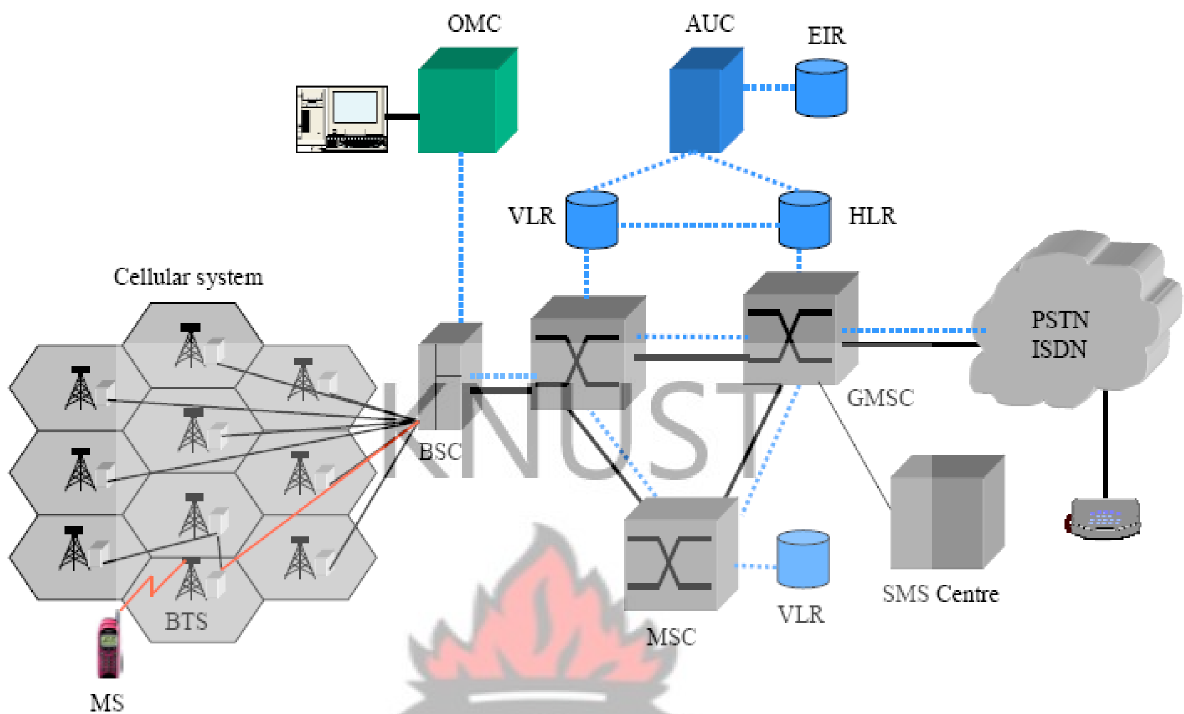

Figure 2- GSM System Structure

2.1.1.1 *Base station subsystem*

This subsystem has two main elements; BTS and BSC. Each BSC has a number of BTSs connected to it. The BSC serves the following functions:

- Radio resource management for BTSs under its control
- Intercell handover
- Reallocation of frequencies among BTSs
- Power management
- Time and frequency synchronization signal for BTSs
- Time delay measurements of received signals from MSs
- Performs trunking to reduce line capacity between BSS and MSC
- Provides interface to OMC

2.1.1.2 Network *subsystem (NSS)*

The central component of the network subsystem, also called Mobile services switching subsystem (MSS), is the Mobile services Switching Center (MSC). It acts like a normal switching node of the PSTN or ISDN, and in addition provides all the functionalities needed to handle a mobile subscriber, including registration, authentication, location updating, inter-MSC handovers, charging, and call routing to a roaming subscriber. The MSC (a Gateway MSC in this case) also provides the connection to the public fixed networks. The Home Location Register (HLR) contains all the administrative information of each subscriber registered in the GSM network, along with the current location of the subscriber. The location assists in routing incoming calls to the subscriber. There is logically one HLR per GSM network, although it may be implemented as a distributed database. The Visitor Location Register contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR. Although the VLR can be implemented as an independent unit, to date all manufacturers of switching equipment implement the VLR together with the MSC, so that the geographical area controlled by the MSC corresponds to that controlled by the VLR. The proximity of the VLR information to the MSC speeds up access to information that the MSC requires during a call. The other two registers are used for authentication and security purposes. The Equipment Identity Register (EIR) is a database that contains a list of all valid mobile equipment on the network. Each mobile equipment is identified by its International Mobile Equipment Identity (IMEI). An IMEI is marked as invalid if it is reported stolen or is not type approved. The Authentication Center (AUC) is a protected database that stores a copy of the secret key stored in each subscriber's SIM card, used for authentication and ciphering on the radio channel [8].

2.1.1.3 Operation and Maintenance subsystem (OMS)

Each network element has built-in functions for operation and maintenance, i.e. functions for supervising and reporting the status and working condition of the network elements. The operation and maintenance subsystem provides the platform for network operators to query these built in functions on a continual basis, from one or more Network Operation centres (NOC). Configuration/provisioning of network services also fall within this system.

2.1.2 The Um Interface (Air interface)

This is the air interface between the MS and BTS for GSM telephone system. Typical frequency bands for GSM are:

- Uplink (MS→BTS): 890 ~ 915MHz for GSM900； 1710 ~ 1785MHz for GSM1800
- Downlink (BTS→MS): 935 ~ 960MHz for GSM900 ； 1805 ~ 1880MHz for GSM1800

GSM's Duplex intervals are: 45MHz (For GSM900) and 95MHz (for GSM1800) and the carrier frequency interval is 200kHz. GSM also supports Frequency hopping.

Besides the standard GSM bands state above, there are many special bands which meet special requirements shown in *Table 2-1[9].*

Table 2- International GSM Frequency Bands

System	Band	Uplink (MHz)	Downlink (MHz)	Channel number
T-GSM-380	380	380.2–389.8	390.2–399.8	dynamic
T-GSM-410	410	410.2–419.8	420.2–429.8	dynamic

GSM-450	450	450.4–457.6	460.4–467.6	259–293
GSM-480	480	478.8–486.0	488.8–496.0	306–340
GSM-710	710	698.0–716.0	728.0–746.0	dynamic
GSM-750	750	747.0–762.0	777.0–792.0	438–511
T-GSM-810	810	806.0–821.0	851.0–866.0	dynamic
GSM-850	850	824.0–849.0	869.0–894.0	128–251
P-GSM-900	900	890.2–914.8	935.2–959.8	1–124
E-GSM-900	900	880.0–914.8	925.0–959.8	975–1023, 0-124
R-GSM-900	900	876.0–914.8	921.0–959.8	955–1023, 0-124
T-GSM-900	900	870.4–876.0	915.4–921.0	dynamic
DCS-1800	1800	1710.2–1784.8	1805.2–1879.8	512–885
PCS-1900	1900	1850.0–1910.0	1930.0–1990.0	512–810

There are two types of channels in the Um interface: physical channels and logical channels. The physical channels are all the time slots (TS) of the BTS. There are again two types in this: half-rate (HR) and full-rate (FR). The FR channel is a 13 kbps coded speech or data channel with a raw data rate of 9.6, 4.8 or 2.6 kbps, while the HR supports 7, 4.8 or 2.4 kbps. Logical channel refers to the specific type of information that is carried by the physical channel.

2.2 GSM Logical Channels

The Um interface has a number of logical channels multiplexed onto the physical channels for the purpose of packet and circuit switching. The logical channels result from the time complexing on the physical channel. Each channel has a fixed ID number, called Absolute Radio Frequency Channel Number (ARFCN) as given in the fifth column of *Table 2.1*.

Different logical channels are used for different kinds of information transmission between BTS and MS. There are two different types of logical channel within the GSM system:

i. Traffic channels (TCHs), which carry speech.
ii. Control channels (CCHs) which carry signaling information.

2.3 The GSM Radio Cell

Coverage in a cell is dependent upon the area covered by the signal and the distance travelled by the signal is dependent upon radio propagation characteristics in the given area. The whole land area is divided into three major classes - urban, suburban and rural -based on artificial structures and natural terrains. The cells (sites) that are constructed in these areas can be classified as outdoor and indoor cells and outdoor cells can be further classified as macro-cellular, micro-cellular or pico-cellular [10].

2.3.1 Macro-cells

When the base station antennas are placed above the average rooftop level, the cell is a known as a macro-cell. As the antenna height is above the average rooftop level, the area that can be covered is wide. A macro-cell's radius ranges between 1km and 30 km, the distance depending upon the type of terrain and the propagation conditions. Hence, this cell type is generally used for suburban or rural environments as shown in *Figure 2-2.*

2.3.2 Micro-cells

When the base station antennas are below the average roof-top level, then the cell is known as a micro-cell. The area that can be covered is small, so this concept is applied in urban and suburban areas. The range of micro-cells' radii is between 200meters and 2000 meters as shown in *Figure 2-2.*

2.3.3 Pico-cells

Pico-cells are defined as the same layer as micro-cells and are usually used for indoor coverage. The cell radius usually ranges between 4 - 200 meters as shown in *Figure 2-2.*

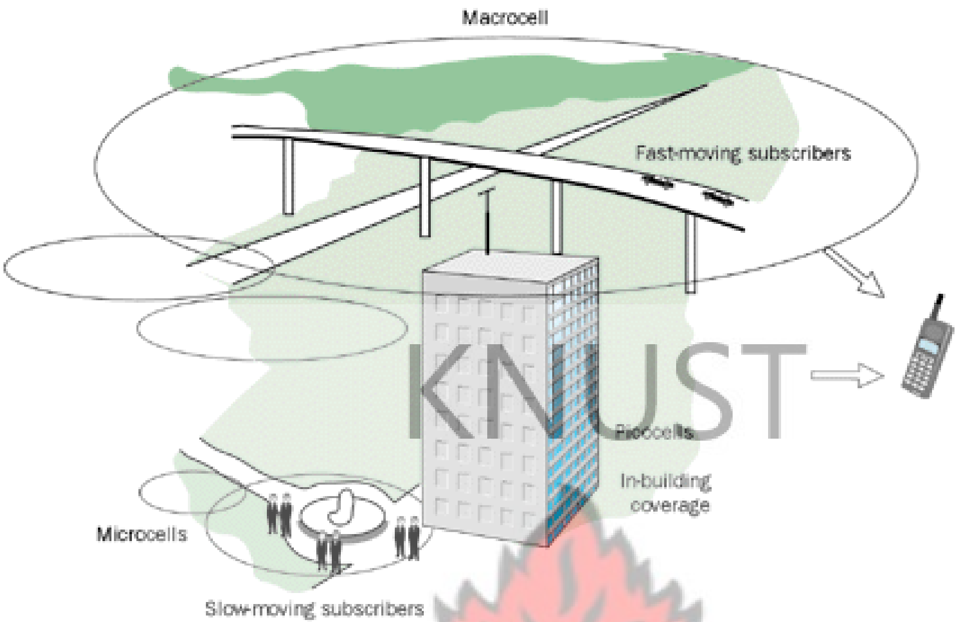

Figure 2- Macro-, Micro- and Pico-cells

2.4 Signal Losses

The amount of power received at any given point in space will be inversely proportional to the distance covered by the signal.

Considering an isotopic antenna where power is radiated equally in all directions, it is assumed that a sphere of power is formed as shown in the *Figure 2-[11]*.

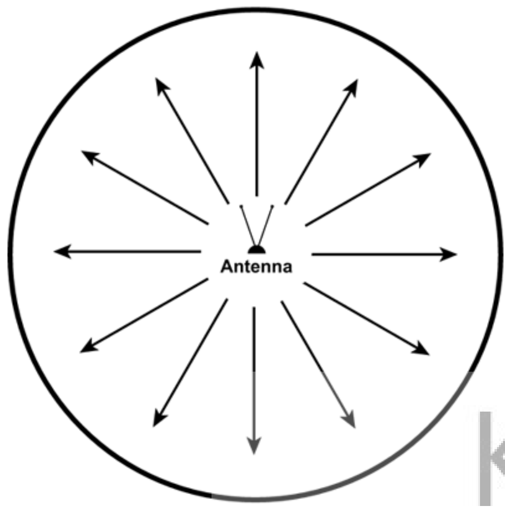

Figure 2- Radiation Pattern of an Isotropic Antenna

The sphere's surface area, A is given as:

¿¿¿

$$A = 4\pi r^2 \ldots\ldots\ldots STYLEREF\ 1 — SEQ\ Equation\ 1$$

The power density at any point S at a distance r from the antenna's (center) can be expressed as:

¿¿¿

$$S = \frac{P * G_t}{A} \ldots\ldots\ldots STYLEREF\ 1 — SEQ\ Equation\ 2$$

Where P and G_t are the antenna's transmitted power and gain respectively.

The received power, P_r at distance r is given by:

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¿
¿

$$P_r = P * G_t * G_r * \left(\frac{4\pi r}{\lambda}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots STYLEREF\ 1 — SEQ\ Equation\ 3$$

G_r is the receiver antenna's gain. Expressing *Equation 2-3* in decibels gives:

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$$[P_r] = [P] + [G_t] + [G_r] + 20\log\left(\frac{4\pi}{\lambda}\right) + 20\log r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots STYLEREF\ 1 — SEQ\ Equation\ 4$$

$[P] + [G_t]$; is the effective isotropic radiated power, EIRP and $20\log\left(\frac{4\pi}{\lambda}\right) + 20\log r$ is the free space loss $[L]$, i.e.

$$[L] = 20\log\left(\frac{4\pi}{\lambda}\right) + 20\log r$$

But, $\lambda = \frac{C}{f}$

So, $[L] = 20\log\left(\frac{4\pi f}{C}\right) + 20\log r$

Or, $[L] = 20\log\left(\frac{4\pi}{C}\right) + 20\log(f) + 20\log r$

$f \times 10^9$ is the frequency in GH_Z and $C = 3.0 \times 10^5 KM/s$ is the speed of light in KM/s

This implies that,

$$[L] = 20\log\left(\frac{4\pi}{(3\times 10^5)}\right) + 20\log(f\times 10^9) + 20\log r$$

$$[L] = -87.5 + 180 + 20\log f + 20\log r$$

$$[L] = 92.5 + 20\log f + 20\log r \ldots\ldots\ldots\ldots\ldots\ldots \text{STYLEREF 1 — SEQ Equation 5}$$

Where *r* is the distance in Km

Equation 2-5 gives the signal power loss that takes place from the transmitting antenna to the receiver antenna. The factors that combine to cause this loss will be explained in *Section 2.4.1-Section 2.4*.3. So in order to improve the received signal power, $[L]$ must be reduced to the barest by:

- Reducing the distance between transmit and receive antennas,
- Increasing the gain of the receiving antenna,
- Increasing the gain of the transmitting antenna,
- Increasing the transmitter power.

Propagation of the radio waves over the air depends on the frequency of the signal and obstacles in its path. Some factors that majorly affect signal behaviour have been briefly described in the following sections.

2.4.1 Reflections and Multipath

The transmitted radio wave nearly never travels in one path to the receiving antenna, which also means that the transmission of the signal between antennas is never line-of-sight (LOS). Thus, the signal received by the receiving antenna is the sum of all the components of the signal transmitted by the transmitting antenna.

2.4.2 Building and Vehicle Penetration

When the signal strikes the surface of a building, it may be diffracted or absorbed. This may cause the signal strength to reduce. The amount of absorption is dependent on the type of building and its environment, the amount of solid structure and glass on the outside surface, the propagation characteristics near the building, orientation of the building with respect to the antenna orientation, etc. This is an important consideration in the coverage planning of a radio network. Vehicle penetration loss is similar, except that the object in this case is a vehicle rather than a building.

2.4.3 Fading of the Signal

As the signal travels from the transmitting antenna to the receiving antenna, it loses strength. This may be due to the phenomenon of path loss or it may be due to the Rayleigh effect. Rayleigh (or Rician) fading is due to the fast variation of the signal level both in terms of amplitude and phase between the transmitting and receiving antennas when there is no line-of-sight. Arrival of the same signal from different paths at different times and its combination at the receiver causes the signal to fade. This phenomenon is multipath fading and is a direct result of multipath propagation. Multipath fading can cause fast fluctuations in the signal level. Atmospheric conditions may cause the signal of a particular frequency to fade. This causes a change in the resultant signal level. Doppler shift in frequency may also occur owing to the movement of the mobile with respect to the receiving frequencies.

2.5 Handover in GSM

Handover is a GSM feature by which the control of communication of a mobile is transferred from one channel to another if certain criteria are met. Handover is one of the most important features in mobile networks and it's required to ensure [12]:

- Continuous speech when one MS moves from one cell to another.
- An MS receives a better channel when the one it's using encounters severe disturbances/fluctuation.
- Cell load redistribution to prevent one cell from being congested when its neighbours are relatively free.

There are two main types of handover: hard and soft handovers. Usually, the hard handover can be further divided into two different types—intracell and intercell handover. The soft handover can also be divided into two different types—multiway soft handover and softer handover. A hard handover is essentially a "break before make" connection [12]. Under the control of the MSC, the BS hands off the MS's call to another cell and then drop the call. In a hard handoff, the link to the prior BS is terminated before or as the user is transferred to the new cell's BS; the MS is linked to no more than one BS at any given time. Hard handover is primarily used in FDMA and TDMA, where different frequency ranges are used in adjacent channels in order to minimize channel interference. So when the MS moves from one BS to another BS, it becomes impossible for it to communicate with both BS's (since different frequencies are used). *Figure 2-[12]* shows a hard handover taking place when a MS is moving from one BS (BS1) to another (BS2).

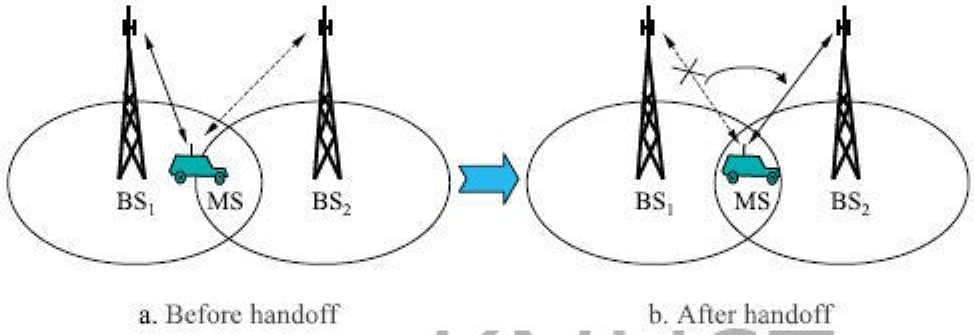

Figure 2- Hard Handover between MS and BSs

The average signal strength of BS1 decreases as the MS moves away from it. Similarly, the average signal strength of BS2 increases as the MS approaches it. A soft handover is one in which the channel in the source cell is retained and used for a while in parallel with the channel in the target cell. In this case the connection to the target is established before the connection to the source is broken, hence this handovers is called *make-before-break*. The interval, during which the two connections are used in parallel, may be brief or substantial. For this reason the soft handovers is perceived by network engineers as a state of the call, rather than a brief event. Soft handovers may involve using connections to more than two cells [13].

2.5.1 The Handover process

During network design process, each cell is assigned a list of potential target cells, which can be used for handing-off calls from this source cell to them. These target cells are called neighbours of the source cell. During a call all the parameters of the signal in the channel in the source cell are monitored and assessed in order to decide when a handover may be necessary. The downlink and/or uplink directions may be monitored. The handover may be requested by the phone or by the source cell and, in some systems, by a BTS of a neighbouring cell. The phone and the BTSs of the neighbouring cells monitor each others' signals and the best target candidates are selected among the neighbouring cells.

For making a handover decision the BSS will process, store and compare these parameters from the measurements made and predefined thresholds. During every slow associated control channel (SACCH) multiframe, the BSS compares each of the processed measurements with the relevant thresholds [13].

2.5.2 The Handover Margin

MSs moving around cell neighbours are susceptible to repetitive handovers, referred to as "ping-pong". Before an MS initiates a handoff, it receives quality measurements from the border area of the neighbour cell. If the neighbour has better quality parameters than the serving cell, the handover is followed through. Sometimes after the handover, the new serving cell does not fulfil the quality requirements and a handover is back on. If the quality parameters seem better in the neighbour cell, a handover is performed again. If this continues, the ping-pong phenomenon occurs. To prevent this occurrence, a handover margin (hysteresis) is used. This serves as a threshold in handover process. The handover can only take place if this threshold is exceeded. *Figure 2-5* shows the handover threshold margin.

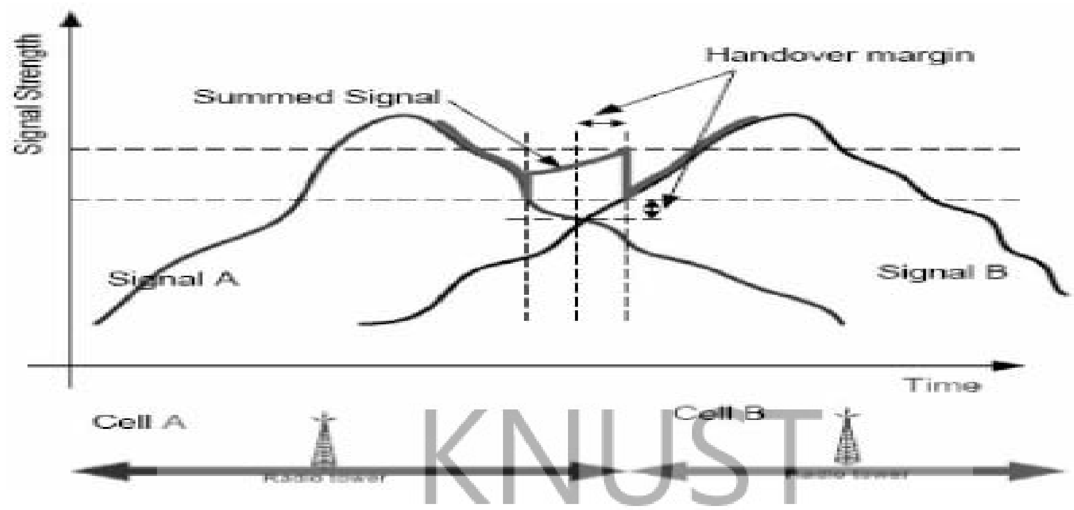

Figure 2- Handover Threshold Margin

2.6 Congestion and User Mobility

As explained in *Section 1.1*, congestion may occur in the GSM cell since the assigned frequencies (channels) to that cell are finite. Users are only assigned channels when they request them. If the number of users requesting channels exceeds the number of channels available, some of the users are bound to be denied their requests and will not be able to access the network.

Congestion may generally occur in:

- The Core network of the GSM system
  - The Access network(Air interface)

In the Access network (Air interface), Boulmalf *et al* [15] gave two situations that give rise to congestion at the air interface. These are:

- Congestion of traffic(speech) channels
- Congestion of control(signaling) channels

Traffic congestion at the air interface as explained by Popoola *et al* [16] is the first level of congestion experienced by the customer. It measures the relative ease by which the customer seizes a traffic channel to set up a call after a signaling seizure has been successful. The higher this value, the relative difficulty it is in making a call so it is imperative to keep this type of congestion as low as possible.

Congestion of the control channels is as a result of several factors including, and increase in the signaling traffic such as handover requests or longer call setup times. One main contributing factor to control channel congestion is increased user mobility. Increased mobility results in increased volumes of handover requests and LU messages on the control channels. When the control channels become congested, call setup becomes difficult even if there are idle traffic channels on the cell.

2.6.1 User Mobility Models and Simulation

Mobility simulation is a kind of a simulation, which has the ability of showing the network performance due to the mobile behaviour of the network subscribers. Doing a mobility simulation on a planned network is an effective way of investigating the capacity and the quality of a wireless network [17].

Bettstetter [18] explains further that the modelling of movement is a very important building block in analytical and simulation based studies of cellular systems including GSM. Mobility models are needed in the design of strategies for location updating and paging, radio resource management (e.g. Dynamic channel allocation schemes), technical network planning and design. So in order to have good results in any simulation, it is important to have a good Model.

2.6.1.1 *Classification of Mobility Models*

There are many different mobility models in literature and their classifications depend on:

- The level of description (microscopic, mesoscopic, and macroscopic).
- The purpose (for radio resource management or for location management or for radio propagation)
- The defined user (pedestrian or Vehicle or both)
- The type of traffic (voice or data)
- The degree of randomness in user behaviour modelling (from a statistical way up to an analytical way).

The details of the classification may be found in the works of Bratanov [20] and Quiles[19].

2.6.1.1.1 *Mobility Models based on the Level of Description*

A microscopic model describes the movement of a single vehicle by its space and speed coordinates at a given time *t*. The aim is obtaining a very detailed model, as for example the Street Unit Model [21] or the Street Pattern Tracing Model [22].

In the mesoscopic (or kinetic) type of mobility, Quiles [19] explains that the homogenized movement behaviour of several vehicles (not only a single vehicle but a set of them) is reflected. These models achieve an accuracy of medium scale. An example of group mobility model is the Reference Point Group Mobility Model (RPGM) [23].

In the third type, Macroscopic, density, mean speed, speed variance, and traffic flow of vehicles are the points of interest. Some families of these macroscopic models include the fluid flow models, the family of gravity models and the random walk models. Fluid flow models [18], describes the mobility in terms of the mean number of users crossing the boundary of a given area. They derive from transportation theory and describe the movement of a group of users. The Reference Point Group Model [23] is also included in this family.

2.6.1.1.2 *Mobility Models based Degree of randomness*

The first of these Models is the Trace based model. This model is purely deterministic since all the mobile users' movements are actually measure in a real network.

The constrained topology model is the second type. Partial randomness is provided by these models, which simulate real scenarios where users' movement is constrained by obstacles or pathways; but speed and direction are still randomly chosen. An example of this type of model is Obstacle Mobility Model [24]. It is based on several real-life observations, taken as assumptions for modelling:

- People move towards specific destinations rather than randomly choosing some destinations.
- In real world there are obstacles, as buildings, parks or rivers for example. These obstacles block people's movements as well as hinder signal propagation.
- It is not realistic to consider random trajectories for people's movement. They do not walk along random directions but along pathways and select shortest paths.

Common scenarios represented by this model are city centres or campuses. A user randomly chooses a building as its destination, moves towards it, then pauses there for a while and finally moves to another building. To reach a destination, the user can only move along pathways, although it may cross buildings through doorways. But, among all these pathways, which one selects the user? The answer is given by the third assumption; the user selects the shortest. This model takes another assumption, in this case not too real, in order to simplify: the communication of a user with other users will be totally blocked by buildings if the transmission is out of Line-Of-Sight.

The statistical model which is the third type, allows users to move to any destination and their velocities and directions are chosen randomly. The movement of each user is described by some stochastic process. These Models are not too much realistic, because users do not move randomly wherever they want to in real life. They move along streets and pathways. Nevertheless, in practice, tracing the actual mobility behaviour of users is a very complicated task and usually such information is hard to obtain from network providers. Thus, researchers often use random models [19].

2.6.2 User Distribution and Border Behaviour

At the beginning of most random direction simulation processes, the users are usually distributed uniformly over the simulation area which is finite. As they move around randomly, they eventually get to the border of the simulation area. At the border there is the possibility of some users moving out of the area and throwing the system out of balance. Betstetter [18] explains three border rules that may be used when a user get to the border to maintain the number of user in the simulation process.

- The leaving user is bounced back to the system area, according to a certain rule,
- The leaving user is "deleted," and a new user is initialized according to the user initialization distribution, or
- The leaving user is wrapped around to the other side of the simulation plane.

Figure 2-6 explains further.

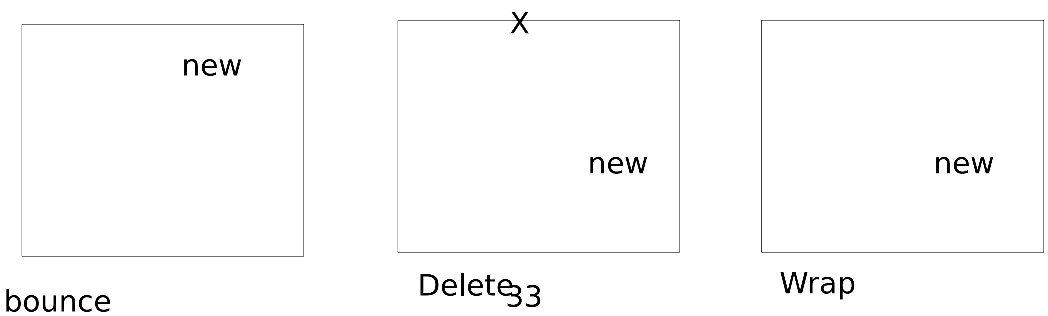

Figure 2- Simulation Border Behaviour

All methods guarantee that the number of nodes in the system area remains constant, which is often required in simulations. But Betsetter [18] also observed that applying a random direction model with "delete and replace" border behaviour or a random waypoint model can create a non-uniform user distribution. The position for the new user in this method is normally in the middle of the simulation area, giving the middle a higher number of users than close to the borders. This can lead to unwanted effects in studies of networking algorithms (e.g., in evaluation of radio resource allocation algorithms).

2.6.3 Simulation

Simulation is the imitation of some real thing available, state of affairs, or process. The act of simulating generally entails representing certain key characteristics or behaviours of a selected physical or abstract system [25]. Simulations rely heavily on the element of randomness. The reason for employing simulation is to examine a part of the real world which [26]:

- is not accessible
- is difficult to experiment with
- evolves over too long or too short time scales
- does not exist anymore/yet

A simulation system comprises three sub fields as shown in *Figure 2-7*.

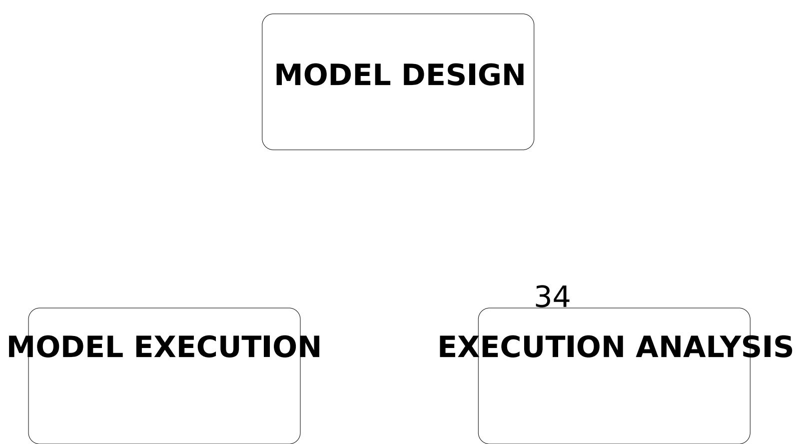

Figure 2- The Three Sub-fields of a Simulation System

The first step in simulating the real world is to create a mathematical model which represents the real world. Models can take many forms including declarative, functional, constraint, spatial or multimodel. A multimodel is a model containing multiple integrated models each of which represents a level of granularity for the physical system.

The next task, once a model has been developed, is to execute the model on a computer. This is done by creating a computer program which steps through time while updating the state and event variables in the mathematical model. The final stage of the simulation process is analysis of the output from the model execution. This stage validates the simulations process.

Several types of simulations exist, and one special type which is Multi-agent Simulation (MAS) (falls under Microsimulation) is used to attempt to explicitly model specific behaviours of specific individuals. MAS is executed by measuring periodically, interactions or communications between individuals of the system, referred to as agents. One characteristic feature of MAS that makes it flexible to use is that, agents are autonomous entities that react to environmental change and proactively change their behaviour.

CHAPTER THREE

3.0 MODEL DESCRIPTION

The behaviour and performance of a GSM network can be investigated by using either simulation or analytical study (or a combination of both). Simulation models are preferred when studying the behaviour of a specific GSM system covering a given area. In this thesis the study of the GSM network performance is based on computer simulation and analytical study. An event-driven simulator has been implemented using RUdimentary Network Emulator (RUNE) written by Magnus Almgren in MATLAB. The simulation focuses on nine cells in a GSM cellular network serving a number of MSs randomly placed within the coverage area of the cells. Each cell behaviour and interaction with the other cells and MSs are studied. The following steps are employed in creating the model to be used in this thesis:

1. Plan and create the cells and cluster
2. Assign unique frequencies to the cells.
3. Create users and assign random speeds, accelerations and directions
4. Estimate the gain values between the MSs and cells based on their positions, speeds and directions. The gain is the main criterion used by the MSs to select cells.

The following sections describe how each of the steps listed above is achieved.

3.1 The Cells (Micro Cells)

The cells are hexagonal in shape and due to the special wrap around functionality in RUNE (explained in *Section 2.6.2*), the interferences are equal amongst all the cells, and users do not leave the simulation area. Only nine cells are chosen for this study. These nine cells each have an assumed cell radius of 300 meters. The use of 120° sector antennas is employed.

The following steps are followed in creating the cells:

1. The cluster, represented by the 3 BTSs is created first with distance, *xyb*, in-between the centres of the BTSs being equal.
2. The distance from the centre of the each BTS to the centre of its 3 cells, *fib*, is calculated next. This distance is represented by complex vectors.
3. Using the distance created and a cell radius of 300 meters, the cells are plotted and the area, *rhombvec*, covered by all the cells is calculated. This area represents the simulation area.

A plot of the gives the cell plan as shown in *Figure 3-1*. The perfect hexagonal shape of the cells as seen in *Figure 3-1* is only the ideal case. Realistically, factors such as lognormal fading will give the cells a more asymmetric shape.

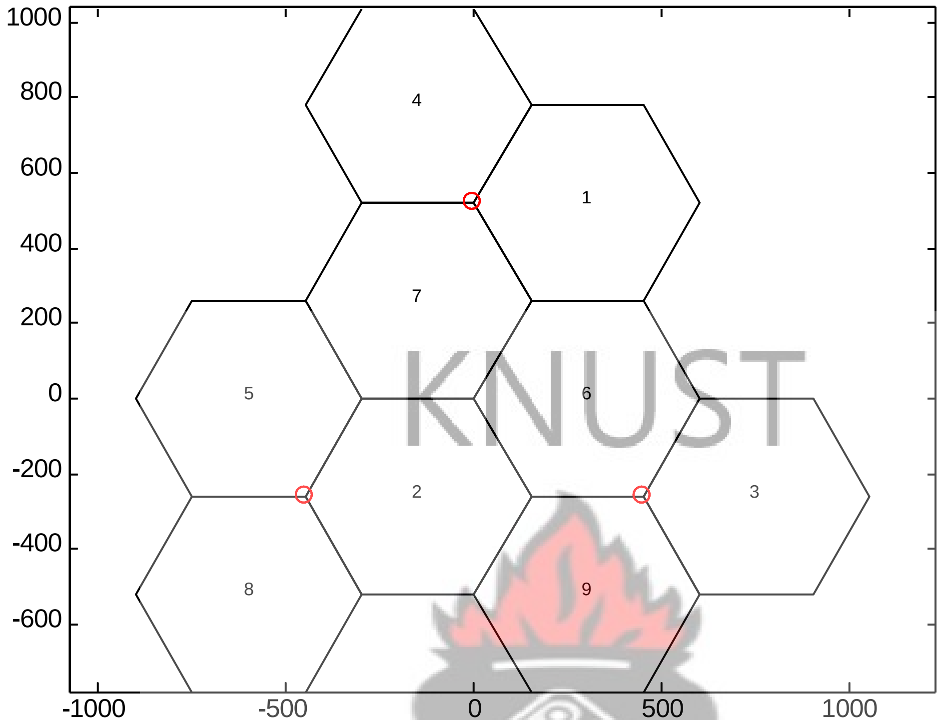

Figure 3- Cell Plan

The code to achieve this is shown in *Appendix A.1.2.*

3.2 The Channels

The number of transceiver units (TRXs) in each cell is set to 1. This implies that, there are 8 physical channels (i.e., $N = 8$) available in each cell (every carrier (TRX) has 8 timeslots). Six out of the 8 are reserved for speech in each cell (i.e., $N_{ch} = 6$) and the other two are reserved for overhead traffic (N_{sig}=2).

The cells are in close proximity, so to avoid frequency interference for this model, unique frequencies are chosen for each physical channel of the cells implying no frequency reuse is employed. The channel plan shown in *Table 3.1;* a table of unique frequencies assigned to each of the cells. Only full rate channels are considered. The code to achieve this is show in the *Appendix A.2.1*.

Table 3-: Channel plan with 6 traffic channels per cell and with no frequency reuse

CELL	1	2	3	4	5	6	7	8	9
FREQ	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*

3.3 Creating the Mobile Stations

Random complex positions representing the positions on the MSs are created and distributed over the simulation area, *rhombvec* already calculated in *Section 3-1*. The wrap functionality explained in *Section 2.7.2* is used to maintain the number of users within the simulation area. Random velocities, *xyv*, are assigned to the MSs. These velocities revolve around a mean velocity of 10m/s. The direction of motion of the users is random.

3.4 Hosting the Mobile Stations

The main criteria for hosting the MSs are the path gain values, *g*, between the MSs and the cells and availability of idle channels on the cell. The gain values are dependent on factors such as obstacles within the LOS of the signal. These obstacles cause the signal between the MS and the cell to fade. The gain values also depend on the angles, at which the signal arrives at the receiver (MS) from the transmitter (Cells).

3.4.1 Fading (Lognormal)

The MS's antenna receives a number of reflected and scattered waves from the cell's antenna due to the presence of obstacles within the signal's path. Because of the varying path lengths of the scattered waves, the phases are random, making the instantaneous received power a random variable. In the case of an unmodulated carrier, the transmitted signal at frequency ω_c reaches the receiver via a number of paths, the i^{th} path having an amplitude, a_i , and a phase, $\varnothing_i$.

Assuming the absence of a direct path or line-of sight (LOS) component, the received signal, *P(t)* can be expressed as :

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$$P(t)=\sum_{i=1}^{N} a_i \cos(\omega_c t+\varnothing_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{STYLEREF}\ 1 — \mathit{SEQ\ Equation}\ 1$$

Where *N is* the number of paths and $\varnothing_i$ is the phase and it depends on the varying path lengths. $\varnothing_i$ changes by 2π when the path length changes by a wavelength. Therefore, the phases are uniformly distributed over *[0,* 2π *].*

When there is relative motion between the transmitter and the receiver, *Equation 3-1* must be modified to include the effects of motion induced frequency and phase shifts.

Assuming that the i^{th} reflected wave with amplitude a_i and phase $\varnothing_i$ arrives at the receiver from an angle ψ_i relative to the direction of motion of the antenna, the Doppler shift (due to the motion of the receiver) of this wave is given by:

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$$\omega_{di} = \frac{\omega_c v}{c} \psi_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots STYLEREF\ 1 - SEQ\ Equation\ 2$$

Where v is the velocity of the mobile, c is the speed of light ($3x10^8$ *m/s*), and the $\psi_i{}'$ s are uniformly distributed over *[0,* 2π *]*.

The received signal *P(t)* can now be written as:

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$$P(t) = \sum_{i=1}^{N} a_i \cos(\omega_c t + \omega_{di} t + \varnothing_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots STYLEREF\ 1 - SEQ\ Equation\ 3$$

The fading over large distances causes random fluctuations in the mean signal power. Evidence suggests that these fluctuations are lognormally distributed. A heuristic explanation for encountering this distribution is as follows: The transmitted signal undergoes multiple reflections at the various objects in its path, before reaching the receiver. Then it splits up into a number of paths, which finally combine at the receiver. The expression for the transmitted signal is the same as that given in *equation 3-3*, except that the path amplitudes

a_i are themselves the products of the amplitudes due to the multiple reflections [28], expressed as:

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$$a_i = \prod_{j=1}^{M_i} a_{ji} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{STYLEREF}\, 1 - \mathit{SEQ}\, \mathit{Equation}\ 4$$

3.4.2 Modelling lognormal Fading

Lognormal fading accounts for random variations in received power (Local Average Power) observed over distances at the receiver. The mean of measurements made as the receiver moves at distances, *d* greater that half the wave length, *λ*, $\left(ie.\lambda > d > \frac{\lambda}{2}\right)$ is the local average power. Random variations are observed in the measured local average power at different locations with the same transmitter-receiver distance. These random variations are due to fading.

The received power $P_r(d)$ at a distance *d* from the receiver can also be expressed by:

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$$P_r(d) = \frac{P_t G_t G_r}{L_t L(d) L_r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{STYLEREF}\, 1 - \mathit{SEQ}\, \mathit{Equation}\ 5$$

Where *Pt* is the transmitted power, G_t is the transmitter gain, G_r is the receiver gain, L_t is the loss at the transmitter, L_r is the loss at the transmitter and *L(d)* is the path loss at a distance, *d*, from the transmitter.

From *Equation 3-5* it is observed that P_r depends explicitly on *L(d)*.

This implies at a distance *d*, the probability that the local average received power P_r is below a certain threshold, ɣ can be expressed as:

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$$P\left(P_r(d) < ɣ\right) = P\left(L(d) > \beta\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{STYLEREF 1 — SEQ Equation 6}$$

Where β is maximum tolerable path loss.

The mean loss in dB follows the power law:

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$$\acute{L}(d) = \acute{L}(d_o) + 10\, n \log_{10}\left(\frac{d}{d_o}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{STYLEREF 1 — SEQ Equation 7}$$

$\acute{L}(d_o)$ is the path loss at the reference distance $d_{0.}$ 1dB chosen for this project

n is the is the path loss coefficient. Empirical values of this coefficient range between 1.8 and 2.4 for GSM900 [30]. *d* is the distance between the TX and RX antennas, d_o is the reference distance. 1 meter is chosen for this thesis.

But the measured loss in dB varies about the mean calculated in *Equation 3-7* according to a zero-mean Gaussian random variable $X_σ$ with standard deviation, *σ*. This implies that:

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$$L(d) = \acute{L}(d_o) + 10n\log_{10}\left(\frac{d}{d_o}\right) + X_\sigma \dots\dots\dots\dots\dots\dots.. STYLEREF\ 1 — SEQ\ Equation\ 8$$

Since *L(d)* is Gaussian the probability calculation involving the Gaussian random variable will have to be considered.

If *X* is a Gaussian random Variable with mean α and standard deviation σ, then

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$$P(X > b) = Q\left(\frac{b - \alpha}{\sigma}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. STYLEREF\ 1 — SEQ\ Equation\ 9$$

Where Q is defined as:

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$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^{+\infty} e^{\left(\frac{-x^2}{2}\right)} dx \dots\dots\dots\dots\dots\dots\dots\dots.. STYLEREF\ 1 — SEQ\ Equation\ 10$$

To calculate the perceived fading between the MSs and cells, the following are followed;

1. An array of random Gaussian variates is created with α = 0 and σ = 5.2.

   Empirical values of σ range between 5.2 and 9.6 for GSM900 [30].

2. Calculate $10n\log_{10}\left(\frac{d}{d_o}\right)$, *d* which represents the distances between the MSs and cells has already been calculated in section 3-1.

3. The outcomes of 1 and 2 above are added to $\acute{L}(d_o)$ according to equation 3-8 to get the lognormal fading value for each of the MSs to each of the cells.

The code to achieve this is shown in *Appendix A-1*. *Figure 3-2* shows a lognormal map.

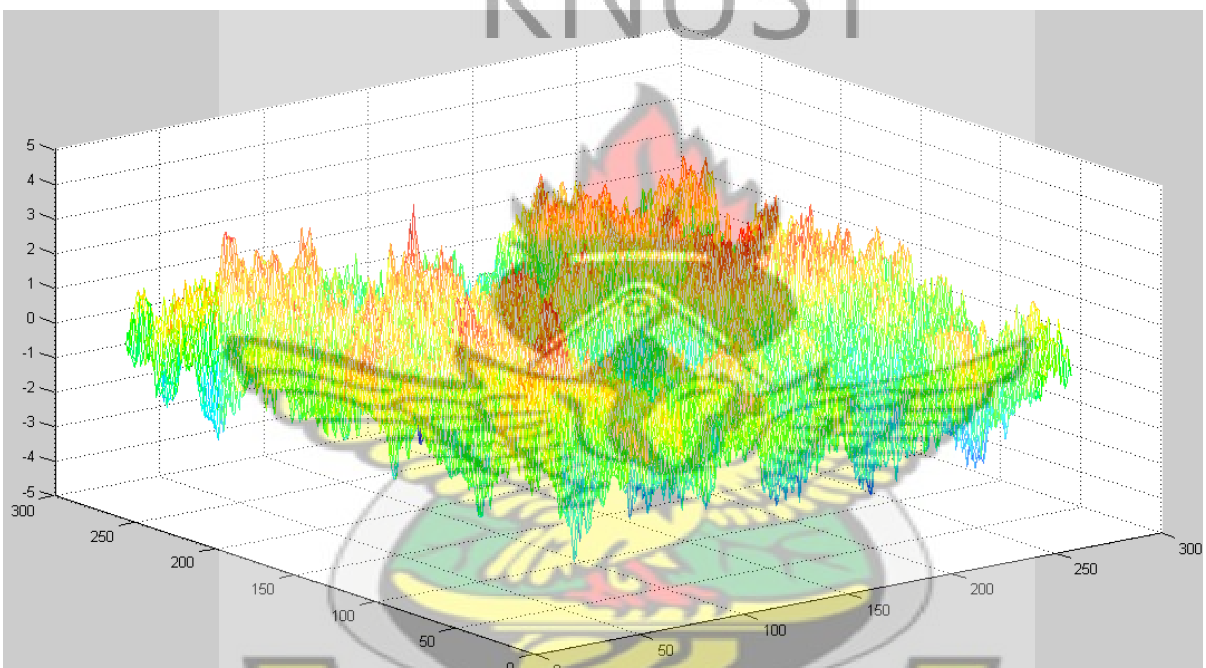

Figure 3- Lognormal Fading Map

3.4.3 Angle Attenuation and Antenna Gain Modelling

Angle attenuation between the direction of the MS relative to the main direction of the cell accounts for the antenna gain. The maximum gain chosen in the forward direction is *12.2 dB* for the Omni directional antenna this project. This power gain increase for the directional antennas. The following steps are followed in simulating the antenna gain:

1. An array, *fi*, of 360 elements, representing the range $-\pi$ *to* $+\pi$, is created. Since 120^o sector antennas are used in this thesis, the best antenna gain is at 60^o, which is the middle of the antenna.
2. To take care of the gain at 60^o, a parameter *lw*, is set to 0.75207 to ensure the least drop at 60^o. Since there are 3 antennas for each BTS, the nominal antenna width, *nantw*, is set to 1/3 for each sector.
3. Each of the 360 elements representing a 1 degree direction to the centre of the antenna is converted to radians. The *wrap* function is used to ensure all angles stay within $-\pi$ *to* $+\pi$.
4. For each *fi*, *z* is calculated according to; $z = \frac{fi}{nantw} \times lw$
5. The sinc lobe gain, *g*, for each element of, *z*, is calculated according to:

$$g = 20\log_{10}\left(\frac{\sin(z)}{z}\right)$$ and the *nantw* is subtracted from the outcome.

6. g is compared to the relative backlobe gain, *blg*. (-30dB chosen for this thesis) and the maximum value of the two is chosen.
7. The maximum value chosen from 3 above for each *fi* is then added to the maximum gain, *maxg*, in the forward direction to obtain the antenna gain for each 1 degree direction. Plotting *fi* against *antg* gives *Figure 3-4*.

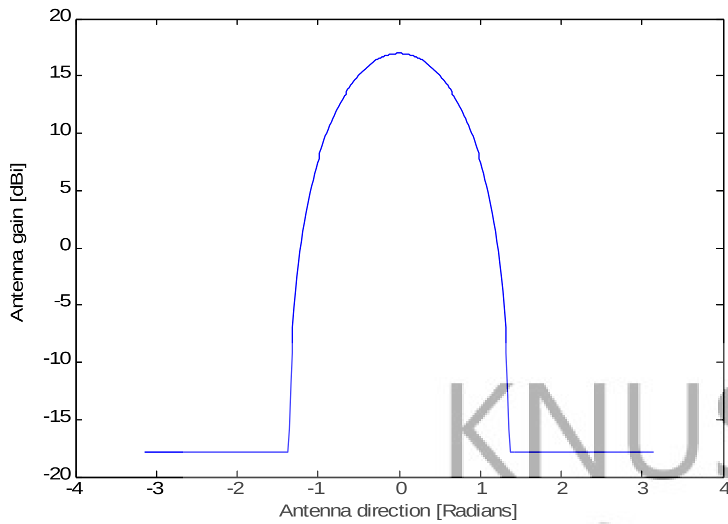

Figure 3- Antenna Gain Diagram

The parameters estimated in *subsections 3.4.2-3.4.3* are combined for each MS to obtain the *pathgain* values. Each MS then latches onto the cell that gives it the best gain. *Figure 3-4* shows how 60 MSs are randomly distributed in the cluster. The gain values which determine where the MSs are hosted are shown in the *Appendix A-2* and the code used to achieve this is shown in *Appendix A-1*.

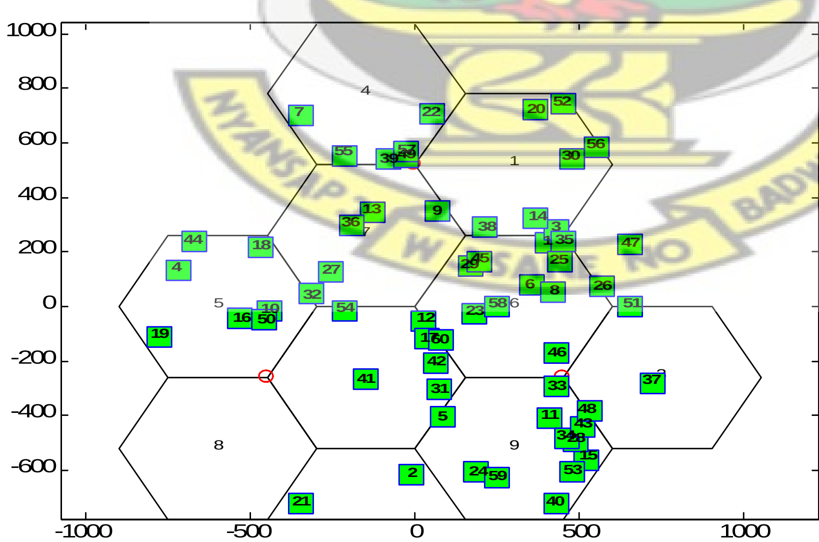

Figure 3- Hosting the MSs

3.5 Traffic Generators (Callers)

The callers are modelled after Poisson and distributed randomly over the network area. The *wrap* around function as described in section 2.6.2 is used to keep the number of callers constant over the simulation area. The simulation is done for varying number of calls, varying number of channels, varying mean holding time and varying interarrival time. The effect of these variations on the blocking probability is observed. The performance of the traffic channels is also observed. Congestion is introduced into one of the cells by increasing the number of calls per Channel on that cell and observing the outcome. The congestion on the cell is eliminated by inducing handover to neighbouring cells and the cell performance is again observed.

3.6 Simulation Process

In the simulation, a random number of busy callers generate traffic based on the model described in *Sections 3.1* to *3.5*. Two sets of simulations are performed. The first is done for a system where load redistribution was not employed; Where the TCHs of a cell can all be used beyond a given threshold. The blocking probability is then checked for varying mean holding times for the MSs and varying arrival rates of calls on the cells.

In the second simulations, the traffic on the cells are checked and those with the number of busy TCHs less than the predefined threshold are freed of some of their traffic(calls) to neighbouring cells with the number of idle TCHs greater than the predefined threshold. This handing off is done using the gain values between the mobiles and the cells.

The under listed parameters of the simulation were varied and assumed one of the values indicated in brackets.

- Call arrival rate(*mIAT*)- (between0.5 and 5 minutes)
- Mean call duration(*mHT*) – (between 1 and 5 minutes)
- Number of Channels (*N*)- (between 5 and 12 channels)

For ease of comparison a total number of 300 calls, *C*, were observed for the first simulation. Some of the calls were successful, *S*, others were not, *B.* The blocking probability, *b*, was determined for each set of *mIAT* and *mHT* pair. The code implementing the model can be found in the *Appendix A.1.2*. The blocking probability, *b*, is estimated as below:

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$$b=\frac{No.\,of\,blocked\,calls\,(B)}{Total\,No.\,of\,call\,attempts\,(C)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\, STYLEREF\ 1 - SEQ\ Equation\ 11$$

The traffic utilization or traffic intensity is also estimated as below:

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$$A=\frac{mHT}{mIAT}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\, STYLEREF\ 1 - SEQ\ Equation\ 12$$

A is the Traffic intensity. *mIAT* is Mean inter-arrival Time and *mHT* is the Mean Holding Time.

Equation 3-13 is used to estimate the mean number of calls per channel (*nCpCh*).

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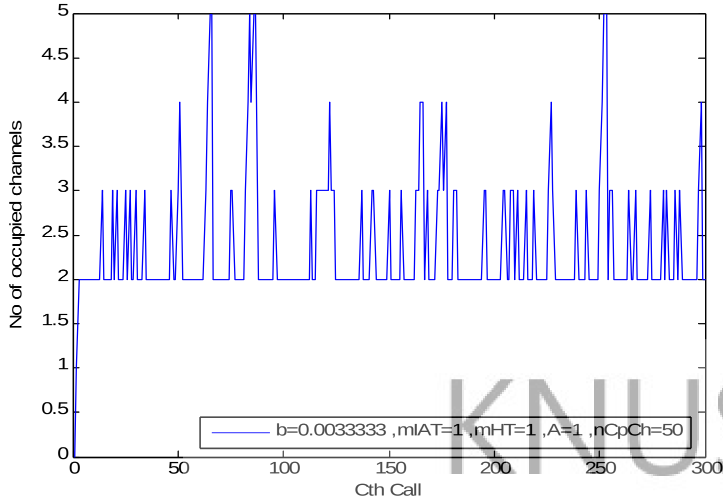
$$nCpCh=\frac{C}{N}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\, STYLEREF\ 1 - SEQ\ Equation\ 13$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

The Traffic intensity is an estimate of the mean number of simultaneous calls in progress and depends on, the mean call duration, *mHT,* and the mean inter-arrival time *mIAT* as seen in *Equation 3.12*. The traffic intensity also depends on the number of channels, *N* and is directly related to the channel utilization. *Figure 4-1* to *Figure 4-3* show how channel utilization varies for different values of *mHT*, *mIAT* and *N*. The variation is shown by the number of spikes at the upper boundary of the graphs. Higher utilization is shown by higher number of spikes at the upper boundary and lower utilization is shown by a lower number of spikes at the upper boundary. *Figure 4-1 (a)* and *Figure 4-1 (b)*, show the channel utilization for a system with *mHT=1* and a system with *mHT=5* respectively. The system with *mHT=5* has a higher utilization than that of a system with *mHT=1* for a given *N* and *mIAT*. *Figure 4-2 (a)* and *Figure 4-2 (b)* also show the effect varying *N* has on the channel utilization for a given *mHT* and *mIAT*. The system with *N=5* has a higher channel utilization than that of a system with *N=10*. *Figure 4-3 (a)* and *Figure 4-3 (b)* also show the effect varying *mIAT has* on the channel utilization for a given *N* and *mHT*. The system with *mIAT=0.5* has a higher channel utilization than that of a system which has *mIAT=3*.

The reasons behind these observations will be analysed and presented in the subsequent section using the model described in chapter three. Each of the simulations used a total number of calls *C*, of 300.



(a) *mHT=1*

(b) *mHT=5*

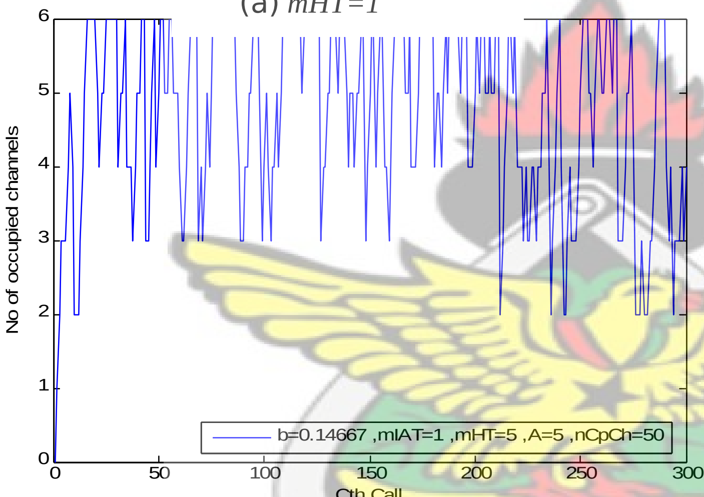
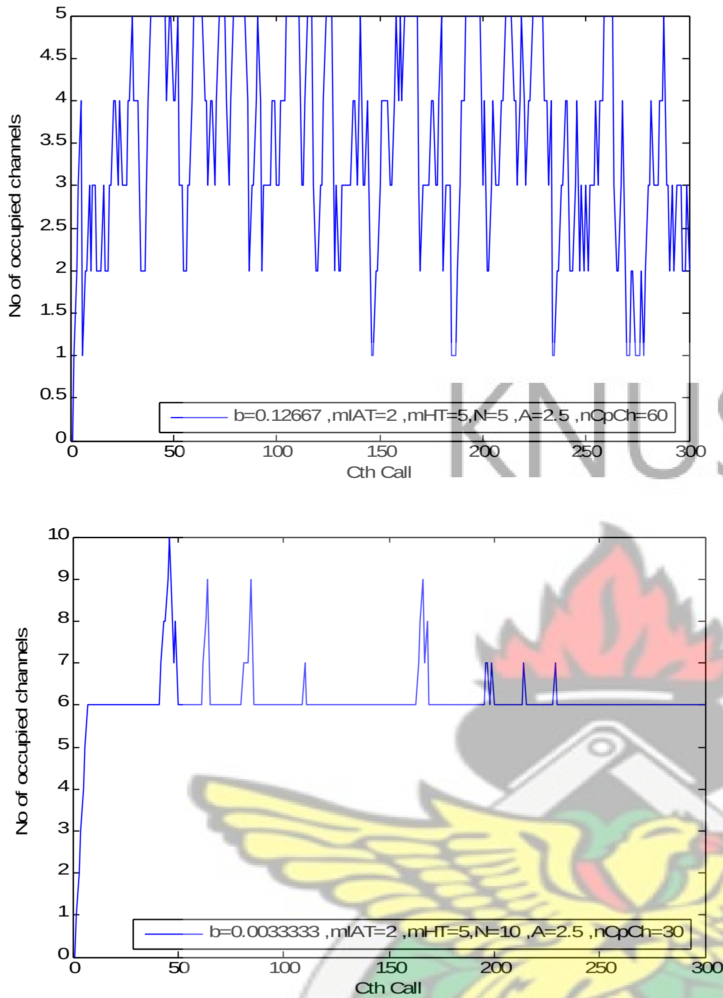


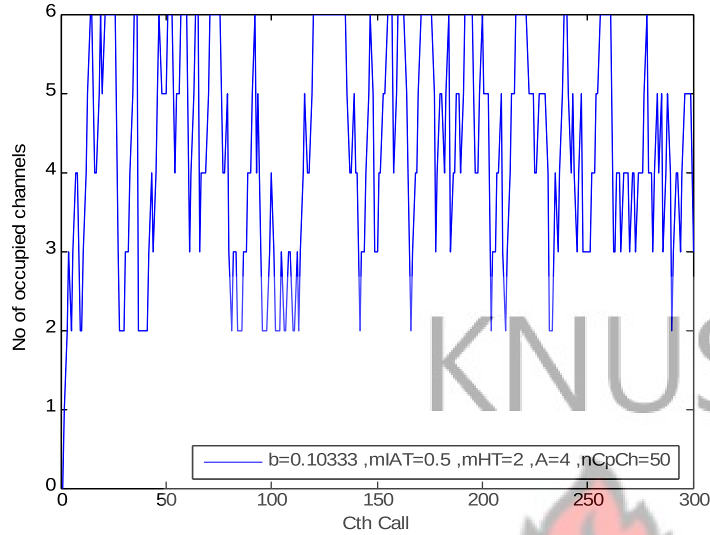
Figure 4- Channel Utilisation for varying mHT

(a) *N=5*



(b) N=10

Figure 4- Channel Utilisation for varying N



(a) *mIAT=3 min*

(b) *mIAT=0.5 min*

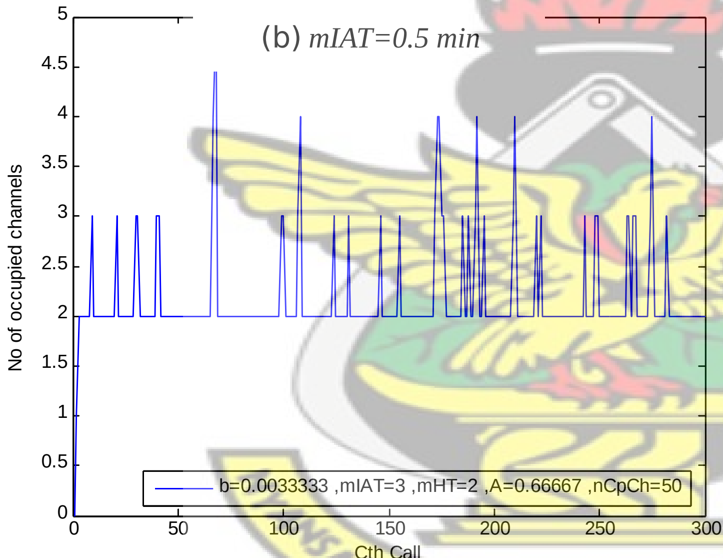


Figure 4- Channel Utilisation for varying mIAT

4.1 System without Cell load redistribution

The effects of varying *mHT*, *mIAT*, and *N* on *b* are investigated for a network which does not employ the use of cell load redistribution.

4.1.1 Effects of Variations in Mean Inter-arrival Rate

The effect of variations in the mean inter-arrival rate for a given mean holding time is analysed first. *Table 4-1* and *Figure 4-4* indicates that for a given value of mean holding time per cell, an increase in the mean inter-arrival time, *mIAT*, generally leads to a decrease in the blocking probability. This happens because, with increasing *mIAT* for a given *mHT* and a given *N*, the call intensity decreases. This has the effect of decreasing the traffic on the channels. The rate at which calls arrive at the cell is lower than the rate at which calls hold on to the channels. So the probability, *b* that a call arrives at a cell which has all its channels busy is reduced. The *nCpCh* remains the same in each case since the number of channels is the same in this case.

Table 4- Blocking probabilities for a given mHT and N and varying mIAT

mIAT	N	nCpCH	mHT				
			0.5	1.0	2.0	3.0	4.0
			b				
0.5	6.0	50.0	0.0033	0.0133	0.1433	0.2700	0.3267
0.8	6.0	50.0	0.0033	0.0067	0.0030	0.0867	0.2200
1.0	6.0	50.0	0.0033	0.0033	0.0167	0.0967	0.1033
1.2	6.0	50.0	0.0033	0.0033	0.0100	0.0267	0.1000
1.5	6.0	50.0	0.0033	0.0033	0.0133	0.0167	0.0567

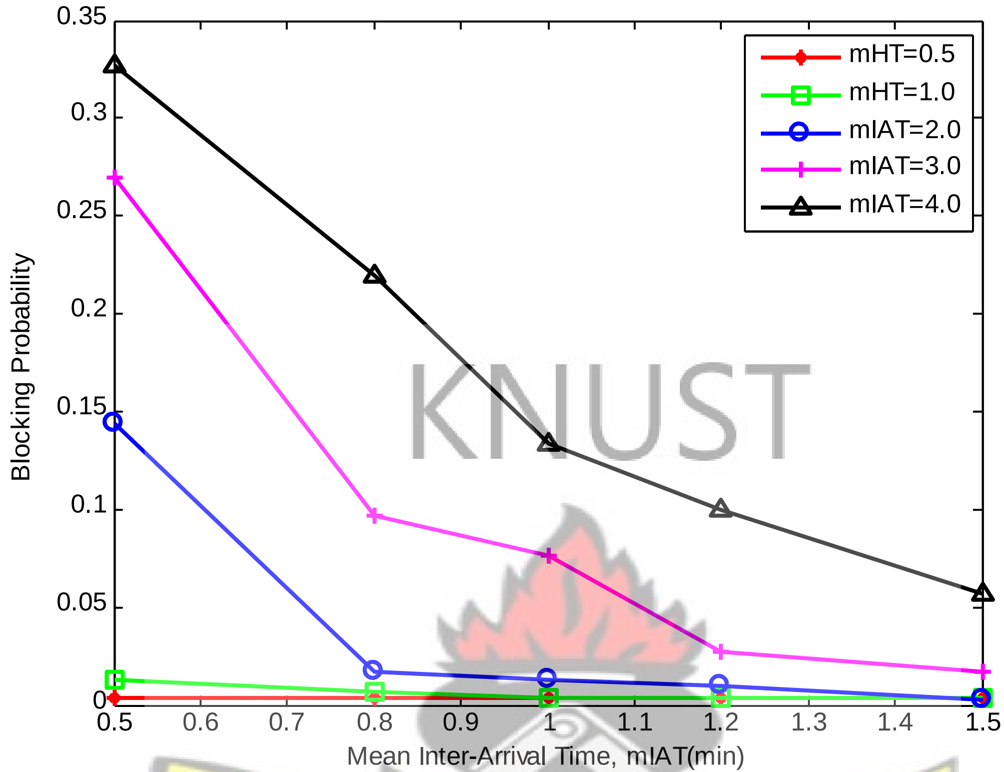


Figure 4- A Plot of Mean Inter-Arrival Time against Blocking Probability

4.1.2 Effects of Variations in Mean Call Duration

The effect of varying the *mHT* for a given *mIAT* is analysed next and the results summarized in *Table 4-* and plotted in *Figure 4-5*. *b* increases with increasing *mHT* for a given *mIAT* and *N*. The reason being that, with increasing *mHT,* the traffic channels' busy times exceed their idle times. The probability therefore, that a call arrives at the cell and there is no idle channel to serve it increases. The *nCpCh* remains the same in each case since the number of channels is the same for all the cells being considered.

Table 4- Blocking probabilities for a given mHT and varying mIAT

mHT	**N**	**nCpCH**	**mIAT**				
			0.5	0.8	1.0	1.2	1.5
			b				
0.5	6.0	50.0	0.0033	0.0033	0.0033	0.0033	0.0033
1.0	6.0	50.0	0.0067	0.0010	0.0033	0.0033	0.0033
2.0	6.0	50.0	0.1200	0.0267	0.0067	0.0100	0.0033
3.0	6.0	50.0	0.2900	0.1000	0.0533	0.0100	0.0100
4.0	6.0	50.0	0.3967	0.1867	0.0700	0.0500	0.0200
5.0	6.0	50.0	0.4333	0.3167	0.2300	0.0867	0.0533

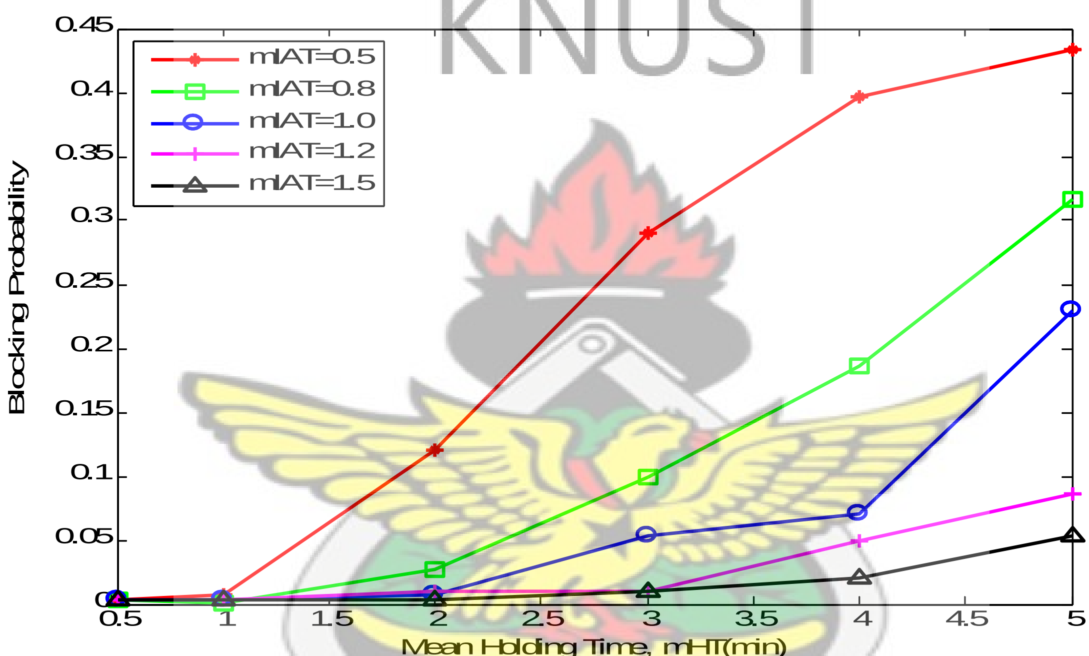


Figure 4- A Plot of Mean Holding Time against Blocking Probability

4.1.3 Effects of Variations in the Number of Channels

The effect of varying *N* for a given *mIAT* and *mHT* is also analysed and the results summarized in *Table 4-* and plotted in *Figure 4.6*. *b* decreases with increasing *N*. The higher the value of *N* means there will be more resources available to serve arriving calls. If the value of *N* is high, the probability that a call arrives at a fully occupied cell is significantly reduced.

Table 4- Blocking probabilities for a given mHT , mIAT and varying N

mIAT	**N**	**nCpCH**	**mHT**				
			1	2	3	4	5
			b				
1	5	60.0	0.0133	0.0367	0.1100	0.1933	0.3133
1	6	50.0	0.0067	0.0167	0.0433	0.1000	0.2167
1	8	37.5	0.0033	0.0033	0.0067	0.0267	0.0833
1	10	30.0	0.0033	0.0033	0.0033	0.0033	0.0200
1	12	25.0	0.0033	0.0033	0.0033	0.0033	0.0033

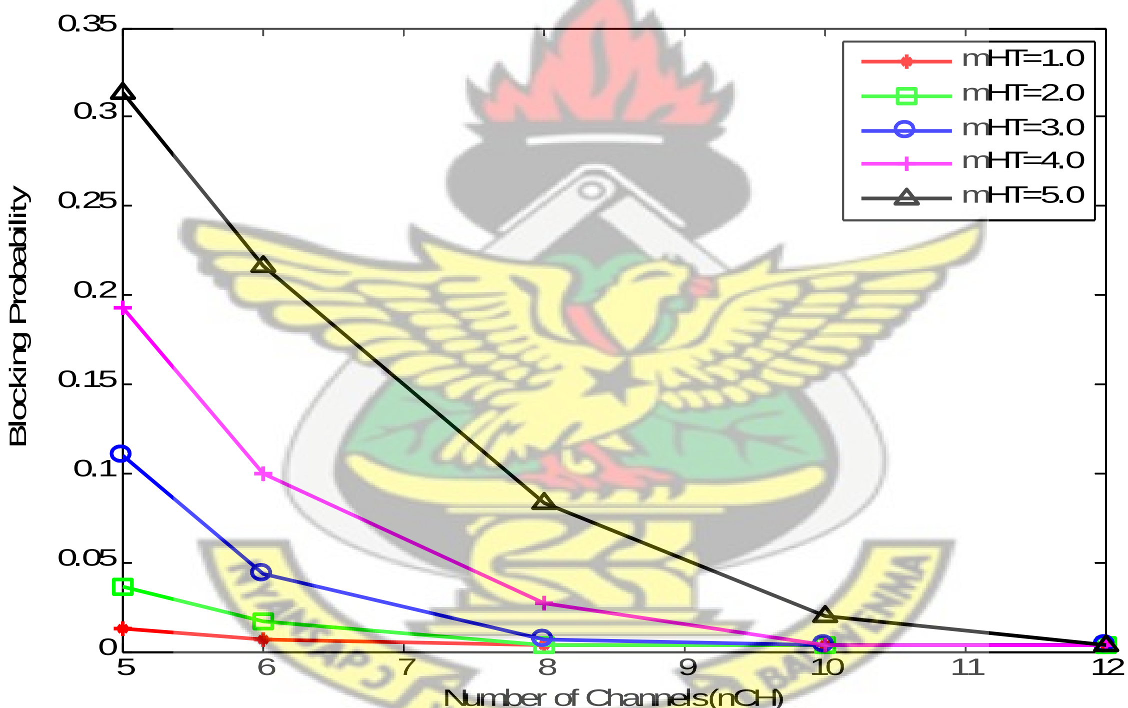


Figure 4- Number of Channels against Blocking Probability

4.2 Automatic Cell Redistribution System

As observed in *Sections 4.1.1 to 4.1.3*, *mIAT*, *mHT* and *N* all play significant roles in determining the value of *b*. But it is worth noting that *mIAT* and *mHT* are often difficult to be controlled by the operator since these values are most often determined by the callers' behaviour. *N* which is relatively easier to be controlled by the operator is therefore the operators' best chance of controlling the value of *b*. To look at how *b* can be controlled using *N*, 3 cells with *N=6*, *N=8* and *N=10* are considered and represented as *CELL 1*, *CELL 2* and *CELL 3* respectively. The same number of calls shall be considered, *C=300*, for each cell. *Table 4-4* represents the cells' data before redistribution.

Table 4- Summarized parameters of CELL 1, 2 and 3 before redistribution

CELL	**mIAT**	**N**	**nCpCH**	**mHT**				
				3	3.5	4	4.5	5
				b				
1	1	6	50.0	0.0567	0.0767	0.0767	0.1300	0.2600
2	1	8	37.5	0.0167	0.0200	0.0333	0.0400	0.0800
3	1	12	25.0	0.0033	0.0033	0.0033	0.0033	0.0067
TOTAL BLOCKING PROBABILITY per mHT				0.0256	0.0333	0.0378	0.0578	0.1156

CELL 1 and CELL 2 are flagged as congested cells since they have higher values of *b*. The cells will therefore be taken through a redistribution process detailed in subsection *Section 4.2.1*.

Cell with N_i < N_Th over Period ΔT

4.2.1 The Redistribution System

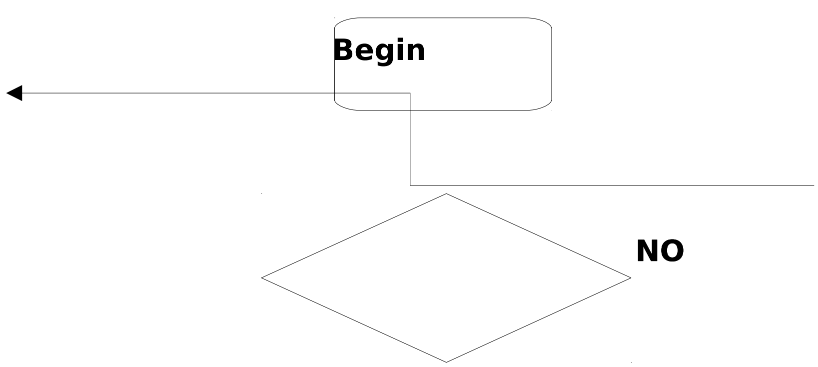
Figure 4-7 shows the flow diagram of the redistribution system. The cells are taken through this system.

YES

NO

NO

YES



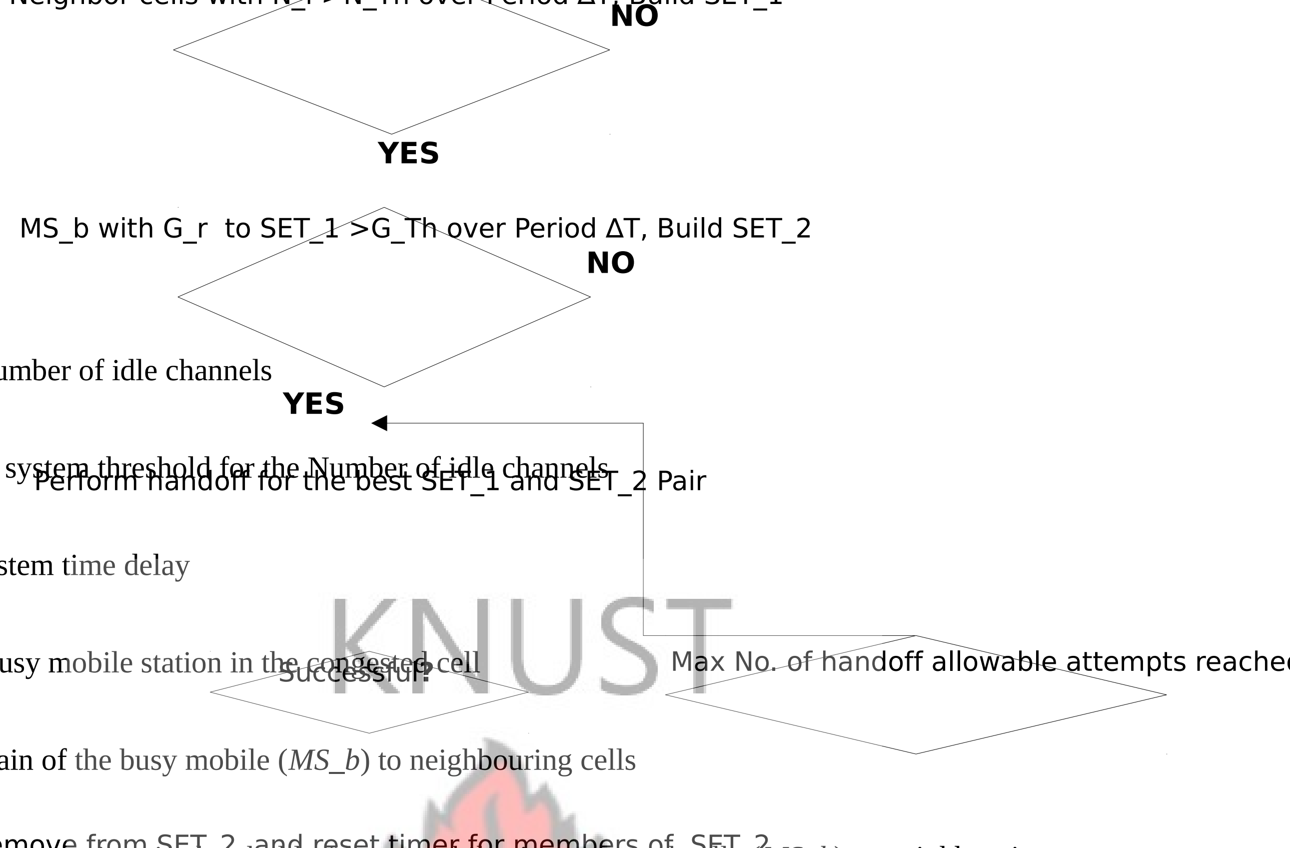


Figure 47 Flow Diagram of the Redistribution Process

Where;

N_i is the number of idle channels

N_Th is the system threshold for the Number of idle channels

ΔT is the system time delay

MS_b is a busy mobile station in the congested cell

G_r is the gain of the busy mobile (*MS_b*) to neighbouring cells

G_Th is the system's gain threshold of busy mobiles in congested cells (*MS_b*) to neighbouring cells

Table 4- Details of SET_1

SET_1	
Neighbour Cell ID	***No. of Idle channels***
A	*u*
B	*v*
C	*w*

Where:

u, v, w are all greater than *N_i*

Table 4- Details of SET_2

SET_2	
Busy Mobile ID in Congested Cell	***Gain to Neighbour Cell(A,B or C)***
1	*A_1*
	B_1
	C_1
2	*A_2*
	B_2
	C_2

Where ; *A_1* is the gain between Mobile 1 and neighbouring cell A, *A_2* is the gain between Mobile 2 and neighbouring cell B and so on. *A_1*, *B_1*, *C_1*, *A_2*, *B_2*, *C_2* are all greater than *G_Th.*

In this scenario, *N_Th* is set to 9 so CELL 1(where N=6) and CELL 2 (where N=8), are both flagged as congested cells. It is also assumed that the *G_r* values of the MSs to be handed over are greater than *G_Th*. In building *SET_1* for CELL 1 only CELL 3 can be included. CELL 2 cannot be included since its *N_i*< *N_Th*. And in building *SET_1* for CELL 2, CELL 3 is again chosen. After putting the cells through the redistribution system, the traffic on 2 channels of CELL 1 is handed over to CELL 3 and the traffic on 1 channel of CELL 2 is handed over to CELL 3. Assuming that *mIAT* and *mHT* remain the same for all 3 cells, the following analysis can be made about the cells;

CELL 1:

The traffic on 2 channels on this cell can be handed over to CELL 3 according to the model describe in *section 4.2.1*.

The New *N_i* after handover = 6+2 =8.

The new *C* after handover = 300-(2×*nCpCh*(from CELL 1)) = 300-(2×50)= 200.

This means CELL 1 will now have more idle channels handling fewer calls.

CELL 2:

The traffic on 1 channel on this cell can also be handed over to CELL 3 according to the redistribution process.

The New *N_i* after handover = 8+1 =9.

The new *C* after handover = 300-(1×*nCpCh*(for CELL 2)) = 300-(1×38)= 262.

This cell will also have more idle channels handling fewer calls.

CELL3

This cell receives traffic from 2 channels of CELL1 and 1 channel of CELL 2.

So CELL 3's new *N_i* =12-(2+1) = 9.

The new *C* after handover = 300+ {(2×*nCpCh*(from CELL 1))+ (1×*nCpCh*(for CELL 2))} = 300 + 100 +38 = 438.

These new parameters yield new values of *b* for the cells and this is shown in *Table 4-7*.

Table 4- Summarized parameters of CELLS 1, 2 and 3 after redistribution

CELL	mIAT	N	nCpCH	mHT				
				3	3.5	4	4.5	5
				B				
1	1	8	25.0	0.0050	0.0250	0.0450	0.0600	0.0950
2	1	9	29.0	0.0038	0.0076	0.0076	0.0305	0.0305
3	1	9	49.0	0.0114	0.0114	0.0205	0.0319	0.0457
TOTAL BLOCKING PROBABILITY per mHT				0.0067	0.0147	0.0244	0.0408	0.0571

To compare the performance of the cells before and after redistribution, the values of *b* *Table 4-6* and *Table 4-7* are plotted on the same graph in *Figure 4-8.*The overall *b* before and after redistribution are also compared in *Figure 4-9.*

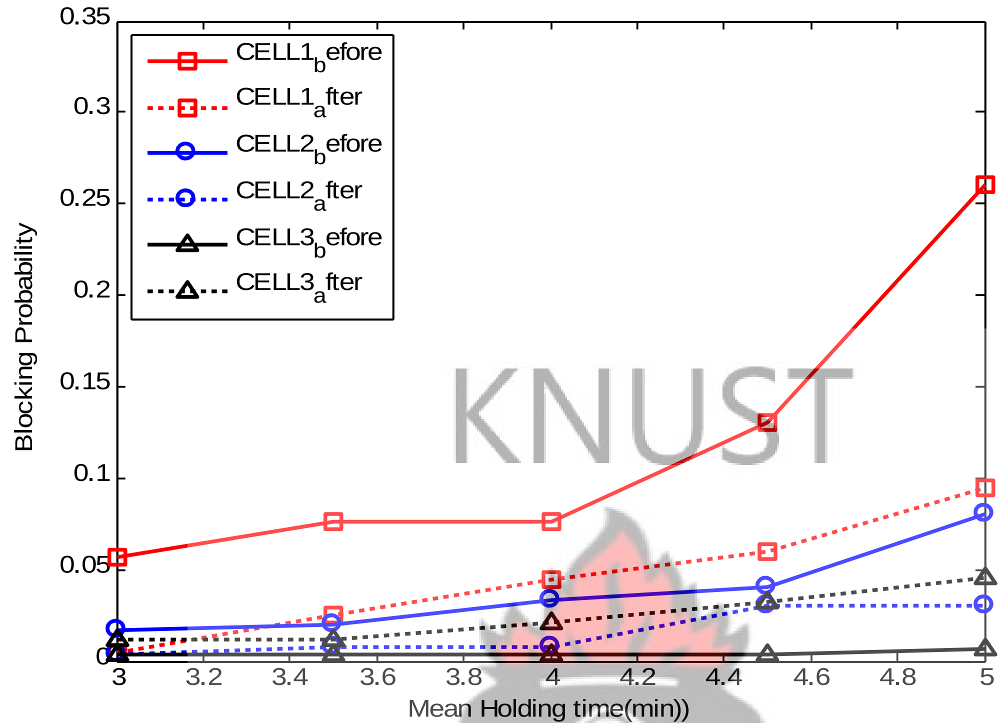


Figure 4- mHT vs Blocking probability before and after Redistribution for CELL1, 2 and 3

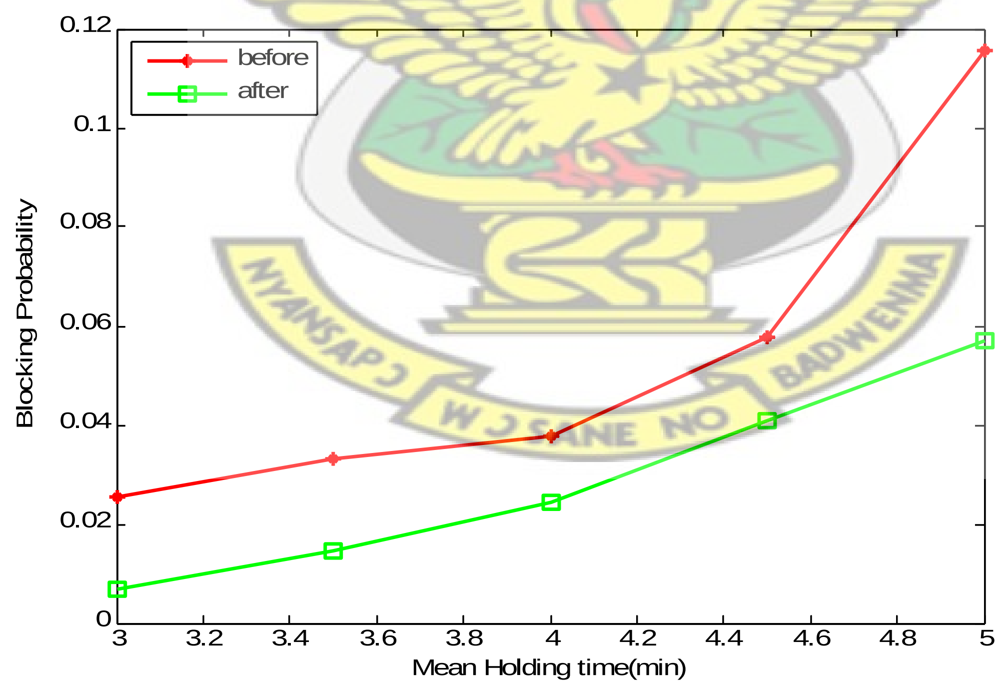


Figure 4- mHT vs Overall Blocking Probability for CELL 1, 2, and 3 before and after Redistribution

4.2.2 Comparison

In this section a comparison is made between the two systems; the one without automatic cell load redistribution and the one with automatic cell load redistribution. *Table 4-4* and *Table 4-7* summarize the difference between the two systems. As seen in these tables, effective load redistribution reduces the blocking probability hence increasing the call success rate. The overall blocking probability for all the 3 cells is higher for every value of *mHT* before redistribution than after redistribution, as shown in *Figure 4-9*. It is worth noting that, blocking probability of CELL 3 increases marginally as seen in *Figure 4-8*. This, however, contributes to the improvement of the overall blocking probability of the 3 cells.

This observation proves that effective redistribution leads to better use of the cell resources and improved GoS.

Klockar et al [5] was mentioned earlier as having used RUNE to study Cell load Sharing. Klockar et al [5] also came to the conclusion that effective cell load sharing (redistribution) could improve the probability of blocking on the traffic Channels. In their study, however, they used the quality based approach and offset to do the cell load distribution.

Qui et al [7] also looked at the load sharing by using cell breathing methods. They used power control on the cells to induce handover whenever a cell is congested. Lower cell power means the MS's perception of the power of the BCCH will be low and will be forced to handover to neighbouring cells with relative higher BCCH power values. The power of a congested cell is reduced and the power of neighbouring uncongested cells is increased making some of the mobile stations on the congested cell request to be handed over to the uncongested cells.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

This thesis focused mainly on two issues. In the first case, the effect of mean interarrival time, mean holding time and the number of channels on GoS of cells was studied. The potential for improving overall performance by optimizing the use of cell resources was also studied.

In the first case, it was found that low mean interarrival time, high mean holding time and a low number of channels have a significant negative impact on cell performance. Operators thus need to invent means of improving these parameters which will in turn lead to better network performance.

Mean interarrival time and mean holding time cannot however be controlled easily by operators, so their best chance of improving on network quality will be to optimize the use of the traffic channels at the air interface of the cells. Since spontaneous increase in traffic at any cell cannot be predicted by operators, a system to take care of these sudden changes could be very helpful to the operators. It was found that redistribution of users amongst unevenly loaded cells in a cluster using a good model in real time could reduce the total number of blocked calls in the cluster by up to 50%, hence reducing the overall blocking probability. This directly improves GoS, reduces subscriber frustration and improve their perception of the operator.

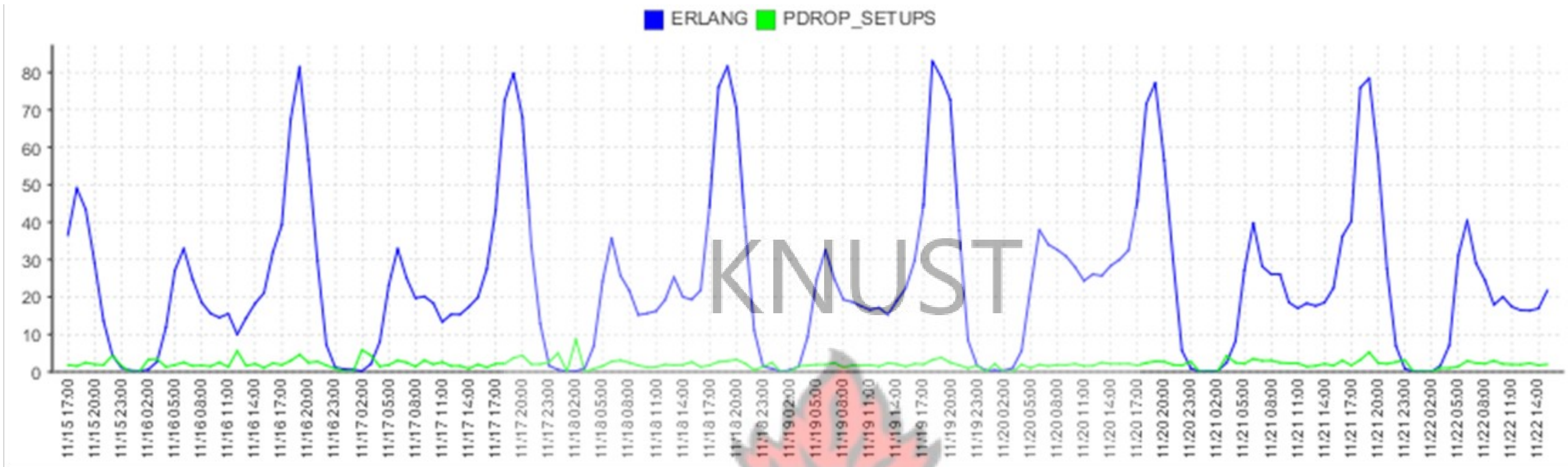


Figure 5- Utilization and Percentage Blocked Calls of CELL A

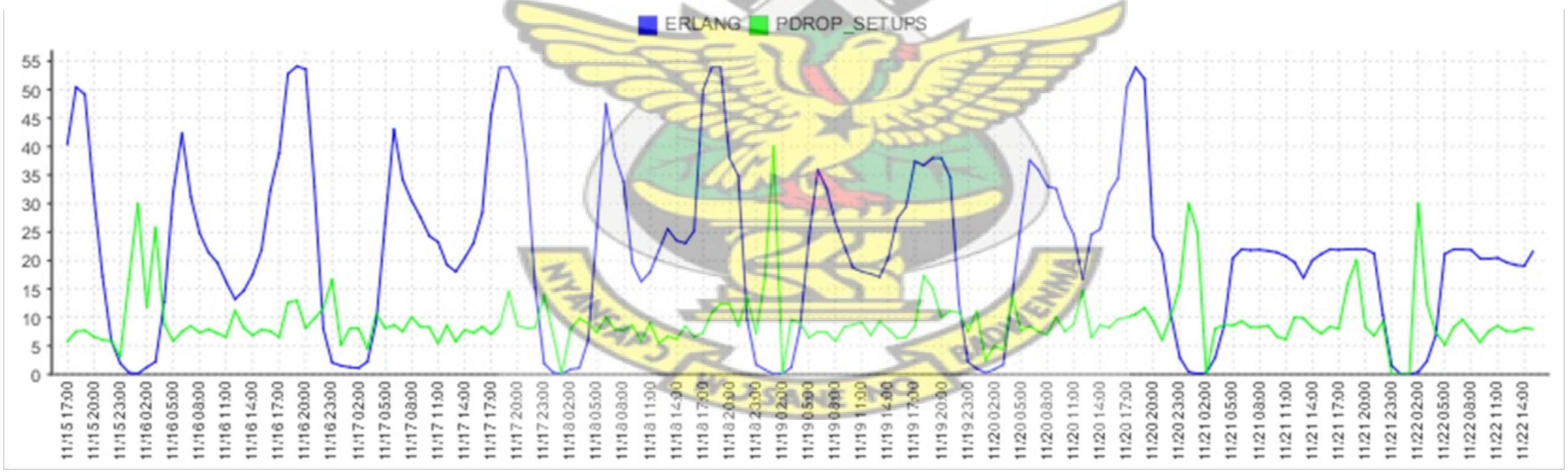


Figure 5- Utilization and Percentage Blocked Calls of CELL B

Legend

- ERLANG: Erlang/ utilization
- PDORP_SETUP: Dropped calls at setup or blocked calls.

*Figure 5-1*and *Figure 5-2* show the utilization and percentage blocked calls trends of two neighbouring cells, CELL A and CELL B respectively, in a live network. CELL A has fewer blocked calls, less than 1% of the offered traffic, compared to CELL B which has about 10% of its calls blocked. Even though CELL A has a higher traffic channel utilization, its superior number of channels ensures fewer blocked calls compared to CELL B. If the redistribution method proposed in this thesis is employed, some of the MSs on CELL B will be handed over to CELL A. This will effectively reduce the traffic intensity and percentage blocked calls on CELL B and also improve the GoS of the system.

The model used in this study used the blocking probability at the cell level as the basic means of measuring air interface performance. The results obtained were more of qualitative rather than a quantitative nature because of the simulation used in the methodology. Based on the experiences of this work there are suggestion for further studies. The first is a more thorough evaluation of how to measure the path gain between each mobile station and the neighbouring cells. The signal fading used in the model was the fast type. Slow fading and other forms of fading may also be present. The second is to carefully dimension the time delay used in the handover model to avoid repeated handover for users on the borders of the cells. A study into how much traffic the redistribution process adds to the signalling channels is another suggestion for further studies.

Some of the solutions and cases suggested above use the already existing overhead resources (signalling channels) which may lead to higher signalling traffic and congestion on the signalling channels. These signalling channels are associated with call set-up at the air interface, SMS and traffic measurement reports by the MSs and congestion on them leads ultimately to poor GoS. It is therefore paramount that the signalling channels be dimensioned carefully to cater for these new demands.

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Appendix

A.1 Simulation code

A.1.1 General Comments

Due to the space considerations the functions used in the simulation code are called from the assembled "RUNE toolbox". Each function and parameter used is described by a comment beside, begun by "%". The different codes used in the various sections are all shown. The beginning of each code shows the section of the work in which the code was used. Some sections of the code employ the use of the "rand" function random variables involved, the results obtain for each time the code is run is a little different, but the general idea remains the same.

A.1.2 Code

```
%3.0 Creating the cells, MS and hosting them.

clc
clear all
close all
addpath C:\MATLAB701\toolbox\rune
run C:\matlab701\toolbox\rune\setp

par.frametime = 1;     % time interval between simulated frames. Could be nslots*sltottime
par.nframes = 5;       % number of iterations in the main loop
par.slottime = 1/8;    % time per slot
par.nslots  = 8;       % nomber of slots per frame
```

```
par.seed = 1;          % seed to all random sequencies in the simulation


figure('name','cells and mobiles','numbertitle','off')
 par.cellradius =100;  % cell radius [m]
par.km =1;             % km^2+lm^2+km*lm => the number of sites
par.lm =1;             % related to km above
par.sps= 3;            % number of sectors per site
par.kn =1;             % kn^2+ln^2+kn*ln => the number of clusters
par.ln = 0;            % related to kn above
par.kpc = 1;           % frequencies per cell
nclusters=1;           % number of clusters
par.usefh =1;          % reselection of frequency every slot if 1 ie no frequency hopping
par.homargin = 3;      % gain margin between two bases used at Hand Off
par.pinit = 20;        % init power set to each new link
par.pmax  =  33;       % max transmit link power [dBm]
par.offtraf =10;       % average number of offered calls to a cell [Erlang/cell]
par.mht = 90;          % mean holding time [seconds]
par.corrdist = 110;    % lognormal fading correlation distance [m]
par.usefastf =1;       % make use of fast fading
sta.time =5;           % sample time
par.rbermax = 1;          % raw bit error level over which a frame is lost
par.lambda= 0.3333;       %wavelength uses to create the rayleigh map.
par.frequency=900;        %carrier frequency in MHz


[sys.xyb, sys.fib, sys.rhombvec] = crecells(par.cellradius,par.sps, par.km, par.lm, par.kn)%create cells
%xyb --  Base station coordinates, given as a complex row vector.
%fib --The base station antenna vector, given as a complex row vector pointing from base to middle of cell.

  plothex(sys.xyb, sys.fib)

    axis equal;
 hold on
```

```
par.vmean=10;
par.amean=5;
par.dt=10;

sta.mtop=60;
     sta.xym=nans(sta.mtop,1);
         sta.xyv=nans(sta.mtop,1);
                sta.m=(1:sta.mtop).';
                  [sta.xym,sta.xyv]=mobmove(sta.xym,sta.xyv,par.vmean,par.amean,par.dt,sys.rhombvec);%find the mobile
positions and average speed of mobiles


hold on

plot(sta.xym, 'bs','MarkerFaceColor','g','markersize',12)


sta.b=1:length(sys.xyb);        %base station index
sta.m =1:length(sta.xym);             %mobile identity number

% Plot MS id
ts=get(gcf,'DefaultTextFontSize'); % Preserve font size
  set(gcf,'DefaultTextFontSize',7);  % Set font size to 7
      pos = sta.xym + sta.xyv ;            % MS text pos
for s=1:sta.mtop
    text(real(pos(s)),imag(pos(s)),num2str(s),'HorizontalAlignment','center','fontWeight','bold')
end


figure ('name','Lognormal map','numbertitle','off')
[sys.lognmap, sys.lognmapvec] = crelognmap(sys.xyb, sys.rhombvec, par.corrdist); %lognormal fading

mesh(crelognmap(sys.xyb, sys.rhombvec, par.corrdist)); %lognormal fading
hold on
```

```
figure('name','Antenna gain','numbertitle','off')

fi = linspace(-pi,pi,361).'; %Direction towards antenna [radians]
plot(fi,antennagain(fi,1/3))%antenna gain for 3 120 degrees sectorial antennas

xlabel('Antenna direction [Radians]')
ylabel('Antenna gain [dBi]')


figure('name','Path gain between mobile and cells','numbertitle','off')

 par.gainconst = 17.5;%Gain at 1 Kilometer distance.
  par.alfa =2.5 ; %Distance attenuation coefficient.Emprical values range from 1.8 to 2.5 depending on the material in the are
for 900MHz
  par.sigma = 0; %Standard deviation for the lognormal fading in dB.
  par.raa = 0.5;%Down link correlation (typical 0.5). This parameter determines
%               the correlation for the lognormal fading on the links
%               between the base stations and one mobile.
% Create a lognormal map. The lognormal map is dependent on the seed.
 oseed1 = setseed(par.seed);  % Set seed of pseudo random generator for the map.



 sta.gmb =
lin2db(abs(pathgain(sta.xym,sys.xyb,sys.fib,par.sps,sys.rhombvec,par.gainconst,par.alfa,par.sigma,sys.lognmap,sys.lognmap
vec)))%path gain between mobile and cells the gain of only one user will require specific values for xym,xyb,fib and asps


set(gca,'xlim',[1 60],'xtick',[1:1:60],'xticklabel',[1:1:60],'GridLineStyle', ':', 'xgrid','on', 'ygrid','on')
 ColorSet = varycolor(9);
   set(gca, 'ColorOrder', ColorSet);

hold on
for m = 1:9
  plot(sta.gmb);
```

```
end

xlabel('Mobiles (1:60)');
ylabel('Pathgain');

legend('CELL1','CELL2','CELL3','CELL4','CELL5','CELL6','CELL7','CELL8','CELL9')

hold off;

xlswrite('totalloss_busy.xls',sta.gmb,'sheet1','B3');

figure ('name','Channel plan','numbertitle','off')

% Create a channel plan for the system.
 % Number of channels that is used in each cluster.
 nclusters = 1;
 nk = length(sys.xyb)/nclusters*par.kpc;
 sys.iniobk  = crechanplan(length(sys.xyb),nk,nclusters);  % Allocate channels to cells

spy(sys.iniobk);%create the channel plan
set(gca,'xlim',[0 9],'xtick',[0:1:9],'xticklabel',[0:1:9],'GridLineStyle', ':', 'xgrid','on', 'ygrid','on'...
    ,'ylim',[1 9],'ytick',[1:1:9],'yticklabel',[1:1:9])
xlabel('Frequency (1:9)');
ylabel('cells (1:9)');
 sta.k = 1:length(sys.iniobk); % channel number



%4.1.1 Effects of Variations in Mean Inter-arrival time%
close all
clear all

run C:\matlab701\toolbox\rune\setp %this is where the RUNE tool box is found
addpath C:\MATLAB701\toolbox\rune\erlangbForm
```

```
C = 300;   %Number of calls made
b=[];
v = [0.5 0.8 1.0 1.2 1.5];

for mIAT= v;

    callInt =exprnd(mIAT,[C-1,1]); %Inter arrival time for 300 calls
            callInt = -mIAT*log(1-rand(C-1,1));

arrvInst = zeros(length(callInt)+1 ,1); % Call arrival instances
%Compute call arrival instances
arrvInst(1) = 0;  %First call arrives at time = 0
for k = 2:C,
    arrvInst(k) = arrvInst(k-1) + callInt(k-1);
end

y = [5];%[0.5 1 2 3 4 5]

for mHT= y;
holdTime = exprnd(mHT,[C,1]); %Holding time for 100 calls.
holdTime = -mHT*log(1-rand(C,1));

termTime = zeros(C,1);  %Termination instances
%Compute call termination time
for k = 1:C,
    termTime(k) = arrvInst(k) + holdTime(k);     %Termination time = arrivalInstance + holdingTime
end


N = 6; %Number of trunked channels available
Serviced = 0;
Blocked = 0;
flagServed = 0;  %Flag is 1 if serviced
channels = zeros(N,1);  %Channel array
```

```
chUsage = N*ones(C,1);
%-----Determine : Serviced, Blocked calls-------------
for i = 1:C,
    for k = 1:N,
       if( channels(k) < arrvInst(i))
          Serviced = Serviced + 1;
          flagServed = 1;
          channels(k) = termTime(i);
          break;
       end
    end
    %Check remaining channels
    if(k < 5 )
       for j = k+1:5,
          if(channels(j) < arrvInst(i))
             channels(j) = 0;      %If calls have been terminated clear the channels
           end
       end
    elseif (flagServed == 0)
       Blocked = Blocked + 1;
    end
    flagServed = 0;  %Reset Flag
    channels = sort(channels);  %Sort channels according to termInst values
   for x = 1:N,
      if (channels(x) == 0)
         chUsage(i) = chUsage(i) - 1;
      end
   end
end

S = Serviced;
B = Blocked;
%b(m)=B(m)./C
display('mIAT :');
disp(mIAT);
```

```
display('mHT :');
disp(mHT);
display('Serviced calls :');
disp(Serviced);
display('Blocked calls :');
disp(Blocked);
b=B./C
nCpCh=C./N %number of calls/channel
figure('name',strcat('Channel Usage Graph for', ' ,mIAT=',num2str(mIAT),' ,mHT=',num2str(mHT)),'numbertitle','off')
A=mHT./mIAT

for m = 1:16
  plot(chUsage);
   legend(strcat('b=',num2str(b),' ,mIAT=',num2str(mIAT),' ,mHT=', num2str(mHT), ' ,A=', num2str(A),'
,nCpCh=',num2str(nCpCh)),'Location', 'SouthEast')
  end
hold on
xlabel('Cth Call');
ylabel('No of occupied channels');



end
end

hold off;

%4.1.1  End of Effects of Variations in Mean Inter-arrival time%


%4.1.2  Effects of Variations in Mean Call Duration%

close all
clear all
```

```
run C:\matlab701\toolbox\rune\setp %this is where the RUNE tool box is found
addpath C:\MATLAB701\toolbox\rune\erlangbForm

C = 300;   %Number of calls made
b=[];
v = [1.5];

for mIAT= v;%[0.5 0.8 1.0 1.2 1.5]




       callInt =exprnd(mIAT,[C-1,1]); %Inter arrival time for 100 calls
          callInt = -mIAT*log(1-rand(C-1,1));

arrvInst = zeros(length(callInt)+1 ,1); % Call arrival instances
%Compute call arrival instances
arrvInst(1) = 0;  %First call arrives at time = 0
for k = 2:C,
   arrvInst(k) = arrvInst(k-1) + callInt(k-1);
end

y = [0.5 1 2 3 4 5];

for mHT= y;
holdTime = exprnd(mHT,[C,1]); %Holding time for 300 calls.
holdTime = -mHT*log(1-rand(C,1));

termTime = zeros(C,1);  %Termination instances
%Compute call termination time
for k = 1:C,
   termTime(k) = arrvInst(k) + holdTime(k);    %Termination time = arrivalInstance + holdingTime
end
```

```
N = 6; %Number of trunked channels available
Serviced = 0;
Blocked = 0;
flagServed = 0;  %Flag is 1 if serviced
channels = zeros(N,1);  %Channel array
chUsage = N*ones(C,1);
%-----Determine : Serviced, Blocked calls-------------
for i = 1:C,
    for k = 1:N,
       if( channels(k) < arrvInst(i))
          Serviced = Serviced + 1;
          flagServed = 1;
          channels(k) = termTime(i);
          break;
       end
    end
    %Check remaining channels
    if(k < 5 )
       for j = k+1:5,
          if(channels(j) < arrvInst(i))
             channels(j) = 0;      %If calls have been terminated clear the channels
           end
       end
    elseif (flagServed == 0)
       Blocked = Blocked + 1;
    end
    flagServed = 0;  %Reset Flag
    channels = sort(channels);  %Sort channels according to termInst values
   for x = 1:N,
      if (channels(x) == 0)
         chUsage(i) = chUsage(i) - 1;
      end
   end
end
```

```
S = Serviced;
B = Blocked;
%b(m)=B(m)./C
display('mIAT :');
disp(mIAT);
display('mHT :');
disp(mHT);
display('Serviced calls :');
disp(Serviced);
display('Blocked calls :');
disp(Blocked);
b=B./C
nCpCh=C./N %number of calls/channel
figure('name',strcat('Channel Usage Graph for', ' ,mIAT=',num2str(mIAT),' ,mHT=',num2str(mHT)),'numbertitle','off')
A=mHT./mIAT

for m = 1:16
  plot(chUsage);
   legend(strcat('b=',num2str(b),' ,mIAT=',num2str(mIAT),' ,mHT=', num2str(mHT), ' ,A=', num2str(A),'
,nCpCh=',num2str(nCpCh)),'Location', 'SouthEast')
  end
hold on
xlabel('Cth Call');
ylabel('No of occupied channels');


end
end

hold off;

%end 4.1.2  Effects of Variations in Mean Call Duration


%4.1.3  Effects of Variations in Number of channels%
```

```
close all
clear all

run C:\matlab701\toolbox\rune\setp %this is where the RUNE tool box is found
addpath C:\MATLAB701\toolbox\rune\erlangbForm

C = 300;   %Number of calls made ( 100 taken for ease of comparision)
b=[];
v = [1.0];

for mIAT= v;

      callInt =exprnd(mIAT,[C-1,1]); %Inter arrival time for 100 calls
         callInt = -mIAT*log(1-rand(C-1,1));

arrvInst = zeros(length(callInt)+1 ,1); % Call arrival instances
%Compute call arrival instances
arrvInst(1) = 0;  %First call arrives at time = 0
for k = 2:C,
   arrvInst(k) = arrvInst(k-1) + callInt(k-1);
end

y =[5.0];%[1 2 3 4 5]

for mHT= y;
holdTime = exprnd(mHT,[C,1]); %Holding time for 100 calls.
holdTime = -mHT*log(1-rand(C,1));

termTime = zeros(C,1);  %Termination instances
%Compute call termination time
for k = 1:C,
   termTime(k) = arrvInst(k) + holdTime(k);    %Termination time = arrivalInstance + holdingTime
end
```

```
z=[5 6 8 10 12];

for N =z;  %Number of trunked channels available
Serviced = 0;
Blocked = 0;
flagServed = 0;  %Flag is 1 if serviced
channels = zeros(N,1);  %Channel array
chUsage = N*ones(C,1);
%-----Determine : Serviced, Blocked calls-------------
for i = 1:C,
    for k = 1:N,
       if( channels(k) < arrvInst(i))
          Serviced = Serviced + 1;
          flagServed = 1;
          channels(k) = termTime(i);
          break;
       end
    end
    %Check remaining channels
    if(k < 5 )
       for j = k+1:5,
          if(channels(j) < arrvInst(i))
             channels(j) = 0;      %If calls have been terminated clear the channels
           end
       end
    elseif (flagServed == 0)
       Blocked = Blocked + 1;
    end
    flagServed = 0;  %Reset Flag
    channels = sort(channels);  %Sort channels according to termInst values
   for x = 1:N,
      if (channels(x) == 0)
         chUsage(i) = chUsage(i) - 1;
      end
   end
```

```
end

S = Serviced;
B = Blocked;
%b(m)=B(m)./C
display('mIAT :');
disp(mIAT);
display('mHT :');
disp(mHT);
display('Serviced calls :');
disp(Serviced);
display('Blocked calls :');
disp(Blocked);
b=B./C
nCpCh=C./N %number of calls/channel
figure('name',strcat('Channel Usage Graph for', ' ,mIAT=',num2str(mIAT),' ,mHT=',num2str(mHT),',N=',
num2str(N)),'numbertitle','off')
A=mHT./mIAT

for m = 1:16
  plot(chUsage);
   legend(strcat('b=',num2str(b),' ,mIAT=',num2str(mIAT),' ,mHT=', num2str(mHT),',N=', num2str(N), ' ,A=', num2str(A),'
,nCpCh=',num2str(nCpCh)),'Location', 'SouthEast')
  end
hold on
xlabel('Cth Call');
ylabel('No of occupied channels');


end
end
end
```

```
hold off;
%4.1.3  End of Effects of Variations in Number of channels
```


A.2 Simulation results

Table A-1 Gain values between each MS and each Cell. Values are negative so the least for each mobile is the best gain.

MS ID	gmb (GAIN VALUE(-) to Cell)								
	CELL1	**CELL2**	**CELL3**	**CELL4**	**CELL5**	**CELL6**	**CELL7**	**CELL8**	**CELL9**
1	17.7304	18.3839	18.5575	18.4859	18.5704	17.6157	18.6174	17.8361	18.4359
2	18.6033	17.9348	18.3429	17.4676	18.4550	18.5151	18.5142	18.6285	17.7796
3	17.6489	18.4456	18.5637	18.4549	18.5984	17.7499	18.5826	17.7735	18.4041
4	18.1197	18.4515	18.3077	18.5655	17.4651	18.6481	18.2210	18.4786	17.9476
5	18.6121	17.6732	18.5727	18.0384	18.3684	18.6531	18.3797	18.4831	17.5225
6	18.1496	18.2076	18.5865	18.5729	18.4751	17.1305	18.6989	17.9681	18.5496
7	18.5518	18.6306	17.7515	17.4198	18.4312	18.4878	18.6295	18.0191	18.3369
8	18.1926	18.2405	18.6324	18.5164	18.4391	17.0558	18.6842	17.8931	18.5905
9	17.5278	18.4583	18.2611	18.7286	18.7129	17.9255	16.8622	18.4905	18.2941
10	18.2362	18.6835	18.3322	18.3746	16.8186	18.5056	17.9006	18.6551	18.6980
11	18.5619	18.1384	18.6755	18.7338	18.0454	18.6755	18.6457	18.3143	15.9540
12	18.5867	17.6608	18.4949	18.4004	18.5444	17.6609	17.8606	18.4110	18.6142

13	18.6537	18.6279	18.0484	18.6599	18.5008	18.1143	16.4285	18.6488	18.3698
14	17.4371	18.4588	18.5083	18.5215	18.6334	17.7885	18.6057	17.9570	18.3337
15	18.2111	18.3237	18.6903	19.6712	17.7554	18.6425	18.3919	18.4118	17.3233
16	18.1259	18.6528	18.4613	18.3807	16.5245	18.6340	18.0340	18.6438	18.6415
17	18.5819	17.5814	18.5551	18.3437	18.5122	17.6832	17.9786	18.4137	18.6542
18	18.3879	18.5816	17.7965	18.5557	17.6087	18.4545	17.7698	18.4630	18.6077
19	17.7487	18.5870	19.7825	18.4592	17.3616	18.4172	18.3275	18.6523	18.0982
20	17.4574	18.4525	18.5109	18.6069	17.9484	18.3409	18.5198	19.6993	17.7766
21	18.4505	18.6554	17.9358	17.5008	18.5397	18.5559	18.5376	17.8000	18.3198
22	18.1834	18.4273	18.2514	16.7656	18.4949	18.3165	18.7086	19.0749	17.9170
23	18.6809	17.9158	18.5466	18.5361	18.4783	17.1928	18.0958	18.2446	18.5961
24	18.4627	18.0656	18.4786	18.0026	18.2137	18.5122	18.6239	18.5399	17.3741
25	17.9286	18.3442	18.6019	18.4557	18.5170	17.4730	18.6280	17.7803	18.5117
26	18.1686	18.3789	18.3970	18.3153	18.4343	17.6148	18.6160	17.6462	18.6460
27	18.4596	18.2460	18.1322	18.4778	18.0056	18.2018	17.4479	18.6591	18.5616
28	18.3462	18.2553	18.7005	19.1002	17.8821	18.6728	18.4801	18.3596	16.8794
29	18.2595	18.1425	18.4330	18.6545	18.5807	17.5198	17.8847	18.2381	18.4614
30	17.4621	18.6661	18.5657	18.4710	18.0114	18.1993	18.4565	18.2014	18.1456
31	18.5975	17.5798	18.6551	18.1607	18.4097	18.2583	18.2680	18.4453	17.7806
32	18.3752	18.1151	18.2222	18.4094	17.6457	18.3050	17.6709	18.6734	18.6256
33	18.7707	18.1350	17.2026	18.7639	18.1387	17.2026	18.7660	18.2002	12.4934
34	18.3715	18.2273	18.6926	18.9797	17.9192	18.6685	18.5179	18.3583	16.7125
35	17.7683	18.4141	18.5859	18.4368	18.5669	17.6727	18.5917	17.7302	18.4534
36	18.5952	18.6500	18.0014	18.6152	18.3109	18.1593	16.8808	18.6019	18.4321
37	18.6458	18.4138	16.7356	18.5541	18.0500	18.6153	18.4261	18.1122	18.6226
38	17.3933	18.3701	18.4040	18.6565	18.6456	17.7399	18.4600	18.2272	18.3353
39	18.0808	18.7654	18.0607	15.4150	18.6530	18.2254	17.2043	18.6410	18.1903
40	17.8319	18.3709	18.5840	19.6493	17.7828	18.4754	18.4603	18.5451	17.5637
41	18.4367	16.8678	18.6624	18.0735	18.5961	18.4679	18.0968	18.5992	18.4179
42	18.5916	17.5621	18.6448	18.2691	18.4560	17.7831	18.1389	18.4147	18.3408

43	18.4352	18.2573	17.8837	19.0960	17.9161	18.7157	18.4890	18.3094	16.8168
44	18.3015	18.4353	17.6622	18.6117	17.6303	18.6504	18.1701	18.3871	18.3290
45	18.0840	18.1819	18.4436	18.6826	18.5801	17.5136	18.0070	18.2018	18.4495
46	18.6715	18.1402	18.1495	18.6975	18.2509	14.9168	18.7645	18.0888	18.1495
47	18.0110	18.5226	18.6032	18.1997	18.5564	18.1073	18.5004	17.2214	18.5991
48	18.5402	18.2558	16.7024	19.0343	17.9781	18.5952	18.5327	18.2452	16.9607
49	17.2169	18.7874	18.1268	12.6504	18.7529	18.1994	17.2169	18.7495	18.1477
50	18.1985	18.6897	18.4142	18.3514	16.5317	18.5560	17.9582	18.6708	18.7201
51	18.3181	18.4106	17.5944	18.2175	18.3682	18.1856	18.6284	17.6813	18.6675
52	17.6502	18.4685	18.5738	18.5655	17.7248	18.4013	18.4349	19.6047	17.7999
53	18.1174	18.3131	18.6511	19.6193	17.7740	18.5904	18.4321	18.4525	17.3034
54	18.4284	17.4838	18.3523	18.3547	18.6173	18.1749	17.6944	18.6384	18.6296
55	18.7118	18.6939	17.8740	17.0686	18.4455	18.3236	17.7862	18.3949	18.2830
56	17.6459	18.6448	18.6158	18.4352	17.6128	18.3161	18.3789	18.4101	18.1665
57	17.6456	18.7558	18.1249	13.6932	18.7495	18.2186	17.6456	18.7429	18.1320
58	18.5558	18.0274	18.5690	18.6196	18.4593	17.0102	18.2740	18.1508	18.5871
59	18.1926	18.1435	18.5073	18.2496	18.1239	18.5031	18.6706	18.5284	17.3141
60	18.6068	17.6505	18.5784	18.3647	18.4827	17.5581	18.0434	18.3775	18.6593

Table A-2 the BTS antenna gain vector(fib) and the BTS coordinates (xyb)

		CELL ID								
		1	**2**	**3**	4	**5**	**6**	7	**8**	**9**
parameter	**fib**	300.00	300.00	300.00	-150000 + 259.81i	-150000 + 259.81i	-150000 + 259.81i	-150.000 - 259.81i	-150.000 - 259.81i	-150.000 - 259.81i
	xyb	0+ 519.62i	-450.00 - 259.81i	450.00 - 259.81i	0+ 519.62i	-450.00 - 259.81i	450.00 - 259.81i	0+ 519.62i	-450.00 - 259.81i	450.00 - 259.81i

Table A-3 The MSs' position(xym) and velocity(xyv)

Mobile ID	xym(*100)	xyv
1	4.0144 + 2.3394i	0.5132 - 1.8550i
2	-0.1094 - 6.1757i	2.6189 + 1.4799i
3	4.3069 + 2.8235i	-4.6589 + 2.9054i
4	-7.2159 + 1.3062i	-1.8375 + 8.4263i
5	0.8273 - 4.0452i	-1.0470 - 5.4148i
6	3.5518 + 0.7965i	-4.8398 - 4.0796i
7	-3.4545 + 7.0088i	-5.2638 + 4.1404i
8	4.1697 + 0.5276i	3.7150 - 1.5551i
9	0.6924 + 3.5007i	0.0449 - 5.5105i
10	-4.4106 - 0.1548i	-2.5738 + 1.2588i
11	4.0669 - 4.1134i	3.2144 + 6.1965i
12	0.2654 - 0.5263i	0.9241 + 2.8241i
13	-1.3005 + 3.4533i	-3.9486 + 7.8088i
14	3.6298 + 3.2455i	5.3442 + 2.0128i
15	5.2127 - 5.6296i	1.1549 + 7.4384i
16	-5.3355 - 0.4457i	5.9000 - 1.3557i
17	0.3514 - 1.1580i	4.5401 - 4.5471i
18	-4.6745 + 2.1868i	-2.7293 - 0.8423i
19	-7.7586 - 1.1249i	-5.1541 + 4.7484i
20	3.6460 + 7.2110i	-0.2909 - 4.4530i
21	-3.4837 - 7.2615i	-1.3189 + 2.5344i
22	0.5155 + 7.0899i	-3.3656 - 2.3993i
23	1.7614 - 0.2485i	1.9858 + 2.1989i

24	1.8368 - 6.0845i	5.9382 - 4.3877i
25	4.3801 + 1.6427i	-2.1801 + 0.3431i
26	5.6858 + 0.7540i	-3.3781 - 7.9971i
27	-2.5803 + 1.2730i	-0.9827 - 1.9671i
28	4.8504 - 4.9372i	2.6451 + 1.8433i
29	1.6790 + 1.5116i	-3.4078 - 1.2806i
30	4.7509 + 5.4084i	-4.7926 + 4.9331i
31	0.7260 - 3.0504i	-0.4782 - 2.5184i
32	-3.1680 + 0.4693i	-0.2605 - 9.2763i
33	4.2894 - 2.9271i	1.9360 - 4.9135i
34	4.6008 - 4.8498i	-2.3757 + 4.2114i
35	4.4814 + 2.3792i	-0.5971 - 0.4517i
36	-1.9517 + 2.9859i	-1.7344 + 1.5129i
37	7.1859 - 2.8310i	-0.3165 + 3.7668i
38	2.1179 + 2.9355i	6.1244 - 8.4593i
39	-0.8204 + 5.4080i	-2.4195 - 2.5719i
40	4.2863 - 7.2204i	-5.3752 - 2.8098i
41	-1.5245 - 2.6842i	1.8726 - 4.0618i
42	0.6288 - 2.0578i	-3.6047 - 0.7264i
43	5.0995 - 4.4358i	0.1431 + 6.0680i
44	-6.7232 + 2.4022i	-2.5035 - 0.1533i
45	1.9442 + 1.6671i	2.1359 + 4.8968i
46	4.2604 - 1.7240i	2.2057 - 2.7775i
47	6.5074 + 2.2705i	-0.8126 + 0.0300i
48	5.2832 - 3.8088i	-8.1956 - 3.1233i
49	-0.2782 + 5.4767i	0.5288 + 2.3415i
50	-4.6126 - 0.5016i	6.3549 - 1.0022i
51	6.5444 + 0.0112i	4.0629 + 1.9155i
52	4.5127 + 7.4288i	-6.3049 + 2.6656i
53	4.7608 - 6.0534i	-0.3138 - 0.3125i

54	-2.1458 - 0.1557i	-2.7194 + 3.5473i
55	-2.1600 + 5.5279i	-4.0874 + 9.2127i
56	5.4996 + 5.8570i	-4.9244 + 2.0930i
57	-0.3115 + 5.6688i	1.1522 - 0.0470i
58	2.4817 - 0.0098i	-1.7127 + 3.6429i
59	2.4600 - 6.2797i	0.2226 + 0.2232i
60	0.7601 - 1.2490i	-1.4676 - 4.4166i